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ON
STUDY ON IMPLEMENTATION OF SUCCESSFUL MAINTENANCE SYSTEM

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MASTER OF TECHNOLOGY

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PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By

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CANDIDATE'S DECLERATION

I hereby certify that the work which is being presented in this thesis entitled, "**Study on Implementation of Successful Maintenance System**" is partial fulfillment of the requirements for the award of degree of **"Master of Technology"** with specialization in **Production & Industrial Engineering** submitted to **Delhi Technological University**, **Delhi** is an authentic work carried out by me under the supervision of. Dr. Rajesh Kumar Singh, Associate Professor in Mechanical & Production Engineering department.

The matter embodied in this report has not submitted to any other university/institute for award of any degree or diploma or any other purpose whatsoever.

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This is to certify that dissertation entitled "**Study on Implementation of Successful Maintenance System"** being submitted by **Mr. Sachin Yadav** in the Fulfillment for the award of degree of **"MASTER of TECHNOLOGY"** with Specialization in **"PRODUCTION AND INDUSTRIAL ENGINEERING"** submitted to **DELHI TECHNOLOGICAL UNIVERSITY, DELHI** is a bona fide thesis work carried out by him under my supervision.

The matter in this dissertation has not been submitted to any other university or institute for the award of any degree.

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ABSTRACT

In twenty-first century, the global manufacturing industry is becoming more competitive not only in India but also across worldwide. The global competition characterized by both technology push and market pull had forced companies so as to achieve performance by continuously improving both products and processes. To maintain the position in the global market, organization has to fulfill their commitment with consumers which they can achieve by proper maintenance of machines. Manufacturing organizations are using indigenous development of technology by incorporating concepts of lean manufacturing, total productive maintenance (TPM) and low cost automation techniques to increase their competitiveness. This new approach helps the company to reduce cost of manufacturing and to increase the productivity by reducing cycle time, waste and down time. However, using new heavy machinery in place of old point towards high cost will decreasing graph of turnover. So organizations need to find new way to survive by using the existing recourses to gain maximum profit. TPM is one of the interesting alternatives as it can deliver competitive advantages such as less error, more flexibility, encourage innovations, reduction in cycle time, reduction in accident, cost effectiveness. Quality and maintenance of manufacturing systems are closely related functions of any organization. Over a period of time two concepts have emerged which is total productive maintenance (TPM) and total quality management (TQM) along with other concepts to achieve world class manufacturing system.

Aim of this research is to identify and prioritize the solutions of maintenance management (MM) to overcome its barriers. It helps organizations to concentrate on high rank solutions and develop strategies to implement them on priority. This research proposes a framework based on fuzzy analytic hierarchy process (FAHP) and fuzzy technique to order performance from similarity to ideal solution (TOPSIS) to identify and rank the solutions of Total Productive Maintenance (TPM) and overcome its barriers. The fuzzy AHP is used to determine weights of the barriers, and fuzzy TOPSIS method is used to obtain final ranking of the solutions of maintenance management (MM).This proposed framework provides a more accurate, effective and systematic decision support tool for stepwise implementation of the solutions of maintenance management to increase its productivity with reduction in accidents & breakdowns.

LIST OF FIGURES

LIST OF TABLE

ABBREVIATIONS

AHP	Analytic Hierarchy Process
AMT	Advanced Manufacturing Technologies
CBDB	Coordination Between Department Barrier
Cci	Closeness Coefficient
CI	Consistency Index
CR	Consistency Ratio
DRR	Defect Rate Reduction
EMJS	Employee Morale and Job Satisfaction
FNIS	Fuzzy Negative-Ideal Solution
FPIS	Fuzzy Positive-Ideal Solution
IEE	Improve Equipment Effectiveness
IP	Improvement in Productivity
IQ	Improvement in Quality
IS	Improvement in Safety
LTR	Lead Time Reduction
MCDM	Multi Criteria Decision Making
MMM	Modern Maintenance Management
OCB	Organization Culture Barrier
OEE	Original Equipment Effectiveness
PV	Priority Vector
QRB	Quality Related Barrier
R & D	Research & Development
RCI	Random Consistency Index
SC	Supply Chain
SOB	Solution of Barriers
TFN	Triangular Fuzzy Number
TMB	Top Management Barrier
TMM	Traditional Maintenance Management
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
TPM	Total Productive Maintenance
TQM	Total Quality Management
Wt.	Weight

CHAPTER 1
INTRODUCTION

1.1 Background of Maintenance Management

Manufacturing organizations are facing the global competition characterized by both technology push and market pull. The reason behind their characterization is global competition and to improve performance by continuously improving both products and processes. To maintain the position in the global market, organizations have to fulfill their commitment with consumers which they can achieve by proper maintenance of machines.

Maintenance engineering uses engineering theories and practices to plan and implement routine maintenance of equipment and machinery. This must be done in conjunction with optimizing operating procedures and budgets to attain and sustain the highest levels of reliability and profit. The onslaught of high-tech machinery, multiple infrastructures and systems, and intricate computerized manufacturing and production systems over the past few decades have elevated these jobs to new levels of responsibility and qualification requirements. A person working in the field of maintenance engineering must have in-depth knowledge of or experience in basic equipment operation, logistics, probability, and statistics. Experience in the operation and maintenance of machinery specific to a company's particular business is also frequently required. Since the position normally requires oral and written communications with various levels of personnel, excellent interpersonal communication and participatory management skills are also desirable.

Maintenance engineering positions require planning and implementing routine and preventive maintenance programs. In addition, regular monitoring of equipment is required to visually detect faults and impending equipment or production failures before they occur. These positions may also require observing and overseeing repairs and maintenance performed by outside vendors and contractors. In a production or manufacturing environment, good maintenance engineering is necessary for smooth and safe daily plant operations. Maintenance engineers not only monitor the existing systems and equipment, but they also recommend improved systems and decide when systems are outdated and in need of replacement. Such a position often involves exchanging ideas and information with other maintenance engineers, production managers, and manufacturing systems engineers.

The maintenance engineer is responsible for the efficiency of daily operations and for discovering and solving any operational problems in the plant. A company's success may depend on a quality maintenance engineering department that can help to discover systematic flaws and can also recommend solid, practical solutions. Positions in this field often require a college education in a related field. Although most of colleges do not offer degrees in maintenance engineering, so degrees in mechanical engineering, industrial engineering, or related subjects are preferred.

There are many different ways in which engineers maintain equipment. Engineering actions are necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful life. Activities required are undertaken to conserve as nearly and as long as possible, the original condition of an assertor resource while compensating for normal wear and tear. Maintenance, repair and operations (MRO) or maintenance, repair and overhaul, involves fixing any sort of mechanical, plumbing or repairing electrical device that are out of order or broken (known as repair, unscheduled, or casualty maintenance). It also includes performing routine actions which keeps the device in working order (known as scheduled maintenance) or prevents trouble from arising (preventive maintenance). MRO may be defined as "all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function”. The actions include the combination of all technical and corresponding administrative, managerial and supervision actions.

A maintenance strategy brings all current maintenance practices and operations together with current industry. In order to provide a strategic and coherent 'road map' for engineering, the following goals should be achieved by improve service provision to operations i.e. reduce breakdowns and improve productivity. Control engineering spending and ensured adherence to budgets consistently provide parts for planned maintenance and breakdowns with the lowest spares holding value. Improved communication between engineering and other business functions ensure engineering compliance to all company and statutory standards and requirements.

The maintenance audit strategic maintenance planning has developed a unique maintenance audit and review process for management to analyze the maintenance function from within the overall organization taking into account all the various functions within the organization. The purpose of a maintenance audit is to derive a maintenance strategy, which aims to deliver improvements to the general maintenance function, provide clearer communications and to develop a set of best practices for the maintenance function. This work is accomplished through the completion of interviews with a wide cross-section of personnel from all functions.

The maintenance audit has been designed to determine thoughts of individuals and groups and ensure that the following objectives are reached: a snapshot of the current engineering function allowing the current situation to be benchmarked, an accurate assessment of other company's functional perceptions of engineering performance, to identify areas of functional weakness to allow improvement strategies to be planned and executed, to provide a ground work of information for the development of a maintenance strategy. The audit is completed with departmental functions outside the engineering function to ensure that a balanced and wide-ranging result is achieved. Engineering, production and administration responses are investigated in isolation and then general perceptions and themes are identified within the conclusions. All information from the maintenance audit is organized into a document that provides a distillation of the perceptions and thoughts of the respondent.

In order to provide a wider industry perspective to the results of the engineering review and to provide additional groundwork for the development of the maintenance strategy, a bench marking exercise is carried out. To complete this exercise, critical "Hard" (systems and processes) and "Soft" (human resources and organization structure) issues within the engineering function are rated and tabled against the experience in wider industry. The maintenance strategy has three main sections: detail of how the implementation of a maintenance strategy integrates with and facilitates the organization's business plans and goals. Provision of an overall maintenance strategy detailing current best practices, provide a basis for development of working method and implementation of the maintenance strategy.

The maintenance strategy will dictate direction. There will be an engineering charter to set service levels to operations. There will be the use of appropriate maintenance methods that will reflect the needs of the business. There will be use of best industry practice. Project engineering will adopt a life cycle asset management approach. There will be compliance with all company systems and standards and auditing of performance which will lead to continuous improvement. The key elements of the maintenance strategy will be distilled into a prioritized plan for implementation. Manufacturing organizations adopt various type of maintenance to achieve their goal, reduce waste, reduction in down time, and increase productivity. Various types of maintenance are discussed below.

1.2 Types of Maintenance-Different types of maintenance are as follows.

Planned maintenance: This is maintenance that you do on a regular basis, which helps keep things in working order. Good examples of this are servicing boilers or sending a car for an M.O.T. (ministry of transport) test. It is usually done to make sure the equipment is safe rather than to improve or upgrade it.

Periodic Maintenance (Time based maintenance - TBM):- Time based maintenance consists of periodically inspecting, servicing and cleaning equipment and replacing parts to prevent sudden failure and process problems.

Predictive Maintenance: - This is a method in which the service life of important part is predicted based on inspection or diagnosis, in order to use the parts to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition based maintenance. It manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system, designed to monitor conditions through an on-line system.

Advantages

- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.

- Improved worker and environmental safety.
- Improved worker morale.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

Disadvantages

- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

Preventive Maintenance: - It is a daily maintenance i.e. cleaning, inspection, oiling and re-tightening. It tries to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance.

The idea of preventive maintenance is to keep something in working order or extend its life. For example, there may not be a leak in your roof, but if you can see that one of the tiles is cracked and know that there is a storm coming, you may well want to take a closer look. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance.

- Preventive maintenance means equipment is maintained before break down occurs. This type of maintenance has many different variations and is subject of various researches to determine best and most efficient way to maintain equipment. Recent studies have shown that preventive maintenance is effective in preventing age related failures of the equipment. For random failure patterns which amount to be 80% of the failure patterns, condition monitoring proves to be effective.
- Preventive maintenance is maintenance performed to avoid failures, unnecessary production loss and safety violations.
- The effectiveness of a preventive maintenance schedule depends on the RCM analysis which it was based on, and the ground rules used for cost-effectively.

Advantages

- Cost effective in many capital-intensive processes.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.
- Estimated 12% to 18% cost savings over reactive maintenance program.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance.

We can also say that it indicates the design of new equipment. Weakness of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning a new equipment.

Corrective Maintenance: - One of the most common kind of maintenance. This involves fixing something that has stopped working properly. This is a form of unplanned maintenance, as you don't normally know when something is going to break! Examples of this include fixing a faulty toaster or replacing a car exhaust when it falls off. It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or to improve maintainability.

- Corrective maintenance, where equipment is maintained after break down. This maintenance is often most expensive because worn equipment can damage other parts and cause multiple damages.

Corrective maintenance is probably the most commonly used approach, but it is easy to see its limitations. When equipment fails, it often leads to downtime in production. In most cases, this is costly business. Also, if the equipment needs to be replaced, the cost of replacing it alone can be substantial. It is also important to consider health, safety and environment (HSE) issues related to malfunctioning equipment.

Corrective maintenance can be defined as the maintenance which is required when an item has failed or worn out, to bring it back to working order. Corrective maintenance is carried out on all items where the consequences of failure or wearing out are not significant and the cost of this maintenance is much greater than preventive maintenance.

Corrective maintenance is the program focused on the regular task that will maintain all the critical machinery and the system in optimum operating conditions. The major objectives of the program are to eliminating breakdown, eliminating deviation, eliminating unnecessary repair, optimize all the critical planned system.

Front-line Maintenance: - This is more complicated, as it involves fixing something while it is still in use. Transport networks do this all the time. When your train is delayed due to 'improvement works', it is usually because part of the track, or certain trains, have been taken out of service temporarily while maintenance work is carried out.

Breakdown Maintenance or Reactive Maintenance:-It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached.

Advantages

• Low cost.

• Less staff.

Disadvantages

• Increased cost due to unplanned downtime of equipment.

. • Increased labor cost, especially if overtime is needed.

• Cost involved with repair or replacement of equipment.

• Possible secondary equipment or process damage from equipment failure.

. • Inefficient use of staff resources.

It doesn't sound like it from the title, but breakdown repair is a form of planned maintenance. It is normally carried out by engineers who want to find the most likely thing to go wrong with a product. Breakdown repair involves running the product over and over until it breaks down. This can give invaluable information to designers and engineers, who can use their tests to find out what common faults might be, and the best way to guard against them.

Maintenance = PPCFB = 'Poor Products Can Fail or Break down!

Reliability Centered Maintenance: - Reliability centered maintenance is an engineering framework that enables the definition of a complete maintenance regime. Reliability centered maintenance (RCM) magazine provides the following definition of RCM: "a process used to determine the maintenance requirements of any physical asset in its operating context".

RCM methodology deals with some key issues not dealt with by other maintenance programs. It recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others.

It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both need to be prioritized and optimized. In a nutshell, RCM is a systematic approach to evaluate a facility's equipment and resources to best mate the two and result in a high degree of facility reliability and cost-effectiveness.

RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a reactive maintenance approach. The following maintenance program breakdowns of continually top-performing facilities would echo the RCM approach to utilize all available maintenance approaches with the predominant methodology being predictive.

- <10% Reactive.
- 25% to 35% Preventive.
- 45% to 55% Predictive.

Advantages

- Can be the most efficient maintenance program.
- Lower costs by eliminating unnecessary maintenance or overhauls.
- Minimize frequency of overhauls.
- Reduced probability of sudden equipment failures.
- Able to focus maintenance activities on critical components.
- Increased component reliability.
- Incorporates root cause analysis.

Disadvantages

- Can have significant startup cost, training, equipment, etc.
- Savings potential not readily seen by management.

1.3 Maintenance Tool's- TPM

TPM (Total Productive Maintenance):- TPM as the name suggests consists of three words:

- Total. This signifies to consider every aspect and involving everybody from top to bottom.
- Productive. Emphasis on trying to do it while production goes on and minimize troubles for production.
- Maintenance. Means keeping equipment autonomously by production operators in good condition – repair, clean, grease, and accept to spend necessary time on it.

For improving productivity, organizations introduced different-different type of maintenance. But to achieve their target, organizations added overall equipment efficiency and manpower with the help of a new maintenance tool called TPM (Total Productive Maintenance). It is a maintenance program which involves a newly defined concept for maintaining plants and equipment. TPM program's goal is to markedly increase productivity, at the same time, increase in employee morale and job satisfaction. TPM brings into focus maintenance as a necessary and virtually important part of the business. It is no longer regarded as an activity with no-profit. Maintenance's down time is scheduled as a part of the manufacturing day and, for some cases, as an integral part of the manufacturing process. The goal is to minimize unscheduled maintenance and hold emergency .The aim of productive maintenance was to maximize plant and equipment.

The objectives to be achieved and for which TPM was introduced are as follows.

- Avoid wastage in a quickly changing economic environment.
- Producing goods without reducing product quality.
- Reduce cost.
- Produce a quantity with low batch at the earliest possible time.

Goods send to the customers must be non defective. Selection of technology and its implementation in a manufacturing industry will be a great challenge for organization to survive in global competitive market. During various operations major or minor barriers occur due to breakdown which leads to loss of productivity and force the organization to implement TPM. It means TPM cannot be successfully implemented until all departments integrate effectively.

For successful implementation of TPMs, top management need to focus on different-different aspects of organizational functioning including organization culture, employees training, integration of departments, etc. In addition to this, management needs to understand structural relationship between different variables, which will help in developing strategies for effective implementation of TPM. Due to the complexity in implementation of TPM following steps discuss in this paper:

- For implementation of TPM, the critical success factors are to be identified;
- The establishment of relationship among identified critical success factors.

1.4 Benefits of TPM

The benefits of Total Productive Maintenance (TPM) are improvements in operational efficiency, improvements in reliability and improvements in quality.

- TPM refuses to accept that machine inevitably fails.
- TPM reduces the total life-cycle costs of equipment.
- Gives operators greater "ownership" of their equipment.
- Increases operators' knowledge of their equipment.
- Ensures equipment is well cleaned and lubricated.
- Identifies emergent issues before they become failures.
- Frees maintenance personnel for higher-level tasks.
- Significantly reduces instances of unplanned down time.
- Enables most maintenance to be planned for times when equipment is not scheduled for production.
- Reduces inventory through better control of wear-prone and failure-prone parts.
- Specifically targets quality issues with improvement projects focused on removing root sources of defects.
- Reduces number of defects.
- Reduces cost by catching defects early (it is expensive and unreliable to find defects through inspection).
- Operators develop skills to routinely maintain equipment and identify emerging problems.
- Maintenance personnel learn techniques for proactive and preventative maintenance.
- Managers are trained on TPM principles as well as on employee coaching and development.
- New equipment reaches planned performance levels much faster due to fewer startup issues.
- Maintenance is simpler and more robust due to practical review and employee involvement prior to installation.
- Recurring problems are identified and resolved by cross-functional teams.
- Combines the collective talents of a company to create an engine for continuous improvement.
- Eliminates potential health and safety risks, resulting in a safer workplace.
- Specifically targets the goal of an accident-free workplace.

- Extends TPM benefits beyond the plant floor by addressing waste in administrative functions.
- Supports production through improved administrative operations (e.g. order processing, procurement, and scheduling).

TPM implementation highlights its contribution towards the manufacturing industry and helped the industry to compete globally. TPM implementation increased productivity of industry as well as maintained quality of product as well. TPM provided healthier environment and safer work policy. TPM decreased cost and increased the efficiency. TPM reduced delays in deliveries and decreased time loss and increased process control. TPM interventions increased the morale of workers and teamwork and ensured efficiency and effectiveness of the manufacturing industry. TPM provided strategically measures that contributes towards performance improvements and provides initiatives to compete in global market. The study highlights the contributions of various TPM implementation initiatives in Indian industry to accruing strategic benefits to meet the challenges posed by global competition. TPM provides alternative solutions as well to help change in product as per the demands with improvement in Time. The study of TPM is far more beneficial and influential in improving performance than traditional practices.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Modern maintenance management tries to keep the equipment running at high capacity and produce high quality product at lowest cost possible. There are many reasons why maintenance is becoming more and more important. In developing countries, old machines are frequently therefore problems are arising. Some time it is difficult to find spare part for equipment if it is possible to find them, they are very expansive which increase the cost of product. In maintenance management, one of the very useful tools for maintenance is TPM, which is discussed in next paragraph in detail.

TPM is an innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from USA. Nippondenso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippondenso, maintenance became a problem as more maintenance personnel were required. So the management decided that the routine maintenance of equipment would be carried out by the operators. (This is Autonomous maintenance, one of the features of TPM). Maintenance group took up only essential maintenance works.

Nippondenso which already followed preventive maintenance also added Autonomous maintenance done by production operators. The maintenance crew went in the equipment modification for improving reliability. The modifications were made or incorporated in new equipment. This help to lead to prevention in maintenance. Thus preventive maintenance along with Maintenance prevention and Maintainability Improvement gave birth to Productive maintenance. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve optimum life cycle cost of production equipment. By then Nippon Denso had made quality circles, involving the employees' participation. Thus all employees took part in implementing Productive maintenance. Based on these developments, Nippondenso was awarded the distinguished plant prize for developing and implementing TPM, by the Japanese Institute of Plant Engineers (JIPE). Thus Nippondenso of the Toyota group became the first company to obtain the TPM certification.

It can be considered as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance program or a part of maintenance management, which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM program is to markedly increase production while, at the same time, increasing employee morale and job satisfaction as well as maintenance management goal is to hold emergency and unscheduled maintenance to a minimum. TPM brings maintenance into focus as a necessary and virtually important part of the business. It is no longer regarded as a non-profit activity. Down time for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process.

TPM is most difficult of all lean tools to implement :- It is important to understand up front that Total Productive Maintenance is the most difficult of all the "lean tools" to implement in companies for two reasons:

- A TPM implementation requires the greatest amount of culture change (as compared to implementing other lean tools) from different groups of people within the organization almost simultaneously.
- Of all of the areas of potential lean process improvement within the four walls of an organization, the maintenance of our equipment is the area which is the furthest behind.

Fortunately, the payback from this implementation – in terms of on-time delivery, reduced scrap, improved productivity and improved associate morale – is probably greater than any of the other lean tools. Let's review both of these challenging implementation issues and consider possible solutions.

2.2 Literature on Maintenance Management

Maintenance Management is considered to be an effective strategic improvement initiative for improving quality in maintenance engineering activities according to Ollila and Malmipuro during 1999 & Pramod et al.(2007). Maintenance management is all of the strategies needed to sustain a healthy maintenance log according to Steinbacher and Steinbacher (1993). Maintenance management is the general movement on the part of businesses to try to do more with less by Lawrence (1999). Maintenance management has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities (Dwyer, 1999; Dossenbach, 2006).

In maintenance management, TPM is a tool which is used as methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. Originally introduced as a set of practices and methodologies focused on manufacturing equipment performance improvement, TPM has matured into a comprehensive equipment-centric effort to optimize manufacturing productivity. It embraces the concept of continuous improvement and total participation by all employees and by all departments (Society of Manufacturing Engineers, 1995).

Total productive maintenance is based on teamwork and provides a method for the achievement of world-class levels of overall equipment effectiveness through people and not through technology or systems alone (Willmott, 1994). Maintenance management is intended to bring both functions (production and maintenance) together by a combination of good working practices, team working, and continuous improvement (Cooke, 2000). Another strategic outcome of maintenance management is the reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually said by Gosavi during 2006. Equipment technology and development capabilities have become major factors that demonstrate the strength of an organization and set it apart from others according to Schuman and Brent (2005) & Braglia et al. (2006).

The scope of maintenance has shifted from a narrowly defined operational perspective, to an organizational strategic perspective. Some authors attribute this shift to the utilization of more advanced technologies (Swanson, 1997), increased emphasis on safety, and new environmental legislations (Cooke, 2003).Due to the changing organizational role of maintenance, and the increasing complexity of manufacturing technologies, maintenance related costs have been on the increase (Parida and Kumar, 2006). In manufacturing organizations, maintenance related costs are estimated to be 25 percent of the overall operating cost (Cross, 1988a; Komonen, 2002). In some industries, such as petrochemical, electrical power, and mining, maintenance related costs might surpass operational cost according to Raouf (1993), De Groote (1995), Eti et al. (2005) & Parida and Kumar (2006). Overall, effective performance measurement approaches can play an important role in focusing people and resources on a particular aspect of organizational task (Waggoner et al., 1999).

According to Parida and Kumar (2000), the following are considered important factors, justifying the implementation of a maintenance performance measurement process:

. Measuring value created by the maintenance;

. Justifying investment;

. Revising resource allocations;

. Health, safety and environment issues;

. Focus on knowledge management;

. Adapting to new trends in operation and maintenance strategy; and

. Organizational structural changes

In this context, several new approaches and strategies/tactics/technologies can be utilized. These include among others, self-maintenance, web-based maintenance, integration of product and maintenance design, proactive maintenance based on intelligent units, life cycle simulation for maintenance strategy planning, model-based maintenance, total productive maintenance (TPM), Reliability Centered Maintenance (RCM), Preventive Maintenance (PM), Condition Based Maintenance (CBM), and Continuous Maintenance (CM) said by Takata et al.(2004). Therefore, approaching maintenance management strategically and systematically has become essential to make the right choices, especially in capital-intensive industries. Information sharing practices, information attributes, information technology use, collaborative foundation, time-related issues, processes and activities are all considered as critical elements of information integration according to Uusipaavalniemi and Juga (2000).

Manufacturing organizations, especially small and medium-sized enterprises would benefit from having easy-to-use tools and methods for determining their maintenance management information technologies needs in order to be able to choose the best solution available from off-the-shelf options (Kans, 2008). This may lead to system design and development significant savings. According to Chaneski (2002), TPM is tool for maintenance management, a maintenance management program with the objective of eliminating equipment downtime. Lawrence (1999) describes TPM as the general movement on the part of businesses to try to do more with fewer resources. According to Besterfield et al. (1999), TPM helps to maintain the current plant and equipment at its highest productive level through the cooperation of all functional areas of an organization.

Maintenance management is a partnership between maintenance and production. Functions in the organization to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company's state of maintenance (Rhyne, 1990). Maintenance management implementation methodology provides organizations with guidelines to fundamentally transform their shop floor by integrating culture, process and technology (Moore, 1997).TPM is an indispensable strategic initiative to meet customer's demands on price, quality and lead times.

TPM has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities (Dwyer, 1999; Dossenbach, 2006). TPM initiatives help in streamlining the manufacturing and other business functions and helps in garnering sustained profits (Ahuja and Khamba, 2007).

TPM is a system (culture) that takes advantage of the abilities and skills of all individuals in an organization (Patterson et al., 1995). Willmott (1994b) portrays TPM as a relatively new and practical application of TQM and suggests that TPM aims to promote a culture in which operators develop "ownership" of their machines, learn much more about them and in the process realize skilled trades to concentrate on problem diagnostic and equipment improvement projects. Maintenance management addresses entire production system over the entire life cycle and builds a concrete, shop floor based mechanism to prevent various losses and wastes (McCarthy, 2004; Sharma et al., 2006). TPM is based on a "Zero-loss" concept viz zero breakdown, accident and defects, to achieve high reliability, flexibility of equipment and reduce cost through minimizing wastage of manpower, raw material, energy, consumables, etc. TPM aims at tapping the "hidden capacity" of unreliable and ineffective equipment.

Maintenance management is about Maintenance management communication. It mandates that operators, maintenance people and engineers collectively collaborate and understand each other's language (Witt, 2006). Maintenance management is based on teamwork and provides a method for the achievement of world-class levels of overall equipment effectiveness through people and not through technology or systems alone (Willmott, 1994a; Prabhu, 1998). Maintenance management is not a maintenance specific policy; it is a culture, a philosophy and a new attitude towards maintenance (Chowdhury, 1995).

Maintenance management implementations are reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually (Gosavi, 2006). Maintenance management is designed to maximize equipment effectiveness, improve overall efficiency by establishing a comprehensive productive-maintenance system during the life of the equipment, while spanning all equipment-related fields such as: planning/buying, use, maintenance, etc. Kodali and Chandra (2001) and Kodali (2001) have presented a model indicating maintenance management benefits using analytical hierarchical process (AHP) technique.

Tripathi (2005) and Seth and Tripathi (2005) have also modeled the benefits of maintenance management in the Indian Industry. The achievements arising from strategic TPM programs can be classified in six categories including Productivity (P), Quality (Q), Cost (C), Delivery (D), Safety (S) and Morale (M) (Nakajima, 1988). Willmott (1997a) suggests that through successful TPM introduction effective maintenance management is cascaded across tradesmen, production planners, team engineers and team leaders. To make TPM become a successful part of factory life will take considerable effort to change mindsets from a traditional maintenance approach. Roy Davis a UK director of Manufacturing Productivity Improvements Ltd. considers a good awareness, education and training strategic plan to be an essential factor in the success of implementation according to Davis (1997).

Selection of technology and its implementation in a manufacturing industry will be a great challenge for organization to survive in global competitive market. During various operations major or minor barriers occur due to breakdown which leads to reduction in productivity and it forced the organization to implement maintenance management. It means maintenance management cannot be successfully implemented until all departments integrate effectively. For successful implementation of maintenance management, top management need to focus on different-different aspects of organizational functioning including organization culture, employees training, integration of departments etc. In addition to this, management needs to understand structural relationship between different variables, which will help in developing strategies for effective implementation of maintenance management. Due to the complexity in implementation of maintenance management following steps discuss in this paper:

- For implementation of maintenance management, the critical success factors are to be identified;
- The establishment of relationship among identified critical success factors.

2.3 Identification of critical success factors

To effectively compete in global markets, firms must be quick and flexible in their response to meet productivity needs. In today's rapidly changing world, competitive advantage in cost need to be achieved by organizations, quality, high productivity, minimize losses, innovation and delivery simultaneously. To meet these challenges, successful implementation of maintenance management can play a significant role. Major critical factors are discussed as:

1. Top Management Support

Highest level executive's direct participated in a specific and critically important aspect or program of an organization. It is important to have top management support, widespread practice of personnel training, promoting early worker participation, the choice of suppliers based on technical expertise and the experience and availability of a project champion for AMT implementation by Sanchez, 1996).According to Ahuja and Khamba, 2008a, It involves everyone in the organization, from top-level management of productivity mechanics, and productivity support groups to outside suppliers.

2.Organization Culture

The values and behaviors that contribute to the unique social and psychological environment of an organization. The culture of organization includes an organization's expectations, experiences, philosophy, and values which hold them together, and that are expressed in their self-image, the outside world interactions, inner workings and expectations for future (Block et al., 2014). Poor organizational competencies in managing the maintenance function effectively can severely affect competitiveness by getting throughput reduced, inventory getting increased, and that leads to poor due-date performance by Patterson et al., 1996, Ashayeri, 2007).

3.Development of Maintenance Strategy

Maintenance managers and maintenance engineers are asked to develop a maintenance strategy for their plant and equipment. A document needs to be developed by them. In the document you explain how the least plant and equipment maintenance expenditure and efforts are used by you to ensure the necessary performance of productivity from your production plant and equipment. Even worst, in a survey of manufacturing organizations conducted by Cholasuke et al.(2004), only one-third part of the organizations, consist of good management practices related to maintenance tended to realize the full benefits of their maintenance management initiatives. Some of the important factors, which need to be considered in the road toward effective performance maintenance management, as identified from the literature by Tsang, 1998; Kumar, 2006; Parida and Kumar, 2006)

4.Employee Training and Empowerment

Training in the skills is necessary in order to carry out the additional responsibilities. Access to information is necessary on which decisions can be made. Skill to take initiative and confidence is necessary on the part of the employee to take on greater responsibility. Companies practicing TPM invariably achieve startling results, including reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening defects and claims in quality boosting productivity, reducing labor and costs, inventory reduction, reduction in accidents, and boosting employee involvement (as shown by the submission of improvement suggestions) By

Suzuki, 1994).Moreover, successful TPM implementation leads to significant intangible benefits such as continuous improvement of workforce skills and knowledge, fostering employee motivation through adequate empowerment, clarification of roles and responsibilities for employees, a system for continuously maintaining and controlling equipment, enhanced quality of life of work , reduced absenteeism and enhanced communication in the workplace by Carannante, 1995. TPM is intended to bring both functions (productivity and maintenance) together by a combination of good working practices, team working, and continuous improvement by Cooke, 2000.

5.Investment on Maintenance System

According to Teresko, 1992 & Mangano and Marco, 2014, investment in maintenance is the basic functions of a firm and returns improved quality, safety, dependability, and flexibility and lead times. Maintenance, being an important support function in enterprises with significant investments in plants and machinery, plays an important role in meeting this tall order. Moreover, the strategic investments in human resources can result in better hardware utilization, higher product quality and reduced labor costs (Chan et al., 2005).

6. Developing the coordination between departments

Productivity enhancement in organizations provides an impetus for enhanced employee alignment to organizational goals, inter-departmental relations, employee motivation-contributions, and providing a culture of kaizens and continuous improvements in the organizations, thereby improving the organizational capabilities (Veldman et al.,2011). It involves everyone in the organisation, from top-level management to production mechanics, and production support groups to outside suppliers (Ahuja and Khamba, 2008a). It encompasses all departments including maintenance, operations, facilities, design engineering, project engineering, construction engineering, inventory and stores, purchasing, accounting and finance, and plant and site management (Wireman,1990).

7.Bench Marking of Processes

Benchmarking is the process of comparing one's business processes and performance metrics to industry bests or best practices from other industries. Dimensions typically measured are quality, time and cost. Benchmarking is simply the comparison of one organization's practices and performance against those of others. It seeks to identify standards, or "best practices," to apply in measuring and improving performance.

Benchmarking is critical toward achieving world-class maintenance performance levels by Chen, 1994; Raouf and Ben-Daya, 1995; Madu, 2000. It is to be noted that although benchmarking is one of the key elements for the continuous improvement process (A° hre´n and Parida, 2009), only 17 of the analyzed papers (11 percent), presented, or even referred to benchmarking techniques in associations with maintenance performance measurement. The challenges of stiff competition and the drive for profits are forcing the organizations to implement various productivity improvement efforts to meet the challenges posed by ever-changing market demands (Samuel et al., 2002).

8. Effective Maintenance System

Today's maintenance organization, like different departments, is under continuous pressure so as to reduce costs, show results, and which in turn supports the mission and goal of the organization. After all, it's an expectation from the business standpoint which is logical.In such an operational environment, maintenance manager's role is critical. As such, maintenance managers are being called on to integrate and direct the maintenance efforts so as to meet strategic goals of organization efficiently and effectively (Alsyouf, 2007; Al-Najjar, 2007; Block et al. ,2014).

In manufacturing organizations, maintenance related costs are estimated to be 25 percent of the overall operating cost (Cross, 1988a; Komonen, 2002). The effective maintenance function integration with engineering and other functions related to manufacturing in the organization can help to save huge amounts of time, money and other useful resources in dealing with reliability and also dealing with availability, maintainability and performance issues (Moubray, 2003).

9. Quality Management System

A quality management system (QMS) is a collection of business processes focused on achieving your quality policy and quality objectives. Its function is to develop standards globally in an effort to improve the exchange of goods and services internationally. maintenance management is considered to be an effective strategic improvement that includes initiative to improving quality in maintenance engineering activities (Ollila and Malmipuro, 1999; Pramod et al., 2007; Macchi and Fumagalli, 2013).TPM is a partnership between maintenance and productivity functions in the organization to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company's state of maintenance (Rhyne, 1990).

10. Reduction in M/C Breakdown

Companies practicing maintenance management invariably achieve startling results, including reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening defects and claims in quality , boosting productivity, trimming labour and costs, inventory shrinkage , reducing accidents, and boosting employee involvement (as shown by the submission of improvement suggestions) by Suzuki, 1994 & Sinkkonen et al. (2013).

11. Improve Safety and Health Management

According to Steinbacher and Steinbacher, 1993, TPM is all of the strategies needed to sustain a healthy maintenance log. As an employer, it is your responsibility to maintain a safe and healthy workplace. A safety and health management system, or safety program, can help you focus your efforts at improving your work environment. In a safe and healthy workplace, employees have a stake in the success of the program-safety and health is everyone's responsibility (Mangano and Marco, 2014).

A safety and health management system means the part of the organization's management system which covers:

- The health and safety work organization and policy in a company
- The planning process for accident and ill health prevention
- The line management responsibilities and
- The practices, procedures and resources for developing and implementing, reviewing and maintaining the occupational safety and health policy.

12. Reduction in Manufacturing Lead Time

Companies practicing TPM invariably achieve startling results including reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening defects and claim sin quality, boosting productivity, trimming labor and costs, inventory shrinkage , reducing accidents, and boosting employee involvement (as shown by the submission of improvement suggestions) (Suzuki, 1994 & Uzun and Ozdogan ,2012).

13. Reduction in Product Rejection Rate

According to Soviet law, output (articles, semi finished products, parts, and so forth) that does not correspond in quality to standards, technical specifications, and other technical norms. A distinction is drawn between reparable and irreparable production rejects. It is technically possible and economically advisable to repair the defects in reparable rejects at the enterprise. Irreparable rejects are articles whose defects are technically impossible or economically disadvantageous to eliminate. Such articles may be used as waste.

Rejects may be the result of incorrect adjustment of a machine tool, malfunctioning of equipment and tools, errors in technical specifications (plans and drafts, for example), disruption of production discipline, or the workers' low level of skill (Kumar et al.,2013). The discovery of defective products is the responsibility of the workers, the foremen, and the employees of the technical control department. Production rejects are reduced by organizational and technical measures, including the mechanization and automation of production processes, proper maintenance of equipment and fittings, and the introduction of advanced forms and methods of technical control. Many factors are of great significance in preventing production rejects: zero-defect manufacturing, strict observance of production discipline in the work area, correct organization of labor, improved worker skills, the development of socialist emulation for high product quality, and material and moral incentives for the workers to manufacture high-quality products

14. Manufacturing Cost Reduction

Intense competition has been witnessed in terms of less costs, quality improvement and diversity in products with superior performance by Chandra and Sastry, 1998. TPM implementation is the reduction in occurrence of unlikely and unexpected machine breakdowns that disrupt production and this may result in losses, which can exceed millions of dollars annually by Gosavi, 2006.

15. Improvement in Performance

Modern manufacturing requires that organizations that wish to be successful and to achieve world-class manufacturing must possess both effective and efficient maintenance. The intense competitive pressure on the organizations is triggering the top management of these enterprises to look at the performance of each and every business function, including manufacturing or maintenance for achieving competitive advantage (Pintelon et al., 2006 & Damjan Maletic et al., 2012). It provides a systematic method for establishing production targets, and incorporates practical management tools and techniques in order to achieve a balanced view of process availability, performance efficiency and rate of quality (Bulent et al., 2000).The objective of TPM is to create a sense of joint responsibility between supervision, operators and maintenance workers, not only to keep machines running smoothly, but also to optimize their overall performance (Tajiri and Gotoh, 1992; Hutchins, 1998). We obtain the overall equipment effectiveness OEE for the production line. The indicator OEE gives us the measurement of equipment performance; taking into account all factors that reduce the capacity utilization. Mathematical formula used for finding the overall performance efficiency is used as below:

$$\text{Performance Efficiency (P)} = \frac{(\text{Processed Amount} \times 100)}{(\text{Operating Time/Theoretical Cycle Time})}$$

Table no. 2.1: Critical success factors for implementation of maintenance management

S.NO.	CRITICAL SUCCESS FACTOR	AUTHOR
1	Top management support	Pintelon et al.(2006); Ng et al.(2011).
2	Organization culture	Parida and Kumar (2006); Block et al. (2014).
3	Development of maintenance strategy	Kans and Ingwald(2008); Parida and Kumar(2006).
4	Employee training and empowerment	Ahmed et al.(2005); Ireland and Dale(2006); Tsarouhas(2007).
5	Investment on maintenance system/technologies	Teresko(1992); Mangano and Marco (2014).
6	Developing the coordination between departments	Veldman et al.(2011); McKone et al.(2001).

7	Bench marking of processes	Ng et al. (2011); A° hre´n and Parida(2009);
8	Effective maintenance system	Chan et al.(2005); Block et al. (2014).
9	Quality management system	Heizer and Render(2001); Macchi and Fumagalli (2013).
10	Reduction in m/c breakdown	Chan et al.(2005); Sinkkonen et al. (2013).
11	Improved safety and health management	Parida and Kumar(2006); Mangano and Marco (2014).
12	Reduction in manufacturing lead time	Al-Najjar and Alsyouf(2000); Uzun and Ozdogan (2012).
13	Reduction in product rejection rate	Chan et al.(2005); Kumar et al.(2013).
14	Manufacturing cost reduction	Concetti et al.(2009); Sharma et al.(2006); Seth and Tripathi, 2005, 2006.
15	Improvement in performance	Pintelon et al.(2006); Damjan Maletic et al. (2012).

This work has tried to identify the critical success factors for successful implementation of maintenance management by manufacturing sectors to improve their performance. Successful implementation of maintenance management depends on different-different barriers related with technical expertise, resources, processes, management systems and performance. In this framework, total 15 critical success factors have been identified from literature review and expert meet from different interest areas. Survey results also indicate the importance of top management support, development of maintenance strategy, investment on maintenance system and organization culture for maintenance management implementation. These variables will help organizations to achieve its desired objectives.

I designed a structure from the complex set of factors, how these factors are related to each other, which one factor is dependent on the other one in “Teh" diagraph model. The relation among the variables always depends on that person’s knowledge and familiarity with the firm, its operations, and its industry (Kannan & Haq, 2006).The relationship between the complex element set helps extract the model and the overall structure. Teh diagraph for showing the relationship between them is as follows:

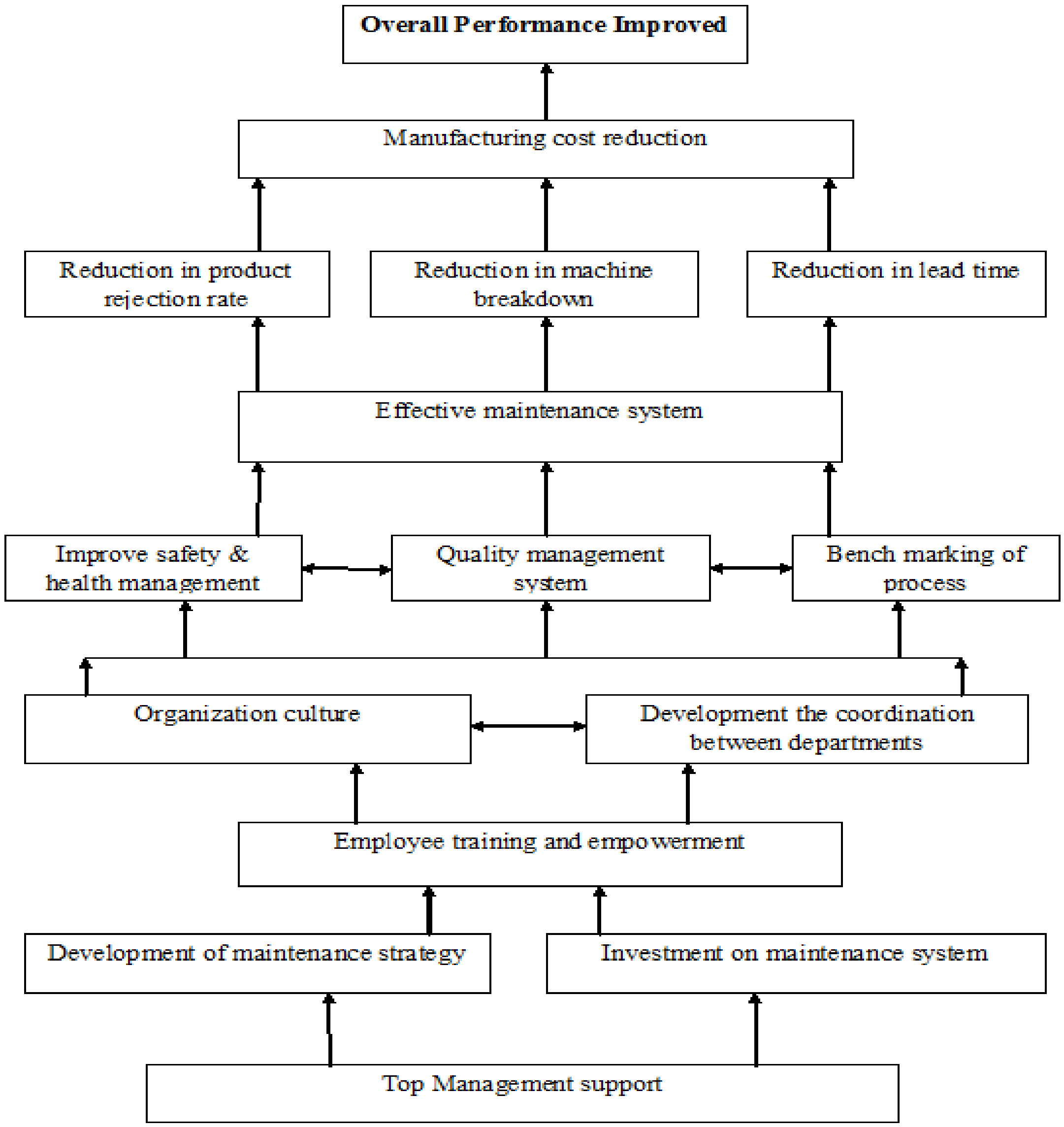


Figure 2.1: Expert's opinion based model for implementation of maintenance management.

In this work, a relationship model among different critical factors has been tried to develop on the suggestion given by the expert team comprising of technical and managerial experts of the manufacturing company and academicians. Management must not ignore managerial aspects such as organization culture, employee training and empowerment, development the coordination between departments, quality management system, and effective maintenance system for effective implementation of maintenance management.

2.4 Reasons for Maintenance Management Failure

Davis (1997) outlines ten main reasons for maintenance management failure within UK manufacturing organizations as:

1. The program is not serious about change.
2. Inexperienced consultants/trainers are used.
3. The program is too high level, run by managers for managers.
4. There is a lack of structure and relationship to strategic needs.
5. The program does not implement change on the shop floor and is not managed.
6. A lack of education and training for those expected to take it on board and provide support.
7. Programs are initiated and run exclusively by engineering and seen by production as a project that does not involve them.
8. Attempts to apply MM in the same way it is implemented in Japan, using the standard approach found in Japanese publications.
9. MM teams lack the necessary mix of skills and experience.
10. Poor structure for supporting the MM teams and their activities.

Implementation of maintenance management in manufacturing organization is achieved by:

(1) The existing organization;

(2) Measures of performance;

(3) Alignment to company mission;

(4) The involvement of people;

(5) An implementation plan;

(6) Knowledge and beliefs;

(7) Time allocation for implementation;

(8) Management commitment;

(9) Motivation of management and workforce. A more comprehensive model is presented by Bamber (1998), showing sub-factors related to each of the nine categories and describes their interrelationships and dependencies.

(10) Communicate, communicate, and communicate by:

- Awareness campaigns at all levels and in all functions;

- Continued integration of the establishing TPM system with management procedures such as: Health and Safety and SQO (see Bamber, 1998);

2.5 Losses in Maintenance Management

Maintenance management describes a relationship between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity, assurance and safety (Nakaiima, 1988). The activity of maintenance management is the deduction and elimination of defectives and is characterized by six types of losses, namely (Nakaiima, 1988; Babicz, 2000; Chan et al., 2005; Van der Wal and Lynn, 2002):

- Breakdown losses: There are two types: firstly, time losses due to equipment failure, when productivity is reduced and secondly, quantity losses, caused by defective products. Eliminating these losses is extremely difficult.

- Set up and adjustment losses: This refers to time losses from the end of the production of the previous item, cleaning, through product-change adjustment to the point where the production of the new item is completely satisfactory.

- Idling and minor stoppage losses: Idling and minor stoppage losses occur when production is interrupted by a temporary malfunction or machine is Idling. These problems are often overlooked as removing the offending item rectifies the problem. Zero minor stoppages are the goal.
- Reduced speed losses: These losses are the difference between design speed and actual operating speed. The reason for the difference in speed could be quality or mechanical problems.

- Quality defects and rework losses: Quality defects and rework are losses in quality caused by malfunctioning production equipment. Elimination of these defects required repairing defective products to turn them into excellent products.

- Start-up losses: Start-up losses are losses that occur during the early stages of production.

- Start-up after periodic repair and start-up after (long-time stoppage) are defined as time losses which are used for calculating the availability of equipment. Start-up after holiday and start-up after lunch breaks are defined as speed losses which measure the performance efficiency of equipment.

TPM is a notion taken from the TQM concept of zero production defects and applying it to equipment where the aim is to have zero breakdowns and minimal production losses (Tajiri and Gotoh, 1992). The objective of TPM is to create a sense of joint responsibility between supervision, operators and maintenance workers, not only to keep machines running smoothly, but also to optimise their overall performance (Tajiri and Gotoh, 1992; Hutchins, 1998). However, in maintenance management implementation various authors have stressed the contribution of training towards performance (Ahmed et al., 2005; Ireland and Dale, 2006; Sharma et al., 2006; Tsarouhas, 2007). Therefore, understanding maintenance as a strategic decision can eliminate any potential of equipment deterioration, failures, breakdowns and stoppages. Teamwork among all employees in various departments in manufacturing companies can ensure better TPM implementation.

Indeed, the complexity of getting commitment and involvement from employees is one of the implementation difficulties of maintenance management (Arca and Prado, 2008). TPM can lead to improvements in quality cost delivery and flexibility (Sharma et al., 2006; Cua et al., 2001; McKone et al., 1999, 2001; Seth and Tripathi, 2005; Seth and Tripathi, 2006). Meanwhile, Ahuja and Khamba (2008) critically analyzed and reviewed maintenance management related articles to show some importance directions in the maintenance management study. The maintenance management team is also a vital element in ensuring that manufacturing performance can be achieved, as without proper team management, maintenance management objectives are difficult to achieve. Moreover, McKone et al. (2001) ascertain that teamwork is very important in maintenance management, and have used it as one of the measures to assess the level of maintenance management implementation.

As both quality and maintenance go hand in hand in a manufacturing set up, TQM and TPM share many threads of commonalties like employee involvement, cross-functional approach and continuous improvement (Cooke, 2000). On the other hand, TPM is considered as an application of TQM concepts to equipment, for zero breakdowns and minimal production loss (Tajiri and Gotoh, 1992). Though TPM is relatively under-researched, but there are some studies reported on its implementation issues.

The six parameters have been considered for the study, which include productivity, quality, cost, delivery as external parameters and safety and hygiene and employee morale as internal environment parameters. These internal parameters are viewed as important outcome of TQM and TPM implementation (Nakajima, 1988; Steinbatcher and Steinbatcher, 1993; Ahire and Rana, 1995; Forker, 1996). Training in small group problem solving, communication, tools and techniques of TQM and TPM including on-the-job training Leonard and Sasser (1982); Oakland (1989); Flynn et al. (1994); Punn and Chin (1999).Includes use of financial support to implement policy, including allocation of resources to reinforce TQM and TPM Hart and Bogan (1992); Khelada (1996); Zink (1998).

The maintenance management implementation methodology provides organizations with a guide to fundamentally transform their shop floor by integrating culture, process, and technology (Moore, 1997). Ahuja and Khamba (2006) report that TPM implementation can significantly contribute towards improvement in organizational behavior in the manufacturing enterprises leading to world class competitiveness. The main goal of an effective maintenance management effort is to bring critical maintenance skilled trades and production workers together (Labib, 1999).

Another significant contributor for failure of maintenance management implementation program is the organization's inability to obviate resistance to change. The resistance to change takes a number of forms, that is, reluctance of individuals to change roles (Riis et al., 1997; Cooke, 2000), inability to create dissatisfaction with the present situation (reason to change) (Maggard and Rhyne, 1992; Ireland and Dale, 2001) and inability to change organizational roles and culture (Patterson et al., 1995; Lawrence, 1999). Moreover Cooke (2000) has attributed the failure of TPM implementation program to the inability of management to holistically implement the TPM(tool of MM) practices at the workplace and highlights that serious deviations have been observed between officially laid out TPM policies and actual practices employed at workplace. Hutchins (1998) has advocated for making considerable efforts for recognizing teams and enabling them to display their work for successful maintenance management implementation.

Maintenance management co-coordinators with time and resources, plus senior level back up; put in place relevant measures of performance and continually monitor and publicize benefits achieved in financial terms by Davis (1997). In order to improve their production processes, various quality programs are implemented by Ahuja and Khamba, 2008a. Two major improvement programs in the field of production and operations management are Total Productive Maintenance and Total Quality Management by Chan et al. (2005). The main objective of TPM is to achieve a reliable manufacturing system according to Ahuja and Khamba, 2008b. This is accomplished by maximizing the overall equipment effectiveness so that plant and equipment productivity is increased said by Ahuja and Khamba, 2008a & Ljungberg (1998).

Both TPM and TQM strive for continuous improvement, organization-wide involvement, and reduction of waste (Cua et al., 2006; Powell, 1995; Ohno, 1988). Several studies on TPM and TQM claim the positive relation- ship between those improvement programs and performance (Seth and Tripathi, 2005; Wilson and Collier, 2000; Yamashima, 2000; Hendricks and Singhal, 1997). Nevertheless, most research approaches investigate general principles or guidelines of TPM or TQM separately. Only a few studies have investigated the relationship between different improvement programs empirically (Cua et al., 2006; Sriparavastu and Gupta, 1997; Flynn et al., 1995).

The success criteria for effective and efficient maintenance management implementation according to Cooke (2000) and Ng et al. (2011), must include steps like top management support, employee involvement, team development, education and training, benchmarking, strategic planning and communication and management of employees.

In TPM, periodic maintenance is directed towards predictive maintenance, which can detect any equipment deterioration and failure more effectively using new embedded technology and condition-based inspection technology such as vibration, spectroscopy, thermographs and others (Parida and Kumar, 2006).Training plays an important role in minimizing the negative effect of system complexity on manufacturing system performance by Guimaraes et al. (1999). However, in maintenance management implementation various authors have stressed the contribution of training towards performance (Ahmed et al., 2005; Ireland and Dale, 2006; Sharma et al., 2006; Tsarouhas, 2007). Ireland and Dale during 2006 suggest that teamwork is not only essential in MM practices, but is considered as one of the criteria for its success. Maintenance management can lead to improvements in quality, cost, delivery and flexibility (Sharma et al., 2006; Cua et al., 2001; McKone et al., 1999, 2001; Seth and Tripathi, 2005, 2006).

Chapter 3

JUSTIFICATION OF MAINTENANCE MANAGEMENT

3.1 Maintenance Management System

The goal of the maintenance management program is to markedly increase production while, at the same time, increasing employee morale and job satisfaction. Maintenance is a kind of repair that uses general-purpose tools. Most of maintenance's tools could be found at a well-equipped hardware or automotive store. A setup is a temporary change to a machine without using any general-purpose tools. While defining job duties, the distinction between maintenance and setup becomes important.

It embraces the concept of continuous improvement and total participation by all employees and by all departments (Society of Manufacturing Engineers, 1995).The ultimate goal of maintenance management is to implement "perfect manufacturing" (Shirose, 1992).Tsang and Chan (2000), revealed the importance of management leadership, employee involvement, education and training, strategic planning and communication for maintenance management in Chinese setup. Effective maintenance can significantly contribute to improving production activities through value addition by Bamber et al. (1999). The quality and maintenance management are the strategic decision areas said by Heizer and Render, 2001.The main objective of TPM (tool of MM) is to achieve a reliable manufacturing system (Ahuja and Khamba, 2008b). This is accomplished by maximizing the overall equipment effectiveness so that plant and equipment productivity is increased according to Ahuja and Khamba, 2008a; Ljungberg, 1998.The OEE measure can be applied at several different levels within a manufacturing environment. Authors approached it from maintenance (Chan et al., 2005; Batumalay and Santhapparaj, 2009) or from productivity improvement (Dal et al., 2000; Braglia et al., 2009; Shetty and Rodrigues, 2010). Batumalay and Santhapparaj (2009) studied it through maintenance management practices across Malaysian industries.

Tsang and Chan (2000) revealed the importance of management leadership, employee involvement, education and training, strategic planning and communication for maintenance management in Chinese setup. Cooke (2000) also identified top management support, alignment of management initiatives and change, employee training, autonomy to employees and communication as important factors for the success of maintenance management in a European context. These studies are related to the benchmarking of implementation practices to explore key areas (Ireland and Dale, 2001), identification of critical factors (Tsang, 2002) and strategies to support its implementation (Ben, 2000).

3.1.1 Benefits of Maintenance Management on large scale which are as follow:

Maintenance management can be defined as a partnership between the maintenance and production organizations to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve organization's overall state of maintenance (Maggard and Rhyne, 1992). Maintenance management permanently improves the overall effectiveness of equipment with the active involvement of operators (Hartmann, 1992). The failure of an organization to successfully implement a maintenance management program has been attributed to the various obstacles including lack of management support and understanding, lack of sufficient training, failure to allow sufficient time for the evolution (Bakerjan, 1994). Benefits of maintenance management on large scale which are as follow:

- Improvement in productivity (IP),
- Improvement in safety (IS),
- Improvement in quality (IQ),
- Defect rate reduction (DRR),
- Improve equipment effectiveness (IEE),
- Employee morale and job satisfaction (EMJS),
- Lead time reduction (LTR).

In fact, Ireland and Dale (2006) suggest that teamwork is not only essential in maintenance management practices, but is considered as one of the criteria for its success. There are three ultimate goals of TPM (tool of MM): zero defects, zero accident, and zero breakdowns according to Willmott(1994) & Noon et al.(2000).

The main objectives of this study are:

- To identify major benefits of maintenance management
- To calculate the global desirability index of modern and traditional maintenance management in manufacturing organizations for justification.

The next section reviewed the literature for the identification of benefits from the modern maintenance management. It is followed by the discussion of AHP methodology and finally the discussion on results and conclusion.

3.2 Literature Review

Teresko (1992) said that the investment in maintenance returned improved quality, safety, dependability, flexibility and lead time; it is one from the most basic functions of a firm. Another strategic outcome of maintenance management implementations is the reduced occurrence of unexpected machine breakdowns that disrupts production and lead to losses, which can exceed millions of dollars annually by Gosavi (2006). According to the views of Gotoh (1991) and Hipkin and Cock (2000) "organizations that want to survive in today's highly competitive business environment must address the need for high quality, lower costs and more effective, swifter research and developed R&D".

It was need to attain shorter lead times, shorter innovation times and reduced inventories have lead to increasing demand on a organization's preparedness, adaptability, versatility and flexibility by Scho¨nberger (1986), Al-Najjar and Alsyouf (2000). These changes have left their unmistakable marks on the different facets of manufacturing organizations said by Gomes et al. (2006). Maintenance management is an indispensable strategic initiative to meet customer's demands on price, quality and lead times. Maintenance management has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities by Dwyer, 1999; Dossenbach, 2006. According to Cua et al., 2001; Mckone et al., 1999, 2001; Sharma et al., 2006; Seth and Tripathi, 2005, 2006 maintenance management can lead to improvements in quality, cost, delivery and flexibility.

By the view of Parida and Kumar, published (2006) "measuring value created by the maintenance, justifying investment, revising resource allocations, health, safety and environment issues, focus on knowledge management, adapting to new trends in operation and maintenance strategy are considered important factors, justifying the implementation of a maintenance performance measurement process. By the view of following author Rankin et al., 2000 and Patankar and Taylor (2000) “the human resources aspect of maintenance has been playing an increasing role in relation to operational environment safety”.

Some authors attribute this shift to the utilization of more advanced technologies (Swanson, 1997), increased emphasis on safety, and new environmental legislations (Cooke, 2003). According to Nakajima (1988), the achievements arising from strategic maintenance management programs can be classified in six categories including productivity, quality, cost, delivery, safety and morale. Cooke (2000) and Ng et al. (2011) said that the success criteria for effective and efficient maintenance management implementation are top management support, benchmarking, strategic planning, employee involvement, team development, education and training and communication and management of employees.

Ahuja and Khamba (2008a) said that TPM provides a comprehensive, life-cycle approach to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers. By the view of McCarthy (2004) & Sharma et al. (2006) “maintenance management addresses entire production system over the entire life cycle and builds a concrete, shop floor based mechanism to prevent various losses and wastes. TPM is based on “zero-loss” concepts which are as zero breakdown, accident and defects, to achieve high reliability, flexibility of equipment and reduce cost through minimizing wastage of manpower, raw material, energy, consumables, etc. Babicz, 2000; Chan et al., 2005; Nakaiima, 1988; Van der Wal and Lynn, 2002 told that the activity of maintenance management is the deduction and elimination of defectives and is characterized by six types of losses, namely: breakdown losses set up and adjustment losses, idling and minor stoppage losses, reduced speed losses, quality defects and rework losses, start-up losses. Tajiri and Gotoh (1992) said that TPM is a notion taken from the TQM concept of zero production defects and applying it to equipment where the aim is to have zero breakdowns and minimal production losses.

The objective of this work is to analyze and study the interactions between the barriers and their solutions for the implementation of maintenance management providers in the manufacturing organizations in India. After a long discussion with experts as well as with highly experienced and various literature review, I found seven benefits of maintenance management on large scale which are as follow: improvement in productivity(IP), improvement in safety(IS), improvement in quality(IQ), defect rate reduction(DRR), improve equipment effectiveness(IEE), employee morale and job satisfaction(EMJS), lead time reduction(LTR). This study has also tried to find levels for different variables. From the model, it is observed that overall performance of organization is at the top. Manufacturing cost reduction is at the second level. Reduction in lead time, reduction in machine breakdown and reduction in product rejection rate are at the third level. Effective maintenance system is at fourth level. Improve safety and health management, quality management system and bench marking a process are at the fifth level. The remaining variables are at the lower levels. This finding implies that effective implementation of maintenance management will help in reducing lead time, manufacturing cost and reduction in m/c breakdown, reduction in product rejection rate and in improving product quality as well as overall performance. Finally the conclusion is that all these factors will help to improve overall performance of the manufacturing organization.

This study has gone through four phases, as follows:

1. Structuring the problem and building the AHP model
2. Collecting data from expert interviews
3. Determining the normalized priority weights of individual factors and sub factors
4. Synthesis-finding solutions to problem.

3.3 Maintenance Management’s Benefits for its Justification

The major benefits of modern maintenance management used in manufacturing organization are improvement in productivity, improvement in safety, improvement in quality, defect rate reduction, improvement in equipment effectiveness, employee morale with job satisfaction and lead time reduction. List of benefits after the adaption of modern Maintenance management in place of traditional Maintenance management are given in table 3.1 which are as:

Table 3.1 benefits of Maintenance management

S.NO.	Abbreviation	Benefits of MAINTENANCE MANAGEMENT	References
1	IP	Improvement in Productivity	Nakajima (1988); Mangano and Marco (2014).
2	IS	Improvement in Safety	Nakajima (1988); Sinkkonen et al. (2013).
3	IQ	Improvement in Quality	Hipkin and Cock (2000); Teresko (1992); So¨derholm and Norrbin (2013).
4	DRR	Defect Rate Reduction	Ahuja and Khamba (2008a), Sharma et al. (2006),
5	IEE	Improvement in Equipment Effectiveness	Ahuja and Khamba (2008a), Block et al. (2014)
6	EMJS	Employee Morale And Job Satisfaction	Ng et al. (2011) Tsang and Chan (2000).
7	LTR	Lead Time Reduction	Al-Najjar and Alsyouf (2000); Too (2012)

3.4 Research Methodology

3.4.1 Introduction of AHP

As competitive pressures intensify on organizations around the globe to be more efficient and effective, a peripheral management activity (maintenance) has now been given a central focus. Not only is maintenance of strategic importance in areas such as manufacturing, power plants, refineries, mining, etc. but also in buildings and facilities management. With economic rents on buildings and facilities being of high value, both commercial and private clients of such facilities no longer accept reactive actions but expect a proactive approach in regards to the management of maintenance (Myeda et al., 2011).

Analytic hierarchy process (AHP) was developed in 1972 as a practical approach in solving relatively complex problems said by Saaty during 1980. The AHP provides a framework to cope with multiple criteria situations involving intuitive, rational, quantitative and qualitative aspects. According to Chan during 2003 hierarchy representation of a system can be used to describe how changes in priority at upper levels affect the priority of criteria in lower levels. It organizes the basic rationality by breaking down a problem into its smaller and smaller constituent parts and then it guides decision makers through a series of pair wise comparison judgments to express relative strength or intensity of impact of the elements in the hierarchy.

The AHP method can support managers in a broad range of decisions and complex problems including supplier-selection decisions, facility-location decisions, forecasting, risks and opportunities modeling, choice of technology, plan and product design. AHP has been used by organizations in both the public and private sectors to deal with complex problems according to Bauer et al. "1992". During the time period of mid-1980s, IBM used AHP as part of its Rochester, Minnesota unit and earned the Malcolm Baldrige National Quality Award in 1990 for its best effort. According to Chan (2006) the performance of a postal company against its competitors used AHP for benchmarking. Kodali and Chandra (2001) have used AHP for justification of total productive maintenance (TPM). According to Varma et al. (2008), AHP is used for evaluating performance of petroleum SC. According to Anand and Kodali (2009), AHP have used for selection of lean manufacturing system. According to Kopytov et al. (2011), AHP have used for development of train schedule information systems. By using AHP methodology, I tried to compare modern maintenance management and traditional maintenance management in terms of global desirability index.

3.4.2 Structuring a Hierarchy Model of Benefits

Phase 1: Structuring a Hierarchy Model

This phase involves formulating appropriate hierarchy of AHP model consisting of goal, main factors and result. The goal of our problem is to justify the modern maintenance management over traditional maintenance management. This goal is placed on the first level of the hierarchy as shown in Figure 3.1. Seven major benefits, namely accurate forecasting of data, agility in maintenance management, improvement in productivity, improvement in safety, improvement in quality, defect rate reduction, improvement in equipment effectiveness, employee morale with job satisfaction and lead time reduction are identified to achieve this goal, which form the second level of hierarchy. AHP model designed for systematic level of justification of maintenance management is shown in Figure 3.1.

The major benefits of modern maintenance management used in second level of hierarchy can be assessed using the basic AHP approach of pair wise comparison of elements in each level with respect to every parent element located one level above. The third and last level consists of two alternatives, modern maintenance management and traditional maintenance management.

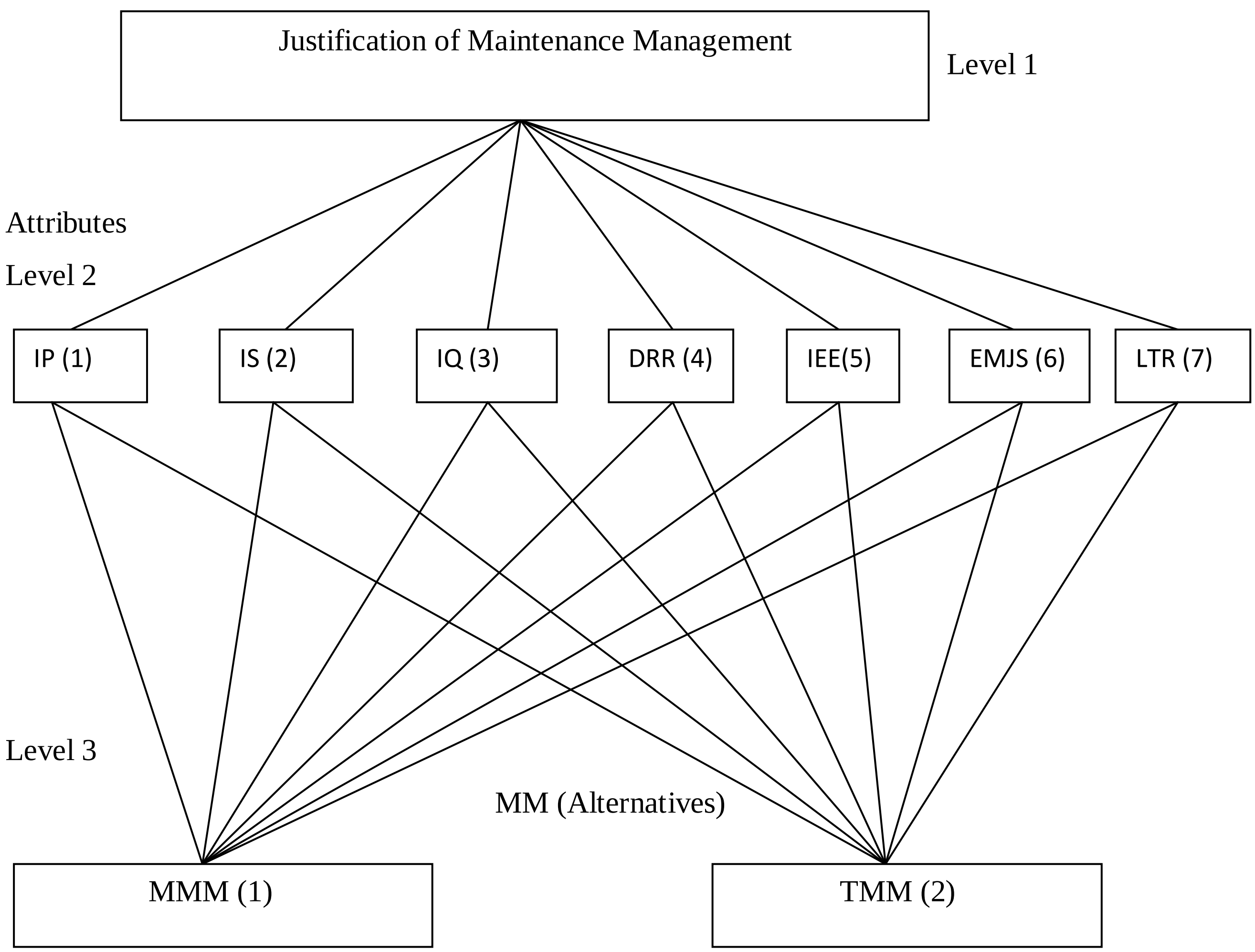


Figure 3.1 Schematic of the AHP model (Source- Rajesh K. Singh, 2012)

3.4.3 Measuring and Collecting Data

Phase2: Measuring and Collecting Data

After building the AHP hierarchy, the next phase is the measurement and data collection. It involves forming a team of experts and assigning pair-wise comparison to the main factors used in the AHP hierarchy. The nine-point scale (Table 3.2) was employed to assign relative scores to pair wise comparisons amongst the main factors.

The experts were involved to assign a score to each comparison using the scale. This process continued till all levels of the hierarchy and eventually a series of judgment matrices for the major factors were obtained. Team consisted of ten members, out of these seven experts belongs to industry, mainly manufacturing sector such as automobile and electrical equipment sectors and three from academia. Each one of them has more than ten year of experience in maintenance management area.

A questionnaire consisting of all main factors of the two levels of AHP model is designed and is used to collect the pair wise comparison judgment from all experts. This process was continued till the consensus was reached otherwise decision of majority was given more importance. In past also, researchers have adopted a team of decision makers consisting less than ten members. AHP approach was applied by Bayazit (2005) in decision making for flexible manufacturing systems by having a team of five managers from different departments. Zaim et al. (2012) also had a team of five decision makers while selecting maintenance strategy.

3.4.4 Determining-Normalized Weights

In order to determine the relative importance of seven major factors, the pair wise comparison judgment matrices were formed based on expert's opinion from various organization and prestigious technical universities, in the measurement and data collection phase.

Table 3.2 Thomas Saaty's nine-point scale

Intensity of importance	Definition	Explanations
1	Equal Importance	Two activities contribute equally to the objective
3	Weak Importance one over another	Experience and judgment slightly favor one activity over another
5	Essential or Strong Importance	Experience and judgment strongly favor one activity over another
7	Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgment	When compromise is needed
Reciprocals of above non-zero	If activity 'i' has one of the above non-zero numbers assigned to it when compared with activity 'j' then 'j' has the reciprocal value when compared with 'i'	A reasonable assumption

Source: Saaty (1994)

For determining normalized weight, following steps are followed:

Construction of pair-wise comparison matrices: - A set of pair-wise comparison matrices is constructed for each of lower levels attributes. An element in the higher level is said to be a governing element for those in lower level. The elements in the lower level are then compared to each other based on their effect on the governing element above it. This yields a square matrix of judgments. The pair-wise comparisons are done in terms of which an element dominates another. These judgments are then expressed as integers. If element A dominates over B, then the whole number integer is entered in row A, column B and reciprocal is entered in row B, column A. If the elements being compared are equal, a one is assigned to both positions. Table 3.4 shows the pair-wise comparison matrix for level 2 criteria. There are $n(n-1)/2$ judgments required to develop the set of matrices (reciprocal are automatically assigned in pair-wise comparison).

Calculating the degree of consistency in order to validate the results:- It is known that people are often inconsistent in answering questions, and thus one of the important tasks of AHP is to calculate the consistency level of the estimated vector. Consistency ratio (CR) is used to measure the consistency in the pair-wise comparison. According to Saaty (1994), acceptable CR value for different matrices size is as 0.05 for a 3**x**3 matrix, 0.08 for a 4**x**4 matrix and 0.1 for large matrices. If consistency level falls in the range of acceptable, the weight results are valid. Having done all pair-wise comparisons after that the consistency is determined using the Eigen values. I normalized the column of numbers by dividing each entry by the sum of all entries in next step, after that sum each row of the normalized values and take the average and this provides priority vector (PV).

To check the consistency of judgments following steps are followed:

- let the pair-wise comparison matrix be denoted M1 and principal matrix be denoted M2
- Then find X3 = X1 * X2; and X4 = X3 / X2
- λ_{max} = average of the elements of X4
- Consistency index (CI) = (λ_{max} – N) / (N – 1)
- Consistency ratio (CR) = CI / RCI corresponding to N. …………. (1)

Where RCI = Random Consistency Index and N = Numbers of elements (Table 3.3).

Table 3.3 Average random index values

N	1	2	3	4	5	6	7
RCI	0	0	.58	.9	1.12	1.24	1.32

Source: Saaty (1980)

If CR is less than 10%, judgments are considered consistent,

If CR is greater than 10%, the quality of judgments should be improved.

So that CR becomes ≤ 10%.

3.5 Finding Solution to the Problem

After computing the normalized priority weights for each pair-wise comparison Judgment matrices of the AHP hierarchy, the next phase is to synthesis the solution for justification of factors for modern maintenance management. A set of global priority weight can then be determined for each of the modern maintenance management and traditional maintenance management by multiplying local weight of lower factors with weight of all the parent nodes above it and then adding all the products for corresponding alternative.

3.6 Results and Discussion

While forming AHP hierarchy model, seven main factors table 3.1 are considered for analysis. AHP model developed as shown in figure 3.1 is used for justification of modern maintenance management in manufacturing sector. After that the pair-wise comparison judgment matrices are formed for determining the normalized weight. Table 3.4 shows criteria pair wise comparison matrix for all seven major benefits of MMM. CR is calculated for checking degree of consistency in the pair-wise comparison.

All the calculation steps related to normalized weight and CR for level 1 are shown in appendix. Same procedure is followed for finding PV and CR for other levels also. From table 3.5, it is observed that for all seven factors has more PV for modern maintenance management in comparison to traditional maintenance management. It is also observed that all decisions are consistent as CR value is less than 0.1 for all factors. Table 3.12 shows local weight ages of attributes for alternatives. Global weights of the seven major benefits for modern maintenance management are shown in table 3.13.

Global weights have been calculated by following method: ..…….. (2)

Individual weight of the main factor = P.V. value from the respective normalized table

Individual weight of the sub factor = P.V. value from the respective normalized table

Global weight of main factor = individual weight of that main factor

Similarly,

Global weights for other strategic factors and sub factors can be calculated: …..…... (3)

Global weights of modern MM (MMM) = Level 2 Wt. × MMM Wt.

Global weights of traditional MM (TMM) = Level 2 Wt. × TMM Wt.

Total global weights = sum of the global wt. of respective column ……….. (4)

Out of major benefits of modern maintenance management, reduced lead time has highest global weight (0.32518). Due to proper maintenance management, lead time decreased in organizations. Second highest global weight is to improve safety (0.2063). Proper maintenance reduced accidents in organizations. Third highest global weight is defect rate rejection (0.173). Fourth major benefit of maintenance management is improving quality (0.07498). Fifth benefit of maintenance management is improvement in effective maintenance (0.05416). Next benefit of maintenance management is employee moral job satisfaction (0.03942). Last benefit of maintenance management is improved productivity (0.01839).

Global desirability index of modern maintenance management (0.8915) is higher than traditional maintenance (0.10845). This analysis shows that application of maintenance management is justified for survival of manufacturing organizations in globalised market.

The pair wise comparison judgment matrix was formed based on expert's opinion by using the table 3.3 "Thomas Saaty's nine-point scale". I normalized the column of numbers by dividing each entry by the sum of all entries, after that sum each row of the normalized values and take the average and this provided priority vector (PV). Table 3.4 a pair wise comparison judgment matrix is as shown below:

Table 3.4 Criteria pair wise comparison matrix (level 2)

	IP	IS	IQ	DRR	IEE	EMJS	LTR	P.V
IP	1	1/8	1/5	1/8	¼	1/6	1/9	.021019
IS	8	1	3	2	6	8	1/3	.232088
IQ	5	1/3	1	1/5	2	4	1/6	0.083316
DRR	8	1/2	5	1	4	6	½	.197725
IEE	4	1/6	1/2	1/4	1	3	1/6	.060183
EMJS	6	1/8	1/4	1/6	1/3	1	1/9	.44353
LTR	9	3	6	2	6	9	1	.361315

Following steps are used to normalize the table of seven main benefits and to calculate the CR value.

Average of elements of X_4 ($\lambda_{max.}$) = 7.75475

Now consistency index (CI) = $\frac{(\lambda_{max} - n)}{n-1}$ = 0.1257917

and consistency ratio (CR) = CI / RCI = 0. 0.0952967,

(CR is less than 0.1, result is consistent)

Let X_1 is pair wise comparison matrix

X_2 is principal vector matrix

$$X_2 = \begin{Bmatrix} 0.021019 \\ 0.232088 \\ 0.083316 \\ 0.197725 \\ 0.060183 \\ 0.044353 \\ 0.361315 \end{Bmatrix}$$

Then $X_3 = X_2 * X_1$

$$X_3 = \begin{Bmatrix} 0.153993238 \\ 1.882003007 \\ 0.663317921 \\ 1.586011165 \\ 0.467309207 \\ 0.313469989 \\ 2.902375827 \end{Bmatrix}$$

$X_4 = X_3/X_2$

$$X4 = \begin{Bmatrix} 7.3262924 \\ 8.1089902 \\ 7.9615032 \\ 8.0212915 \\ 7.7647435 \\ 7.0676161 \\ 8.0328133 \end{Bmatrix}$$

Now pair wise matrices have been constructed by using the table 3.3 “Thomas Saaty’s nine-point scale”. Table 3.5 to table 3.11 shows pair wise comparison, priority vector and consistency ratio. I normalized the column of numbers by dividing each entry by the sum of all entries, after that sum each row of the normalized values and take the average and this provided priority vector (PV for each table).Then CR values for each table is calculated by using the equation 1. After calculating the value of CR, its consistency is also checked. Table 3.5 shows pair wise comparison between modern maintenance management and traditional maintenance management for improvement in productivity.

Pair wise comparison judgment matrices

Table 3.5: Alternative analysis with respect to improvement in productivity

	MMM	TMM	P.V.
MMM	1	7	.875
TMM	1/7	1	.125
TOTAL	1.1428	8	**CR≤0.1**

Table 3.6 shows pair wise comparison between modern maintenance management and traditional maintenance management for improvement in safety.

Table 3.6: Alternative analysis with respect to improvement in safety

	MMM	TMM	P.V.
MMM	1	8	.8889
TMM	1/8	1	.1111
TOTAL	1.125	9	**CR≤0.1**

Table 3.7 shows pair wise comparison between modern maintenance management and traditional maintenance management for improvement in quality.

Table 3.7: Alternative analysis with respect to improvement in quality

	MMM	TMM	P.V.
MMM	1	9	0.9
TMM	1/9	1	0.1
TOTAL	1.1111	10	**CR≤0.1**

Table 3.8 shows pair wise comparison between modern maintenance management and traditional maintenance management for reduction in defect rate.

Table 3.8: Alternative analysis with respect to reduction in defective rate

	MMM	TMM	P.V.
MMM	1	8	.875
TMM	1/8	1	.125
TOTAL	1.125	9	**CR≤0.1**

Table 3.9 shows pair wise comparison between modern maintenance management and traditional maintenance management for improvement in equipment effectiveness.

Table 3.9: Alternative analysis with respect to improvement in equipment effectiveness

	MMM	TMM	P.V.
MM	1	7	.9
NMM	1/7	1	.1
TOTAL	1.1428	8	**CR≤0.1**

Table 3.10 shows pair wise comparison between modern maintenance management and traditional maintenance management for employee morale and job satisfaction.

Table 3.10: Alternative analysis with respect to employee morale and job satisfaction

	MMM	TMM	P.V.
MMM	1	9	.88889
TMM	1/9	1	.11111
TOTAL	1.1111	10	**CR≤0.1**

Table 3.11 shows pair wise comparison between modern maintenance management and traditional maintenance management for lead time reduction.

Table 3.11: Alternative analysis with respect to reduction in lead time

	MMM	TMM	P.V.
MMM	1	7	.9
TMM	1/7	1	.1
TOTAL	1.1428	8	**CR≤0.1**

Weights of attributes for alternatives are calculated by using the equation 2. Table for weights of attributes for alternatives is as shown below:

Table 3.12: Weights of attributes for alternatives

S.NO.	ATTRIBUTES	Level 2 Wt. (P.V.)	MMM Wt. (P.V.)	TMM Wt.(P.V.)
1	IP	.021019	.875	.125
2	IS	.232088	.8889	.1111
3	IQ	0.083316	.9	.1
4	DRR	.197725	.875	.125
5	IEE	.060183	.9	.1
6	EMJS	.44353	.8889	.1111
7	LTR	.361315	.9	.1

Desirability index of alternatives global weight of modern maintenance management and traditional maintenance management is calculated by using the equation 3. Table for desirability index table of alternatives global weight is as shown below:

Table 3.13: Desirability index table of alternatives global weight

S.NO.	ATTRIBUTES	MMM global Wt.	TMM global Wt.
1	IP	.01839	.89145
2	IS	.206300	.002624
3	IQ	.074984	.025787
4	DRR	.173009	.024715
5	IEE	.054165	.006018
6	EMJS	.039424	.004928
7	LTR	.325183	.036313

Global desirability index of modern maintenance management and traditional maintenance management is calculated by using the equation 4. Table for global desirability index of alternatives is as shown below:

Table 3.14: Global desirability index of alternatives

1.	Global desirability index of Modern Maintenance Management	.89145
2.	Global desirability index of Traditional Maintenance Management	.10854

Global competition, technological changes and demanding customers are creating a more knowledge intensive, turbulent, complex and uncertain environment. In such a dynamic environment, manufacturing organizations will be benefited if they adapted modern maintenance management. They will be able to continually improve their operational and business performance.

3.7 Conclusion & Remarks

In this work, AHP is applied to justify the application of modern maintenance management in manufacturing organizations on basis of major benefits derived from literature review and expert opinion. From analysis, it is observed that out of seven major benefits of modern maintenance management, modern maintenance management has got highest global desirability index. Modern maintenance management is followed by, improvement in productivity, improvement in safety, improvement in quality, defect rate reduction, improvement in equipment effectiveness, employee morale with job satisfaction and lead time reduction.

These findings will have significant managerial implications in motivating manufacturing organizations to work for modern maintenance management for improving performance in terms of, improvement in productivity, improvement in safety, improvement in quality, defect rate reduction, improvement in equipment effectiveness, employee morale with job satisfaction and lead time reduction. Scientifically it will motivate researchers for future research considering more holistic and industry-based approach for improving productivity in maintenance management. Although findings will be highly useful for manufacturing organizations but they cannot be generalized because of some limitations due to smaller size of respondent's team and that also from few selected sectors.

Further this study has assumed that there is no overlapping among different factors therefore in case of interdependency among some of the factors. Findings can be further validated with empirical study and case studies from different sectors. This study can be also extended to identify and prioritize different factors responsible for modern maintenance management as well as for developing a framework to evaluate index of maintenance management.

CHAPTER 4

ANALYSING BARRIERS AND SOLUTIONS FOR MAINTENANCE MANAGEMENT BY FUZZY TOPSIS

4.1 Introduction

Now a day, most of the manufacturing organizations are trying to implementing maintenance management in their production house. But unfortunately their attempts are failing. There are lots of barriers which cause of fail in implementation of maintenance management. This paper aims to conduct a detailed study in order to understand the cause of failure and seeks to propose various solutions. However, finding of such solution of barriers in maintenance systems raises the following question: if an organization is planned to implement and improvement in their existing maintenance system then how can the maintenance management team make a decision between choosing alternative of barriers such as preventive maintenance system , integration of corporate strategies with operation strategies, establishing quality management system, top management support and commitment, encouragement of cross functional team and quality circles i.e.

Maintenance is a kind of repair that uses general-purpose tools. Most of maintenance's tools could be found at a well-equipped hardware or automotive store. A setup is a temporary change to a machine without using any general-purpose tools. While defining job duties, the distinction between maintenance and setup becomes important.

Maintenance Management (MM) is a maintenance program which involves a newly defined concept for maintaining plants and equipment. MM program's goal is to markedly increase productivity, at the same time, increase in employee morale and job satisfaction with rise in quality and cost of production is low as possible. Maintenance management brings into preventive maintenance as a necessary and virtually important part of the business. It is no longer regarded as an activity with no-profit. Maintenance's down time is scheduled as a part of the manufacturing day and, for some cases, as an integral part of the manufacturing process. The goal is to unscheduled maintenance to a minimum and hold emergency .The aim of productive maintenance is to maximize plant and equipment efficiency.

The objectives to be achieved and for which MM was introduced are as follows.

- Avoid wastage in a quickly changing economic environment.
- Producing goods without reducing product quality.
- Reduce cost.
- Produce a quantity with low batch at the earliest possible time.

Goods send to the customers must be non defective. Selection of technology and its implementation in a manufacturing industry will be a great challenge for organization to survive in global competitive market. During various operations major or minor barriers occur due to breakdown which leads to reduction in productivity and it forced the organization to implement maintenance management. It means maintenance management cannot be successfully implemented until all departments integrate effectively. For successful implementation of maintenance management, top management need to focus on different-different aspects of organizational functioning including organization culture, employees training, integration of departments etc. In addition to this, management needs to understand structural relationship between different variables, which will help in developing strategies for effective implementation of maintenance management.

Maintenance engineering not only requires engineers to monitor large production machine operations and heavy duty equipment, but also often requires involvement with computer operations. Maintenance engineers may have to deal with PCs, routers, servers, and software so as to get solution for their complex issues like local and off-site networks, configuration systems, end user support, and scheduled upgrades. Supervision of technical personnel may also be required. Good maintenance engineering is vital to the success of any manufacturing or processing operation, regardless of size.The rest of this work is organized as follows:

Section 2: Briefly reviews the literature on barriers and solutions of MM adoption in manufacturing sector.

Section 3: The Fuzzy AHP and fuzzy TOPSIS methods are presented.

Section 4: The proposed framework for prioritize the solutions of MM adoption in manufacturing sector is described.

Section 5: The empirical case study is conducted and described.

Section 6: Finally, the conclusion is discussed in.

4.2 Literature Review

The ultimate goal of maintenance management is to implement “perfect manufacturing” (Shirose, 1992).Maintenance management provides a comprehensive, life-cycle approach to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers (Ahuja and Khamba, 2008a). It encompasses all departments including maintenance, operations, facilities, design engineering, project engineering, construction engineering, inventory and stores, purchasing, accounting and finance, and plant and site management (Wireman, 1990).

Maintenance has now become a strategic tool to increase competitiveness rather than simply an overhead expense that must be controlled according to Waeyenbergh and Pintelon (2007). Investment in maintenance, one of the basic functions of a firm, returns improved quality, safety, dependability, flexibility and lead times said by Teresko (1992). Shamsuddin et al. (2005) fall out that TPM can go much beyond maintenance and may encompass a host of business functions within an organization.

4.2.1 Identification of barriers and solutions for Maintenance management

Maintenance management is a partnership between maintenance and production organizations to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company’s over state of maintenance (Rhyne, 1990). Proper maintenance is one of them, which protects the firm’s investment (Heizer and Render, 2001), prolongs equipment life and can lead to substantial savings in capital investment (Noori and Radford, 1995; Macchi and Fumagalli, 2013).Maintenance management is based on teamwork and provides a method for the achievement of world class levels of overall equipment effectiveness (OEE) through people, not through technology or systems (Willmott, 1994).

Maintenance management practices can improve manufacturing performance (Brah and Chong, 2004; Seth and Tripathi, 2005). The structure of the maintenance management team can perhaps be evaluated and improved further. As proposed by Lee (2008) & Veldman et al.(2011). team members need to have sufficient knowledge, in new product development. However, in maintenance management, team members who are able to demonstrate the ability to apply their skills and knowledge to improve performance are certainly very important. This implies that top management should look closely at the maintenance management team and pay extra attention to utilizing maintenance management team members. Hence, Ferrari et al. (2002) suggest the role of the maintenance management team in TPM implementation. Many other potential factors exist that can affect manufacturing performance, such as leadership, continuous improvement activities, focus on customer satisfaction, information architecture according to Seth and Tripathi (2005); Ng et al. (2011) & Lazim and Ramayah (2010).

Descriptions of successful maintenance management implementations talk about establishing new cultures (Patterson et al., 1996), changing attitudes (Turbide, 1995), creating new work environments (Maggard and Rhyne, 1992), and accomplishing paradigm shifts (Jeszenka, 1993); while organizations that are not ready for maintenance management are characterized by mistrust and poor communication between operators, maintenance personnel, and management according to Patterson et al., 1995.

Maintenance management is intended to bring both functions (production and maintenance) together by a combination of good working practices, team working, and continuous improvement (Cooke, 2000). Tsang and Chan (2000) revealed the importance of management leadership, employee involvement, education and training, strategic planning and communication for maintenance management in Chinese setup. Cooke (2000) also identified top management support, alignment of management initiatives and change, employee training, autonomy to employees and communication as important factors for the success of maintenance management in a European context.

Maintenance management co-coordinators with time and resources, plus senior level back up; put in place relevant measures of performance and continually monitor and publicize benefits achieved in financial terms by Davis (1997). Indeed, the complexity of getting commitment and involvement from employees is one of the implementation difficulties of maintenance management (Arca and Prado, 2008). The success criteria for effective and efficient maintenance management implementation according to Cooke (2000) and Ng et al. (2011), must include steps like top management support, employee involvement, team development, education and training, benchmarking, strategic planning and communication and management of employees.

Training plays an important role in minimizing the negative effect of system complexity on manufacturing system performance by Guimaraes et al. (1999). However, in maintenance management implementation various authors have stressed the contribution of training towards performance (Ahmed et al., 2005; Ireland and Dale, 2006; Sharma et al., 2006; Tsarouhas, 2007). Ireland and Dale (2006) suggest that teamwork is not only essential in TPM practices, but is considered as one of the criteria for its success. Maintenance management can lead to improvements in quality, cost, delivery and flexibility (Sharma et al., 2006; Cua et al., 2001; McKone et al., 1999, 2001; Seth and Tripathi, 2005, 2006).

Maintenance management provides a comprehensive, life-cycle approach to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers (Ahuja and Khamba, 2008a). It encompasses all departments including maintenance, operations, facilities, design engineering, project engineering, construction engineering, inventory and stores, purchasing, accounting and finance, and plant and site management (Wireman, 1990).

Maintenance Management is considered to be an effective strategic improvement initiative for improving quality in maintenance engineering activities according to Ollila and Malmipuro (1999) & Pramod et al.(2007). Maintenance management is all of the strategies needed to sustain a healthy maintenance log according to Steinbacher and Steinbacher (1993). Maintenance management is the general movement on the part of businesses to try to do more with less by Lawrence (1999). Maintenance management has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities (Dwyer, 1999; Dossenbach, 2006).

Table 4.1: Initial hierarchy model of barriers of Maintenance Management and its criteria

Main Criterion	**C. Code**	**Sub Criteria**	**Reference**
TOP MANAGEMENT BARRIERS	TMB 1	LACK OF STRATEGIC PLANNING	Cooke (2000); Ng et al. (2011),
	TMB 2	LACK OF FINANCIAL SUPPORT	Khelada (1996); Zink (1998); Macchi and Fumagalli (2013).
	TMB 3	LACK OF INVESTMENT IN TECHNOLOGY	Ireland and Dale (2001); Shamsuddin et al., (2005).
	TMB4	LACK OF POSITIVE AND QUALITY IN LEADERSHIP	Seth and Tripathi (2005); Khazraei and Deuse (2011).
COORDINATION B/W DEPT BARRIERS	CBDB 1	LACK OF INTEGRATED PRODUCTION PLANNING	Takata et al.(2004); Gosavi (2006); Ng et al. (2011).
	CBDB 2	LACK OF SHOP-FLOOR MANAGEMENT & PLANNING	McCarthy (2004); Sharma et al., (2006); Narayan (2012).
	CBDB 3	LACK OF INFORMATION & DATA SHARING	Uusipaavalniemi and Juga (2009); Kans and Ingwald (2008).
	CBDB 4	LACK OF MUTUAL TRUST AMONG DEPARTMENT	Ng et al. (2011).
	CBDB 5	LACK OF VERBAL & WRITTEN COMMUNICATION SKILLS	Ng et al. (2011); Lazim and Ramayah (2010).
QUALITY RELATED BARRIERS	QRB 1	LACK OF QUALITY AWARENESS	Ireland and Dale (2001); Shamsuddin et al. (2005); Veldman et al.(2011).
	QRB 2	LACK OF BENCH MARKING	A° hre´n and Parida (2009); Ng et al. (2011).
	QRB 3	LACK OF STANDARDIZATION	Seth and Tripathi (2005); Too (2012).
	QRB 4	LACK OF AWARENESS OF QUALITY TOOLS	Ireland and Dale (2001); Shamsuddin et al. (2005).
	QRB5	LACK OF RIGHT FIRST TIME APPROACH	Arca and Prado(2008).
ORGANIZATION CULTURE BARRIERS	OCB 1	LACK OF TEAM WORK OR CROSS FUNCTIONAL TEAM	Arca and Prado (2008); Ireland and Dale (2006).
	OCB 2	LACK OF EMPLOYEE EMPOWERMENT &	Ng et al. (2011); Lazim and Ramayah (2010);

		TRAINING	Batumalay and Santhapparaj (2009).
	OCB3	LACK OF KNOWLEDGE SHARING	Uusipaavalniemi and Juga, (2009); Eti et al.(2006).
	OCB4	LACK OF STANDARD OPERATING PRACTICES FOR MAINTENANCE	Brah and Chong (2004); Seth and Tripathi (2005); Uzun and Ozdogan (2012).

Table 4.2: Solutions of Maintenance Management (MM).

Code of solutions	Solutions	Descriptions	References
SOB 1	INTEGRATION OF CORPORATE STRATEGIES WITH OPERATION STRATEGIES	TPM describes a relationship between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity, assurance and safety.	Naughton and Tiernan (2012); Nakaiima (1988).
SOB 2	OPTIMAL RESOURCE ALLOCATION	The relationship between TQM practices like leadership, strategic planning, human resource management and quality performance.	Damjan Maletic et al. (2012); Raghunathan and Subba Rao (1999).
SOB 3	ESTABLISHING PREVENTIVE MAINTENANCE SYSTEM	Maintenance has now become a strategic tool to increase competitiveness rather than simply an overhead expense that must be controlled. Investment in maintenance, one of the basic functions of a firm, returns improved quality, safety, dependability, flexibility and lead times.	Block et al. (2014); Waeyenbergh and Pintelon(2007).
SOB 4	ESTABLISHING QUALITY MANAGEMENT SYSTEM	The quality and maintenance management as the strategic decision areas. In order to improve their production processes, various quality programs are implemented. Two major improvement programs in the field of production and operations management are Total Productive Maintenance (TPM) and Total Quality Management (TQM).	Ahuja and Khamba, (2008a) , Chan et al. (2005).
SOB 5	ENCOURAGEMENT	As both quality and maintenance go	Stenstro¨m et al.

	OF CROSS FUNCTIONAL TEAM AND QUALITY CIRCLES	hand in hand in a manufacturing set up, TQM and TPM share many threads of commonalties like employee involvement, cross-functional approach and continuous improvement.	(2013); Cooke (2000).
SOB 6	EMPLOYEE TRAINING AND EMPOWERMENT	The implementation of quality improvement programs, modern information systems, continuous improvement programs, and the evolution of performance measurement systems, tended to promote the proliferation of maintenance performance measures and measurement. Training plays an important role in minimizing the negative effect of system complexity on manufacturing system performance.	Seth and Tripathi (2006); Ireland and Dale(2006); Sharma et al. (2006); Tsarouhas (2007); Lee (2008).
SOB 7	TOP MANAGEMENT SUPPORT AND COMMITMENT	Top management should look closely at the TPM team and pay extra attention to utilising TPM team members. Top management of manufacturing enterprises look at the performance of each and every business function, including manufacturing or maintenance, for achieving competitive advantage. top management support, alignment of management initiatives and change, employee training, autonomy to employees and communication as important factors for the success of TPM.	Ferrari et al. (2002); Pintelon et al.(2006); Ng et al. (2011).
SOB 8	INTEGRATED INFORMATION SYSTEM	Approaching maintenance management strategically and systematically has become essential to make the right choices, especially in capital-intensive industries. Information sharing practices, information attributes, information technology use, collaborative foundation, time-related issues, processes and activities are all considered as critical elements of information integration. Information	Kumar et al.(2013); Uusipaavalniemi and Juga, (2009); Seth and Tripathi (2005).

		system architecture is important for quality management practices companies	

4.3 Research Methodology

The aim of this study is to identify and prioritize the solutions of maintenance management problems in manufacturing sector to overcome its barriers in the way of productivity. It helps organizations to concentrate on high rank solutions and develop strategies to implement them on priority. This work proposes a framework based on fuzzy analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) to identify and rank the solutions of MM adoption in manufacturing sector and overcome its barriers.

The AHP is used to determine weights of the barriers as criteria, and fuzzy TOPSIS method is used to obtain final ranking of the solutions of maintenance management adoption in manufacturing sector. The case study of manufacturing organization is conducted to illustrate the use of the proposed framework for ranking the solutions of maintenance management adoption in manufacturing sector to overcome its barriers. This proposed framework provides a more accurate, effective and systematic decision support tool for stepwise implementation of the solutions of maintenance management adoption in manufacturing sector to increase its success rate. The barriers of maintenance management adoption in manufacturing sector can identify through literature review and expert opinion from various industries. However, in a strategic view, these barriers are significant but not possible to overcome all at the same time. Even a same barrier may be differently important to the individual organization with the varied priorities; due to each organization has its own purposes, strategies, conditions of resources, and capabilities. Hence it is noticed that in order to enhance MM adoption in manufacturing sector successful, concrete and feasible solutions must be proposed and ranked to overcome these barriers in stepwise manner.

To prioritize the solutions of MM adoption is multi criteria decision making (MCDM) problem. Human judgment in decision making has been often unclear and hard to estimate by exact numerical values. Hence fuzzy logic is necessary for handling problems characterized by vagueness and imprecision. This thesis proposes hybrid fuzzy Analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) framework to prioritize the solutions of maintenance management adoption in manufacturing sector. Fuzzy AHP (Saaty, 1980) determined importance weights of the barriers and fuzzy TOPSIS (Hwang & Yoon, 1981) obtained performance ratings of feasible solutions with triangular fuzzy numbers (TFN). Lastly, empirical case study is presented to demonstrate the application of proposed framework.

4.3.1 Fuzzy sets:

Decision making is very difficult for vague and uncertain environment so vagueness and uncertainty handled by using fuzzy set theory. Zadeh during 1965 gave fuzzy set theory. A fuzzy set defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually vary from [0, 1]. If, I assign zero value then the element does not belong to the fuzzy set i.e. it has no membership. If, I assign one value assigned then the element belongs completely to the fuzzy set i.e. it has total membership. If the value lies between the intervals, the element has a certain degree of membership. In particular, to deal with the ambiguities involved in the process of linguistic estimation, it is a constructive way to convert these linguistic terms into fuzzy numbers. These linguistic terms can be represented by fuzzy numbers, and the Triangular Fuzzy Number (TFN) is commonly used. I used a character tilde ‘‘ ˜ ’’ above a symbol if the symbol shows a fuzzy set. I briefly analyze some essential definitions of fuzzy logic.

Definition 1: A Fuzzy set $\tilde{Q}$ is a subset of universe of discourse R, which is a set of ordered pairs and is characterized by a membership function $U_{\tilde{Q}}(r)$ representing a mapping $U_{\tilde{Q}}$:- r→[0,1]. The function value of $U_{\tilde{Q}}(r)$ for the fuzzy set $\tilde{Q}$ is called the membership value of r in $\tilde{Q}$, which represent the degree of truth that r is a element of fuzzy set $\tilde{Q}$. It is assumed that $U_{\tilde{Q}}(r) \in [0, 1]$, where $U_{\tilde{Q}}(r) = 1$ reveals that d completely belongs to $\tilde{Q}$, while $U_{\tilde{Q}}(r) = 0$ indicates that r does not belong to the fuzzy set $\tilde{Q}$.

$$\tilde{Q} = \{(r, U_{\tilde{Q}}(r))\}, \qquad r \in R$$

Where $U_{\tilde{Q}}(r)$ is the membership function and R = {r} represent a collection of elements r.

Definition 2: A fuzzy set Q̃ of the universe of discourse r is normal if max

Max $U_{\tilde{Q}}(r) = 1$

Definition 3: A Fuzzy set Q̃ of the universe of discourse r is convex if

$U_{\tilde{Q}}(\lambda_{r1} + (1-\lambda)_{r2}) \geq \min(U_{\tilde{Q}}(r_1), U_{\tilde{Q}}(r_2)) \forall r \in [r_1, r_2]$,

Where $\lambda \in [0, 1]$

Definition 4: A fuzzy number Q̃ is a fuzzy subset in the universe of discourse r, which is both convex and normal.

Definition 5: In a triangular fuzzy number (TFN) if the membership function $U_{\tilde{Q}}(r)$ of fuzzy set Q̃ = (A, B, C) in universe R is defined as follows, where A, B, C are real numbers and A≤B≤C.

$$\psi_{\tilde{n}} = \begin{cases} 0 & (r < A) \\ \dfrac{r-A}{B-A} & (A \leq r \leq B) \\ \dfrac{d-r}{d-B} & (B \leq r \leq C) \\ 0 & (r < C) \end{cases}$$

Definition 6: The α- cut of fuzzy set Q̃ of the universe of discourse R is defined as

$$\tilde{Q}_{\alpha} = \{r \in R; U_{\tilde{Q}} \geq \alpha\} \qquad \text{Where } \alpha \in [0, 1]$$

Definition 7: Alternatively, by defining the interval of confidence level α, the triangular fuzzy number can be characterized using the following equation.

$\forall\alpha$ [0,1] $\tilde{M}_{\alpha} = [A^{\alpha}, C^{\alpha}] = [(B-C)\alpha + A, -(C-B)\alpha + C]$

Definition 8: Suppose m = (m_1, m_2, m_3) and n = (n_1, n_2, n_3) are two triangular fuzzy numbers, then distance between them is calculated as:

$$d_v(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2]}$$

4.3.2 Fuzzy AHP

AHP introduced by Satty (1980) is a quantitative technique that structures a multi-criteria, multi person, multi period problem hierarchically so that solutions are facilitated. The application of Satty's AHP has some limitation as follows:

(1) The AHP method mainly used in nearly crisp decision application.
(2) The AHP methods create and deal with the very unbalanced scale of judgment.
(3) The AHP method cannot handle the uncertainty and ambiguity associated with mapping of one's judgment to a number.
(4)Ranking of AHP method is rather imprecise.
(5)The subjective judgment, selection and preference of decision makers have great influence on the AHP results. Therefore Fuzzy AHP methodology extended Satty's AHP by combining it with fuzzy set theory to solve hierarchical fuzzy problems.

The fuzzy AHP method offer the number of benefits like, it can capture uncertain imprecise judgment of experts by handling linguistic variables. According to Ozdago-glu & Ozdagoglu, 2007; it is not completely captured the importance of qualitative aspects because its discrete scale couldn't reflect the human thinking style. Recently fuzzy AHP is widely used to solve multi-criteria decision problems in few other areas e.g. selection of thermal power plant by

Choudhary & Shankar (2012), strategic analysis of electronic service quality by Buyukozkan & Cifci (2012), renewable energy planning by Kaya & Kahraman (2010).

Step 1: According to Chang's method (1996), for each level of the constructed hierarchy, the pair-wise linguistic judgments has converted in TFNs and organized in fuzzy comparison matrices as follows:

$$\tilde{Z} = (\tilde{z}_{ij})_{n\times m} = \begin{pmatrix} (1, 1, 1) & \ldots & (L_{12}, M_{12}, N_{12}) & \ldots & (L_{1n}, M_{1n}, N_{1n}) \\ (L_{21}, M_{21}, N_{21}) & \ldots & (1, 1, 1) & \ldots & (L_{2n}, M_{2n}, N_{2n}) \\ . & & . & & . \\ (L_{n1}, M_{n1}, N_{n1}) & \ldots & (L_{n2}, M_{n2}, N_{n2}) & \ldots & (1, 1, 1) \end{pmatrix}$$

Where

$$\tilde{z}_{ij} = (L_{ij}, M_{ij}, N_{ij}) \qquad \ldots\ldots\ldots (1)$$

$$\tilde{z}_{ji}^{-1} = \left(\frac{1}{N_{ji}}, \frac{1}{M_{ji}}, \frac{1}{L_{ji}}\right) \quad \text{'i' \& 'j' varies such as } i, j = 1, 2\ldots\ldots\ldots\ldots n;\ i \neq j \qquad \ldots\ldots\ldots (2)$$

Represent the linguistic judgment for the items i and j; thus $\tilde{Z}$ is a square and symmetrical matrix

Table 4.3: Triangular fuzzy conversion scale (chang, 1996; Lee, 2010)

Linguistic Scale	Triangular Fuzzy Conversation scale	Triangular Fuzzy reciprocal scale
JUST EQUAL	(1,1,1)	(1,1,1)
EQUALLY IMPORTANCE	(2/3,1,3/2)	(2/3,1,3/2)
WEAKLY MORE IMPORTANCE	(1,3/2,2)	(1,3/2,2)
MODERATERLY MORE IMPORTANCE	(3/2,2,5/2)	(3/2,2,5/2)
STRONGLY MORE IMPORTANCE	(2,5/2,3)	(2,5/2,3)
EXTREMELY MORE IMPORTANCE	(5/2,3,7/2)	(5/2,3,7/2)

Step 2: Yager (1981) gives centroid defuzzification method which is also called center of gravity. This method converted the fuzzy comparison matrices into crisp comparison matrices. In case of triangular fuzzy number the translating formula was given by Wang & Elhag (2007). Translating formula is:

$$\tilde{z}_{ij}(\tilde{z}_{ij}) = \frac{L_{ij} + M_{ij} + N_{ij}}{3} \qquad \text{……….. (3)}$$

Where

$\tilde{z}_{ij} = (L_{ij,} M_{ij,} N_{ij})$

Step 3: Calculated the consistency of each comparison matrix by calculating the consistency index (CI) and also calculated consistency ratio (CR).

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \qquad \text{……….. (4)}$$

$$CR = (CI - RI(n))100\% \qquad \text{……….. (5)}$$

Where largest eigen value of the comparison matrix is λ_{max} and dimension of matrix is n and random index is RI (n). Random index is depending upon the value of n which is shown in table 5.4.

Table 4.4: RI of random matrices.

N	1	2	3	4	5	6	7	8	9
RI(n)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: Golden, Harker & Wasil, 1989.

The consistency of the matrix is acceptable only if CR is less than 10%. Nevertheless, the threshold of 10% can be increased or decreased depending on the tolerance of the decision makers. If a matrix gives result inconsistent then it is necessary to obtain new pair-wise comparison judgments. Then determining a new pair-wise fuzzy comparison matrix to analyze. The matrix review must be continuing until the consistency is obtained.

Step 4: I calculated the relative sum of each row of $\tilde{Z}$ as:

$$\tilde{RS} = \sum_{j=1}^{n} z_{ij} = \sum_{j=1}^{n} L_{ij} , \sum_{j=1}^{n} M_{ij} , \sum_{j=1}^{n} N_{ij} \qquad i = 1, 2\ldots\ldots,n \qquad ..\ldots\ldots.. (6)$$

Step 5: According to Wang and Elhag's (2006), I normalized the row sum ($\tilde{S}_i$) as:

$$\tilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j}$$

$$= \frac{\sum_{j=1}^{n} L_{ij}}{\sum_{j=1}^{n} L_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} N_{kj}}, \frac{\sum_{j=1}^{n} M_{ij}}{\sum_{k=1,k\neq 1}^{n} \sum_{j=1}^{n} M_{kj}}, \frac{\sum_{j=1}^{n} N_{ij}}{\sum_{j=1}^{n} N_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} L_{kj}} \qquad \ldots\ldots\ldots. (7)$$

Step 6: calculated the local priority weight of each criterion and sub criterion.

$$A_i = S\ (\tilde{S}_i) = \frac{L_i + M_i + N_i}{3} \qquad \ldots\ldots\ldots (8)$$

Where

$\tilde{S}_i = (L_{ij}, M_{ij}, N_{ij})$

4.3.3 Fuzzy TOPSIS:

TOPSIS one of the classic multi-criteria decision making method which was developed by Hwang and Yoon (1981). It is based on the concept that i choose such alternative which has the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). In the traditional formulation of the TOPSIS method, personal judgments have done with crisp values. But in real life, measurement by using crisp values is not always possible so i went for better approach and use linguistic value rather than crisp value. Fuzzy set theory gives linguistic value. For this reason, *i* used fuzzy TOPSIS method to solve real life application problems under a fuzzy environment (Zeydan & Colpan, 2009, Aiello, Enea, Galante, & La Scalia, 2009; Onut, Kara, & Isık, 2009; Amiri, 2010; Baykasoglu, Kaplanoglu, Durmusoglu, & Sahin, 2013; Aydogan, 2012; Sadi-Nezhad & Damghani, 2010; Afshar, Marino, Saadatpour, & Afshar, 2011).

Step 1: Chosen the linguistic rating values for the alternatives with respect to criteria.

Let us assume that there are n possible alternatives called $X = \{X_1, X_2, X_3 \ldots\ldots\ldots X_n\}$ which are evaluated against the criteria, $Y = \{Y_1, Y_2, Y_3 \ldots\ldots\ldots\ldots Y_m)$. The criteria weights are represented by w_j (j= 1, 2, 3………..n). The performance rating of each expert P_k (k = 1,2,3,…….. k) for each criteria K_j (j = 1,2,3,…………….n) with respect to alternative Y_i (i = 1,2,3,……………….m) are denoted by $\tilde{R}_k = T_{ijk}$ (i = 1,2,3,…………………m; j = 1,2,3,………………..n; k = 1,2,3,…………………….k) membership function $\psi\tilde{R}_k(t)$. Table shows the scale used for solution rating.

Table 4.5: Linguistic variables for solutions ratings

Linguistic variables	Corresponding TFN
Very poor	(1,1,3)
Poor	(1,3,5)
Medium	(3,5,7)
Good	(5,7,9)
Very good	(7,9,11)

Step 2: Found out aggregate fuzzy ratings for alternatives.

All the experts gave fuzzy rating in triangular fuzzy number (TFN) $\tilde{R}_k$ = (xk, yk, zk), k = 1, 2, 3…………………k. Then converted fuzzy rating of all experts into aggregate fuzzy rating $\tilde{R}$ = (x, y, z) k = 1, 2, 3…………….k

Where

$$x = \min_k \{ x_k \}$$

$$y = \frac{1}{k}\sum_{k=1}^{k} y_k$$

$$z = \max_k \{ z_k \}$$

Fuzzy rating of R_{th} decision maker, $\tilde{R}_{ijk} = (x_{ijk}, y_{ijk}, z_{ijk})$,

i = 1, 2, 3……..m,

j = 1, 2, 3……n,

Then aggregated fuzzy rating $\tilde{X}_{ij}(l_{ij}, m_{ij}, n_{ij})$

Where

$$x_{ij} = \min_k \{ x_{ijk} \}$$

$$y_{ij} = \frac{1}{k}\sum_{k=1}^{k} y_{ijk}$$

$$z_{ij} = \max_k \{ z_{ijk} \} \qquad \text{…………. (9)}$$

Step 3: Constructed the fuzzy decision matrix

The fuzzy decision matrix for the alternatives (R) has constructed as follows:

$$\tilde{A} = \begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \\ . \\ . \\ . \\ . \\ . \\ S_m \end{array} \begin{array}{c} \begin{array}{cccc} B_1 & B_2 & \ldots\ldots\ldots & B_n \end{array} \\ \begin{pmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \ldots\ldots\ldots\ldots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \ldots\ldots\ldots\ldots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & \ldots\ldots\ldots\ldots & \tilde{a}_{3n} \\ . & . & \ldots\ldots\ldots\ldots & . \\ . & . & \ldots\ldots\ldots\ldots & . \\ \tilde{a}_{m1} & \tilde{a}_{m2} & & \tilde{a}_{m3} \end{pmatrix} \end{array} \quad \begin{array}{l} i = 1, 2, 3\ldots m; \\ j = 1, 2, 3\ldots.n \end{array}$$

Step 4: Constructed the normalized fuzzy decision matrix

I normalized the raw data with the help of linear scale transformation. So that various criteria scales is converted into comparable scale. The normalized fuzzy decision matrix Ã was given by:

$$\tilde{A} = [a_{ij}]_{m\times n}, \quad i = 1,2,3,\ldots\ldots\ldots\ldots m; \quad j = 1,2,3,\ldots\ldots\ldots\ldots\ldots n,$$

Where

$$\tilde{a}_{ij} = \left(\frac{x_{ij}}{z_j^*}, \frac{y_{ij}}{z_j^*}, \frac{z_{ij}}{z_j^*} \right) \quad \text{and} \quad z_j^* = \max_i \{ z_{ij} \} \quad \text{(benefit criteria)} \qquad \ldots\ldots\ldots\ldots (10)$$

$\tilde{b}_{ij} = \left(\frac{x_j^-}{z_{ij}}, \frac{x_j^-}{y_{ij}}, \frac{x_j^-}{x_{ij}} \right)$ and $x_j^- = \min_i \{ x_{ij} \}$ (cost criteria) ……….. (11)

Step 5: Constructed the weighted normalized matrix

I multiplied the weight (a_j) of evaluated criteria with normalized fuzzy decision matrix ($\tilde{b}_{ij}$) to get weighted normalized matrix ($\tilde{w}$).

$\tilde{W} = [\tilde{w}_{ij}]_{m\times n}$ i = 1,2,3,…………m; j = 1,2,3,……………..n ……….. (12)

Where $\tilde{w}_{ij} = (\tilde{b}_{ij})\times(a_j)$

$\tilde{w}_{ij}$ is a triangular fuzzy number which is represented by ($\tilde{x}_{ijk}$, $\tilde{y}_{ijk}$, $\tilde{z}_{ijk}$)

Step 6: Found out fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

The FPIS and FNIS of the alternatives find out by:

$B^* = (\tilde{I}_1^*, \tilde{I}_2^*, \tilde{I}_3^* \ldots\ldots\ldots\ldots \tilde{I}_n^*)$ ……….. (13)

Where $\tilde{I}_j^* = (\tilde{m}_j^*, \tilde{m}_j^*, \tilde{m}_j^*)$ and $\tilde{m}_j^* = \max_i \{ \tilde{m}_{ij} \}$

$B^- = (\tilde{I}_1^-, \tilde{I}_2^-, \tilde{I}_3^- \ldots\ldots\ldots\ldots\ldots \tilde{I}_n^-)$ ……….. (14)

Where $\tilde{I}_j^- = (\tilde{n}_j^*, \tilde{n}_j^*, \tilde{n}_j^*)$ and $\tilde{n}_j^* = \min_i \{ \tilde{n}_{ij} \}$

i = 1, 2, 3……………….m; & j = 1, 2, 3………………..n

Step 7: Found out the distance of each alternative from fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

I calculated the distance (d_i^+ , d_i^-) of each alternative i = 1, 2, 3………m from FPIS and FNIS was computed as follows:

$d_i^+ = \sum_{j=1}^{n} dv\,(\tilde{w}_{ij}, \tilde{I}_j^*)$, i = 1, 2, 3…………m ……….. (15)

$d_i^- = \sum_{j=1}^{n} dv\,(\tilde{w}_{ij}, \tilde{I}_j^-)$, i = 1, 2, 3…………m ……….. (16)

Step 8: Found out the closeness coefficient (Cc_i) of each alternative

The closeness coefficient shows the distance to the fuzzy ideal solution and fuzzy negative ideal solution simultaneously. I found closeness coefficient of each alternative by following formula:

$$Cc_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad \text{……….. (17)}$$

Step 9: Given rank to the alternatives

I gave the rank to the different alternatives according to decreasing order of closeness coefficient (Cc_i).

4.4 Application of the proposed fuzzy AHP TOPSIS framework to rank the solutions of MM in industry:

The proposed framework is used to find out the rank to the solutions of MM adoption in manufacturing sector to overcome its barriers. The application is based on three phases which is provided in previous section and explained as following.

Phase 1: Identification of the barriers and solutions of MM in industry

In the first phase, i identified and evaluated the barriers with the help of expert panel which comprising senior managers, MM project representatives, IT representatives, and customers. Then the barrier of MM adoption in industry was determined through experts opinion and literature review. When i found out the barriers then another expert panel is formed for evaluation of solutions of MM adoption in industry. Then i made hierarchy structure such that objective is at the first level, main barriers in the second level, sub barriers at third level and solutions was in the fourth level.

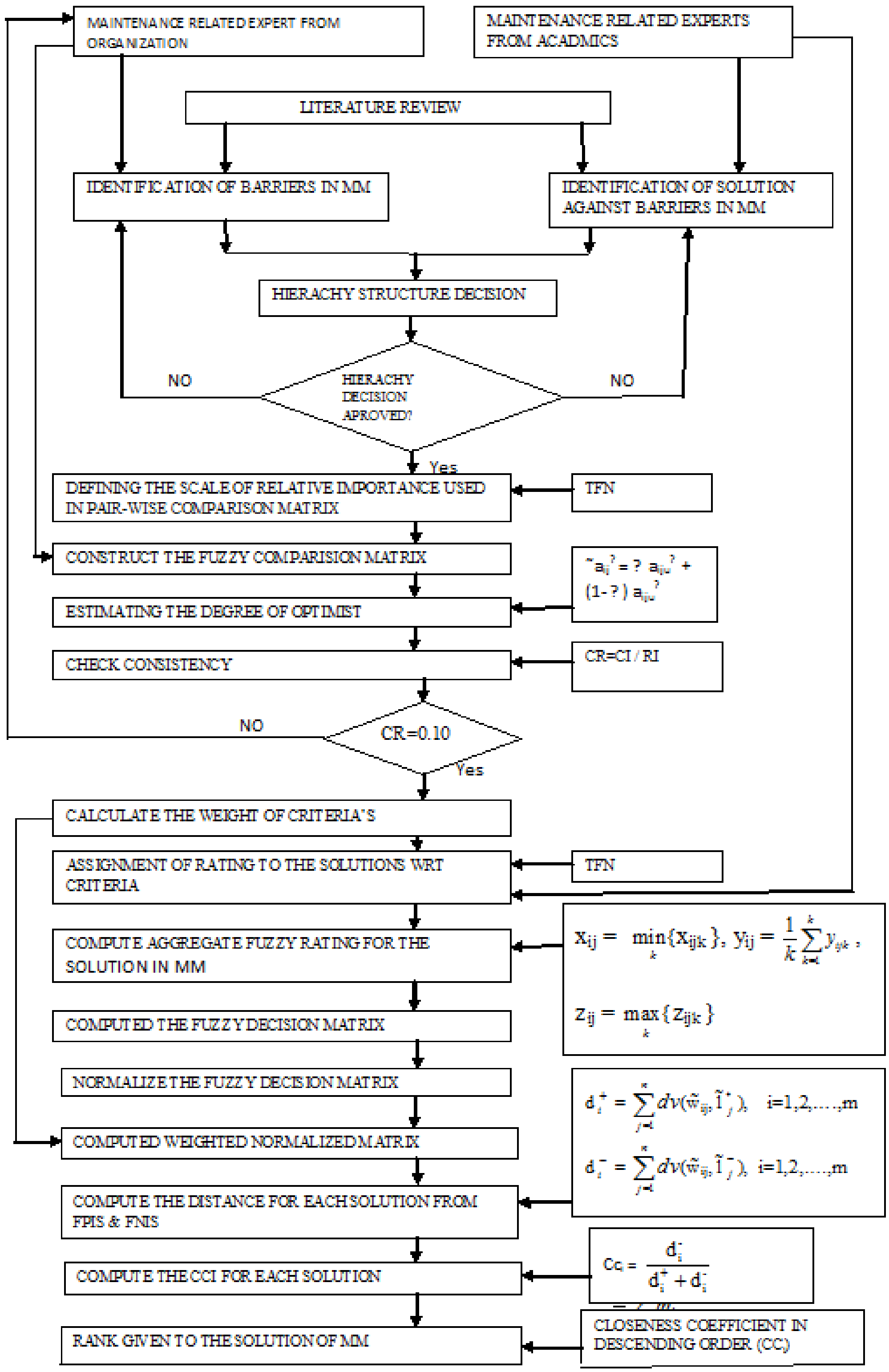
Phase 2: Found out the weight of barriers of MM with the help of fuzzy AHP.

After forming a decision hierarchy, i found out the weights of the barriers of MM with the help of fuzzy AHP. I made pair wise comparison matrixes of expert's evaluation were constructed to acquire criteria weights by using the scale in table 4.3 then i checked the consistency of matrix. Matrix is consistence when CI is less than 10%. Then i found out the row sum. Then i normalized the row sum. Then i found out the weights of barriers.

Phase 3: Evaluation of the solutions of maintenance management and determined the final rank with the help of Fuzzy TOPSIS. I used the Fuzzy TOPSIS to give the ranking to the solutions of alternatives. The ratings of solutions towards the barriers have been done by linguistic scale. I finalized the ranking of solutions according to Cc_i value. I gave the ranking to the solutions in descending order of Cc_i value.

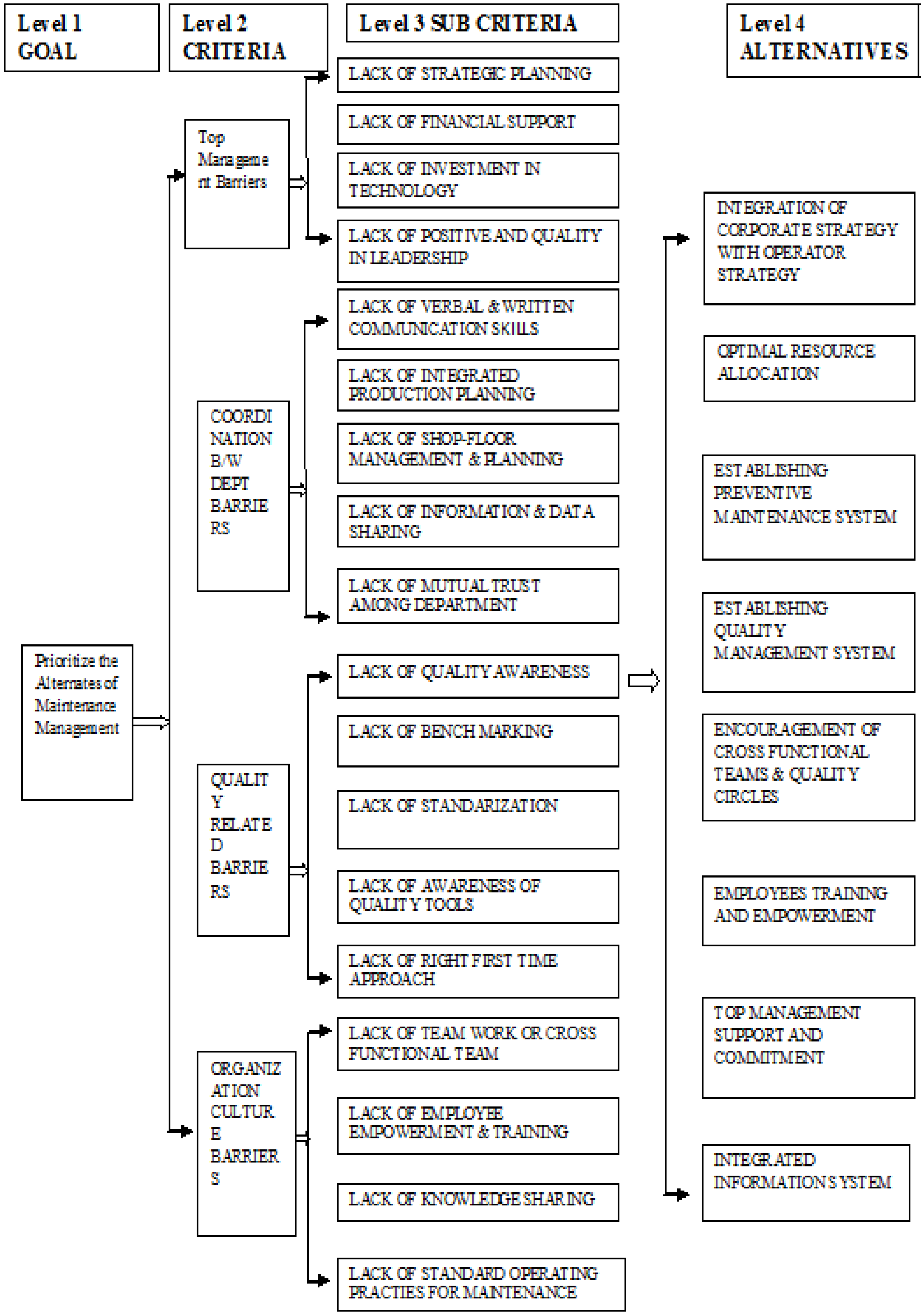
4.5 Case Illustration

Nowadays, more and more Indian organizations realize that maintenance management plays an important role in business success. Some Indian organizations have implemented TPM tool of maintenance management. But the success rate is not so good due to barriers of maintenance management.



Source: Modified based on PATIL & KANT, 2013.

Figure 4.1: Proposed fuzzy AHP-TOPSIS framework to prioritize the solution of MM



Source: Modified based on PATIL & KANT, 2013.

Figure 4.2: Decision hierarchy for prioritizing solutions of MM

4.5.1 Case profile

In the manufacturing organization and more exclusively in the production of automobile spare part products, the procedure of manufacture requires the unrestricted process of mechanical equipment. An attitude in one of the line workstations can be a reason of failure, and beyond the reduction of production, can also involve qualitative problems in the produced products. For this motive we built up a methodology analyzing to resolve the barriers in production process. After detailed study of literature review, we proceeded towards selection of manufacturing industry "Danblock Brakes India Pvt. Ltd". This case study has been based on an Indian plant of Danblock Brakes India Pvt.Ltd. Its regd. office at 110, Ist Floor, Rishabh Corporate Tower,16 Community Centre, Karkardooma, Delhi 110 092 and plant located at village Joshi Chohan, P.O Bahalgarh, District Sonepat – 131021, Haryana (India) and Danblock was opened in 1995 to increase production in the range of disc break pad products produced by the group. The group has around 2200 to 2500 employees and the fast-growing market for disc break pad in world's automobile spare part. Danblock has a gross turnover of Rs 1000 crores. Visit to plant is essential after selection of Industry so as to understand its working processes and its merits and demerits. Permission to communicate with Higher Administration was taken from board of members of Danblock and Interviews with Employees and workers were also conducted. This leads us to easily identify the Problem like accidents, breakdowns, low production, etc.

Our research strategy was based on the problems identified after communication with employees. I collected data and records related to these accidents, breakdown, productivity, etc. in the earlier years. Danblock Brakes India Pvt. Ltd. has ISO 9001:2000, TS 16949:2002 certified company. It is a Subsidiary of M.A.T. Inc. (USA) group. "Roland's Brakes, Alliance Friction Technology & Meneta Automotive Components" are its sister concerns in INDIA engaged in large scale manufacturer and suppliers (OEM/OES/after Market) of disc brakes pads to all over the world and now having a joint venture with AFFINIA group. M.A.T. Inc. group is the largest manufacturer in Asia in the same category.

4.6 Result and discussion

Identification of the barriers and solutions of MM in industries:

The decision group is composed of the 15 expert's panel in which seven experts from industry, one IT representatives and seven academic representatives. In this study 18 qualitative and quantitative barriers (sub-criteria) of Maintenance management. This was identified through literature review and intensive discussion with decision group members. Four expert of MM found out the solutions against its barriers. Total 8 solutions identified through literature review and finalized it by discussion with the expert panel. There were four levels in decision hierarchy structure for this problem. The overall goal of decision process determined as ''ranking the solutions of MM to overcome its barriers'' is in the first level of hierarchy. The second level carries main Barriers, third level carries the sub barriers and fourth level carries solutions of hierarchy.

Find out the weight of barriers of MM with the help of fuzzy AHP:

In this phase the decision group was asked to make pair wise comparisons of four main barriers and 18 sub barriers. Pair wise comparison matrixes of expert's evaluation have constructed to acquire criteria weights by using the scale in table 4.3 of triangular fuzzy conversion scale. Then i checked the consistency of matrix. Matrix is consistence when CI is less than 10%. Then i found out the row sum. Then i normalized the row sum. Then i found out the weights of barriers.

To improve the productivity it was essential to identify these barriers and solutions to overcome these obstacles in production. Hence it was very essential to priorities these solutions of maintenance management adoption in manufacturing sectors. Pair wise comparison matrixes of expert's evaluation have been taken by using the scale in table 4.3 of triangular fuzzy conversion scale. Table 4.06 to 4.10 for pair wise comparison matrix of major criterion and sub criterion are as shown below:

TABLE 4.6: Pair wise comparison matrix of the major criteria

		TMB			CBDB			QRB			OCB	
	p	q	r	p	q	r	p	q	r	p	q	r
TMB	1	1	1	2.5	3	3.5	2	2.5	3	2.5	3	3.5
CBDB	0.28571	0.33333	0.4	1	1	1	1	1.5	2	2.5	3	3.5
QRB	0.33333	0.4	0.5	0.5	0.66667	1	1	1	1	0.4	0.5	0.6667
OCB	0.28571	0.33333	0.4	0.28571	0.33333	0.4	1.49993	2	2.5	1	1	1

TABLE 4.7: Pair wise comparison matrix of Top Management Barriers

		TMB 1			TMB 2			TMB 3			TMB 4	
	p	q	r	p	q	r	p	q	r	p	q	r
TMB 1	1	1	1	2.5	3	3.5	1.5	2	2.5	1	1.5	2
TMB 2	0.28571	0.33333	0.4	1	1	1	2.5	3	3.5	1	1.5	2
TMB 3	0.4	0.5	0.66667	0.28571	0.33333	0.4	1	1	1	1.5	2	2.5
TMB 4	0.5	0.66667	1	0.5	0.66667	1	0.4	0.5	0.66667	1	1	1

TABLE 4.8: Pair wise comparison matrix of Coordination B/W Dept. Barriers

		CBDB1			CBDB2			CBDB3			CBDB4			CBDB5	
	p	q	r	p	q	r	p	q	r	p	q	r	p	q	r
CBDB1	1	1	1	1	1.5	2	1.5	2	2.5	2	2.5	3	2.5	3	3.5
CBDB2	0.5	0.6667	1	1	1	1	0.4	0.5	0.67	0.6667	1	1.5	0.4	0.5	0.6667
CBDB3	0.4	0.5	0.6667	1.4925	2	2.5	1	1	1	1	1.5	2	2	2.5	3
CBDB4	0.3333	0.4	0.5	0.6667	1	1.4999	0.5	0.6667	1	1	1	1	2/3	1	1.5
CBDB5	0.2857	0.3333	0.4	1.4999	2	2.5	0.3333	0.4	0.5	0.6667	1	1.5	1	1	1

TABLE 4.9: Pair wise comparison matrix of Quality related Barriers

		QRB1			QRB2			QRB3			QRB4			QRB5	
	p	q	r	p	q	r	p	q	r	p	q	r	p	q	r
QRB1	1	1	1	1.5	2	2.5	2	2.5	3	0.6667	1	1.5	2	2.5	3
QRB2	0.4	0.5	0.6667	1	1	1	0.4	0.5	0.67	0.6667	1	1.5	0.4	0.5	0.6667
QRB3	0.3333	0.4	0.5	1.4925	2	2.5	1	1	1	1	1.5	2	2.5	3	3.5
QRB4	0.6667	1	1.4999	0.6667	1	1.4999	0.5	0.6667	1	1	1	1	0.6667	1	1.5
QRB5	0.3333	0.4	0.5	1.4999	2	2.5	0.2857	0.3333	0.4	0.6667	1	1.4999	1	1	1

TABLE 4.10: Pair wise comparison matrix of Organization Culture Barriers

		OCB1			OCB2			OCB3			OCB4	
	p	q	r	p	q	r	p	q	r	p	q	r
OCB1	1	1	1	2.5	3	3.5	2	2.5	3	1.5	2	2.5
OCB2	0.285714	0.333333	0.4	1	1	1	1	1.5	2	0.4	0.5	0.6667
OCB3	0.333333	0.4	0.5	0.5	0.666667	1	1	1	1	2.5	3	3.5
OCB4	0.4	0.5	0.666667	1.499925	2	2.5	0.285714	0.333333	0.4	1	1	1

By using the equation 3, values of crisp comparison matrixes of major criterion and sub criterion have been calculated. Table 4.11 to 4.15 for crisp comparison matrixes of major criterion and sub criterion are as shown below:

TABLE 4.11: Crisp comparison matrix of major criteria

	TMB	CBDB	QRB	OCB
TMB	1	2.5	2	2
CBDB	0.4	1	0.66667	0.5
QRB	0.5	1.5	1	0.33333
OCB	0.5	2	3	1

TABLE 4.12: Crisp comparison matrix of Top Management Barriers

	TMB 1	TMB 2	TMB 3	TMB 4
TMB 1	1	3	2.5	3
TMB 2	0.3333	1	1.5	2.5
TMB 3	0.4	0.6667	1	0.5
TMB 4	0.3333	0.4	2	1

TABLE 4.13: Crisp comparison matrix of Coordination B/W Dept. Barriers

	CBDB 1	CBDB 2	CBDB 3	CBDB 4	CBDB 5
CBDB 1	1	3	2.5	2	2.5
CBDB 2	0.33333	1	0.5	0.4	1.5
CBDB 3	0.4	2	1	0.66667	2
CBDB 4	0.5	2.5	1.5	1	2
CBDB 5	0.4	0.66667	0.5	0.5	1

TABLE 4.14: Crisp comparison matrix of Quality Related Barriers

	QRB 1	QRB 2	QRB 3	QRB 4	QRB 5
QRB 1	1	3	2.5	1.5	3
QRB 2	0.33333	1	0.66667	0.4	1.5
QRB 3	0.4	1.5	1	0.66667	1.5
QRB 4	0.66667	2.5	1.5	1	2.5
QRB 5	0.33333	0.66667	0.66667	0.4	1

TABLE 4.15: Crisp comparison matrix of Organization Culture Barriers

	OCB 1	OCB 2	OCB 3	OCB 4
OCB1	1	2.5	2	1.5
OCB 2	0.4	1	0.5	0.5
OCB 3	0.5	2	1	0.66667
OCB 4	0.66667	2	1.5	1

Then i analysed the consistency index by using the equation 4 and consistency ratio by using the equation 5 of above matrices. Values for CI and CR as given below:

CI= 0.045186 and CR= 0.050771 of major criteria matrix.

CI= 0.073575 and CR= 0.082668 of Top Management barriers matrix.

CI= 0.023871 and CR= 0.021505 of Coordination B/W Dept. barriers matrix.

CI= 0.007306 and CR= 0.006582 of Quality Related barriers matrix.

CI= 0.009064 and CR= 0.010184 of Organizational cultural barriers matrix.

The results obtained from the calculations based on pair wise comparison matrixes provided CR values of all the matrixes are less than 0.1. Hence, these matrixes are consistent.

By using the equation 6, values of row sum of each criterion and sub criterion have been calculated. Table 4.16 to 4.20 for row sum of each criterion and sub criterion are as shown below:

TABLE 4.16: Row sum of each indicator with respect to major criteria

	p	q	r
$\widetilde{RS}1$	8	9.5	11
$\widetilde{RS}2$	4.78571	5.83333	6.9
$\widetilde{RS}3$	2.23333	2.56667	3.1667
$\widetilde{RS}4$	3.07135	3.66667	4.3

TABLE 4.17: Row sum of each indicator with respect to Top Management Barriers

	p	q	r
$\widetilde{RS}1$	6	7.5	9
$\widetilde{RS}2$	4.78571	5.83333	6.9
$\widetilde{RS}3$	3.18571	3.83333	4.56667
$\widetilde{RS}4$	2.4	2.83333	3.66667

TABLE 4.18: Row sum of each indicator with respect to Coordination B/W Dept. barriers

	p	q	r
$\widetilde{RS}1$	8	10	12
$\widetilde{RS}2$	2.9667	3.66667	4.8367
$\widetilde{RS}3$	5.89254	7.5	9.16667
$\widetilde{RS}4$	3.16667	4.06667	5.49993
$\widetilde{RS}5$	3.78564	4.73333	5.9

TABLE 4.19: Row sum of each indicator with respect to Quality Related barriers

	p	q	r
$\widetilde{RS}1$	7.1667	9	11
$\widetilde{RS}2$	2.8667	3.5	4.50337
$\widetilde{RS}3$	6.32587	7.9	9.5
$\widetilde{RS}4$	3.50003	4.66667	6.49985
$\widetilde{RS}5$	3.78564	4.73333	5.89993

TABLE 4.20: Row sum of each indicator with respect to Organizational cultural barriers

	p	q	r
$\widetilde{RS}1$	7	8.5	10
$\widetilde{RS}2$	2.68571	3.33333	4.0667
$\widetilde{RS}3$	4.33333	5.06667	6
$\widetilde{RS}4$	3.18564	3.83333	4.56667

By using the equation 7, values of normalized row sum of each criterion and sub criterion have been calculated. Table 4.21 to 4.25 for normalized row sum of each criterion and sub criterion are as shown below:

TABLE 4.21: Normalized row sum of each indicator with respect to major criteria

	p	q	r
S̃1	0.35767	0.78729	0.52156
S̃2	0.20582	0.37076	0.3415
S̃3	0.09141	0.13509	0.16646
S̃4	0.12724	0.20484	0.22258

TABLE 4.22: Normalized row sum of each indicator with respect to Top Management barriers

	p	q	r
S̃1	0.28391	0.6	0.4646
S̃2	0.21734	0.41176	0.37326
S̃3	0.14002	0.23711	0.25724
S̃4	0.10496	0.16505	0.20788

TABLE 4.23: Normalized row sum of each indicator with respect to Coordination B/W Dept. barriers

	p	q	r
S̃1	0.2395	0.50083	0.43148
S̃2	0.08349	0.13942	0.18833
S̃3	0.17265	0.33383	0.33843
S̃4	0.0903	0.15701	0.21036
S̃5	0.10728	0.18758	0.22757

TABLE 4.24: Normalized row sum of each indicator with respect to Quality Related barriers

	p	q	r
S̃1	0.21349	0.43269	0.40032
S̃2	0.08015	0.13308	0.17813
S̃3	0.18481	0.36073	0.35423
S̃4	0.10174	0.18568	0.24394
s5	0.10728	0.18883	0.22904

TABLE 4.25: Normalized row sum of each indicator with respect to Organizational cultural barriers

	p	q	r
$\tilde{S}1$	0.32357	0.69482	0.49493
$\tilde{S}2$	0.1155	0.19157	0.21881
$\tilde{S}3$	0.18868	0.3234	0.31794
$\tilde{S}4$	0.137	0.22682	0.24571

By using the equation 8, values of local priority weight of each criterion and sub criterion have been calculated. Table 4.26 to 4.30 for local priority weight of each criterion and sub criterion are as shown below:

TABLE 4.26: Weight of major criteria

	WEIGHT
TMB	0.55551
CBDB	0.30603
QRB	0.13098
OCB	0.18489

TABLE 4.27: Weight of Top Management barriers

	weight
TMB 1	0.4495
TMB 2	0.33412
TMB 3	0.21146
TMB 4	0.1593

TABLE 4.28: Weight of Coordination B/W Dept. barriers

	WEIGHT
CBDB1	0.3906
CBDB2	0.13708
CBDB3	0.28164
CBDB4	0.15256
CBDB5	0.17414

TABLE 4.29: Weight of Quality Related barriers

	WEIGHT
QRB1	0.34883
QRB2	0.13045
QRB3	0.29992
QRB4	0.17712
QRB5	0.17505

TABLE 4.30: Weight of Organizational cultural barriers

	weight
OCB1	0.50444
OCB2	0.17529
OCB3	0.27668
OCB4	0.20318

Complete table of criterion for criterion weight and CR value as well as weight for sub criterion are given in table 4.31, shown below:

TABLE 4.31: Final weight of barriers

Main Criterion	Main Criterion wt.	Code	CR	Ratio Wt.	final Wt.
Top		TMB 1		0.4495	0.19872
Management	0.442088	TMB 2	0.06712	0.33412	0.14771
Barriers		TMB 3		0.21146	0.09348
		TMB 4		0.1593	0.07042
Coordination		CBDB1		0.3906	0.09655
between	0.24719	CBDB2	0.02685	0.13708	0.03388
Dept. barrier		CBDB3		0.28164	0.06962
		CBDB4		0.15256	0.03771
		CBDB5		0.17414	0.04305
Quality		QRB1		0.34883	0.05723
Related barrier	0.164048	QRB2	0.06339	0.13045	0.0214
		QRB3		0.29992	0.0492
		QRB4		0.17712	0.02906
		QRB5		0.17505	0.02872
Organization		OCB1		0.50445	0.08963
culture barrier	0.177677	OCB2	0.07042	0.17529	0.03115
		OCB3		0.27668	0.04916
		OCB4		0.20318	0.0361

Evaluated solutions of maintenance management and determination of final rank with the help of Fuzzy TOPSIS:

Expert's panel gave fuzzy evaluation scale (very poor (VP), poor (P), fair (F), good (G), very good (VG)) and corresponding linguistic variables as shown in table 4.5. Linguistic scale evaluation matrixes were established by comparing solutions under each of the barriers separately. Table 4.32 to 4.34 for linguistic scale evaluation matrixes are as shown below:

TABLE 4.32: Linguistic scale evaluation matrix for solution (**EXPERT** 1)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	VG	F	P	G	VG	G	G	VG	VG	P	P	F	F	G	G	P	G	G
S2	G	G	F	F	G	VG	VG	G	F	G	G	VG	VP	F	P	G	F	F
S3	P	G	G	P	F	G	F	P	VP	VG	G	VG	VG	G	G	F	G	VG
S4	P	G	G	F	F	P	G	VP	F	G	G	G	G	VG	G	F	F	VG
S5	F	P	G	G	G	VG	G	G	P	VP	F	P	F	G	VG	G	P	G
S6	VP	VG	VG	P	P	G	P	VP	F	P	G	F	P	F	F	VG	G	G
S7	G	VP	G	VG	G	F	VG	F	VG	F	P	F	VP	G	G	F	P	F
S8	F	P	G	G	G	P	G	F	G	G	VP	P	F	G	G	F	VG	G

TABLE 4.33: Linguistic scale evaluation matrix for solution (**EXPERT** 2)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	F	P	F	G	VG	F	VG	F	G	VP	F	G	P	F	P	VP	P	G
S2	VG	F	G	P	VG	G	G	F	VP	VG	F	G	VP	P	G	G	VP	G
S3	F	F	F	VP	F	F	G	P	F	F	F	F	F	P	P	VP	P	G
S4	VP	VG	F	G	P	VP	G	P	G	G	VG	F	F	G	VG	G	G	G
S5	P	G	F	G	F	G	F	F	G	F	G	VP	G	VG	F	VG	F	F
S6	P	VG	VG	F	G	F	F	VP	G	F	G	G	G	F	F	G	F	F
S7	VG	P	VG	G	F	F	G	G	G	G	F	P	P	G	F	G	F	P
S8	G	F	F	F	F	VP	G	VP	G	F	P	P	F	F	F	G	G	F

TABLE 4.34: Linguistic scale evaluation matrix for solution (**EXPERT** 3)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	G	VP	P	VG	G	VG	F	G	G	F	VP	F	F	1,3,5	F	F	G	F
S2	G	VG	P	P	G	G	VG	F	P	F	G	G	P	VP	F	F	F	P
S3	VP	VG	G	P	P	P	F	F	P	G	P	F	G	G	G	P	VP	F
S4	P	G	VG	VG	P	F	F	VP	F	F	G	G	G	F	F	G	F	G
S5	G	VP	F	F	G	VG	G	F	G	P	G	P	G	G	G	G	P	G
S6	F	G	G	VP	F	G	G	F	G	P	F	G	F	G	G	VG	G	G
S7	G	VP	G	G	F	G	G	F	F	G	F	F	F	F	F	F	F	F
S8	F	G	P	F	F	P	F	P	F	P	F	F	P	P	P	F	F	F

Fuzzy evaluation matrixes for solution are designed between sub criterions and solutions.

By using the linguistic variables from table 4.5, values of fuzzy evaluation matrixes for solution have been taken. Table 4.35 to 4.37 for fuzzy evaluation matrixes are as shown below:

TABLE 4.35: Fuzzy evaluation matrix for solution (**EXPERT 1**)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(7,9,11)	(3,5,7)	(1,3,5)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(7,9,11)	(7,9,11)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)
S2	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,11)	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,11)	(1,1,3)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)
S3	(1,3,5)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(3,5,7)	(1,3,5)	(1,1,3)	(7,9,11)	(5,7,9)	(7,9,11)	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,11)
S4	(1,3,5)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(1,1,3)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(3,5,7)	(7,9,11)
S5	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(1,3,5)	(1,1,3)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,11)	(5,7,9)	(1,3,5)	(5,7,9)
S6	(1,1,3)	(7,9,11)	(7,9,11)	(1,3,5)	(1,3,5)	(5,7,9)	(1,3,5)	(1,1,3)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(7,9,11)	(5,7,9)	(5,7,9)
S7	(5,7,9)	(1,1,3)	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(7,9,11)	(3,5,7)	(7,9,11)	(3,5,7)	(1,3,5)	(3,5,7)	(1,1,3)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)
S8	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(1,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,11)	(5,7,9)

TABLE 4.36: Fuzzy evaluation matrix for solution (**EXPERT 2**)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,11)	(3,5,7)	(7,9,11)	(3,5,7)	(5,7,9)	(1,1,3)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)	(1,3,5)	(1,1,3)	(1,3,5)	(5,7,9)
S2	(7,9,11)	(3,5,7)	(5,7,9)	(1,3,5)	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(1,1,3)	(7,9,11)	(3,5,7)	(5,7,9)	(1,1,3)	(1,3,5)	(5,7,9)	(5,7,9)	(1,1,3)	(5,7,9)
S3	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(3,5,7)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,1,3)	(1,3,5)	(5,7,9)
S4	(1,1,3)	(7,9,11)	(3,5,7)	(5,7,9)	(1,3,5)	(1,1,3)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(7,9,11)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(5,7,9)
S5	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,1,3)	(5,7,9)	(7,9,11)	(3,5,7)	(7,9,11)	(3,5,7)	(3,5,7)
S6	(1,3,5)	(7,9,11)	(7,9,11)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(1,1,3)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)
S7	(7,9,11)	(1,3,5)	(7,9,11)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(1,3,5)
S8	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(5,7,9)	(1,1,3)	(5,7,9)	(3,5,7)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)

TABLE 4.37: Fuzzy evaluation matrix for solution (**EXPERT 3**)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(5,7,9)	(1,1,3)	(1,3,5)	(7,9,11)	(5,7,9)	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(1,1,3)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)
S2	(5,7,9)	(7,9,11)	(1,3,5)	(1,3,5)	(5,7,9)	(5,7,9)	(7,9,11)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(1,1,3)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)
S3	(1,1,3)	(7,9,11)	(5,7,9)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(1,1,3)	(3,5,7)
S4	(1,3,5)	(5,7,9)	(7,9,11)	(7,9,11)	(1,3,5)	(3,5,7)	(3,5,7)	(1,1,3)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)
S5	(5,7,9)	(1,1,3)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)
S6	(3,5,7)	(5,7,9)	(5,7,9)	(1,1,3)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)
S7	(5,7,9)	(1,1,3)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)
S8	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)

By using the equation 9, values of aggregate fuzzy decision matrix for solution has been found out. Table 4.38 to 4.40 for aggregate fuzzy decision matrix is as shown below:

TABLE 4.38: Aggregate fuzzy decision matrix for solutions (PART I)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2
S1	(3,7,11)	(1,3,7)	(1,3.666667,7)	(5,7.666667,11)	(5,8.333333,11)	(3,7,11)
S2	(5,7.666667,11)	(3,7,11)	(1,5,9)	(1,3.666667,7)	(5,7.666667,11)	(5,7.666667,11)
S3	(1,3,7)	(3,7,11)	(3,6.333333,9)	(1,2.333333,5)	(1,4.333333,7)	(1,5,9)
S4	(1,2.333333,5)	(5,7.666667,11)	(3,7,11)	(3,7,11)	(1,3.666667,7)	(1,3,7)
S5	(1,5,9)	(1,3.666667,9)	(3,5.666667,9)	(3,6.333333,9)	(3,6.333333,9)	(5,8.333333,11)
S6	(1,3,7)	(5,8.333333,11)	(5,8.333333,11)	(1,3,7)	(1,5,9)	(3,6.333333,9)
S7	(5,7.666667,11)	(1,1.666667,5)	(5,7.666667,11)	(5,7.666667,11)	(3,5.666667,9)	(3,5.666667,9)
S8	(3,5.666667,9)	(1,5,9)	(1,5,9)	(3,5.666667,9)	(3,5.666667,9)	(1,2.333333,5)
						Contd……

TABLE 4.39: Aggregate fuzzy decision matrix for solutions (PART II)

	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3
S1	(3,7,11)	(3,7,11)	(5,7.666667,11)	(1,3,7)	(1,3,7)	(3,5.666667,9)
S2	(5,8.333333,11)	(3,5.666667,9)	(1,3,7)	(3,7,11)	(3,6.333333,9)	(5,7.666667,11)
S3	(3,5.666667,9)	(1,3.666667,7)	(1,3,7)	(3,7,11)	(1,5,9)	(3,6.333333,11)
S4	(3,6.333333,9)	(1,1.666667,5)	(3,5.666667,9)	(3,6.333333,9)	(5,7.666667,11)	(3,6.333333,9)
S5	(3,6.333333,9)	(3,5.666667,9)	(1,3.666667,9)	(1,3,7)	(3,6.333333,9)	(1,2.333333,5)
S6	(1,5,9)	(1,2.333333,7)	(3,6.333333,9)	(1,3.666667,7)	(3,6.333333,9)	(3,6.333333,9)
S7	(5,7.666667,11)	(3,5.666667,9)	(3,7,11)	(3,6.333333,9)	(1,4.333333,7)	(1,4.333333,7)
S8	(3,6.333333,9)	(1,3,7)	(3,6.333333,9)	(1,5,9)	(1,3,7)	(1,3.666667,7)
						Contd……..

TABLE 4.40: Aggregate fuzzy decision matrix for solutions (PART III)

	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(1,4.333333,7)	(1,5,9)	(1,5,9)	(1,3,7)	(1,5.666667,9)	(3,6.333333,9)
S2	(1,1.666667,5)	(1,3,7)	(1,5,9)	(3,6.333333,9)	(1,3.666667,7)	(1,5,9)
S3	(3,7,11)	(1,5.666667,9)	(1,5.666667,9)	(1,3,7)	(1,3.666667,9)	(3,7,11)
S4	(3,6.333333,9)	(3,7,11)	(3,7,11)	(3,6.333333,9)	(3,5.666667,9)	(5,7.666667,11)
S5	(3,6.333333,9)	(5,7.666667,11)	(3,7,11)	(5,7.666667,11	(1,3.666667,7)	(3,6.333333,9)
S6	(1,5,9)	(3,5.666667,9)	(3,5.666667,9)	(5,8.333333,11	(3,6.333333,9)	(3,6.333333,9)
S7	(1,3,7)	(3,6.333333,9)	(3,5.666667,9)	(3,5.666667,9)	(1,4.333333,7)	(1,4.333333,7)
S8	(1,4.333333,7)	(1,5,9)	(1,5,9)	(3,5.666667,9)	(3,7,11)	(3,5.666667,9)

By using the equation 11, values of normalized fuzzy decision matrix for solution has been calculated. Table 4.41 to 4.43 for normalized fuzzy decision matrix is as shown below:

TABLE 4.41: Normalized fuzzy decision matrix for solutions (PART I)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2
S1	(0.090909,0.142857,0.333333)	(0.142857,0.333333,1)	(0.142857,0.272727,1)	(0.090909,0.130435,0.2)	(0.090909,0.12,0.2)	(0.090909,0.142857,0.333333)
S2	(0.090909,0.130435,0.2)	(0.090909,0.142857,0.333333)	(0.111111,0.2,1)	(0.142857,0.272727,1)	(0.090909,0.130435,0.2)	(0.090909,0.130435,0.2)
S3	(0.142857,0.333333,1)	(0.090909,0.142857,0.333333)	(0.111111,0.157895,0.333333)	(0.2,0.428571,1)	(0.142857,0.230769,1)	(0.111111,0.2,1)
S4	(0.2,0.428571,1)	(0.090909,0.130435,0.2)	(0.090909,0.142857,0.333333)	(0.090909,0.142857,0.333333)	(0.142857,0.272727,1)	(0.142857,0.333333,1)
S5	(0.111111,0.2,1)	(0.111111,0.272727,1)	(0.111111,0.176471,0.333333)	(0.111111,0.157895,0.333333)	(0.111111,0.157895,0.333333)	(0.090909,0.12,0.2)
S6	(0.142857,0.333333,1)	(0.090909,0.12,0.2)	(0.090909,0.12,0.2)	(0.142857,0.333333,1)	(0.111111,0.2,1)	(0.111111,0.157895,0.333333)
S7	(0.090909,0.130435,0.2)	(0.2,0.6,1)	(0.090909,0.130435,0.2)	(0.090909,0.130435,0.2)	(0.111111,0.176471,0.333333)	(0.111111,0.176471,0.333333)
S8	(0.111111,0.176471,0.333333)	(0.111111,0.2,1)	(0.111111,0.2,1)	(0.111111,0.176471,0.333333)	(0.111111,0.176471,0.333333)	(0.2,0.428571,1)
						Contd..........

TABLE 4.42: Normalized fuzzy decision matrix for solutions (PART II)

	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3
S1	(0.090909,0.142857,0.333333)	(0.090909,0.142857,0.333333)	(0.090909,0.130435,0.2)	(0.142857,0.333333,1)	(0.142857,0.333333,1)	(0.111111,0.176471,0.333333)
S2	(0.090909,0.12,0.2)	(0.111111,0.176471,0.333333)	(0.142857,0.333333,1)	(0.090909,0.142857,0.333333)	(0.111111,0.157895,0.333333)	(0.090909,0.130435,0.2)
S3	(0.111111,0.176471,0.333333)	(0.142857,0.272727,1)	(0.142857,0.333333,1)	(0.090909,0.142857,0.333333)	(0.111111,0.2,1)	(0.090909,0.157895,0.333333)
S4	(0.111111,0.157895,0.333333)	(0.2,0.6,1)	(0.111111,0.176471,0.333333)	(0.111111,0.157895,0.333333)	(0.090909,0.130435,0.2)	(0.111111,0.157895,0.333333)
S5	(0.111111,0.157895,0.333333)	(0.111111,0.176471,0.333333)	(0.111111,0.272727,1)	(0.142857,0.333333,1)	(0.111111,0.157895,0.333333)	(0.2,0.428571,1)
S6	(0.111111,0.2,1)	(0.142857,0.428571,1)	(0.111111,0.157895,0.333333)	(0.142857,0.272727,1)	(0.111111,0.157895,0.333333)	(0.111111,0.157895,0.333333)
S7	(0.090909,0.130435,0.2)	(0.111111,0.176471,0.333333)	(0.090909,0.142857,0.333333)	(0.111111,0.157895,0.333333)	(0.142857,0.230769,1)	(0.142857,0.230769,1)
S8	(0.111111,0.157895,0.333333)	(0.142857,0.333333,1)	(0.111111,0.157895,0.333333)	(0.111111,0.2,1)	(0.142857,0.333333,1)	(0.142857,0.272727,1)
						Contd..........

TABLE 4.43: Normalized fuzzy decision matrix for solutions (PART III)

	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(0.142857,0.230769,1)	(0.111111,0.2,1)	(0.111111,0.2,1)	(0.142857,0.333333,1)	(0.111111,0.176471,1)	(0.111111,0.157895,0.333333)
S2	(0.2,0.6,1)	(0.142857,0.333333,1)	(0.111111,0.2,1)	(0.111111,0.157895,0.333333)	(0.142857,0.272727,1)	(0.111111,0.2,1)
S3	(0.090909,0.142857,0.333333)	(0.111111,0.176471,1)	(0.111111,0.176471,1)	(0.142857,0.333333,1)	(0.111111,0.272727,1)	(0.090909,0.142857,0.333333)
S4	(0.111111,0.157895,0.333333)	(0.090909,0.142857,0.333333)	(0.090909,0.142857,0.333333)	(0.111111,0.157895,0.333333)	(0.111111,0.176471,0.333333)	(0.090909,0.130435,0.2)
S5	(0.111111,0.157895,0.333333)	(0.090909,0.130435,0.2)	(0.090909,0.142857,0.333333)	(0.090909,0.130435,0.2)	(0.142857,0.272727,1)	(0.111111,0.157895,0.333333)
S6	(0.111111,0.2,1)	(0.111111,0.176471,0.333333)	(0.111111,0.176471,0.333333)	(0.090909,0.12,0.2)	(0.111111,0.157895,0.333333)	(0.111111,0.157895,0.333333)
S7	(0.142857,0.333333,1)	(0.111111,0.157895,0.333333)	(0.111111,0.176471,0.333333)	(0.111111,0.176471,0.333333)	(0.142857,0.230769,1)	(0.142857,0.230769,1)
S8	(0.142857,0.230769,1)	(0.111111,0.2,1)	(0.111111,0.2,1)	(0.111111,0.176471,0.333333)	(0.090909,0.142857,0.333333)	(0.111111,0.176471,0.333333)

By using the equation 12, values of weighted normalized fuzzy decision matrix for solution has been calculated. Table 4.44 to 4.46 for weighted normalized fuzzy decision matrix is as shown below:

TABLE 4.44: Weighted normalized fuzzy decision matrix for solutions (PART I)

	TMB1	TMB2	TMB3	TMB4	CBDB1	CBDB2
S1	(0.018066,0.028389,0.06624)	(0.021102,0.049237,0.147712)	(0.013355,0.025495,0.093483)	(0.006402,0.009186,0.014085)	(0.008778,0.011586,0.019311)	(0.00308,0.004841,0.011295)
S2	(0.018066,0.02592,0.039744)	(0.013428,0.021102,0.049237)	(0.010387,0.018697,0.093483)	(0.01006,0.019206,0.070423)	(0.008778,0.012594,0.019311)	(0.00308,0.00442,0.006777)
S3	(0.028389,0.06624,0.198721)	(0.013428,0.021102,0.049237)	(0.010387,0.01476,0.031161)	(0.014085,0.030181,0.070423)	(0.013793,0.022281,0.096553)	(0.003765,0.006777,0.033885)
S4	(0.039744,0.085166,0.198721)	(0.013428,0.019267,0.029542)	(0.008498,0.013355,0.031161)	(0.006402,0.01006,0.023474)	(0.013793,0.026333,0.096553)	(0.004841,0.011295,0.033885)
S5	(0.02208,0.039744,0.198721)	(0.016412,0.040285,0.147712)	(0.010387,0.016497,0.031161)	(0.007825,0.011119,0.023474)	(0.010728,0.015245,0.032184)	(0.00308,0.004066,0.006777)
S6	(0.028389,0.06624,0.198721)	(0.013428,0.017725,0.029542)	(0.008498,0.011218,0.018697)	(0.01006,0.023474,0.070423)	(0.010728,0.019311,0.096553)	(0.003765,0.00535,0.011295)
S7	(0.018066,0.02592,0.039744)	(0.029542,0.088627,0.147712)	(0.008498,0.012193,0.018697)	(0.006402,0.009186,0.014085)	(0.010728,0.017039,0.032184)	(0.003765,0.00598,0.011295)
S8	(0.02208,0.035068,0.06624)	(0.016412,0.029542,0.147712)	(0.010387,0.018697,0.093483)	(0.007825,0.012428,0.023474)	(0.010728,0.017039,0.032184)	(0.006777,0.014522,0.033885)
						Contd..........

TABLE 4.45: Weighted normalized fuzzy decision matrix for solutions (PART II)

	CBDB3	CBDB4	CBDB5	QRB1	QRB2	QRB3
S1	(0.006329,0.009945,0.023206)	(0.003428,0.005387,0.01257)	(0.003913,0.005615,0.008609)	(0.008175,0.019075,0.057225)	(0.003057,0.007134,0.021401)	(0.005467,0.008683,0.016401)
S2	(0.006329,0.008354,0.013924)	(0.00419,0.006655,0.01257)	(0.006149,0.014349,0.043046)	(0.005202,0.008175,0.019075)	(0.002378,0.003379,0.007134)	(0.004473,0.006418,0.00984)
S3	(0.007735,0.012286,0.023206)	(0.005387,0.010285,0.037711)	(0.006149,0.014349,0.043046)	(0.005202,0.008175,0.019075)	(0.002378,0.00428,0.021401)	(0.004473,0.007769,0.016401)
S4	(0.007735,0.010992,0.023206)	(0.007542,0.022627,0.037711)	(0.004783,0.007596,0.014349)	(0.006358,0.009036,0.019075)	(0.001946,0.002791,0.00428)	(0.005467,0.007769,0.016401)
S5	(0.007735,0.010992,0.023206)	(0.00419,0.006655,0.01257)	(0.004783,0.01174,0.043046)	(0.008175,0.019075,0.057225)	(0.002378,0.003379,0.007134)	(0.00984,0.021087,0.049202)
S6	(0.007735,0.013924,0.069618)	(0.005387,0.016162,0.037711)	(0.004783,0.006797,0.014349)	(0.008175,0.015607,0.057225)	(0.002378,0.003379,0.007134)	(0.005467,0.007769,0.016401)
S7	(0.006329,0.009081,0.013924)	(0.00419,0.006655,0.01257)	(0.003913,0.006149,0.014349)	(0.006358,0.009036,0.019075)	(0.003057,0.004939,0.021401)	(0.007029,0.011354,0.049202)
S8	(0.007735,0.010992,0.023206)	(0.005387,0.01257,0.037711)	(0.004783,0.006797,0.014349)	(0.006358,0.011445,0.057225)	(0.003057,0.007134,0.021401)	(0.007029,0.013419,0.049202)
						Contd..........

TABLE 4.46: Weighted normalized fuzzy decision matrix for solutions (PART III)

	QRB4	QRB5	OCB1	OCB2	OCB3	OCB4
S1	(0.004151,0.006705,0.029056)	(0.003191,0.005743,0.028716)	(0.009959,0.017926,0.089629)	(0.004449,0.010382,0.031146)	(0.005462,0.008675,0.049159)	(0.004011,0.0057,0.012033)
S2	(0.005811,0.017434,0.029056)	(0.004102,0.009572,0.028716)	(0.009959,0.017926,0.089629)	(0.003461,0.004918,0.010382)	(0.007023,0.013407,0.049159)	(0.004011,0.00722,0.0361)
S3	(0.002641,0.004151,0.009685)	(0.003191,0.005068,0.028716)	(0.009959,0.015817,0.089629)	(0.004449,0.010382,0.031146)	(0.005462,0.013407,0.049159)	(0.003282,0.005157,0.012033)
S4	(0.003228,0.004588,0.009685)	(0.002611,0.004102,0.009572)	(0.008148,0.012804,0.029876)	(0.003461,0.004918,0.010382)	(0.005462,0.008675,0.016386)	(0.003282,0.004709,0.00722)
S5	(0.003228,0.004588,0.009685)	(0.002611,0.003746,0.005743)	(0.008148,0.012804,0.029876)	(0.002831,0.004063,0.006229)	(0.007023,0.013407,0.049159)	(0.004011,0.0057,0.012033)
S6	(0.003228,0.005811,0.029056)	(0.003191,0.005068,0.009572)	(0.009959,0.015817,0.029876)	(0.002831,0.003738,0.006229)	(0.005462,0.007762,0.016386)	(0.004011,0.0057,0.012033)
S7	(0.004151,0.009685,0.029056)	(0.003191,0.004534,0.009572)	(0.009959,0.015817,0.029876)	(0.003461,0.005496,0.010382)	(0.007023,0.011344,0.049159)	(0.005157,0.008331,0.0361)
S8	(0.004151,0.006705,0.029056)	(0.003191,0.005743,0.028716)	(0.009959,0.017926,0.089629)	(0.003461,0.005496,0.010382)	(0.004469,0.007023,0.016386)	(0.004011,0.006371,0.012033)

By using the equation 13, 14, 15 and 16, values of fuzzy positive ideal solution and fuzzy negative ideal solution of alternatives have been calculated. Table 4.47 for fuzzy positive ideal solution and fuzzy negative ideal solution of alternatives are as shown below:

TABLE 4.47: Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution of alternatives

Code	Solutions	d_i^+	d_i^-
SOB1	INTEGRATION OF CORPORATE STRATEGY WITH OPERATOR STRATEGY	0.45434	17.63607
SOB2	OPTIMAL RESOURCE ALLOCATION	0.396351	17.67774
SOB3	ESTABLISHING PREVENTIVE MAINTENANCE SYSTEM	0.530942	17.57962
SOB4	ESTABLISHING QUALITY MANAGEMENT SYSTEM	0.396485	17.66215
SOB5	ENCOURAGEMENT OF CROSS FUNCTIONAL TEAMS & QUALITY CIRCLES	0.463498	17.63114
SOB6	EMPLOYEES TRAINING AND EMPOWERMENT	0.45738	17.63194
SOB7	TOP MANAGEMENT SUPPORT AND COMMITMENT	0.369747	17.68183
SOB8	INTEGRATED INFORMATION SYSTEM	0.485836	17.61666

By using the equation 17, Cci value has been calculated against the solutions of barrier. Table 4.48 for closeness coefficient of alternatives are as shown below:

TABLE 4.48: Closeness coefficient of alternatives

Code	Solutions	Cci
SOB1	INTEGRATION OF CORPORATE STRATEGY WITH OPERATOR STRATEGY	0.974885
SOB2	OPTIMAL RESOURCE ALLOCATION	0.978071
SOB3	ESTABLISHING PREVENTIVE MAINTENANCE SYSTEM	0.970683
SOB4	ESTABLISHING QUALITY MANAGEMENT SYSTEM	0.978045
SOB5	ENCOURAGEMENT OF CROSS FUNCTIONAL TEAMS & QUALITY CIRCLES	0.974385
SOB6	EMPLOYEES TRAINING AND EMPOWERMENT	0.974715
SOB7	TOP MANAGEMENT SUPPORT AND COMMITMENT	0.979517
SOB8	INTEGRATED INFORMATION SYSTEM	0.973162

4.7 Concluding Remarks

Solution of maintenance management adoption in maintenance sector to overcome its barriers is more important, but the ranking process by using hybrid fuzzy AHP-TOPSIS approach made it more comprehensive and systematic. This hybrid approach used in manufacturing organization was intended to improve the success rate of maintenance management adoption in manufacturing sector. This will be achieved by implementing the solutions of maintenance management adoption in manufacturing sector by stepwise manner to overcome its barriers. Total 18 barriers and 08 solutions were identified by literature review and expert opinion. In this research, i found out the barriers of maintenance management. The weight of the barriers of maintenance management adoption in manufacturing sector are calculated by fuzzy AHP and by using these barriers weight the solutions of maintenance management problems in manufacturing sector are ranked by fuzzy TOPSIS method.

I gave the rank to the difference alternatives according to decreasing order of closeness coefficient (Cci). Table for ranking to alternatives are as shown below:

TABLE 4.49: Ranking to alternatives

Code	Solutions	Cci	Rank
SOB1	INTEGRATION OF CORPORATE STRATEGY WITH OPERATOR STRATEGY	0.974885	5
SOB2	OPTIMAL RESOURCE ALLOCATION	0.978071	7
SOB3	ESTABLISHING PREVENTIVE MAINTENANCE SYSTEM	0.970683	1
SOB4	ESTABLISHING QUALITY MANAGEMENT SYSTEM	0.978045	6
SOB5	ENCOURAGEMENT OF CROSS FUNCTIONAL TEAMS & QUALITY CIRCLES	0.974385	3
SOB6	EMPLOYEES TRAINING AND EMPOWERMENT	0.974715	4
SOB7	TOP MANAGEMENT SUPPORT AND COMMITMENT	0.979517	8
SOB8	INTEGRATED INFORMATION SYSTEM	0.973162	2

It is difficult to implement all solutions at the same time due to various constraints; therefore ranking the solutions is essential for stepwise implementation of these solutions. Final barrier's weight is shown in table 4.31 and ranking to the solutions shown in table 4.49. The solutions are SOB3-SOB8-SOB5-SOB6-SOB1-SOB4-SOB2-SOB7 from most important (rank 1) to least important (rank 8). Use of establishing preventive maintenance system was found to be best solution of highest importance in order and integrated information system is ranked second. Encouragement of cross functional teams & quality circles is ranked third, employees training and empowerment is ranked fourth, integration of corporate strategy with operator strategy is ranked fifth, establishing quality management system is ranked sixth and optimal resource allocation is ranked second last. Top management support and commitment is lowest ranked.

CHAPTER 5

CONCLUSION & REMARKS

5.1 Conclusion & Scope for future work

Indian organizations are failing to get maximum productivity due to traditional maintenance management system used by them. In this research, it has been tried to analyze different barriers and solutions in modern maintenance management for improving productivity. Literature available on maintenance management discusses the importance of maintenance management but does not sufficiently describe mechanisms through which modern maintenance management can be adopted into the organization culture to achieve its best result.

In this study major benefits have been discussed. Based on AHP, comparative analysis for modern and traditional maintenance management has been done. In this research it has been analyzed that modern maintenance management has more global desirability index than traditional maintenance management.

But in dynamic environment, manufacturing organizations productivity graph is not rising due to the presence of various type of barriers. Barriers of modern maintenance management have been identified. After that, solutions to overcome these barriers have been analyzed. In this research, a scientific framework has been presented to rank the solutions of modern maintenance management to overcome its barriers by using a multi criteria technique. It combines fuzzy AHP and fuzzy TOPSIS approach. Humanists are often uncertain in assigning the evaluation scores. Therefore AHP and TOPSIS methods are performed in fuzzy environment.

Fuzzy AHP was used to get weights of the barriers of modern maintenance management, while fuzzy TOPSIS was utilized to give rank to the solutions. Through literature review and expert's opinion, total 18 barriers and 8 solutions of modern maintenance management have been identified and through hybrid fuzzy AHP-TOPSIS framework, solutions are ranked. Result shows that establishing preventive maintenance is the highest rank solutions to overcome the barriers of modern maintenance management. This solutions ranking will help organizations to decide their solutions for implementation priorities to overcome the barriers and increase the success rate of modern maintenance management in organization.

These finding will motivate organizations to implement modern maintenance management for improving their productivity and reducing waste.

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