Int J Syst Assur Eng Manag
DOI 10.1007/s13198-012-0088-7

ORIGINAL ARTICLE

An ISM approach for modelling the enablers in the implementation of Total Productive Maintenance (TPM)

Rajesh Attri · Sandeep Grover · Nikhil Dev · Deepak Kumar

Received:11September2014/Revised:9January2015

Abstract Total Productive maintenance (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. But, implementation of TPM is not an easy task. There are certain enablers, which help in the implementation of TPM. The utmost need is to analyse the behaviour of these enablers for their effective utilization in the implementation of TPM. The main objective of this paper is to understand the mutual interaction of these enablers and identify the 'driving enablers' (i.e. which influence the other enablers) and the 'dependent enablers' (i.e. which are influenced by others). In the present work, these enablers have been identified through the literature, their ranking is done by a questionnaire-based survey and interpretive structural modelling (ISM) approach has been utilized in analysing their mutual interaction. An ISM model has been prepared to identify some key enablers and their managerial implications in the implementation of TPM.

Keywords TPM · Total productive maintenance · Enablers · Interpretive structural modelling

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

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

1 Introduction

In the present high-stress, turbulent business-environment, well run organisations strive continually to enhance their capabilities to create excellent value for their customers by improving the cost effectiveness of their operations. Maintenance is thus a vital support function in business, especially as increasingly large investments are being required in physical assets (Tsang et al. 2000). Strategic investments in the maintenance function can lead to improved performance of manufacturing system and enhance the competitive market position of the organization (Coetzee 1999; Jonsson and Lesshammar 1999). This has provided the impetus to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM), over the traditional fire fighting reactive maintenance approaches such as Breakdown maintenance (BDM) (Sharma et al. 2005). Ahuja and Khamba (2008b) have discussed that maintenance concept has progressed from Breakdown maintenance to Total productive maintenance (Fig. 1) over the years.

TPM can be regarded as an improvement program establishing a comprehensive productive-maintenance system throughout the entire life of the equipment, encompassing all equipment-related fields, and with the participation of all employees, to promote productive maintenance through motivation or voluntary team- based activities (Dal et al. 2000). TPM is designed to maximize equipment effectiveness by establishing a comprehensive productive maintenance system covering the entire life of the equipment, spanning all equipment-related fields and with participation of all employees from the top

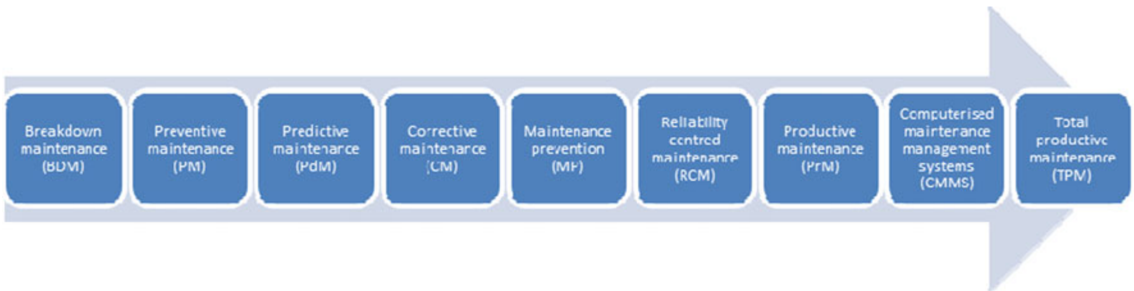

Fig. 1 Journey of maintenance concept

management to the shop-floor workers, to promote productive maintenance through motivation management or voluntary small group activities (Tsuchiya 1992).

TPM can be defined as an approach to achieve rapid improvement of manufacturing processes by involving and empowering production related employees and introducing an ongoing process of quality improvement (Nakajima 1988). TPM implementation has resulted into increased equipment effectiveness, higher productivity, better quality, fewer breakdowns, lower costs, reliable deliveries, motivating working environments, enhanced safety and improved morale of the employees (Ahuja and Khamba 2008b).

Though TPM provides a lot of benefits but implementation of TPM is difficult task. It has been observed that many of the organizations that attempt to implement TPM initiatives experience difficulties and are not able to achieve the anticipated benefits. Mora (2002) has stated that though in recent years, many companies have attempted to implement TPM programs, less than 10 % of companies succeed in implementing TPM. Implementing TPM requires the change of the organizational culture and change of existing behaviours of all employees, operators, engineers, maintenance technicians, and managers. The TPM implementing process has been fraught with roadblocks and pitfalls. These roadblock or pitfall which make this implementation a difficult task include: lack of management support, lack of involvement of production associates, lack of resources, lack of term vision, lack of sustained momentum, no delegate person (Chan et al. 2005). No doubt there are certain barriers which inhibit TPM implementation process but despite this, there are certain enablers for successful implementation of TPM. These enablers help the management to implement TPM in their firms. But need to be properly analysed and the effectiveness of these enablers understood so that the implementation process is completed without many hurdles. These enablers not only affect the implementation process of TPM but also influence one another. So it is really necessary to understand the nature of these enablers and their mutual relationship so that those enablers which support other enablers (called 'driving enablers') and those which are most influenced by others (called 'dependent enablers') are identified.

In the present paper, an attempt has been made to accomplish the task of analysis of enablers of total productive maintenance (TPM) through an interpretive structural modelling (ISM) approach. It is a well-established methodology for identifying relationships among specific items which define a problem or an issue (Sage 1977). Therefore, in this research TPM enablers have been analysed using the ISM approach, which shows the inter-relationships of the enablers, their driving power and dependencies. In this paper, 10 enablers have been identified through the literature, a questionnaire-based survey and opinions of experts both from industry and academia. A questionnaire based survey was conducted on Indian industries to seek their views regarding the main enablers for the successful adaptation of TPM. In accordance with the ISM methodology, the opinions of experts were sought to develop the relationship matrix, which is later used in the development of ISM model.

The main objectives of this paper are as follows:

- To identify and rank the enablers the implementation of TPM.
- To establish relationships among these enablers using ISM.
- To discuss managerial implication of this research and suggest directions for future research.

In the remainder of this paper, identification of various enablers through the literature survey and discussion with experts is presented in Sect. 2. In Sect. 3, an overview of ISM technique is given. Use of the ISM approach in the modelling of various enablers is discussed in Sect. 4. MICMAC analysis of these enablers is presented in Sect. 5. The results of this research are followed by discussion and conclusions in Sect. 6 respectively.

2 Identification of enablers 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). Based on the extent literature review, questionnaire survey and discussion with experts in the organizations, ten major enablers were identified, which can serve as an invaluable lesson to those organizations that are planning to implement TPM or are in the process of implementation. Beside these enablers, some enablers like teams, preventive maintenance, strategic planning, knowledge and beliefs were excluded from the study due to very low mean score in the questionnaire survey.

Moreover, the enablers like worker training, cross-functional training, employee involvement, operator involvement, committed leadership which are often cited with different names and headings are covered in this study under a common name like training and education, total employee involvement and Top management commitment and support. Hence, these ten enablers are assumed to be major TPM enablers in the successful implementation of TPM. Enablers along with their references/sources are being represented in Table 1.

2.1 Top management commitment and support

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). Bamber et al. (1999) have found management commitment as factor affecting successful implementation of TPM in UK manufacturing firms.

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. Top management has the primary responsibility of preparing a suitable and supportive environment before the official kick-off of TPM within their organization. Only with the sustained commitment and enthusiasm of top and senior management can changes in corporate strategy be properly devised and executed. Such support is necessary to ensure the incorporation of TPM into the business strategy, and continuity of policy across company divisions (Park and Han 2001).

The successful implementation of TPM requires top management support, commitment and involvement. Top management needs to have a strong commitment to the TPM implementation program and should go all-out for evolving mechanisms for multi-level communication to all employees explaining the importance and benefits of the whole program, and whole heartedly propagating the TPM benefits to the organization, employees by linking TPM to the overall organizational strategy and objectives (Ahuja and Khamba 2008a). Nakajima (1989) stated that the top management's primary responsibility is to establish a favourable environment where the work environment can support autonomous activities. Chan et al. (2005) have also found management support as the critical success factor in implementation of total productive maintenance in an electronics manufacturing company.

Table 1 TPM enablers and their references/sources

S. no	TPM enablers	References/sources
1	Top management commitment and support	Patterson et al. (1996), Park and Han (2001), Tsang and Chan (2000), Bamber et al. 1999, Patterson et al. 1995, Ahuja and Khamba (2008a), Nakajima (1989), Chan et al. (2005)
2	Cultural change	Ahuja and Khamba (2008a), Park and Han (2001)
3	Coordination	Badiru and Schlegel (1994), Park and Han (2001)
4	Communication	Eti et al. (2004), Park and Han (2001)
5	Cooperation	Park and Han (2001)
6	Total employee involvement	Ahuja and Khamba (2008a), Nakajima (1989), Chen (1997)
7	Training and Education	Maggard and Rhyne (1992), Turbide (1995), Moore (1997), Swanson (1997), Blanchard (1997), Chan et al. (2005), Ahuja and Khamba (2008a), Eti et al. 2004, Thiagarajan and Zairi (1997)
8	Integration of TPM goals and objectives into business plans	Ahuja and Khamba (2008b)
9	Motivation	Bamber et al. (1999)
10	Empowerment and encouragement	Davis and Willmott (1999), Eti et al. (2004), Agyris (1998), Patterson et al. (1995)

Before TPM implementation, top management should decide the vision, mission, and goals for the organization. Top management should lay down sound foundation for initiating TPM activities. Top management must develop overall TPM framework by formulating policies.

2.2 Cultural change

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).

Preparing for TPM implementation includes creating a favourable environment for effective change. TPM is a significant cultural change; motivating individuals to change from "that's not my job" to "this is what I can do to help" will require major adjustments by everyone involved (Park and Han 2001). Organizations require a change in mindset of people for successfully implementing TPM.

2.3 Coordination

The efforts of the TPM implementation team must be coordinated after successfully initiating the communication and cooperation functions. Coordination facilitates conducive organization of implementation efforts (Badiru and Schlegel 1994; Park and Han 2001). In TPM program coordinated effort is emphasized along with individual efforts. Management must evolve a mechanism to coordinate activities. Coordination will help in achieving TPM objectives and goals more easily.

The TPM program should be coordinated within the company by an enthusiast who is appointed on a full-time basis, at least during the planning and implementation phases, and who can lead an implementation team that is representative of different company divisions (Park and Han 2001).

2.4 Communication

Communication is an exchange of information and understanding between two or more persons or groups. Communications should be in the recipients' language and within his/her understanding: therefore the message must be in terms of that individual's experience and perception (Eti et al. 2004). Implementing new technology may generate concerns both within and outside the organization. A frequent concern is the loss of jobs. Sometimes, there may be uncertainties about the impact of the proposed technology. Proper communication can help alleviate the fears of those to be affected by the implementation effort. Well-developed, two-way communication is required to support a TPM system. Wide communication is a vital factor in securing support for a TPM implementation project (Park and Han 2001). Communication will help the employee to know the technical and philosophical aspects of TPM.

2.5 Cooperation

The successful implementation of TPM presupposes the ready cooperation of all within the organization. TPM emphasizes that people—operators, maintenance technicians, engineers, designers, and planners—must work as a team if they are to maximize the overall effectiveness of their equipment, by actively seeking creative solutions for eliminating waste owing to equipment problems (Park and Han 2001). TPM is a team activity not a single man activity which requires overall cooperation of all employees especially production and maintenance personnel's.

2.6 Total employee involvement

Total employee involvement is indeed a pre-requite to successful TPM implementation and can be ensured by enhancing the competencies of employees towards the jobs, evolving the environment of equipment and system ownership by the employees, adequate employee counseling, union buy-in, effective appropriate suggestions schemes and deploying encouraging and safe work environment in the organizations (Ahuja and Khamba 2008a). TPM demands active participation from the shop floor operators in the continuous improvements activities, crossfunctional teamwork, work suggestion schemes (Nakajima 1989).

TPM accomplished the maximization of equipment effectiveness through total employee participation and incorporated the use of Autonomous Maintenance in the small group activities to improve on the equipment reliability, maintainability and productivity (Chen 1997).

2.7 Training and education

Training and education is an ongoing process for everyone in the organization. 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 total productive maintenance in an electronics manufacturing company.

The top management must endeavor to train and develop the employee competencies by updating their skill, knowledge and attitude to enable higher productivity and achieve highest standards of quality, to eliminate product defect, equipment failure (breakdowns) and accidents, to develop multi skilled work force, and to create a sense of pride and belonging among all employees (Ahuja and Khamba 2008a). Employee training should focus on appropriate multi-skills and knowledge (Eti et al. 2004). Thiagarajan and Zairi (1997) have recommended education and training as the single most important factor once the necessary commitment has been assured.

2.8 Integration of TPM goals and objectives into business plans

In order to realize the true potential of TPM and ensure successful TPM implementation, TPM goals and objectives need to be fully integrated into the strategic and business plans of the organizations, because TPM affects the entire organization, and is not limited to production. The first course of action is to establish a strategic direction for TPM. The transition from a traditional maintenance program to TPM requires a significant shift in the way the production and maintenance functions operate. Rather than a set of instructions, TPM is a philosophy, the adoption of which requires a change of attitude by production and maintenance personnel (Ahuja and Khamba 2008b).

2.9 Motivation

Management must create an environment for the individual to motivate themselves. Bamber et al. (1999) have found motivation of management and workforce as a factor affecting successful implementation of total productive maintenance in UK manufacturing organizations. Motivation is the changing behaviour of employee towards work from negative to positive. The employee should be motivated to participate in maintenance activities.

2.10 Empowerment and encouragement

Empowerment and encouragement are significant enablers for successful implementation of total productive maintenance initiatives in the manufacturing organizations (Davis and Willmott 1999). Employee empowerment is desirable in order to create excellent commitments amongst the concerned personnel: for this, management, within the overall aims of the organisation, must involve employees in setting challenging targets and specifying how to achieve them (Eti et al. 2004; Agyris 1998). Empowerment is an environment in which people have the ability, the confidence, and the commitment to take the responsibility and ownership. In such an environment employees/operators will fully participate in TPM activities. The employees should be encouraged to take part in TPM activities.

Patterson et al. (1995) stated that TPM requires employee empowerment and the attitude that TPM is not a maintenance department's program but it's everyone's program. Under TPM, production workers assume ownership of their work area and become responsible for routine maintenance of machines and equipment. In some organizations, the managers do not trust operators to make any repairs and adjustments on the machine because they feel that the expensive equipment will be damaged. In such cases, the organizations are not ready to implement TPM programs (Patterson et al. 1995).

Besides these enablers, the eight pillars of TPM (Fig. 2) will also serve as an effective tool in implementation of TPM.

Pillar 1: 5S TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work place involving the employees. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. The different S are as represented below:

Japanese term	English 5S	Features
Seiri	Sort	Sorting and organizing items as per frequency of usage
Seiton	Systematise	Storing the items in organized way
Seisio	Sweep	Cleaning of workplace to make it free from dust, dirt etc.
Seiketsu	Standardise	Maintaining standards for keeping workplace & machine in neat and clean condition
Shitsuke	Self-discipline	Treating 5S as a way of life and develop self-discipline for following good housekeeping disciplines

Making problems visible is the first step of improvement. 5s is a foundation program before the implementation of TPM (Venkatesh 2007)

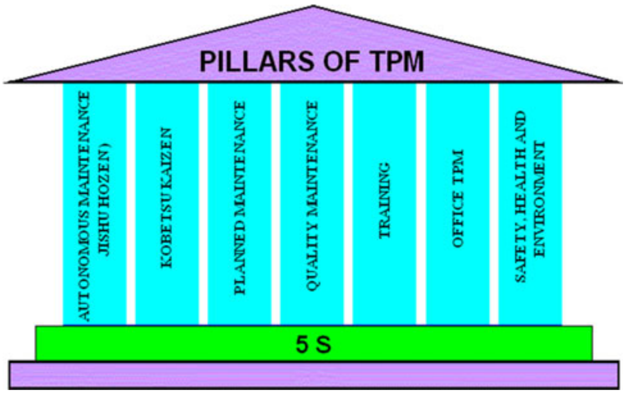

Fig. 2 Pillars of TPM (Venkatesh 2007)

Pillar 2: autonomous maintenance This pillar aims to prepare the operators to take care of routine maintenance tasks which will help to free the core maintenance personnel to concentrate on high maintenance activities. The operator's act of taking care of small maintenance tasks will avoid the equipment's from deterioration (Paneerselvam 2010).

Pillar 3: Kaizen The word kaizen means change for better in Japanese. It is that philosophy that focuses upon continuous improvement of processes in manufacturing. Kaizen focuses on zero losses, cost in reduction in all resources, improvement of overall plant effectiveness.

Pillar 4: planned maintenance Planned maintenance aims to have trouble free machines and equipment's to produce defect free products to satisfy the customer's requirement (Paneerselvam 2010).

Pillar 5: quality maintenance Quality maintenance aims to maintain the equipment's in good operating condition such that highest quality products are delivered to customers through defect free manufacturing (Paneerselvam 2010). QM activities is to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The condition is checked and measure in time series to very that measure values are within standard values to prevent defects (Venkatesh 2007).

Pillar 6: training It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill (Venkatesh 2007).

Pillar 7: office TPM Office TPM mainly aims to improve the productivity and efficiency in the administrative functions by identifying and eliminating losses in them.

Pillar 8: safety, health and environment Office TPM mainly aims to improve the productivity and efficiency in the administrative functions by identifying and eliminating losses in them.

3 Methodology

A questionnaire-based survey and ISM approach have been used to achieve the objectives of this research. These methodologies and their 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 ten listed enablers on this five-point Likert scale. On this scale, 1 and 5 correspond to 'very low' to 'very high, respectively. The questionnaire had a wide range of research objectives and involved many questions.

The questionnaire was administered to companies from Indian manufacturing industries. In total, questionnaires were sent to 125 Indian companies. Out of the 125 questionnaires, 35 completed questionnaires were received. Three questionnaires were incomplete and were discarded for further analysis. So, only 32 questionnaires were analyzed. This gives a response rate of 25.6 %. 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 32 respondents is presented in Table 2 and the enablers 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	Description of firms
1	Number of employees	Less than 100	5
		101–500	22
		501–1000	45
		1001–3000	15
		More than 3000	13
2	Turnover (US $ million)	Less than 10	10
		10–20	35
		20–100	25
		100–200	12
		200–400	9
		More than 400	9

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

S. no	Enablers in the implementation of TPM	Mean score	Rank
1	Top management commitment and support	3.24	1
2	Communication	3.15	2
3	Cultural change	3.02	3
4	Total employee involvement	2.85	4
5	Training and education	2.80	5
6	Integration of TPM goals and objectives into business plans	2.76	6
7	Motivation	2.64	7
8	Empowerment and encouragement	2.32	8
9	Cooperation	2.12	9
10	Coordination	1.98	10

3.2 ISM approach

In this section, first rationale for choosing ISM methodology for this research is explained, then subsequently details of ISM methodology is enumerated. Ill-defined problems tend to be dynamic problems that involve human factors. Soft systems methodology (SSM) is generally used for dealing ill-defined problems as to what shall be done, because at the onset there is no obvious or clearly defined objective. Ill-defined problems tend to be dynamic problems that involve human factors. But the main limitation of SSM is that it can be used to solve only some ill-parts of the system and not for building the system as a whole. In addition, SSM is a very time-intensive process (Ravi et al. 2005; Faisal et al. 2007).

Delphi method is a structured technique which follows a series of steps to develop a consensus among a group of experts. The main disadvantage of Delphi method is that it is very difficult to collect questionnaires from busy individuals. The structural equation modeling (SEM) is a confirmatory approach to data analysis requiring a priori assignment of inter-variable relationships. It tests a hypothesized model statistically to determine the extent the proposed model is with the sample data (Faisal et al. 2007; Wisner 2003; Schumacker and Lomax 1996). Another limitation of SEM is that it requires the statistical data to obtain results (Ravi et al. 2005).

ISM is a process that helps groups of people in structuring their collective knowledge. The use of ISM methodology is also comparable to other methods such as focus groups, Qsort or paired comparison. ISM methodology uses mathematical algorithms that minimize the number of queries necessary for exploring relationships among a set of ideas, while these techniques do not so. Therefore, ISM is quantitative as well as qualitative (Georgakopoulos 2009).

Successful implementation of TPM depends on a number of variables. A model depicting those key variables that should be focused on such that desired results could be achieved would be of great value to the top management. So ISM can be employed under such circumstances because on the basis of relationship between the variables, an overall structure can be extracted for the system under consideration.

ISM is an interactive learning process. In this technique, a set of different directly and indirectly related elements are structured into a comprehensive systematic model (Warfield 1974; Sage 1977). The model so formed portrays the structure of a complex issue or problem in a carefully designed pattern implying graphics as well as words (Raj et al. 2007; Singh et al. 2003; Ravi and Shankar 2005). The ISM process transforms unclear, poorly articulated mental models of systems into visible and well defined models. The information added (by the process) is zero. The value added is structural (Farris and Sage 1974). ISM is a well-established methodology for identifying relationships among specific items, which define a problem or an issue (Jharkharia and Shankar 2005).

The various steps involved in the ISM technique are:

(1) Identify the elements which are relevant to the problem. This could be done by a survey or group problem solving technique.
(2) Establish a contextual relationship between elements with respect to which pairs of elements would be examined.
(3) Develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pair-wise relationship among elements of the system. This matrix is checked for transitivity.
(4) Develop a reachability matrix from the SSIM.
(5) Partition the reachability matrix into different levels.
(6) Convert the reachability matrix into conical form.
(7) Draw digraph based on the relationship given in reachability matrix and remove transitive links.
(8) Convert the resultant digraph into an ISM-based model by replacing element nodes with the statements.
(9) Review the model to check for conceptual inconsistency and make the necessary modifications.

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.

Table 4 Application of ISM approach for decision making

S. no	Name of the authors (year)	Application
1	Raj and Attri (2011)	TQM barriers
2	Parmod and Banwet (2010)	Inhibitors of service supply chain
3	Singh and Kant (2008)	Knowledge management barriers
4	Thakkar et al. (2008)	Evaluation of supply chain relationships
5	Thakkar et al. (2007)	Development of balanced scorecard (BSC) for a real life case company KVIC
6	Qureshi et al. (2007)	Logistics outsourcing relationships
7	Faisal et al. (2007a)	Supply chain agility enablers
8	Faisal et al. (2007b)	Information risks management in supply chains
9	Singh et al. (2007)	Advanced manufacturing technologies critical success factors
10	Raj et al. (2007)	Flexible manufacturing system enablers
11	Agarwal et al. (2006)	Agility of supply chain
12	Faisal et al. (2006)	Supply chain risk mitigation
13	Ravi et al. (2005)	Productivity improvement of a computer hardware supply chain
14	Ravi and Shankar (2005)	Reverse logistics barriers
15	Jharkharia and Shankar (2005)	IT enablement in supply chain barriers
16	Bolaños et al. (2005)	Decision making process
17	Jharkharia and Shankar (2004)	IT enablement in supply chain enablers
18	Singh et al. (2003)	Knowledge management in engineering industries
19	Sharma et al. (1995)	Waste management in India
20	Mandal and Deshmukh (1994)	Vendor selection
21	Saxena et al. (1992)	Energy conservation in Indian cement industries
22	Saxena et al. (1990)	Energy conservation

2007). For complex problem, like the one under consideration, ISM approach has been used to develop a comprehensive systematic model. Application of ISM process to analyze systems and problems in various fields is well documented in literature as represented in Table 4.

4 An ISM approach for modelling of enablers

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

4.1 Structural self-interaction matrix (SSIM)

Experts, both from industry and academia, have been consulted in identifying and developing the contextual relationship among the enablers.

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

- V is used for the relation from enabler *i* to enabler *j* (i.e. if enabler *i* influences or reaches to enabler *j*).
- A is used for the relation from enabler *j* to enabler *i* (i.e. if enabler *j* reaches to enabler *i*).
- X is used for both direction relations (i.e. if enablers *i* and *j* reach to each other).
- O is used for no relation between two enablers (i.e. if enablers *i* and *j* are unrelated).

Based on this contextual relationship, the SSIM has been developed. To obtain consensus, the SSIM was discussed in a group of experts and based on their responses, SSIM has been finalised and it is presented in Table 5.

4.2 Reachability matrix

The SSIM is transformed into a reachability matrix format by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix. The substitution of 1s and 0s are as per the following rules:

(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.

Table 5 Structural self-interactive matrix (SSIM)

Enablers	10	9	8	7	6	5	4	3	2
1	V	V	V	V	X	V	V	V	V
2	O	V	V	V	A	A	V	V	
3	A	A	A	A	A	A	A		
4	O	O	A	A	A	A			
5	V	V	V	V	A				
6	V	V	O	O					
7	O	X	V						
8	X	O							
9	O								

Table 6 Initial reachability matrix

Enablers	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	1	0	0	1	1	1	0
3	0	0	1	0	0	0	0	0	0	0
4	0	0	1	1	0	0	0	0	0	0
5	0	1	1	1	1	0	1	1	1	1
6	1	1	1	1	1	1	0	0	1	1
7	0	0	1	1	0	0	1	1	1	0
8	0	0	1	1	0	0	0	1	0	1
9	0	0	1	0	0	0	1	0	1	0
10	0	0	1	0	0	0	0	1	0	1

Table 7 Final reachability matrix

Enablers	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	1	0	0	1	1	1	1*
3	0	0	1	0	0	0	0	0	0	0
4	0	0	1	1	0	0	0	0	0	0
5	0	1	1	1	1	0	1	1	1	1
6	1	1	1	1	1	1	1*	1*	1	1
7	0	0	1	1	0	0	1	1	1	1*
8	0	0	1	1	0	0	0	1	0	1
9	0	0	1	1*	0	0	1	1*	1	0
10	0	0	1	1*	0	0	0	1	0	1

Following the above rules, the initial reachability matrix is prepared and is shown in Table 6.

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 7.

4.3 Partitioning the reachability matrix

The matrix is partitioned, by assessing the reachability and antecedent sets for each variable (Warfield 1974). The reachability set consists of the element itself and other elements, which it may help to achieve, whereas the antecedent set consists of the element itself and other elements, which may help achieving it. Thereafter the intersection of these sets is derived for all the elements. The elements for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. The top-level element in the hierarchy would not help achieve any other element above its own level. Once the top-level element is identified, it is separated out from the other elements. Then, the same process is repeated to find out the elements in the next level. This process is continued until the level of each element is found. These levels help in building the diagraph and the ISM model. In

Table 8 Iteration 1

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4,5,6,7,8,9,10	1,6	1,6	
2	2,3,4,7,8,9,10	1,2,5,6	2	
3	3	1,2,3,4,5,6,7,8,9,10	3	I
4	3,4	1,2,4,5,6,7,8,9,10	4	
5	2,3,4,5,7,8,9,10	1,5,6	5	
6	1,2,3,4,5,6,7,8,9,10	1,6	1,6	
7	3,4,7,8,9,10	1,2,5,6,7,9	7,9	
8	3,4,8,10	1,2,5,6,7,8,9,10	8,10	
9	3,4,7,8,9	1,2,5,6,7,9	7,9	
10	3,4,8,10	1,2,5,6,7,8,10	8,10	

Table 9 Iteration 2

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,4,5,6,7,8,9,10	1,6	1,6	
2	2,4,7,8,9,10	1,2,5,6	2	
4	4	1,2,4,5,6,7,8,9,10	4	II
5	2,4,5,7,8,9,10	1,5,6	5	
6	1,2,4,5,6,7,8,9,10	1,6	1,6	
7	4,7,8,9,10	1,2,5,6,7,9	7,9	
8	4,8,10	1,2,5,6,7,8,9,10	8,10	
9	4,7,8,9	1,2,5,6,7,9	7,9	
10	4,8,10	1,2,5,6,7,8,10	8,10	

Table 10 Iteration 3

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5,6,7,8,9,10	1,6	1,6	
2	2,7,8,9,10	1,2,5,6	2	
5	2,5,7,8,9,10	1,5,6	5	
6	1,2,5,6,7,8,9,10	1,6	1,6	
7	7,8,9,10	1,2,5,6,7,9	7,9	
8	8,10	1,2,5,6,7,8,9,10	8,10	III
9	7,8,9	1,2,5,6,7,9	7,9	
10	8,10	1,2,5,6,7,8,10	8,10	III

the present case, the ten enablers, along with their reachability set, antecedent set, intersection set and levels, are presented in Tables 8, 9, 10, 11, 12, 13, 14.

4.4 Development of conical matrix

In this step, a conical matrix is developed by clubbing together enablers in the same level, across rows and columns of the final reachability matrix (Table 15).

4.5 Development of digraph and ISM model

On the basis of conical matrix, an initial digraph including transitivity links is obtained. It is generated by nodes and lines of edges. After removing the indirect links, a final digraph is developed (Fig. 3). 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. Next, the digraph is converted into an ISM model by replacing nodes of the elements with statements as shown in Fig. 4.

5 MICMAC analysis

Matrice d'Impacts croises-multiplication appliqúe an classment (cross-impact matrix multiplication applied to

Table 11 Iteration 4

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5,6,7,9	1,6	1,6	
2	2,7,9	1,2,5,6	2	
5	2,5,7,9	1,5,6	5	
6	1,2,5,6,7,9	1,6	1,6	
7	7,9	1,2,5,6,7,9	7,9	IV
9	7,9	1,2,5,6,7,9	7,9	IV

Table 12 Iteration 5

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5,6	1,6	1,6	
2	2	1,2,5,6	2	V
5	2,5	1,5,6	5	
6	1,2,5,6	1,6	1,6	

Table 13 Iteration 6

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,5,6	1,6	1,6	
5	5	1,5,6	5	VI
6	1,5,6	1,6	1,6	

Table 14 Iteration 7

Enablers	Reachability set	Antecedent set	Intersection set	Level
1	1,6	1,6	1,6	VII
6	1,6	1,6	1,6	VII

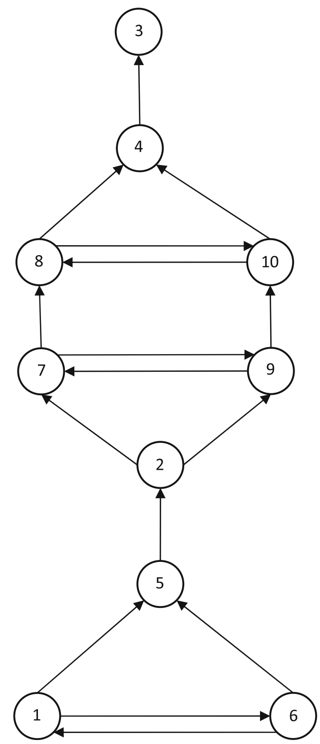

Fig. 3 Digraph showing levels of TPM enablers

classification) is abbreviated as MICMAC. The purpose of MICMAC analysis is to analyze the drive power and dependence power of enablers. MICMAC principle is based on multiplication properties of matrices (Sharma et al. 1995). It is done to identify the key enablers that drive the system in various categories. Based on their drive power and dependence power, the enablers, have been classified into four categories as follows:

- Autonomous enablers: These enablers have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong.

Table 15 Conical matrix

Enablers	3	4	9	8	10	7	2	5	1	6	Driver power
3	1	0	0	0	0	0	0	0	0	0	1
4	1	1	0	0	0	0	0	0	0	0	2
9	1	1	1	1	0	1	0	0	0	0	5
8	1	1	0	1	1	0	0	0	0	0	4
10	1	1	0	1	1	0	0	0	0	0	4
7	1	1	1	1	1	1	0	0	0	0	6
2	1	1	1	1	1	1	1	0	0	0	7
5	1	1	1	1	1	1	1	1	0	0	8
1	1	1	1	1	1	1	1	1	1	1	10
6	1	1	1	1	1	1	1	1	1	1	10
Dependence power	10	9	6	8	7	6	4	3	2	2	

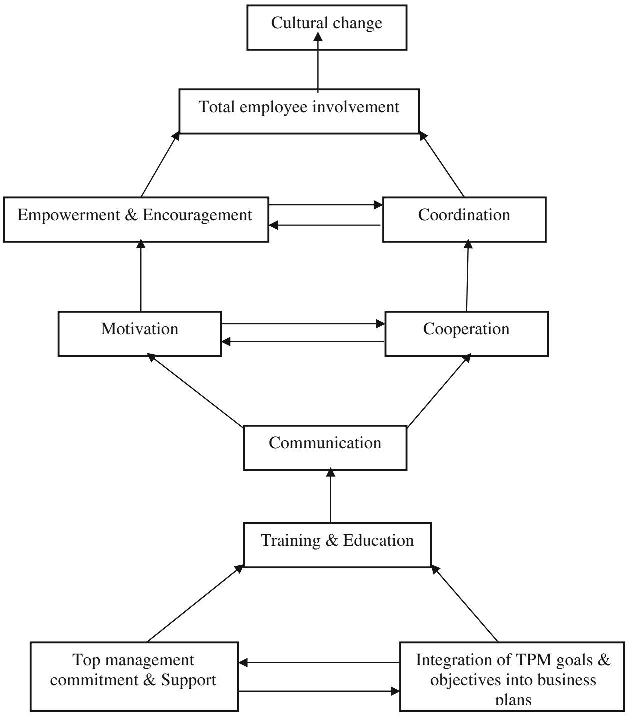

Fig. 4 Interpretive structural model showing levels of TPM Enablers

- Linkage enablers: These enablers have strong drive power as well as strong dependence power. They enablers are unstable in the fact that any action on these enablers will have a effect on others and also a feedback effect on themselves.
- Dependent enablers: These enablers have weak drive power but strong dependence power.
- Independent enablers: These enablers have strong drive power but weak dependence power. An enabler with a very strong drive power, called the 'key enabler' falls into the category of independent or linkage enablers.

This classification is similar to that by Mandal and Deshmukh (1994). The drive power and dependence power of enablers is shown in Table 15. The drive power-dependence power diagram is drawn as shown in Fig. 5. This Figure has been divided into four clusters. First cluster includes 'autonomous enablers', second cluster includes 'dependent enablers', third cluster includes 'linkage enablers' and fourth cluster contains 'independent enablers'.

6 Conclusion and discussion

The major objective of this paper is to identify the enablers that significantly affect the successful implementation of TPM in any industry so that management may successfully implement TPM in their organizations. In this paper, an ISM-based model has been developed to analyze the interactions among different TPM enablers. It identifies the key enablers on which management should focus for the successful implementation of TPM.

The driver dependence diagram helps to classify various enablers of TPM implementation. There are no variables in the autonomous cluster, which indicates no variable can be considered as disconnected from the whole system and the management has to pay an attention to all the identified enablers of TPM implementation.

The next cluster consists of dependent variables like cultural change, total employee involvement, empowerment

Fig. 5 Clusters of enablers in the implementation of TPM

Driving Power

10		1,6								
9										
8		**IV**	5					**III**		
7				2						
6						7				
5						9				
4							10	8		
3			**I**					**II**		
2									4	
1										3
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Dependence power

and encouragement, cooperation and coordination. In this particular cluster, these variables have the least driving power and have highest dependence and form the topmost level in the ISM hierarchy. They represent those variables that are resultant actions for effective implementation of TPM. The managers should take special care for handling these enablers.

The next cluster consists of those variables that are termed as linkage variables like motivation which is influenced by lower level variables and in turn impacts other variables in the ISM model. The management should motivate their employee by empowerment. The employees/operators should be encouraged for participating TPM activities. Besides this, management should introduce reward schemes from time to time to motivate the employees which will boost the employee's willingness to participate in TPM activities.

The last cluster includes independent variables like top management commitment and support, communication, training and education and integration of TPM goals and objectives into business plans. These variables have strong driving power and weak dependency on other enablers. They may be treated as the 'key enablers' for the successful implementation of TPM. Management should communicate the concepts, principles of TPM to its entire employee by forming the policies and through training and education. To apply TPM concepts successfully to plant-maintenance activities, the entire workforce must first be convinced that the top-level management is committed to the programme. The senior management team should set company-wide PM policies. The middle management must oversee the departmental polices and goal-setting and departmental PM promotional committees. The shop-floor management should set the PM goals according to team groups' activities. Along with this, management should integrate goals and objectives of TPM into business plans.

The ISM model developed in this paper acts as a tool for top management to understand/identify the key enablers of TPM implementation. This model has been developed on the basis of consensus of experts (both from industry and academia), the results are quite generic and helpful for top management to steer efforts towards the successful implementation of TPM.

Finally, it would be useful to suggest the direction of future research in this area. In this research, through ISM, a relationship model among the enablers has been developed. But this model has not been statistically validated. The present model can be statistically tested with use of SEMwhich 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.

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