Total Productive Maintenance And Role Of Interpretive Structural Modeling And Structural Equation Modeling In Analyzing Barriers In Its Implementation – A Literature Review

Prasanth S. Poduval, Dr. Jagathy Raj V. P., Dr. V. R. Pramod

Abstract - The aim of the authors is to present a review of literature of Total Productive Maintenance and the barriers in implementation of Total Productive Maintenance (TPM). The paper begins with a brief description of TPM and the barriers in implementation of TPM. Interpretive Structural Modeling (ISM) and its role in analyzing the barriers in TPM implementation is explained in brief. Applications of ISM in analyzing issues in various fields are highlighted with special emphasis on TPM. The paper moves on to introduction to Structural Equation Modeling (SEM) and its role in validating ISM in analyzing barriers in implementation of TPM. The paper concludes with a gap analysis from the current literature, research that can be carried out and expected outcomes from the proposed research.

Index Terms: TPM, ISM, Barriers, SEM

1.0 Introduction

Total Productive Maintenance (TPM) is a movement popularized by the Japanese. A small revolution was brewing in Japan in the manufacturing field to reduce costs and at the same time to improve efficiency, reliability and quality. The Japanese had been using the American concept of Preventive Maintenance since the 1950s but due to automation and the increased complexity of the equipments and machines, was encountering high costs as a result of increase in maintenance force to maintain the equipments. To alleviate this problem, they started looking at ways to reduce costs and hit upon the idea of expanding the domain of work of the Operations team. Nippondenso, an automotive component manufacturer in 1960 was the first Japanese organization to radically change its work culture by asking its operators to do the simple routine maintenance of its machines. Thus was born the culture of Total Productive Maintenance. The main emphasis in TPM is to persuade the operating personnel to carry out the regular daily maintenance while the maintenance crew would carry out specialized maintenance, upgrades and modification jobs to minimize failures thereby increasing machine availability, reducing costs and improving profitability of the organization

- *Prasanth S. Poduval, B.Tech, MBA*
- *Dr. Jagathy Raj V. P., M.Tech, MBA, PhD*
- *Dr. V. R. Pramod, M.Tech, PhD*
- *About the Authors*
- *Prasanth S. Poduval is currently pursuing his Ph.D in Total Productive Maintenance from Karpagam University, Coimbatore. He is working as Deputy General Manager in Electrical Maintenance in Mangalore Refinery and Petrochemicals Limited (MRPL), Mangalore, India. He can be contacted at sunitha_prasanth@rediffmail.com*
- *V. P. Jagathy Raj is Professor in school of Management Studies, Cochin university of Science and Technology, Kochi, India. He can be contacted at jagathy@cusat.ac.in*
- *Pramod. V. R is an Associate Professor in Mechanical Engineering Department of NSS College of Engineering, Palakkad, India. He can be contacted at pramodvram@rediffmail.com*

2.0 TPM

TPM is a maintenance program in which

a. Field operations personnel look after the routine maintenance of the equipment through their day-to-day activities
b. Maintenance personnel develop modifications to improve reliability and availability of the equipment reducing breakdowns
c. Thereby maximizing equipment efficiency and effectiveness and productivity of processes
d. By eliminating losses and reducing costs
e. Thus improving quality of the products
f. Ensuring higher top and bottom lines for the organization.

Japan Institute of Plant Maintenance has described TPM as a mechanism to maximize equipment effectiveness covering the entire life of the equipment involving everyone in all departments at all levels. Goal of TPM is to enzure zero accidents, zero breakdowns and zero defects [82]. It helps to continuosly improve and sustain quality products and processes by involving management, workforce, suppliers and customers [34], [83], [99]. By incorporating TPM, an organization strives to transform the shop floor by integrating culture, process and technology [81]. TPM has a positive impact on an organization's business performance [21], [18], [45], but it takes time and dedicated effort. It results in improvement in productivity, quality and safety, employee morale and cost effectiveness of the manufacturing function [59], [124], [122]. Adoption of TPM helps in improvement of Mean-Time-Before-Failure and Mean-Time-To-Repair parameters of equipments [13]. Production challenges in industries can be tackled by implementation of TPM backed by management strategy and motivated employees [41]. TPM plays an important role in improving maintenance functions thereby resulting in business excellence through improvement in productivity and quality and reduction in costs [36]. TPM demands specifically the operating personnel to carry out routine maintenance of the equipment and on the maintenance personnel to study corrective methods to enhance life of the equipment and prevent breakdowns. The importance of TPM is that by dedicating more time to study the design of equipment and to implement corrective methods / design changes, it helps to dramatically reduce breakdowns and eliminate losses.

3.0 Barriers in Implementing TPM

Implementation of TPM is not an easy task. Organizations have failed in their attempts to implement TPM due to behavioral, cultural and bureaucratic challenges and above all, due to their inflexible attitude to change and to adopt to change. The TPM concept looks simple but the practical aspect of implementation is very complex involving various stages, each of which requires focused attention without which the TPM implementation process is bound to result in failure. Due to this very reason, industries in India and world over have struggled and failed in TPM implementation. TPM is not a quick-fix methodology resulting in instant results; it requires commitment, dedication and perseverance on part of the management and employees over the long run to deliver measurable visible results. In the Indian context, Ahuja and Khamba have

a. Evaluated the challenges before Indian manufacturing organizations to adapt to TPM initiatives
b. Examined the factors influencing the implementation of TPM practices in the Indian manufacturing industry
c. Developed an understanding of contributions of TPM initiatives towards building core competencies in the Indian manufacturing industry.

They have explained that TPM seeks to maximize equipment effectiveness throughout the life time of the equipment and strives to maintain the equipment in optimum condition in order to prevent unexpected breakdowns, speed losses and quality defects occurring from process activities [3], [4], [5], [6] and [7]. Implementing TPM in industries requires time, money, manpower, resources and commitment from all the stake holders. The organization as a whole should be willing to change its outlook and adapt itself to the new practices and cultural changes that are required for the successful implementation of TPM. Many companies implement TPM on a superficial level and the resulting productivity gains fall short of their potential [105]. Organizations have time and again failed to put into practice TPM as either they were not serious or they have not grasped the enormity of the situation and the requirements for successful implementation. The following paragraphs describe in brief some of the factors which have a bearing on implementation of TPM.

3.1 Management Commitment

TPM programs can be effective if and only if the top management and employees are totally committed and involved [14], [125]. TPM is driven by the effective leadership from the top management and the senior management has to be committed, demonstrate leadership and include maintenance and reliability excellence in the organization's top priority initiatives [72], [73], [35], [32], [94]. A study of implementation of TPM carried out by Ireland and Dale found that the senior management by building the necessary infrastructure for TPM implementation had shown its support and motivation to promote and implement TPM [48]. The top management should necessarily a) recognize forces encouraging change, b) engage in a problem solving process to design the change and c) then implement and evaluate the change [42].

3.2 Employee Commitment

Success of TPM is closely connected to equipment utilization and employee management [100], [39]. Long term commitment of all the personnel from the organization right from the top management to the lowermost level and across all streams and disciplines is a prerequisite for successful TPM implementation. An effective TPM implementation is based on empowerment and encouragement of personnel from all areas of the organization [3], [4], [5], [6], [7], [33]. The biggest challenge before any management is to be able to make radical transformation in an organization's culture for ensuring overall employee participation towards manufacturing performance improvement through TPM initiatives [17].

3.3 Clearly Specified Goals

For TPM to be successful, the employees must have a clear goal explicitly and precisely stated in numbers and figures. Companies have to set goals that are SMART: **S**pecific, **M**easurable, **A**ttainable, **R**ealistic and **T**ime-based [72], [73]. Management has an important role in determining the TPM policies, objectives and strategies to align with the company's business goals [95]. According to Gupta, TPM policies and goals should be made clear to everyone involved in TPM implementation [43]. TPM policy has to be based on the company's business policy related to the company's long-range and mid-range business goals and to be fully integrated into the strategic and business plans of the organizations [3], [4], [5], [6], [7], [116].

3.4 Teams

Literature reviews point out that "*Cross-Functional Teams*" are integral to TPM implementation. Teams have to be self directed and made up of personnel from cross-functional departments (operations, engineering, maintenance) who directly have an impact on the problem along with the shift supervisors and the top management personnel [98], [65], [67], [68]. Cross-functional teams break down organizational barriers, identify problems and are charged with the responsibility of pinpointing problem areas, detailing a course of corrective action and initiating the corrective process [98], [78]. The team work concept exploiting the abilities and skills of human assets, the collective collaboration between Operations and Maintenance and the philosophy of empowerment of personnel from the top level to the shop floor and between all functional areas in the organization were also highlighted by Willmott and McCarthy [128], Davis and Willmott [33], Patterson et al. [92] and Witt [131].

3.5 Involvement of Operations in Maintenance Activities

One concept central to TPM is "*Autonomous Maintenance*" which means that the regular maintenance of equipments like cleaning, replacing oil, greasing and lubricating is carried out by the operating personnel while the maintenance group will be actively involved in the more complex task of developing maintenance programs and schedules, equipment design modifications and carrying out reliability focused maintenance for maintaining the health and ensuring maximum availability of equipments. TPM calls for focused operator involvement in routine maintenance of an equipment and that a TPM approach will teach operators to identify the root cause of a deteriorating equipment performance [81], [43], [58]. The most important requirement for operators is to have the ability to detect abnormalities in the working of the equipment with respect to the operation of the equipment and the quality of output [106], [109]. When using TPM, the operator and maintenance staff become partners in seeking to improve equipment performance while the maintenance staff and engineers become partners in designing equipment for enhanced performance [38]. One of the reasons for difficulty in implementing TPM is on one hand the unwillingness of operations to accept the philosophy of autonomous maintenance and on the other, the lack of trust by maintenance in the competence of operations to carry out simple maintenance tasks [89]. The goal of autonomous maintenance is not to eliminate maintenance personnel by involving operations but to allow the maintenance personnel to be better used in high-level diagnostic and problem-solving activities [130].

3.6 Training

Education and Training are two major success factors for implementation of TPM and are important stages in autonomous maintenance [61]. TPM is designed to help operators learn more about how their equipment functions, what common problems can occur and why, and how those problems can be prevented through early detection and treatment of abnormal conditions and this cross-training allows operators to maintain the equipments and to identify and resolve many basic equipment problems [58], [76]. Organizations opting for TPM should be willing to invest in training and imparting education to the employees. An organization should identify the specific knowledge, skills and management abilities that it wants its employees to have and then design suitable training to develop these skills [95], [116]. Training is important to overcome misunderstanding about TPM and job security [27].

3.7 Appropriately Scheduled Maintenance Programs

TPM implementation can be successful only when the maintenance team carries out scheduled maintenance and equipment design program with the operations team having taken care of routine maintenance. The key objective of maintenance management is the total asset life cycle optimization by employing best practices to realize maximum value of the assets [93]. The mission of the maintenance department is to provide reliable physical assets and excellent support for its customers by reducing and eventually eliminating the need for maintenance services [49], [64]. Implementation of TPM is directly related to work culture in an organization where-in frequent breakdowns are tolerated and not analyzed, processes are inefficient, product quality is not checked and customer feedback not monitored. In a large number of organizations, instead of carrying out maintenance jobs to avoid failure and repair, focus is on carrying out immediate repair and bringing the machine back on line as fast as possible. The ultimate goal of the maintenance department is maintenance prevention for which the organizations should develop Preventive, Corrective, Predictive and Reliability Centered maintenance programs. "*Preventive Maintenance*" program is a set of scheduled maintenance activities at pre-defined intervals by means of inspection and detection thereby helping the maintenance team to determine whether a particular component has worn out and require replacement rather than waiting for the component to result in equipment [47], [129]. TPM is a team based preventive and productive maintenance involving all levels from the top executive to the floor operator [101]. It is a combination of preventive maintenance and total quality through employee involvement incorporating the strategies of operator ownership and preventive maintenance activities to keep machines free from failure or malfunctioning during production [28]**,** [108]. A follow-up to Preventive Maintenance is *"Corrective Maintenance"* and is initiated on the occurrence of symptoms of impending failure which can be found out during PM checks. Corrective maintenance improves equipment reliability, maintainability and safety, reduces deterioration and failures and aims at maintenance-free equipment. It is the act of performing some repair or adjustment for a condition that was identified during the accomplishment of a preventive or predictive maintenance [24] and will increase the productivity of a manufacturing system [54]. In *"Predictive Maintenance"* the health of the equipments is monitored either on-line continuously or at regular intervals and the parameters indicating machine condition collected and processed in order to determine machine condition and predict its failure [121], [23]. Predictive Maintenance is a condition driven program that uses the actual operating condition of plant equipment and systems to optimize total plant operation [80]. Renwik and Babson have shown Vibration Analysis as a proven tool in Predictive Maintenance for obtaining cost benefits, reduced machinery downtime and production losses which is a vital aspect in TPM implementation [97]. To compliment the above strategies, *"Reliability Centered Maintenance (RCM)"* was introduced by Nowlan and Heap [86] as a program consisting of a set of scheduled tasks generated on the basis of specific reliability characteristics of the equipment they are designed to protect. The primary goal of RCM should be to ensure that the right maintenance activity is performed at the right time with the right people, and that the equipment is operated in a way that maximizes its opportunity to achieve a reliability level that is consistent with the safety, environmental, operational and profit goals of the organization [53]. Implementing the RCM process requires the application of a decision logic that enables systematic analysis of failure mode, rate and criticality data to determine the most effective maintenance requirements for strategy and plan [22].

3.8 Administrative Support

For TPM to be successful, the administrative support function should be in place. "*Office TPM*" is the application of TPM principles in the organization's administrative function and it ensures that the function provides an all round support to the manufacturing process. Understanding, commitment and involvement of top management are needed for effective implementation of office TPM [91]. Office TPM must be followed to improve productivity and efficiency in the administrative functions by identifying and eliminating losses [84], [90]. To facilitate the concepts discussed in the previous paragraphs, it is essential that the organization should undergo a transformation in its work culture. The cultural, social and organizational barriers must be brought down. Management and employees must learn to trust each other. Ideas should flow freely both horizontally and vertically in an organization. There should be voluntary exchange of data and information among the departments to generate new ideas. The biggest challenge before any management is to be able to make radical transformation in an organization's culture for ensuring overall employee participation towards manufacturing performance improvement through TPM initiatives [17]. Employees must view themselves working for the organization and not for the department. It is the task of the management to align employees to the organization's vision and goals. Organizational work culture is always resistant to change and it is this resistance that the management must overcome. The work culture has to undergo an attitude reform so as to alter the organization's outlook from a departmental viewpoint to an organizational viewpoint. Panneerselvam [89] has listed out behavioral, organizational, cultural, technological, departmental, operational and financial challenges that Indian industries face in implementing TPM. According to him the broad critical success factors for implementation of TPM are

1. Top management commitment
2. Total employee involvement
3. Cultural transformation
4. Conventional and proactive maintenance strategies
5. Training and education
6. Failure prevention
7. Focused production system enhancement

Cooke [32] has concluded that implementation of TPM is affected by political, financial, departmental and inter-occupational barriers. Gupta et al. [43] have expressed their point of view that insufficient resources, resistance to change, incomplete understanding of the methodology, treating TPM as additional burden and inability to invoke cultural change are some of the difficulties faced in TPM implementation. Lack of management support, lack of training and failure to allow sufficient time for evolution are some of the obstacles in implementing TPM as mentioned by Bamber et al. [15]. Ahuja and Khamba [3], [4], [5], [6] and [7] have inferred that success of TPM program is closely associated with the way of managing people. They have cited some stumbling blocks in TPM implementation as given below:

1. Cultural resistance to change
2. Partial implementation of TPM
3. Overly optimistic expectations from TPM
4. Lack of well-defined routine
5. Lack of training and education
6. Lack of support system to facilitate learning and to transform learning into effective diffusion of TPM practices
7. Lack of organizational commitment

Kulkarni and Dabade [58] and Narender and Gupta [84] have quoted the following obstacles:

1. Not considering workers' suggestions
2. Work stress
3. Lack of commitment
4. Lack of confidence to acquire new skills
5. Misunderstanding and an atmosphere of distrust
6. General feeling of operations personnel not to carry out maintenance jobs

In addition to the factors mentioned above, Paropate et al. [90] cite linking TPM to business strategy and quality and spreading TPM to all departments as requirements for successful implementation of TPM. Pomorski [95] has added the following barriers to TPM implementation:

1. Implementing to a rigid schedule regardless of results
2. Deploying insufficient resources,
3. Not recognizing the benefits of TPM
4. Presenting TPM as a short-term initiative

All these barriers are also recognized by Attri et al. [12] and ChoyDS [31]. Various challenges and obstacles in TPM implementation are explained in the preceding paragraphs but it will be interesting to know the interrelationships among these barriers. Which are the most influential barriers? Is the interrelationship between the barriers unidirectional or bidirectional? Are there any barriers which are not affected by other barriers? Are there any barriers which affect other barriers as a result of interaction of some other barriers? These interrelationships can be studied in depth by using the ISM approach, details of which are explained in the forthcoming paragraphs.

4.0 Introduction to Interpretive Structural Modeling

The origin of ISM can be traced to Structural Modeling (SM) which was defined by **Warfield** as a "methodology which employs graphics and words in carefully defined patterns to portray the structure of a complex issue, a system or a field of study". ISM is a process which transforms unclear, poorly articulated mental models of systems into visible and well defined models [9]. Lendaris [63] refers SM to those modeling activities in which the intention of the modeler is to embody the geometric rather than algebraic and of describing form rather than calculating or measuring quantitative output. A structural model focuses on the task of selecting the components of a model and explicitly stating the interaction between them [79]. What this means is that in SM, the model showing the relationships of the various variables is not in a mathematical form but in a qualitative form in terms of graphs and interconnections.

Warfield expanded SM to ISM by adding judgment of group of experts as another dimension to structural modeling. The interrelationships between the various elements in the problem are based on pair wise relationship of the elements, interpretation of which is based on the judgment of a group of experts. The structural model employing words and digraphs thus formed out of the interrelationships of the elements can be interpreted in terms of practical information which will guide in developing managerial actions to mitigate the problem. The ISM method can be used to analyze the various inhibiting factors in implementation of TPM and to find out the interrelationships among these barriers. For example, in case of TPM the task is to develop an action plan to mitigate factors inhibiting TPM implementation by systematically analyzing them using ISM which will show how these inhibitors are interrelated in a structured easy-to-understand format. Based on these interrelationships, action plan can be developed to mitigate these factors and to help industries in the implementation of TPM. In the ISM method a digraph or directed graph is developed. In a nutshell, a digraph consists of nodes connected by arrows with the direction of the arrows showing the relationship between the variables represented by the nodes. A typical digraph is shown below which shows the nature of relationships among the six variables. Double arrows between two variables indicate a 2-way relationship i.e. each affecting the other. Single arrow indicates a 1-way relationship with the direction of the arrow signifying the forward relationship from one variable to the other. Absence of arrow shows that there is no relationship between the variables. The digraph is converted to the final Interpretive Structural Model by replacing the node numbers by the variable description written in the text boxes. Readers are advised to go through the paper "*Interpretive Structural Modeling (ISM) and is application in analyzing factors inhibiting implementation of Total Productive Maintenance (TPM)*" by the authors of this paper for details on ISM.

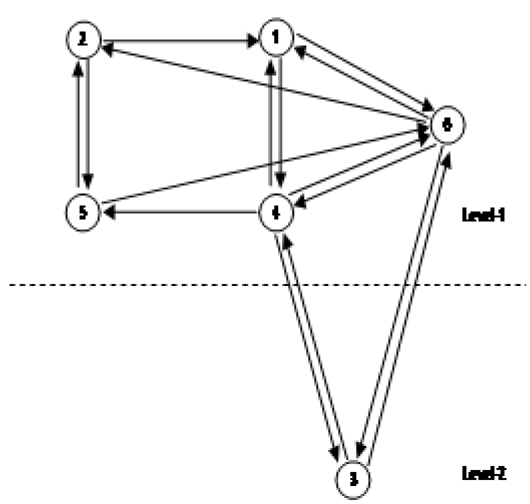


Fig-1: *Typical Digraph*

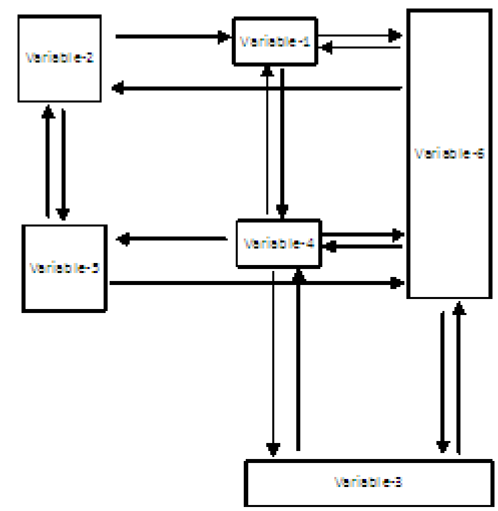


Fig-2: *Typical Interpretive Structural Model*

By carrying out structural modeling, the following questions can be answered:

- How complex is the problem? What is the complexity involved?
- How are the variables interconnected? What are the direct and indirect linkages? Action on which variable will affect the system the most? Which are the key variables that influence the system? Which are the variables that need to be considered the least in analyzing the problem?
- The ISM developed can be analyzed to determine the driving power and dependence of each of the variables. Higher driving power shows the extent of influence that the variable has on the other variables while higher dependence power shows the extent to which the variables are affected by / depend on the other variables. The driving / dependence power is plotted on a MICMAC graph as shown below.

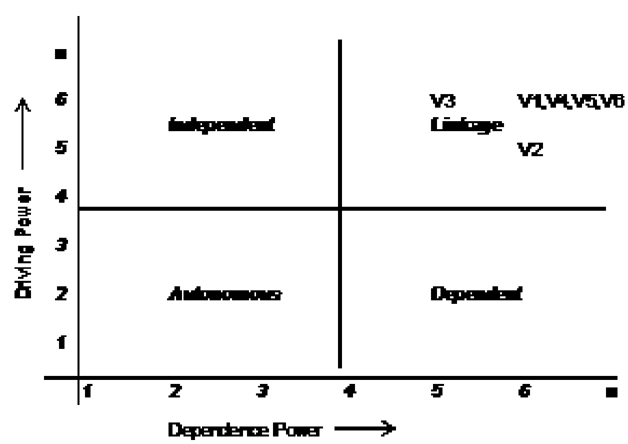


Fig-3: *MICMAC Graph*

The four quadrants of the graph show the categories of variables as given in the following table:

TABLE-1
CATEGORIES OF VARIABLES

Categories	Driving Power	Dependence Power	Characteristics	Quadrant in MICMAC Graph
Autonomous	Low	Low	These variables do not affect the system to a great extent. They remain extraneous variables.	Bottom-Left
Linkage	High	High	These variables cause instability of the system. Any action on these variables will cause volatility in the system	Top-Right
Independent	High	Low	Strongly influences the system but is not influenced by the system. Any action on these variables will affect other variables which are dependent on these variables.	Top-Left
Dependent	Low	High	Strongly influenced by the system but does not influence the system. These variables are sensitive to the action taken on the influent variables.	Bottom-Right

- What activities are required to be taken up by the management to take the necessary action on the variables of the problem? What will be the effect on the organization as a result of the activities? Are new equipments and machines required? What will be the financial implications?

5.0. Applications of ISM

ISM has been used in a host of fields like marketing, advertising, business processes, education, supply chain management etc. Salimifard et al. [102] have used ISM to study the critical factors in banking process re-engineering. ISM has also been used to study advertising strategy by Shukla et al. [110]. Sohani and Sohani [113] have used ISM to analyze the factors for success of quality management system in higher education. Wu and Bian [132] have analyzed the factors affecting implementation of cost control in a hydropower construction project using ISM. An ISM based analysis was carried out by Jharkharia [51] for analyzing critical failure factors in Enterprise Resource Planning implementation. ISM has been extensively used in supply chain management. Kubde and Bansod [57] have used ISM approach for adopting Collaborative Planning Forecasting and Replenishment (CPFR) to improve supply chain effectiveness. Mandal and Deshmukh [70] have used ISM for vendor selection. Similar study was also carried out by Kumar and Kant [60] who have studied enablers for selecting a suitable supplier for an organization. Similarly Pramod and Banwet [96] have carried out a study to develop an integrated model to enumerate the interrelationship between the inhibitors hindering the smoothness of a telecom service supply chain. Govindan et al. [40] have created a model to analyze risks in a food supply chain. Knowledge Management is another field researchers have exploited using ISM. Tabrizi et al. [117] has used ISM to establish relationships among the criteria for measuring Knowledge Management results. Critical implementation factors for Knowledge Management implementation in project based business have been studied by Jafari et al. [50]. Sharma B. P. et al. [107]; Joshi et al. [52]; Singh and Kant [111] have studied the barriers that hinder knowledge sharing and management in an organization. ISM has also been used in the manufacturing field. Sarkis et al. [103] have used ISM to analyze the factors hindering adoption of environmentally conscious manufacturing practices. ISM has been used interestingly by Xiao-lin [133] in analyzing how product parts influence each other in a product structure design. Abbasi et al. [1] have employed ISM in determining optimal manufacturing strategy.

6.0 ISM in TPM

ISM is aptly suited for analyzing the various inhibiting factors in implementation of TPM and to find out the interrelationships among these barriers. Based on the model developed in the ISM approach, action plan can be developed to mitigate these factors and to help industries in implementation of TPM. The literature survey has revealed only a few studies related to TPM involving ISM. A paper was published by Kodali and Chandra [56] describing a decision model using Analytical Hierarchy Process (AHP) for justification of requirement of TPM for Indian industries versus the traditional maintenance strategies. AHP is defined as a multi-criteria decision making approach using pair wise comparison of factors to represent simultaneous interaction of factors in complex and unstructured situations. The authors have used AHP to justify implementation of TPM in terms of the benefits accrued in productivity, quality, cost, delivery, employee morale, safety, work environment and competitive advantage against the traditional maintenance strategies Attri, Grover, Dev and Kumar [11] in January 2012 have published a paper, which illustrates the employment of ISM for modeling enablers in the implementation of TPM. By carrying out research using questionnaire survey and Likert scale, they have identified ten enablers as given below:

1. Top management commitment and support
2. Communication
3. Cultural change
4. Total employee involvement
5. Training and education
6. Integration of TPM goals and objectives into business plan
7. Motivation
8. Empowerment and encouragement
9. Cooperation
10. Coordination

They then proceed to describe ISM and how it can be used to analyze the interrelationships of enablers and determine the key enablers in TPM implementation. As per their study, the key enablers to successful implementation of TPM are a) Top management commitment, b) Communication, c) Training and education and d) Integration of TPM goals and objectives into business plan. These enablers, in turn, affect the remaining enablers. As scope for future research, the authors have recommended statistically validating the model developed in the ISM approach using Structural Equation Modeling (SEM). The same group of authors has also published an article in July 2012, on employment of ISM in determining barriers in the implementation of TPM. They state that implementation of TPM in industries is a very difficult proposition and many industries have failed in their implementation efforts. Similar to their paper on the enablers, they have used in this research questionnaire survey and Likert scale and have identified ten barriers in implementation of TPM:

1. Lack of top management support and commitment towards TPM
2. Lack of training and education
3. Lack of motivation of workforce
4. Employee resistance
5. Cultural resistance
6. Failure to allow sufficient time for evolution
7. Low synergy between maintenance and production
8. Lack of organization communication
9. Financial obstacles
10. Lack of knowledge of TPM

By using ISM, the authors have determined the key barriers to successful implementation of TPM to be a) Lack of top management commitment, b) Lack of motivation, c) Low synergy between maintenance and operation, d) Lack of communication and e) Financial constraints. As scope for future research, the authors have recommended statistically validating the model developed in the ISM approach using Structural Equation Modeling (SEM). The same concepts and ideas were described in identical fashion by Fakhraddin Maroofi in his paper published in 2013. Attri, Grover, Dev and Kumar [10] have taken the concept of using ISM in determining the barriers in TPM implementation forward by computing the intensity of the barriers using Graph Theoretical Approach (GTA). In this study, they have grouped barriers under five broad categories as given below:

TABLE-2

GROUPING OF BARRIERS

Barriers	Sub-Barriers	Barriers	Sub-Barriers
Behavioural	Lack of top management commitment	Human and Cultural	Lack of motivation
	Employee resistance		Lack of coordination
	Lack of clear vision		Inability to change organizational culture
	Lack of job security		Unwillingness of human resources to adopt TPM
	Poor coordination between maintenance and production		Less empowerment
Strategic	Ineffective long term planning	Operational	Lack of standard operating procedure,
	Non-clarity of organizational objectives		Absence of preventive maintenance schedule
	Non clarity of organization policy on TPM		Poor workplace environment
	Failure to allow sufficient time for evolution		Inadequate use of tools, techniques and methodologies
	Poor structure to support TPM initiatives		Lack of follow up of progress of TPM initiatives
Technical	Lack of technical knowledge,		
	Lack of educated workforce		
	Lack of training and development		
	Lack of understanding of TPM concepts and principles		
	Absence of CMMS		

GTA is an extension of the ISM approach in the sense that it integrates the relationship obtained among different variables. With respect to the issue of implementation of TPM, GTA mathematically categorizes the inhibiting strength of the various barriers and offers a synthetic score for the complete system known as the Intensity-Of-Barriers (IOB) score. Higher intensity indicates greater resistance to implementation of TPM. The authors have concluded that, in general, Behavioural barriers have the maximum intensity followed by Operational, Human and Cultural, Strategic and Technical barriers in that order. ISM approach for analyzing barriers in TPM implementation was also explored by Singh, Sachdeva and Bhardwaj [112] in their paper published in 2014.

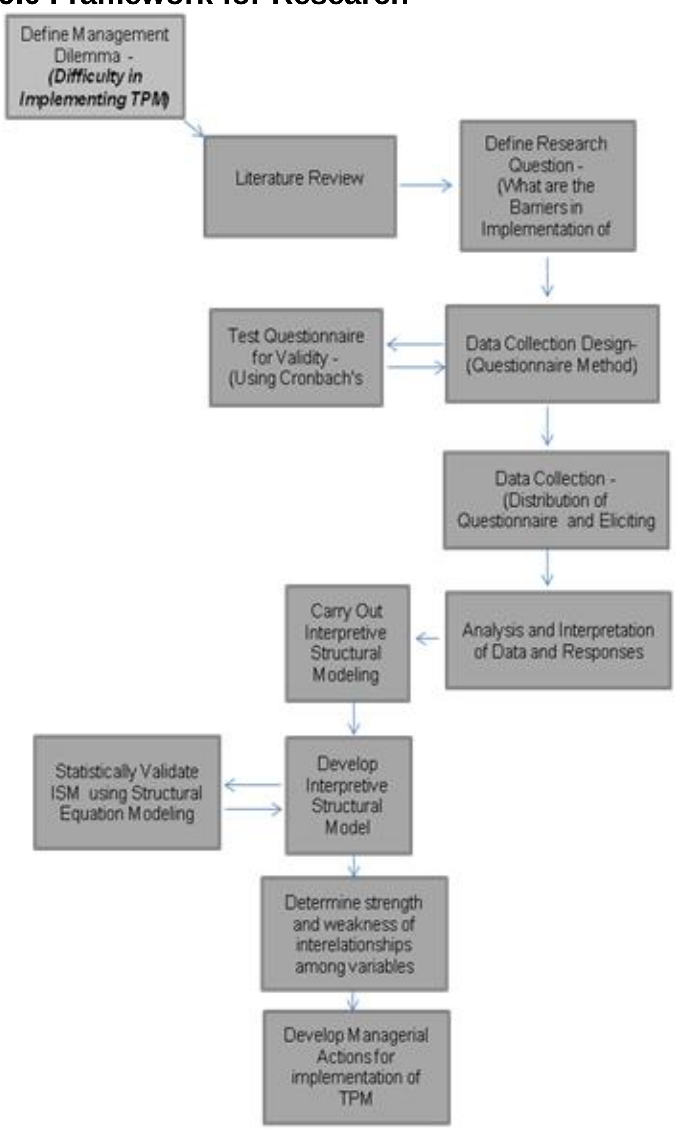
7.0 Structural Equation Modeling

Structural Equation Modeling (SEM) is a statistical technique to carry out multivariate analysis of a structural theory that stipulates causal relations among multiple variables [62]. It is a collection of statistical techniques that allows a set of relationships between one or more independent variables, either continuous or discrete, and one or more dependent variables, either continuous or discrete, to be examined [123]. SEM goes beyond ordinary regression models to incorporate multiple independent and dependent as well as hypothetical latent constructs that clusters of observed variables might represent and provide a way to test the specified set of relationships among observed and latent variables as a whole [104]. In simple terms, it is a methodology for representing, estimating and testing a network of relationships between measured variables and latent constructs [115]. Latent variables in SEM generally correspond to hypothetical constructs or factors which are explanatory variables presumed to reflect a continuum that is not directly observable [55]. SEM has been used as a validation technique in many fields. Carvalho and Chima [26] have described how SEM can be applied in social sciences research. Applications of SEM can be seen in many marketing, medical, behavioral and management related researches - Baumgartner and Homburg [16], Fornell and Bookstein [37], Hair et al. [44], Steenkamp and Baumgartner [114], Chin et al. [30], McIntosh and Gonzalez-Lima [75], Tomarken and Waller [119], McDonald and Ringo [74], Oort et al. [88], Nelson et al. [85], Weston et al. [127], Carter and Jennings [25], Tomas et al. [120], Nunkoo et al. [87], Lu et al. [66] etc. to name a few of the hundreds of articles available. SEM has been used by McKone et al. [76] to investigate relationship between TPM and manufacturing performance. Ahmad et al. [2] have used SEM to examine relationship between TQM, TPM, Statistical Process Control and Lean Production Practices. Similar study to examine relationship between TPM, TQM and Six Sigma practices in Jordan was carried out by Al-Refaie [8]. Hashim et al. [46] has proposed a conceptual model using SEM to study the relationship between TPM and Kaizen. ***Extensive literature search has yet to throw up any research involving use of SEM in validating ISM in analyzing barriers inhibiting TPM implementation.***

8.0 Observations from Current Literature and Gap Analysis

There is an enormous amount of literature on TPM depicting its aspects in great detail and dedicated to the concepts and factors for implementation in industries. There are also articles on barriers in implementing TPM gathered from academicians and researchers based on questionnaire method of data collection. ISM is a preferred method by researchers to analyze the interrelationships of variables in any complex issue in an organization. From the literature review it is seen that ISM has been used to analyze the barriers in TPM implementation only by a few authors [9], [10], [11], [12], [71], [112]. Hence there is more scope for carrying out detailed analysis by ISM on barriers in TPM implementation. The model developed by ISM can be validated using Structural Equation Modeling (SEM). Extensive literature search has not thrown up any research involving use of SEM in validating Interpretive Structural Model of barriers inhibiting TPM even though SEM has been used by one author to investigate relationship between TPM and manufacturing performance. As proposed by Attri et al. [9], [10], [11] and [12], the ISM model of barriers in TPM implementation can be statistically validated using SEM. In many of the research studies using ISM, authors have suggested using SEM to validate the models developed in ISM as future research. With this background further research can be carried out on analyzing barriers in TPM implementation using ISM and validating the model using SEM. The authors are presently carrying out research on the same.

9.0 Framework for Research



10.0 Expected Outcomes of the Research on TPM, ISM in analyzing barriers in implementation of TPM and SEM to validate the model developed in ISM

By carrying out research on barriers in TPM implementation, the following are the expected outcomes:

1. An Interpretive Structural Model showing the interrelationships among the various factors which are impediments to TPM implementation
2. By analyzing the model, the following issues can be dissected
   a. Which are the critical factors that are to be analyzed? Which factors are the driving powers?
   b. How are all the factors interlinked?
   c. What is the depth and significance of inter-linkages between the factors?
3. Statistical Validation of the Model using Structural Equation Modeling
4. Derive managerial actions for TPM implementation based on the interrelationships in the Interpretive Structural Model. What are the key aspects to be focused upon by the management to ensure a successful implementation of TPM?
5. Benefits of implementing the model in terms of cost, efficiency, productivity and profits.

11.0 Conclusion

It can be inferred from this paper that though there is a vast amount of literature on TPM and its concepts, what is available on the aspects affecting the implementation of TPM in industries is limited. There is great scope for carrying out additional research on this issue using ISM. It is also seen that statistical validation of the model developed in ISM is yet to be carried out by researchers and there is an opportunity in this space for further research.

REFERENCES

[1] Abbasi, Mehdi; Shirazi, Mohsen Akbarpour; Aryanezjad, Mir Bahador - Determination of Manufacturing Strategy using Interpretive Structural Modeling, African Journal of Business Management, Volume 6 (3), January 2012

[2] Ahmad, M. F.; Zakuan, N.; Jusoh, A.; Takala, J. - Relationship of TQM and Business Performance with Mediators of SPC, Lean Production and TPM, International Congress on Interdisciplinary Business and Social Science, Procedia Social and Behavioural Sciences, 2012

[3] Ahuja, I.P.S.; Khamba, J.S. – An Evaluation of TPM Initiatives in Indian Industry for Enhanced Manufacturing Performance, International Journal of Quality and Reliability Management, Volume 25, Issue 2, 2008

[4] Ahuja, I.P.S.; Khamba, J.S. - Investigation of Manufacturing Performance Achievements through Strategic TPM Initiatives, International Journal of

Productivity and Quality Management, Volume 4, No.2, 2009

[5] Ahuja, I.P.S.; Khamba, J.S. - Justification of TPM Initiatives in Indian Manufacturing Industry for Achieving Core Competitiveness, Journal of Manufacturing Technology Management, Volume 19, Issue 5, 2008

[6] Ahuja, I.P.S.; Khamba, J.S. - Strategies and Success Factors for Overcoming Challenges in TPM Implementation in Indian Manufacturing Industry, Journal of Quality in Maintenance Engineering, Volume 14, Issue 2, 2008

[7] Ahuja, I.P.S.; Khamba, J.S. - Total Productive Maintenance, Literature Review and Directions, International Journal of Quality and Reliability Management, Volume 25, No.7, April 2008

[8] Al-Refaie, Abbas; Hanayneh, Bassel – Influences of TPM, TQM, Six Sigma Practices on Firms Performance in Jordan, International Journal of Productivity and Quality Management, Volume 13, No.2, 2014

[9] Attri, Rajesh; Dev, Nikhil; Sharma, Vivek - Interpretive Structural Modeling (ISM): An Overview, Research Journal of Management Sciences, Volume 2(2), 3-8, February 2013

[10] Attri, Rajesh; Grover, Sandeep; Dev, Nikhil; Kumar, Deepak – A Graph Theoretic Approach to Evaluate Intensity of Barriers in the Implementation of Total Productive Maintenance (TPM), International Journal of Production Research, December 2013

[11] Attri, Rajesh; Grover, Sandeep; Dev, Nikhil; Kumar, Deepak - An ISM Approach for Modeling the Enablers in the Implementation of Total Productive Maintenance (TPM), International Journal of System Assurance and Engineering Management, January 2012

[12] Attri, Rajesh; Grover, Sandeep; Dev, Nikhil; Kumar, Deepak - Analysis of Barriers of Total Productive Maintenance, International Journal of System Assurance and Engineering Management, July 2012

[13] Aziz, Iftekhar; Karim, Sazedul; Hossain, Md. Mosharraf - Effective implementation of Total Productive Maintenance and Impacts on Breakdown Time and Repair and Maintenance: A Case Study of Printing Industry in Bangladesh, International Journal of Engineering Research and Development, Volume 8, Issue 1, July 2013

[14] Bakri, Adnan Hj.; Rahman, Abdul; Rahim, Abdul; Yusof, Noordin Mohd. - Towards Successful Total Productive Maintenance (TPM): How Well the Management Commitment being Assessed?, International Conference on Management, Economics and Finance, 15-16 October 2012

[15] Bamber, C.J.; Sharp, J.M.; Hides, M.T – Factor Affecting Successful Implementation of Total Productive Maintenance: A UK Manufacturing Case Study Perspective, Journal of Quality in Maintenance Engineering, Volume 5, Issue 3, 1999

[16] Baumgartner, Hans; Homburg, Christian – Applications of Structural Equation Modeling in Marketing and Consumer Research: A Review, International Journal of Research in Marketing, 01/1996

[17] Ben-Daya, Mohamed; Duffuaa, Salih O.; Raouf, Abdul; Knezevic, Jezdimir; Ait-Kadi, Daoud - Handbook of Maintenance Management and Engineering, 2009

[18] Bin Bon, Abdul Talib; Karim, Noorazira - TPM Applications to Reduce Defect of Products, Journal of Applied Sciences Research, 7 (1), 2011

[19] Blanchard, Benjamin S.; Verma, Dinesh; Peterson, Elmer L. – Maintainability: A Key to Effective Serviceability and Maintenance Management, 1995

[20] Bohlouli, Nader; Farabi, Mohammad; Tirabadi Peyman; Tajvidi, Mina - Analyzing the Impact of Effective Factors of Implementing TPM System in Manufacturing Organizations (Case Study: Motorsazan Co.), Australian Journal of Basic and Applied Sciences, 7(7), 2013

[21] Brah, Shaukat A.; Chong, W. K. - Relationship Between TPM and Performance, International Journal of production Research, January 2004

[22] Brauer, Douglas C.; Brauer, Greg D. – Reliability Centered Maintenance, IEEE Transactions on Reliability, Volume R-36, Issue 1, 1987

[23] Brook, R. - “Total Predictive Maintenance Cuts Plant Costs”, Plant Engineering, Volume 52, No. 4, 1998

[24] Call, Robert - Analyzing the Relationship of Preventive Maintenance to Corrective Maintenance, Maintenance Technology, June 2007

[25] Carter, Craig R.; Jennings, Marianne M. – The Role of Purchasing in Corporate Social Responsibility: A Structural Equation Analysis, Journal of Business Logistics, Volume 25, Issue 1, February 2004

[26] Carvalho, Jackson de; Chima, Felix O. – Applications of Structural Equation Modeling in Social Sciences Research, American International Journal of Contemporary Research, Volume 4, No.1, January 2014

[27] Chan, F.T.S.; Lau, H.C.W.; Ip, R.W.L.; Chan, H.K.; Kong, S. - Implementation of Total Productive Maintenance – A Case Study, International Journal of Production Economics, Volume 95, Issue 1, January 2005

[28] Chand, G.; Shirvani, B - Implementation of TPM in Cellular Manufacture, Journal of Materials Processing Technology, 103, 2000, pp.149-154

[29] Chaneski, W.S. - "Total Productive Maintenance – An Effective Technique", Modern Machine Shop, Volume 75, No. 2, 2002

[30] Chin, Wynne W.; Peterson, Robert A.; Brown, Steven P. – Structural Equation Modeling in Marketing: Some Practical Reminders, Journal of Marketing Theory and Practice, Volume 16, No.4, 2008

[31] ChoyDS, Siam Yoke - TPM Implementation Experiences, Maintenance Resources Inc., 2003

[32] Cooke, F.L. - Implementing TPM in Plant Maintenance: Some Organizational Barriers, International Journal of Quality & Reliability Management, Vol. 17, No. 9, 2000

[33] Davis, R.; Willmott, P. – Total Productive Maintenance, Alden Press, 1999

[34] Dean, J.W.; Bowen, D.E – Management Theory and Total Quality: Improving Research and Practice through Theory Development, Academy of Management Review, 1994

[35] Dunbrack, Fred – Senior Management Commitment, Maintenance Technology, 2005

[36] Eti, M.C.; Ogaji, S.O.T.; Probert, S.D. – Implementing TPM in Nigerian Manufacturing Industries, Applied Energy, Volume 79, Issue 4, December 2004

[37] Fornell, Claes; Bookstein, Fred L. – Two Structural Equation Modules: LISREL and PLS Applied to Consumer Exit – Voice Theory, Journal of Marketing Research, Volume 19, No.4, November 1982

[38] Frendall; Patterson; Kennedy - Maintenance: Modeling Its Strategic Impact, Journal of Managerial Issues, December 1997

[39] Goriwondo, William M.; Mhalanga, Samson; Kazembe, Tapiwa – Optimizing a Production System Using Tools of TPM: Datlabs Pharmaceuticals As a Case Study, 2011 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia, January 22 – 24, 2011

[40] Govindan, Kannan; Diabat, Ali; Panicker, Vinay V - Supply Chain Risk Management and its Mitigation in a Food industry, International Journal of Production Research, 2012

[41] Graisa, Mustafa; Al-Habaibeh, Amin - An Investigation into Current Production Challenges facing the Libyan Cement Industry and the Need for Innovative TPM Strategy, Journal of Manufacturing Technology Management, Volume 22, Issue 4, 2011

[42] Griffin, Ricky W.; Moorhead, Gregory - Organizational Behaviour: Managing People and Organizations, 2008

[43] Gupta, Sorabh; Tewari, P.C.; Sharma, Avadhesh Kumar – TPM Concept and Implementation Approach

[44] Hair, Joe F.; Sarstedt, Marko; Ringle, Christian M.; Mena, Jeannette A. – An Assessment of the Use of Partial Least Squares Structural Equation Modeling in Marketing Research, Journal of the Academy of Marketing Science, 7 June 2011

[45] Hasan, Khalid; Chan, Joseph, Fat-Lam; Metcalfe, Andrew Viggo - The Role of TPM in Business Excellence, Total Quality Management, Volume 11, No.4,5&6, 2000

[46] Hashim, Suzaituladwini; Habidin, Nurul Fadly; Conding, Juriah; Zubir, Anis Fadzlin Mohd; Jaya, Nurzatul Ain Seri Lanang – The Integrated between Total Productive Maintenance Practices and Kaizen Event Practices in Malaysian Automotive Industry, International Journal of Engineering Research and Applications, Volume 2, Issue 5, September-October 2012

[47] Herbaty, F. - Handbook of Maintenance Management: Cost Effective Practices, 2nd ed.,1990

[48] Ireland, F.; Dale, B. G. - A Study of Total Productive Maintenance Implementation, Journal of Quality in Maintenance Engineering, Volume 7, Issue 3, 2001

[49] Jadhav, Ranjeet M.; Alessandro, Morosin; Sawant, S. H. - Total Productive Maintenance Theoretical Aspect: A Journey towards Manufacturing Excellence, IOSR Journal of Mechanical and Civil Engineering

[50] Jafari, Mostafa; Akhavan, Peyman; Naeini, Hamid Reza; Nejati, Hamed S. - Using Interpretive Structural Modeling to Analyze Critical Factors of Knowledge Management in Project-based Business, Industrial Management Journal, Volume 7, No. 22, 2013

[51] Jharkharia, Sanjay - Interrelations of Critical Failure Factors in ERP Implementation: An ISM Based

Analysis, 3rd International Conference on Advanced Management Science, Volume 19, 2011

[52] Joshi, Yash; Parmer, Satendre; Chandrawat, Saurabh S. - Knowledge Sharing in Organizations: Modeling the Barriers, an Interpretive Structural Modeling Approach, International Journal of Engineering and Innovative Technology, Volume 2, Issue 3, September 2012

[53] Keeter, Bill; Plucknette, Doug – The Seven Questions of Reliability Centered Maintenance, RCM-2008, Reliability Centered Maintenance Manager's Forum

[54] Kenne, J.P.; Boukas, E.K.; Gharbi, A. - Control of Production and Corrective Maintenance Rates in a Multiple-machine Multiple-product Manufacturing System, Mathematical and Computer Modeling, February 2003

[55] Kline, Rex B. – Principles and Practices of Structural Equation Modeling, The Guilford Press, 3rd Edition, 2011

[56] Kodali, Rambabu; Chandra, Subhash - Analytical Hierarchy Process for Justification of Total Productive Maintenance, Production Planning and Control, Volume 12, No. 7, 2001

[57] Kubde, Rajesh A.; Dr. Bansod, Satish V - Interpretive Structural Modeling based Approach for Adopting CPFR in Indian Industries, International Journal of Research in Commerce, IT and Management, Volume 2, Issue 12, December 2012

[58] Kulkarni, Abhay; Dr. Dabade, B. M. - Investigation of Human Aspect in Total Productive Maintenance: Literature Review, International Journal of Engineering Research and Development, Volume 5, Issue 10, January 2013

[59] Kumar, Jitendra; Sonia, Vimlesh Kumar; Agnihotri, Geeta – Impact of TPM Implementation on Indian Manufacturing Industry, Indian Journal of Productivity and Performance Management, Volume 63, No.1, 2014

[60] Kumar, Sudarshan; Kant, Ravi - Supplier Selection Process Enablers: An Interpretive Structural Modeling Approach, International Journal of Mechanical and Industrial Engineering, Volume 3, Issue 1, 2013

[61] Lazim, H.M; Ramayah, T; Norzieiriani, Ahmad - Total Productive Maintenance and Performance: A Malaysian SME experience, International Review of Business Research Papers, Volume 4, No. 4, Aug-Sep 2008

[62] Lei, Pui-Wa; Wu, Qiong – Introduction to Structural Equation Modeling: Issues and Practical Considerations

[63] Lendaris, George G. - Structural Modeling: A Tutorial Guide, IEEE Transactions on Systems, Man and Cybernetics, Volume 5, MC-10, No 12, December 1980

[64] Levitt, Joel - A Complete Guide to Preventive and Predictive Maintenance, Industrial Press Inc., 2003

[65] Life Cycle Engineering - Working without Supervision: Overcoming Inefficiencies and Lost Productivity, 2008

[66] Lu, Chin-Shan; Lai, Kee-Hung; Cheng, T.C.E. – Application of Structural Equation Modeling to Evaluate the Intention of Shippers to Use Internet Services in Liner Shipping, European Journal of Operational Research, June 2006

[67] Lycke, Liselott - Implementing TPM: Driving Force and Obstacles, Lulea University of Technology, Thesis March 2000

[68] Lycke, Liselott - Team Development when Implementing TPM, Total Quality Management and Business Excellence, Volume 14, Issue 2, 2003.

[69] Maggard, B.N.; Rhyne, D.M. - "Total Productive Maintenance: A Timely Integration of Production and Maintenance", Production and Inventory Management Journal, Vol. 33 No. 4, 1992

[70] Mandal, Anukul; Deshmukh, S.G. - Vendor Selection using Interpretive Structural Modeling, International Journal of Operations and Production Management, Volume 14, Issue 6, 1994

[71]

[72] Maroofi, Fakhraddin – Total Productive Maintenance for Modeling the Enablers in the Performing of ISM Access, International Research Journal of Applied and Basic Sciences, Volume 6(8), 2013

[73] McBride, David - How to Implement TPM?, www.reliableplant.com

[74] McBride, David - Implementing TPM Total Productive Maintenance (TPM), Lean Manufacturing, 2004

[75] McDonald, Roderick P.; Ringo Ho, Moon-Ho – Principles and Practice in Reporting Structural Equation Analysis, Psychological Methods, Volume 7, No.1, 2002

[76] McIntosh, A.R.; Gonzalez-Lima, F – Structural Equation Modeling and Its Application to Network Analysis in Functional Brain Imaging, Human Brain Mapping 2:2-22, 1994

[77] McKone, Kathleen; Schroeder, Roger G and Cua, Kristy O: The Impact of TPM practices on Manufacturing Performance, Journal of Operations Management, October 1999.

[78] McKone, Kathleen; Schroeder, Roger G and Cua, Kristy O: TPM – A Contextual View, Journal of Operations Management, April 1998

[79] McKone, Kathleen; Weiss, Elliot N. – TPM: Planned and Autonomous Maintenance: Bridging the Gap between Research and Practice, Production and Operations Management, Volume 7, No.4, 1998

[80] McLean, J.M.; Shepherd, P - The Importance of Model Structure, Futures, February 1976

[81] Mobley, Keith - An Introduction to Predictive Maintenance, 2nd Edition, 2002

[82] Moore, Ron - Combining TPM And Reliability Focused Maintenance, Plant Engineering Journal, June 1997

[83] Nakajima, S. – Introduction to TPM: Total Productive Maintenance, 1988

[84] Nakamura, T. - Total Productive Maintenance, Encyclopedia of Statistics in Quality and Reliability, March 2008

[85] Narender; Gupta, A.K. - A Review of Total Productive Maintenance System into an Indian Service Sector, International Journal of Mechanical and Production Engineering, Volume 1, Issue 1, 2012

[86] Nelson, Timothy D.; Aylward, Brandon S.; Steele, Ric G.– Structural Equation Modeling in Pediatric Psychology: Overview and Review of Applications, Journal of Pediatric Psychology, Volume 33, Issue 7, 2007

[87] Nowlan, Stanley; Heap, Howard - Reliability Centred Maintenance, US Department of Commerce, December 1978

[88] Nunkoo, Robin; Ramkissoon, Haywantee; Gursoy, Dogan – Use of Structural Equation Modeling in Tourism Research: Past, Present and Future, Journal of Travel Research, March 2013

[89] Oort, Frans J.; Visser, Mechteld R. M.; Sprangers, Mirjam A. G. – An Application of Structural Equation Modeling to Detect Response Shifts and True Change in Quality of Life Data from Cancer Patients undergoing Invasive Surgery, Quality of Life Research, 14, 2005

[90] Panneerselvam, Murugadoss K. - TPM Implementation to Invigorate Manufacturing Performance: An Indian Industrial Rubric, International Journal of Scientific & Engineering Research, Volume 3, Issue 6, June 2012

[91] Paropate, Ravikant V.; Jachak, Shrikant R.; Hatwalne, Prasad A. - Implementing Approach of Total Productive Maintenance in Indian Industries and Theoretical Aspect: An Overview, International Journal of Advanced Engineering Sciences and Technologies, Volume 6, Issue 2, 2011

[92] Patra, Nihar Kanta; Tripathy, Jayanta Kumar; Dr Choudhary, B. K. - Implementing the Office Total Productive Maintenance program: A Library Case Study, Library Review Volume. 54 No. 7, 2005

[93] Patterson, J.W.; Kennedy, W.J.; Frendall, L.D. - Total Productive Maintenance is Not for This Company, Production and Inventory Management Journal, Volume 36, No. 2, 1995

[94] Pintelon, Liliane; Parodi-Herz, Alejandro – Maintenance: An Evolutionary Perspective

[95] Poduval, Prasanth S; Dr. Pramod, V. R.; Dr. Jagathy Raj V.P. - Barriers in Implementation of TPM in Industries, International Journal of Scientific and Technology Research, Volume 2, Issue 5, May 2013

[96] Pomorski, Thomas R. - Total Productive Maintenance (TPM), Concepts and Literature Review, April 30 2004

[97] Pramod, V.R.; Banwet, D.K - Analyzing the Synergic Power of Inhibitors of an Indian Telecom Supply Chain, International Journal of Business Excellence, Volume 6, No 4, 2013

[98] Renwik, John T; Babson, Paul E - Vibration Analysis: A Proven Technique as a Predictive Maintenance Tool, IEEE transactions on Industry Applications, Volume IA-21, Issue-2, March 1985

[99] Roberts, Jack - Total Productive Maintenance, Technology Interface, 1997

[100] Robinson; Ginder – Implementing TPM: The North American Experience, 1995

[101] Rodrigues, M.; Hatakeyama, K. - Analysis of the Fall of TPM in Companies, Journal of Materials Processing Technology, Volume 179, Nos 1-3, 2006

[102] Sahu, Hemlatha; Batham, J. M.; Bangar, A. - Implementing Total Productive Maintenance in Jamna Auto Industry Malanpur, International Journal of Engineering Research and Technology, Volume 1, Issue 9, Nov 2012

[103] Salimifard, Khodakaram; Abbaszadeh, Mohammad Ali; Ghorbanpur, Ahmad - Interpretive Structural Modeling of Critical

Success Factors in Banking Process Re-engineering

[104] Sarkis, Joseph; Hasan, Mohd. Asif; Shankar, Ravi - Evaluating Environmentally Conscious Manufacturing Barriers with Interpretive Structural Modeling, Social Science Research Network

[105] Savalei, Victoria; Bentler, Peter M. – Structural Equation Modeling, The Handbook of Marketing Research: Uses, Misuses and Future Advances, 2006

[106] Sekine, Ken'ichi; Arai, Keisuke - TPM for the Lean Factory, Innovative Methods and Worksheets for Equipment Management, 1998

[107] Sharma, Ashok Kumar; Shudhanshu; Bhardwaj, Awadhesh - Manufacturing Performance and Evolution Of TPM, International Journal of Engineering Science and Technology (IJEST), Voume.4, No.3, March 2012

[108] Sharma, B.P.; Singh, M.D.; Neha - Modeling the Knowledge Sharing Barriers using an ISM Approach, International Conference on Information and Knowledge Management, Volume 45, 2012

[109] Sharma, Rajiv Kumar; Kumar, Dinesh; Kumar, Pradeep - Methodology and Theory to Select Suitable Maintenance Strategy in Process Industries using MISO model, Journal of Quality in Maintenance Engineering, Volume 11, No. 4, 2005

[110] Shiroze, K. - TPM - Total Productive Maintenance: New Implementation Program in Fabrication and Assembly Industries, 1996

[111] Shukla, Arpit; Talankar, Amol; Dr. Mishra, Ashish - Advertising Strategy for FMCG product: Analysis using Interpretive Structural Modeling, International Journal of Engineering Research and Technology, Volume 1, Issue 8, October 2012

[112] Singh, M.D.; Kant, R - Knowledge Management barriers: An Interpretive Structural Modeling Approach, International Journal of Management Science and Engineering Management, Volume 3, No.2, 2008

[113] Singh, Manjinder; Sachdeva, Anish; Bhardwaj, Arvind – An Interpretive Structural Modeling Approach for Analyzing Barriers in Total Productive Maintenance, International Journal of Industrial and Systems Engineering, Volume 16, No.4, 2014

[114] Sohani, Neena; Sohani, Nagendra - Developing Interpretive Structural Model for Quality Framework in Higher Education: Indian Context, Journal of Engineering, Science and Management Education, Volume 5, Issue 2, June 2012

[115] Steenkamp, Jan-Benedict E. M.; Baumgartner, Hans – On the Use of Structural Equation Models for Market Modeling, International Journal of Research in Marketing, Volume 17, Issues 2-3, September 2000

[116] Suhr, Diana – The Basics of Structural Equation Modeling

[117] Suzuki, T. - TPM in Process Industries, 1992

[118] Tabrizi, Reza Sigari; Foong, Yeap Peik; Ebrahimi, Nazli - Using Interpretive Structural Modeling to Determine the Relationships Among Knowledge Management Criteria inside Malaysian Organizations, World Academy of Science Engineering and Technology, 2010

[119] Taisir, Osama - Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement, Jordan Journal of Mechanical and Industrial Engineering, Volume 4, No.4, September 2010

[120] Tomarken, Andrew J.; Waller, Niels G. – Structural Equation Modeling: Strengths, Limitations and Misconceptions, Annual Review of Clinical Psychology, Volume-1, 31-65

[121] Tomas, Ines; Marsh, Herbert W.; Gonzalez-Roma, Vicente; Valls, Victor; Nagengast, Banjamin – Testing Measurement Invariance Across Spanish and English Versions of the Physical Self Description Questionnaire: An Application of Exploratory Structural Equation Modeling, Journal of Sport and Exercise Psychology, 36, 2014

[122] Tranter, Jason - The Fundamentals of and the Application of Computers to Condition Monitoring and Predictive Maintenance, COMADEM International, 1989

[123] Tsarouhas, Panagiotis - Implementation of TPM in Food Industry – A Case Study, Journal of Quality in Maintenance Engineering, Volume 13, Issue 1, 2007

[124] Ullman, Jodie B.; Bentler, Peter M. – Structural Equation Modeling

[125] Van der Wal, R.W.E.; Lynn, D. - TPM in a South African Pulp and Paper company –A Case Study, The TQM Magazine, Volume 14, Issue 6, 2002

[126] Volkert, P.; Farrow, B. - Orchestrating the Pillars of TPM, 11th Total Productive Maintenance Conference and Exposition, Productivity Inc.

[127] Wang, Fu Kwun - Evaluating the Efficiency of Implementing TPM, Total Quality Management and Business Excellence, Volume 17, Issue 5, 2006

[128] Weston, Rebecca;. Gore Jr., Paul A; Chan, Fong; Catalano, Denise – An Introduction to Using Structural Equation Models in Rehabilitation Psychology, Rehabilitation Psychology, Volume 53, No.3, 2008

[129] Willmott, Peter; McCarthy, Dennis - TPM A Route to World-Class Performance, Butterworth-Heinemann, 2001

[130] Wireman, Terry - How is TPM different?, Adams Business Media Inc., 2000

[131] Wireman, Terry – Inspection and Training for TPM, 1992

[132] Witt, C.E. – TPM: The Foundation of Lean, Material Handling Management, Volume 61, No.8, 2006

[133] Wu, Yunna; Bian, Qing - An Analysis of the Driver Affecting Implementation of Cost Control in Hydropower Construction Project based on ISM-FAHP, Communications in Information Science and Management Engineering, Volume 2, Issue 7, 2012

[134] Xiao-lin, Deng - Product Structure Analysis Method based on the Interpretive Structural Modeling, International Conference on Mechanical Engineering and Material Science, 2012