ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECANICAL &INDUSTRIAL ENGINEERING

SELECTION OF MAINTENANCE STRATEGY FOR LIGHT RAIL TRANSIT BY USING AHP ALGORITHM

A Thesis Submitted to Addis Ababa Institute of Technology, Addis AbabaUniversity, In Partial Fulfillment for the Degree of Master of Science in Railway Engineering

Advisor

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By

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APPROVAL BY BOARD OF EXAMINERS

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Declaration

I, the undersigned,declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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Date of submission: ______________________

Place: Addis Ababa

This thesis has been submitted for examination with my approval as a university advisor.

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Advisor’s Name Signature

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ABSTRACT

Maintenance has infinite number of functions and its strategic formulation needs infinite number of factors. This kind of multi criteria problems should be handled by multi criteria decision making process. Therefore, the main objective of this research is identifying key maintenance factors and then model maintenance strategy with AHP to select the possible priorities of maintenance strategy by using expert decision method. Selection of efficient maintenance strategy can be achieved by pairwise comparison of the identified functions. This qualitative survey assessed the opinion of maintenance professionals (11 personals) and rolling stock manufacturing & design experts (7 personals) at METEC locomotive division to select the maintenance system. The research method comprises identification of maintenance factors and suggestion of possible maintenance strategies. AHP analysis shows that safety (38.2%) become the highest priority of LRT system. value added (20%), implementation cost (13.2%), support system integration (11.5%), and implementation capability (8.2%), performance measurement (5%) and stock & material management (3.9%) are the succeeding priority factors on implementing maintenance system. The analysis discovered that total productive maintenance is the most suitable strategy to be implemented for LRT system and corrective maintenance is the least to follow. Sensetivity and sanity is checked for the input data to the software. Introducatory step for implementation of TPM is proposed for LRT system . Finally the bigest contribution of this thesis is an application of the AHP algorithm, which is one of multi criterea decission method for selection of maintenance strategy instead of traditional way of selecting " based on experience method" in Ethiopian industries.

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NOMENCLATURE

ACE	Achieving Competitive Excellence
AHP	Analytic Hierarchy Process
BCM	Business centered model
BDM	Break down Maintenance
BRT	Bus Rapid Transit
CBM	Condition-Based Maintenance
CMMS	Computerized Maintenance Management System
FBM	Frequency-Based Maintenance
FMECA	Failure Mode Effect and Criticality Analysis
GA	Genetic Algorithm
HR	Human resource
HVAC	Heating Ventilation and Air Conditioning
IT	Information Technology
LRT	Light Rail Transit
LRV	Light Rail vehicle
MADM	Multi Attribute Decision Making
MCDM	Multi Attribute Decision Making
MDBF	Mean Distance between Failures
MDT	Mean down Time
MDTF	Mean Distance to Failure
MMP	Measuring Maintenance Performance

MRO	Maintenance and Repair Organization
MTBF	Mean Time between Failures
MTTF	Mean Time to Failure
MTTR	Mean time to repair
MWT	Mean Waiting Time
NDT	Non Destructive Testing
OEE	Overall Equipment Effectiveness
PM	Preventative Maintenance
R&D	Research and Development
RCM	Reliability Centered Maintenance
SMART	Simple Multi-Attribute Rating Technique
SOP	Standard Operating Procedures
TOPSIS	Technique for Order Preferences by Similarity to an Ideal Solution
TPM	Total Productive Maintenance
TQM	Total Quality Maintenance

CHAPTER1. INTRODUCTION

1.1 Background

In light rail transit system (LRT) there is an ongoing demand for performance increase, which is driven by the need to keep a competitive edge against other means of transportation such a bus rapid transit (BRT) and taxi. This calls for high technical and economical requirements such as higher train velocities, larger passenger transport capacity, lower energy consumption, greater traveler comfort, low emission better safety levels and lower life cycle costs. In this dynamic transport service productivity is playing a key role to stay competitive for railway Transport Company. Productivity can be achieved through availability and availability can be increased through adopting efficient maintenance practicesparida(2009). Availabilityoffleet of a rolling stock will be an important and noticeable aspect for customers of light rail transit system, which makes rolling stock availability a key aspect for the business reputation. For LRT project that willcover the scheduled services. operate multiple train units forecasting and maintaining a required level of fleet availability is a challenging task unless well-organized maintenance strategy carefully implemented. The stochastic nature of train breakdowns and the corrective maintenance to fix them will be problems to keep the required availability of the fleet Felix(2010). If more trains are withdrawn from a fleet due to failure service provider cannot provide the required transportation capacity.

Maintenance strategy problems could be classified with respect to the time scale involved. It starts early in the design phase of systems, the type of equipment, the level of redundancy and the accessibility that strongly affects the maintainability Dhillon (2002). Furthermore, a very critical decision should be made regarding which event (e.g. failure, the passing of time, etc) triggers what type of maintenance, i.e. inspection, repair or replacementMoubray(2002). In LRT business the maintenance objective is to reduce failures of rolling stock, fixed infrastructure, facility and equipment/component. This objective can be achieved using various maintenance strategies. However the current practices in equipment maintenance and replacement decisions are frequently based on informed opinions such as following the original equipment manufacturers recommendations and previous experience Alsyouf (2004).

The maintenance strategy of rolling stock becomes an important factor in the company's total quality management to become safe, reliable and dependable transport operator. A strategy (direction) is always followed either consciously or unconsciously. When strategy is not stated only followed unconsciously the result is often considered as reactive approach, which causes events and others to choose the direction Wireman(1998).Salonen A. (2009) performed a case study on Swedish industries the view on maintenance strategy was investigated. Six companies were included in the study and four of these companies had no maintenance strategy, nor did they use measures relevant for maintenance control. Implementation of efficient maintenance system early on the initial establishment of a business organization has good opportunity if it is carefully studied and designed with overall objective of an organization. Usually maintenance strategy consists of various critical success factors that are necessary to achieve the overall goals for maintenance.

The critical success factors include the guidelines for the functions (reliability, safety and quality of service) to be achieved. There should be methods for establishing the relationship between the operational reliability, the condition of the railway vehicle, associated infrastructure, maintenance work carried out and for measuring the performance of maintenance strategy. Alsyouf (2004) showed that most Swedish firms, i.e. about 81%, use the accumulated knowledge and experience within the company as a method for maintenance selection. Besides, about 31% use a method based on modeling the time to failure and optimization. About 10% use failure mode effect and criticality analysis (FMECA) and decision trees and only 2% use multiple criterion decision making (MCDM). Even if in Ethiopia there is no quantified data how maintenance strategy is formulated the experience shows that almost all companies use their own experience as a source of maintenance selection method. Therefore, there is a need to develop effective maintenance strategy which can achieve the overall goals of the maintenance activity in a cost effective way. This research tries to use one of MCDM approaches, AHP as a method for selection of maintenance strategy. The complexity, unavailability of previous data on LRT and the nature of maintenance factors makes AHP the ideal method in this research. AHP is a powerful and flexible multi-criteria decision making tool for complex problems where both qualitative and quantitative aspects need to be considered. It helps the analysts to organise the critical aspects of a problem into a hierarchical structure similar to a family tree saaty (1980). By reducing complex decisions to a series of simple comparisons and rankings, then synthesising the results, the AHP not only helps the analysts to arrive at the best decision, but also provides a clear explanation for the choices made.

1.2 Statement of the Problem

Currently substantial part of the maintenance work in mostEthiopian industries and transport operators is performed as a reaction to unexpected events. This leads to a quick fix mentality where the maintenance staff acts more like firefighters rather than continuously improving the operation system. Working unstructured obviously does not solve all problems in an optimum way; the problem is fixed for now but the probability of reoccurrence will not be alleviated. Most maintenance mechanics and managers relay almost entirely on their past experience instead of following the changing dynamics of maintenance and engineering science. Even though the skill of technicians to solve the problems is adequate, an organization should not operate unstructured. Working structured within clear work procedure and good documentation would be beneficial. It is important that all fixes regardless of it is a quick fix or a permanent solution must be evaluated, documented and standardized as a way to minimizing the risk of reoccurrence.

Addis Ababa light rail transit is working aggressively on fixed infrastructure building but there is no comparable progress seen on implementing better fleet and maintenance management system. Unless the fleet system and maintenance strategy is clearly stated and incorporated as part of a company management strategy initially rolling stock repetitive failure will decreases the capacity of the transit which leads to the system will face difficulty on staying at business. Implementing a complete and sustainable maintenance strategy will have immense influence on railway system operation. It is also decrease the systems life cycle cost and improves the quality of rail transport operation.

On earlier problem identification process the researcher found that the LRT system does not have specific maintenance strategy. According to an engineer working in ERC/LRT they are on the way to adapt the well-recognized international operator's experience by outsourcing the maintenance system to foreign consultancy firm. The main problem observed on adopting other operators experience prior to setting the company overall maintenance strategic goal become a mix up of maintenance strategy and it is difficult to understand both for the managers or technical stuff. The other problem observed in some industries in Ethiopia is purchasing CMMS software from Developers and venders without studying their demand and real working situation. Before implementation of CMMS the companies need research on their maintenance strategy analyze constraint of working condition ,type of business, type of ownership and extra factors must be selected.

From the discussion with different organization professionals it is observed that the main reason of not implementing better maintenance strategy is lack of awareness on quickly growing technological advancement on maintenance related functions both in the skilled crafts and higher management. The other point noted out on problem identification is the higherinitialcost of CMMS software and other prediction equipment's that will discourage the top managements not to approve the necessary budget.

1.3 Research Questions

The following research questions are drawn from the above research problem statement and guided this research

Q1. What are the possible maintenance strategies for light rail transit operations?

Q2. What are critical factors for LRT maintenance strategy selection?

Q3. How is carefully selected maintenance strategy related with operational availability, reliability, safety and service quality?

Q4. What will be the role of CMMS in maintenance strategy?

Q5. How is maintenance strategy modeled with multi criteria decision method, AHP?

Q6. Which maintenance strategy is the most suitable for LRT system?

1.4 Objective

1.4.1 General Objective

The general objective of this thesis to select better maintenance strategy based on analytic hierarchy process (AHP) on addressing long run fleet availability for LRT system.

1.4.2 Specific Objective

- To show the effect of effective maintenance strategies on achieving reliable and dependable rolling stock operation.
- To review and evaluate five different maintenance strategies applicable to LRT system.
- To recommend the new LRT maintenance management system with suitable maintenance strategy in order to formulate maintenance management system.
- Introducing MCDM for selection of maintenance strategy instead of traditional previous knowledge based selection.
- To apply AHP, multi criteria decision method for selection of maintenance strategy.

1.5 Research Methodology

This thesis applies expert decision methodology to obtain the appropriate maintenance strategy for light rail transit. As shown below in the figure 1.1 the first stepof the research is identifying maintenance factors, sub factors and alternative strategy from different research papers, journals and international LRT operators experience. Then first level questioner prepared.Form focus group of experts and discuss on identified factors and alternative strategy. The next step is formulateAHP model as shown in fig 3. 1 and prepare second level questioner by using Saaty (1980)critereia comparison method . Here the expert judgments are completed on AHP questioner and transferred to super decision software. AHP survey analyzed , sensitivity and sanity of data is checked then the result will be discussed. Introductory step of the selected maintenance strategy will be prepared with possible LRT depot facility and work process. Finally conclusion and recommendation with future work will be given at the end of the paper.

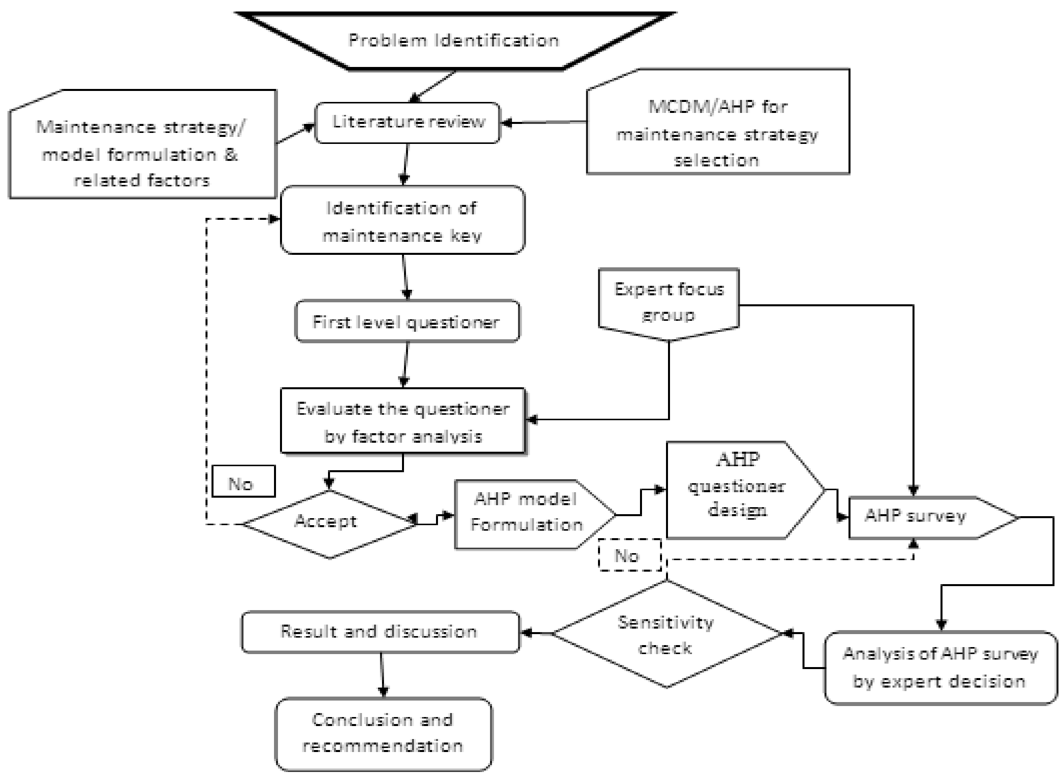

Figure 1-1Research methodology

1.6 Limitation of the study

Due to unavailability of the LRT system in Ethiopia the study was targeted to conduct with maintenance engineers in Ethiopian Railway Corporation. The light rail transit division has only experts for construction of railway infrastructure no one was assigned as maintenance professional specifically. The researcher tried to contact the former Ethio-Djibouti railway workers in main office Legahar, we didn't found any technical person instead human resource, finance and legal department are only left in the office. Hence, the author persuaded to relay on the literature and the experience of foreign light rail transit companies and only the expertise judgment of metal technology and engineering corporation/locomotive division engineers.

1.7 Thesis outline

This thesis organized by six chapterschapter one explains introduction of the thesis including back ground information, problem formulation, objective, methodology and limitation of the study. chapter two describes literature related to maintenance process and how AHP is applied to selection of maintenance strategy is reviewed.chapter three briefly Illustrate how maintenance factor is identified? how AHP model is formulated based on specified goal (maintenance strategy selection), criteria (main factors and sub factors) and alternative strategy, questioner design, data collection and software analysis.chapter four discusses the identified result by using super decission analysis.Chapter five includesan introductory step on selected strategy, the necessary facility and maintenance program of light rail transit. The lastchapter conclude the research withpossible recommendation and future work.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Now a day's organizations are under pressure to continuously enhance their capabilities to create value for their customers and improve the cost effectiveness of their operations Tsang (2000). In this regard, the maintenance of high value locomotives and machineries, which was once thought to be a necessary evil, is now considered key to improving the cost effectiveness of an operation, creating additional value by delivering better and more innovative services to customers. With the change in the strategic thinking of organizations, the increased amount of outsourcing and separation of maintenance organization and asset owners, it is becoming crucial to measure, control and improve the assets' maintenance performance Parida and Kumar(2009). As technology has advanced, various maintenance strategies have evolved, including condition based maintenance, predictive maintenance, remote-maintenance, preventive maintenance, e-maintenance etc. The main challenges faced by organizations today are choosing the most efficient and effective strategies to enhance and continually improve operational capabilities, to reduce maintenance costs and to achieve competitiveness in the industry (Wireman, T. 2010). Therefore, in addition to formulating maintenance policies and strategies for asset maintenance, it is important to evaluate their efficiency and effectiveness. Equipment reliability must be maintained in order to achieve operation goals, safety goals, and to reduce overall production costs from avoidance of catastrophic failures that require extensive downtime, labor, and parts to recoverIAEA(2007).

2.2 Maintenance Strategy

Traditionally, maintenance, with its directional activities, resources, measurement, and management, has been important to rail transport operational organizations. However, in recent years, the need to manage the different direction of maintenance more effectively has gained added importance, due to changing operational technologies and the changing organizational role of maintenance. In light rail transport organization, maintenance has a broader perspective. In such organizations, the scope of maintenance has shifted from a narrowly-defined operational perspective to an organizational strategic perspective. Maintenance strategy is a Management method used in order to achieve the maintenance objectives Alsyouf (2007).Maintenance Objectives are the targets assigned to or accepted by the management and maintenance departmentAlsyouf(2007).These targets may include availability, cost reduction, product quality, environment preservation and safety. A strategy is the idea of how to reach the objectives ,which means to take different steps or performing activities. The overall direction, a plan which describes the activities to be performed is described by the strategy Campbell (2006).The content in the maintenance strategy is a mix of techniques and/or policies which depends on factors such as the nature of the plant, the maintenance goals or the equipment that will be maintained, the work environment and the work flow patterns Alsyouf(2007).

In a competitive strategy are the firm's goals and the means needed to reach the goals should be combined Salonen (2009). A number of maintenance strategies and concepts have been suggested by intellectuals or implemented by researchers. Researching, identification and execution of many inspect, repair and replace decisions (maintenance actions) are involved in the maintenance strategy, and the Strategy describes which events (e.g. condition, passing of time, failure) that trigger which type of maintenance action. The concern is about formulating the facility's optimal maintenance schedule, and also the best life plan for each unit of the facility, which should be done in co-ordination with operation and other concerned functions (Alsyouf, 2007).

2.2.1 Maintenance Strategic Mission

Maintenance existsbecause we have physical assets which deteriorate (Moubray 2002). The function we wish to preserve must be one the user wants it to be. Maintenance affects three distinct sets of customers the owners of the system, its users (usually the operators) and society as a whole. Owners are usually satisfied if their system generates a satisfactory financial return on their financial investment. Users are satisfied if their system continues to operate at the required standard of performance. Society as whole is satisfied if the system does not fail in any way that threatens public safety or damages the environment.

The technology of maintenance is concerned with finding and applying suitable ways of managing or preventing failure. Failure management includes predictive and preventive maintenance, failure-finding, run-to-failure and necessary one-time changes to the design of the system or the way it is operated. Each category includes a host of options, some being more effective than others. Maintainers not only need to learn what these options are but also have to decide which are worthwhile applying in their own organizations. If they make the right choices, it is possible to improve a system's performance and simultaneously contain or even reduce the cost of maintenance. If they make wrong choices, new problems arise while existing problems get worse. So the mission statement should stress the need to make the most cost–effective choices from the full array of options.

Failure can affect output, safety, environmental integrity, product quality, customer service, protection and operating cost in addition to incurring repair costs. The severity and frequency with which a failure occurs make these consequences dictate the type of failure-management technique that is worthwhile applying. So the mission statement should acknowledge the key role of consequence avoidance on the maintenance procedures employed. The most effective maintainers are those who apply the required available resource ; people, spares and tools at minimum cost, but not so cheaply as to reduce the long-term functionality of their system. In other words, the lifetime cost ofownership must be minimized (Moubray 2002). Finally, the mission statement must recognize that maintenance depends on people including designers, constructors and operators. Everyone involved should share a common and correct understanding of what needs to be done, and to be able and willing to do whatever is required right every time. Hence the mission statementshouldemphasize; preserving the function of the physical system throughout its useful life. Satisfying the system's owners and users, as well as ensuring the safety of the society. Selecting and applying the most cost-effective techniques for managing the consequences of failure. Visser (1998) modeled maintenance as a transformation process encapsulated in an enterprise system such as shown in figure 2.1 .

The way maintenance is performed will influence the availability of production facilities, the rate of production, quality of end-product and cost of production, as well as the safety of the operation. These factors in turn will determine the profitability of the enterprise.

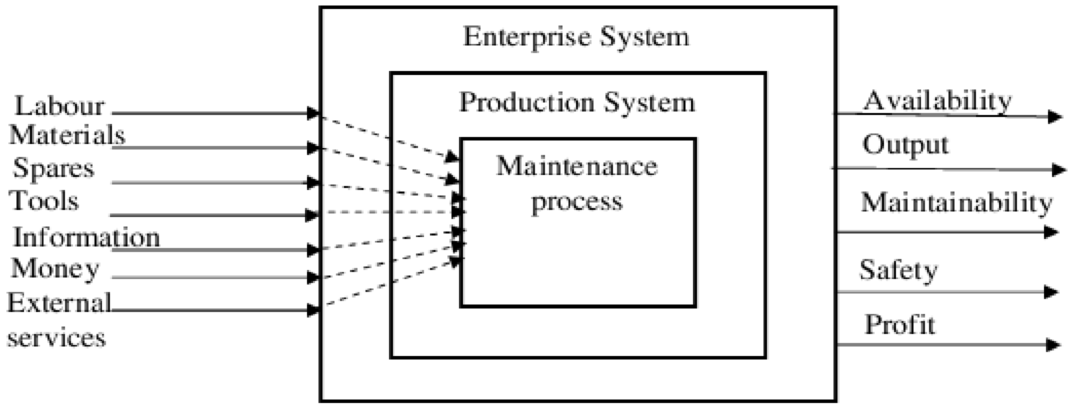

Figure 2-1Input-output model for an activity Visser (1998)

2.2.4 Maintenance Strategy Framework

Maintenance framework is the essential supporting structure and the basic system needed to manage maintenance effectively (Wireman, T. 2010).Industrial systems evolve rapidly, to keep up with the changing systems and environment. The maintenance strategy therefore needs to be reviewed periodically. This requires not only a structured but also a flexible maintenance strategy which allows feedback, improvement and responds to requirement changes WaeyenberghandPintelon (2002).Furthermore, the strategy should be customized, which implies that it should consider all relevant factors of the situation on hand. As such, the needs of the company will be tailored in the maintenance strategy. By that, the maintenance strategy will be unique for each company but the underlying structure needed to develop such strategy may be very comparable. The expectations of a structured framework for maintenance concept development are very comparable in almost

Kelly (2006) has presented a business-centered model (BCM) for the formulation of a maintenance strategy. The approach is called business-centered because it is derived from, and driven by, the business objectives identification, which then are translated into maintenance objectives and support the formulation of the maintenance strategy (Kelly, 2006). Provide a framework for identifying, mapping and then auditing the elements of any maintenance management system.

In Figure3the large circle is his strategic thought process starting with the maintenance organization objective (which is subordinate to the business objectives) and proceeding via life plans and organization through .When to formulate a maintenance strategy it is important to understand how the operation department functioning the relationship between the operation and its market and the maintenance function within this context (Kelly, 2006).

According to Kelly (2006) does the maintenance objectives need to be established in relation with the operation and business objectives, and before this is done it need to be understood how the maintenance function will be affected by its dynamic relation with the operation function. When to set the objectives it need to be done in conjunction with the operation department, this is, due to the fact that the operation and maintenance objectives are inseparable (Kelly, 2006). The production and maintenance objectives also need to be compatible with the business objectives which can be obtained in Figure 2.2 below.

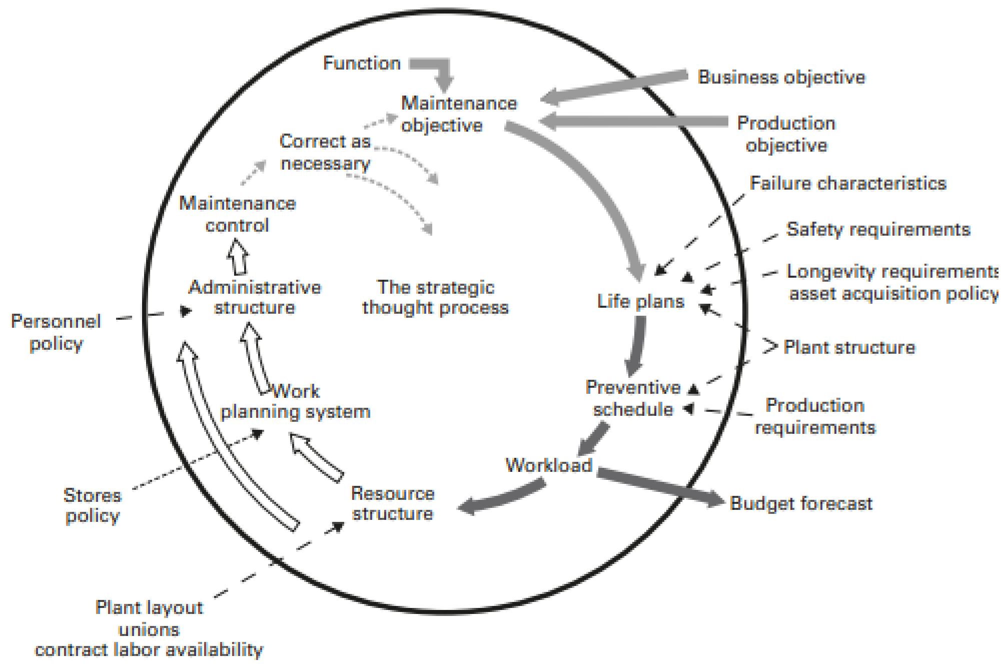

Figure 2-2A business-centered model (BCM) for the formulation of a maintenance strategy (Kelly, 2006)

McAllister (1999) has also presented a model for the formulation and review of a maintenance strategy. It is pointed out that maintenance should be considered as a partner within the business with the shared overall aim, that is, to produce and sell products at an acceptable margin of profit. In order for this to be achieved it must be understood that all functions within the business contributes to profitability. Thus, the maintenance function should align with the overall business goals. McAllister (1999) also points out that before developing a maintenance strategy the need for change should be established. In the maintenance philosophy should change be embraced as a major expectation and constituent McAllister, (1999). The maintenance strategy development process starts with stating the maintenance philosophy which is an expression of the maintenance function's role within the company and the chosen approach for how to fulfill it. The next step is to consider the aims and objectives of the maintenance function. The aims can be at corporate, production and maintenance levels and the objectives must respond to the driving forces from production. The third step is to assess and evaluate the maintenance practices and issues. Figure 2.3 below represents the range of maintenance policy sectors and corresponding practices to consider for this assessment which, after completion, may be used to develop a maintenance program. Then should tactics, for how to integrate existing practices with new ones, be developed. The last step is to determine the implementation planMcAllister, (1999).

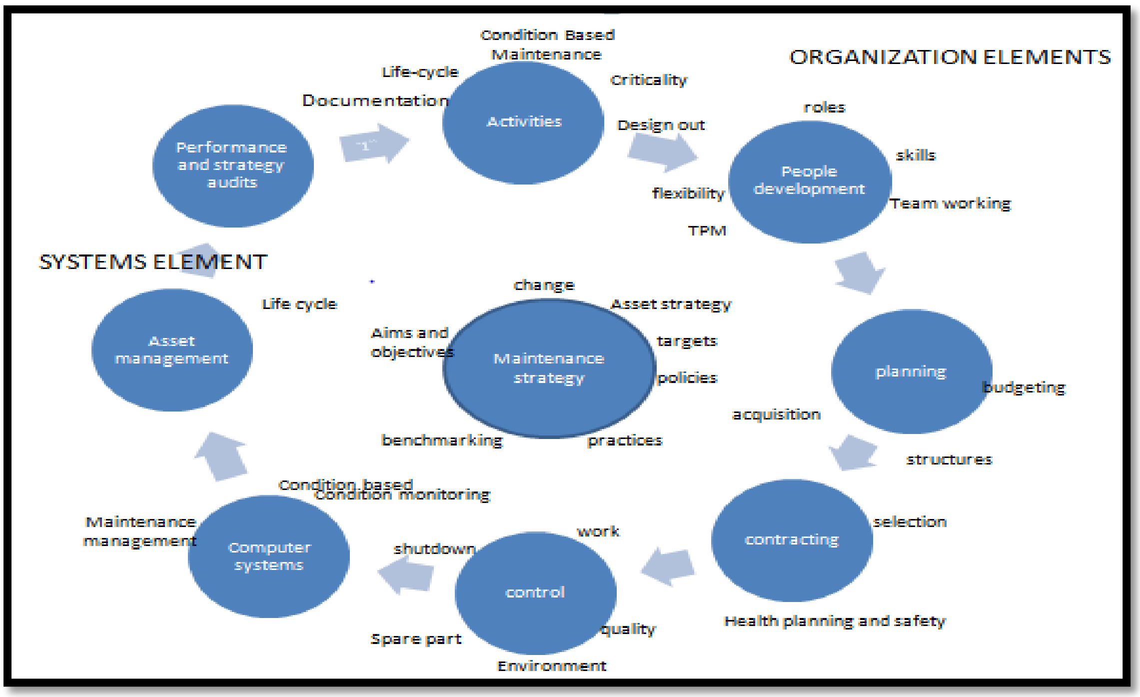

Figure 2-3 the range of maintenance strategy sectors and corresponding practices McAllister(1999) modified

Factors that describe the general organizational structure, technically describe each system to maintain, as well as factors that describe interrelations between the different systems should be addressed. The maintenance concept will not reach its full potential if some of the required aspects are not included in the development of the strategy. A careless analysis, lost data or lack of knowledge might be reasons for an inadequate strategy. Due to the operational impact that maintenance may have on the equipment's performance and the involvement of high direct as well as indirect cost, for both in-house and outsourcing maintenance, the development of the maintenance strategy should be done in a structured way WaeyenbergandPintelon, (2002). Concerning the formulation of a maintenance strategy a model proposed by Salonen (2009) will also be presented in this thesis. This model is a schematic view of the work-process when formulating a maintenance strategy and is presented in Figure 2.4 below.

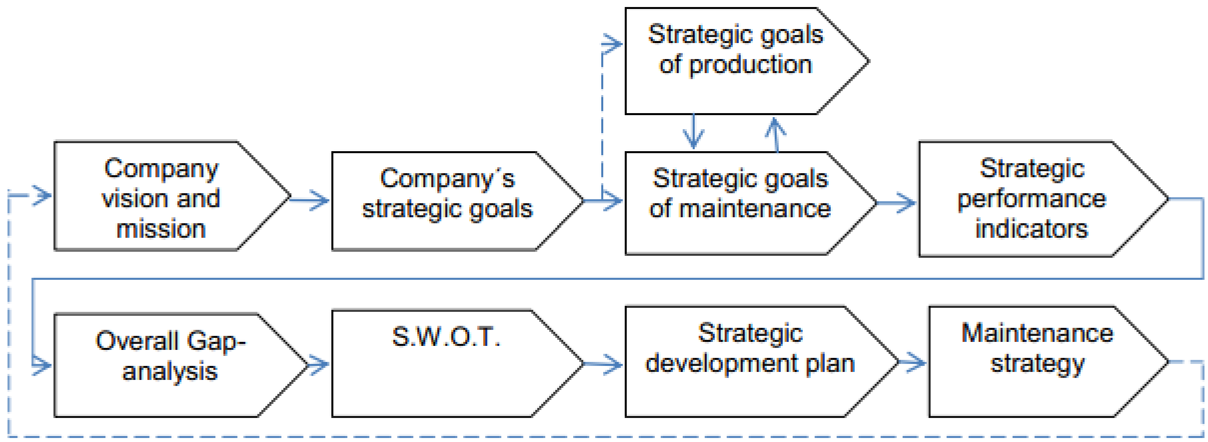

Figure 2-4 Process for formulation of maintenance strategies Salonen (2009)

2.3 Goals and Objectives of Maintenance Organizations

The goals and objectives of the maintenance organization determine the type of maintenance organization that is established. If the goals and objectives are progressive and the maintenance organization is recognized as a contributor to the corporate bottom line, variations on some of the more conventional organizational structures can be used.

According to Terry wireman (2005), Objectives of maintenance management are:-

- √ Maximum production at the lowest cost, the highest quality and within optimum safety standards
- √ Identify and implement cost reductions
- √ Provide accurate equipment maintenance records
- √ Collect necessary maintenance cost information
- √ Optimize maintenance resources

√ Optimize capital equipment life

√ Minimize energy usage

√ Minimize inventory on hand

2.3.1 Identify and Implement Cost Reductions

In rolling stock operation reducing costs is sometimes an overlooked aspect of maintenance. With regard to managing the overall cost of the rail transport service, it is essential to control the costs associated with maintenance, maximizing the utilization of the fleet while minimizing the equipment that is held out of service. Moreover, the equipment is engineered such that work can be organized to reduce the frequency and duration of periods where the equipment is held out of service. This sustains practical limits on investments in new train set equipment. However, a maintenance organization can help LRT operation reduce costs in many ways. For example, a change in a maintenance policy may lengthen operation hours without damaging the rolling stock and associated infrastructure. This change reduces maintenance cost and, at the same time, increases operational capacity. By examining its practices, maintenance can usually make adjustments in tools, training, repair procedures, and work planning, all of which can reduce the amount of labor or materials that may be required to perform a specific job. Good repair transforms into reduced downtime or increased availability. Downtime is more costly than maintenance expenditures Terry wireman (2005),before making adjustments to reduce costs, studies should be conducted to show the before-and-after results. This quantifying of improvements builds management support for maintenance activities.

2.3.2 Provide Accurate Equipment Maintenance Records

Providing accurate equipment maintenance records enables a company to accurately track rolling stock life cycle which is the key information from its procurement to disposal. Success in this attempt, however, requires accurate records of each maintenance repair, the duration of the repair, and the run-time between repairs, maintenance program and accident record. In LRT, for which this activity produces a tremendous amount of paperwork, there must be some form of a computerized maintenance management system (CMMS) to track this information. But whether or not a computer is used, all of the maintenance data must be accurately tracked. Maintenance records are generally collected as work orders and then must be compiled into reports showing meaningful information or trends. The problem is finding enough time to put valuable information on each individual work order. Because of excessive amounts of maintenance are performed in a reactive mode, it is difficult to record events after the fact. Accurate record keeping is mandatory if maintenance is going to fully meet its responsibilities.

2.3.3 Collect Necessary Maintenance Cost Information

Collecting necessary maintenance cost information enables companies to track engineering information. For example, by using life-cycle costing information, the LRT can purchase rolling stock with the lowest life-cycle costs rather than lowest initial costs. In order to track overall life-cycle costs accurately, all labor, material, contracting, and other miscellaneous costs must be tracked accurately at the equipment level. This tracking is primarily an activity for the maintenanceplanningdepartment. In addition to life cycle costing is the need for maintenance budgeting Terry wireman (2005). Labor figures should not available in birramounts;the reason is the differences in pay scales may make it difficult to determine how much labor was used in total hours by craft. Themaintenanceinformation must be collected both in birr and in hours by craft.

2.3.4Optimize Maintenance Resources

Optimizing maintenance resources includes eliminating waste through effective planning and scheduling techniques. In reactive maintenance organizations, up to one-third of maintenance expenditures are often wasted Terry wireman (2005). By optimizing maintenance resources, organizations improve their effectiveness in eliminating this waste. When 80-to-90 percent of all maintenance activities are planned and scheduled on a weekly basis, there is very little waste to the maintenance process wireman(2005).

Optimizing maintenance resources also has an effect on maintenance man-power. For example, with good planning and scheduling practices, a reactive maintenance organization may increase the “wrench time” of their craft technicians from 25 % to as much as 60 % wireman (2005). This reduces the amount of overtime or outside contracting that an organization currently utilizes, reducing the overall maintenance cost. These types of reductions, while improving service, are essential to optimizing the present resources. Optimizing maintenance resources can only be achieved by good planning and scheduling practices.

2.3.5 Optimize Capital Equipment Life

Optimizing the life of the capital equipment means maintaining it so that it lasts 30 to 40 percent longer than poorly maintained equipmentwireman(2005)The maintenance department’s goal is to keep the equipment properly maintained to achieve the longest life cycle. A preventive maintenance program designed for the life of the equipment to obtaining a maximum life cycle. The maintenance department will then need to perform the correct level of preventive maintenance, performing enough maintenance, but without performing excessive maintenance. According to wireman (2005) one way to determine a problem in this area is to examine new equipment purchases. Are equipment purchases used to replace equipment in kind? If so, could the purchase of the equipment have been deferred if proper maintenance had been performed on the older equipment? If long life cycles are not being achieved, then the proper level of maintenance is not being performed, and maintenance tasks should be revised.

2.3.6 Minimize Energy Usage

Minimizing energy usage is a natural result of well-maintained equipment, which requires 5-to-11 percent less energy to operate than poorly-maintained equipment wireman (2005). These percentages, established by international studies, indicate that maintenance organizations would benefit from constantly monitoring the energy consumption in a plant. Most plants and facilities have equipment that consumes considerable energy if not properly maintained. For example, heat exchangers and coolers that are not cleaned at the proper frequency consume more energy. HVAC systems that are not properly maintained require more energy to provide proper ventilation and comfort. Even small things can have a dramatic impact on energy consumption. For example, equipment with a poor maintenance schedule will have bearings without proper lubrication or adjustment, couplings not properly aligned, or gears misaligned, all of which contribute to poor performance and require more energy to operate. The key to achieving this objective is having good preventive and predictive maintenance schedules.

2.3.7 Minimize Inventory On Hand

Minimizing inventory on hand helps maintenance organizations eliminate waste. Approximately 50 percent of a maintenance budget is spent on spare parts and material consumption Wireman, (2005). In organizations that are reactive, up to 20 percent of spare parts cost may be waste wireman, (2005). As organizations become more planned and controlled, this waste is eliminated. Typical areas of waste in the inventory and purchasing function include:

- Stocking too many spare parts
- Expediting spare part delivery
- Allowing shelf life to expire
- Single line item purchase orders
- Vanished spare parts

It is important for the maintenance organization to focus on controlling spare parts and their costs.

2.4 Computerized Maintenance Management System

2.4.1 What is CMMS

According to Fernandez (2003), information is an essential resource, which can be leveraged by management to determine if the organization's objectives are being met. Fernandez et al. (2003) suggested that maintenance information can be used to gain knowledge about the status of the equipment and the information can be utilized to measure the overall performance of the assets. According to Fernandez et al,(2003) Information systems were no longer being used to supply management with information about the operation of the organization. CMMS are computerized systems that are specifically developed along with software applications to monitor the work, as well as report how assets are working (Fernandez et al. 2003). CMMS software is a tool that can be used with any of several maintenance strategies, offering management tools to make decisions about maintenance strategies. Labib (2005) suggested that several factors were a driving force behind CMMS. The onset of such a requirement is driven by the mere fact that record keeping in an RCM program is paramount, which can be the difference between success and failure. Labib (2005) stated that CMMS is a set of computer based software programs used to control resources and work activities, as well as monitor conditions of equipment located in the plant. The ability to have information readily available on equipment in real time is critical for management to make decisions.

A CMMS can be used to retain equipment performance and compare against previously defined metrics. This can assist management to easily identify bad actors or frequently ineffective pieces of equipment. Maintenance and equipment historical records can assist management in gaining an insight into how well the facility is functioning Fernandez et al. (2003). This is an important indicator of the effectiveness and efficiency of computerized maintenance program.

2.4.2 The Benefit of CMMS

Without a system that tracks vital maintenance records and information, it becomes challenging to measure the effectiveness of maintenance program; the lack of a CMMS can influence an RCM program from operating efficiently and effectively. With a CMMS, all employees in the organization can track equipment performance and compare the data to similar equipment on the property Labib(2005). The CMMS may be used to track the asset management to realize how well the equipment performs against the required overall efficiency. With a CMMS system, maintenance and operation personnel may easily identify when the last service of rolling stock was conducted as well as the next scheduled date for service, allowing planners to schedule work accordingly. With safety on the mind of many regulatory agencies require companies to remain compliant with scheduled maintenance. These companies often required to provide a copy of their service records, or the information may be requested during an accident investigation or a safety audit Labib(2005). A CMMS offers management and employees the ability to generate customized reports that satisfy the needs of regulatory bodies. Labib (2005) suggested that organizations that implement a CMMS into their maintenance center often achieve world-class maintenance. He stated that such a tool offers a number of functions and supports for various maintenance programs, such as Reliability Centered Maintenance (RCM), Condition-Based Maintenance (CBM) and Total Productive Maintenance (TPM). A CMMS has the capability of tracking spare parts and inventory levels with automatic order replenishment. This system facilitates Labib, (2005).

- Inter-departmental communication,
- Provides historical information about equipment,
- Schedules preventative maintenance,
- Provides senior management with the health status of the plant.
- CMMS has the ability to run statistical analysis to assist in locating problematic assets.

According to Campbell and Reyes and Picknell (2006), using data management clearly has a direct impact on maintenance output. The authors' declare that equipment effectiveness can jump from 50 % to 85 %, reliability can rise to 20 %, workforce productivity can increase 20 to 30 %, and material usage can be reduced 20 to 50 %.

2.4.3 CMMS to Aid Planning and Scheduling

Maintenance planners can effectively use the CMMS tools to schedule work based upon information made available on the system, track maintenance costs, and develop an accurate budget. Effective planning, coordination, and scheduling of the maintenance function can be, and for many years was, accomplished without computer support. However, in these days of high technology and rapid, economic data communication, job preparation is accomplished far more efficiently with the support of a sound Computerized

Maintenance Management System (CMMS). CMMS accomplishes nothing in isolation, but must be integrated with the other building blocks maintenance functions. Bottom-line impact results from actions taken on the basis of information provided by the system, not directly from the system itself. It is no longer an economically sound decision to manage a function as critical as maintenance without on-line informational support. Computerization of the work order system allows easier access to large amounts of data enabling analyses too time consuming to perform manually.

The maintenance planning system is generally part of a much larger maintenance information system. To effectively support the functions discussed throughout this paper the chosen CMMS (hardware and software) must offer the following characteristics. The selected CMMS must be a sound, comprehensive, on-line, real-time, user-friendly, computerized work order control system. If it is not real time, the maintenance staff (planners and clerks) must perform all administrative input and output. A preferable strategy is for all parties to do their own share of informational input and retrieval. If these responsibilities are not shared, all too often, planners become little more than clerks.

2.5 Material Control

Experience indicates that, on average, material costs account for approximately 30 to 40% of total direct maintenance costs. Efficient utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead to false starts, excess travel time, delays, unmet due dates, etc. Steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance of materials, and reviewing the completed job can help reduce material related problems. Deciding whether to keep spares in storage is one of the most important problems of material control. In many maintenance organizations, materials account for one-third to one-half of the operating budget, and more in some capital intensive industrial sectors. Needless to say, maintenance functions rely heavily on the availability of items such as spares for production equipment and machinery. A well-managed inventory system of such items helps reduce maintenance cost, worker and equipment downtime, and improves productivity.

2.5.1 ABC Classification Approach for Maintenance Inventory Control

In any maintenance inventory control system, parts/materials required for routine maintenance should be readily available. In the case of non-routine maintenance, items must be controlled in such a way that the capital inventory investment is most effective. In controlling inventory, one must seek information on areas such as those listed below.

- Importance of the inventory item
- The way it should be controlled
- Quantity to be ordered at one time
- Specific point in time to place an order

The ABC classification approach provides information for routine and non-routine maintenance. Consequently, it allows different levels of control based on the item's relative importance. The ABC approach is based on the reasoning that a small percentage of items usually dictate the results achieved under any condition. This reasoning is often referred to as Pareto principle, named after Vilfredo Pareto (1848–1923), an Italian sociologist and economist. The ABC approach classifies in-house inventory into three categories (i.e., A, B and C) based on annual birr volume. The following approximate relationship between the percentage of inventory items and the percentage of annual birr usage is observed:

Items, 20% are responsible for 80% of the birr usage.
B items, 30% are responsible for 15% of the birr usage.
C items, 50% are responsible for 5% of the birr usage.

2.5.2 Safety Stock

The main purpose of having the safety stock is to mitigate the risk of running out of items at the moment of need. One technique for providing safety stock is known as the "two-bin system." In this case, a fixed replenishment order is placed as soon as the stock level hits the preset reorder point. More specifically, the items are stored in two bins, the replenishment order is placed as soon as the first bin becomes empty, and the items from the second bin are used until receiving the ordered items. The value of the preset reorder point depends upon factors such as the rate of demand and its associated variability, the stock out cost, and the lead time and its associated variability. Campbell (1995) states the following five factors on which the safety stock required depends:

- Reorder frequency
- Desired level of service
- Ability to forecast/control lead times
- Demand variability during the lead time
- Length of the lead time interval

As the uncertainty in demand raises the possibility of a stock out, the demand for items can be specified by means of a probability distribution. Past experience indicates that often demand during the lead time follows the normal probability distribution.

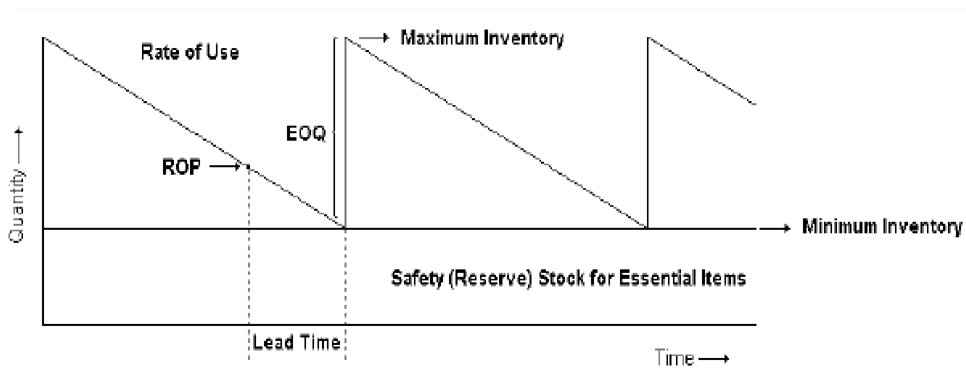

Figure 2-5Statistical inventory order cycle Dhillon (2002)

2.5.3 Maintenance Inventory Associated Factors

There are a number of factors that tend to increase the amount of maintenance related inventory and, ultimately, the cost of maintenance. Careful consideration of these factors can help reduce inventory costs and, in turn, the cost of maintenance. Some of the factors are as follows:

- Cost of operation downtime
- Lack of parts standardization
- Poor attention to inventory or order quantities
- Maintenance scheduling requirements

- Existence of multiple storage depots
- Inadequate attention paid to the economics of quantity purchasing
- Undependable supplier
- Nature and condition of facilities

The factors that tend to decrease maintenance-related inventory include good service from suppliers, infrequent equipment breakdown, availability of cash, and the cost associated with storeroom activity.

2.6 Maintenance Performance Measurement

2.6.1 Performance Measurement

Successful maintenance organizations regularly measure their performance through various means. Performance analyses contribute to maintenance department efficiency and are essential to revealing the downtime of equipment, peculiarities in operational behavior of the concerned organization, developing plans for future maintenance, and so on. Tsang et al. (1999) expresses since maintenance spending constitutes a large part of the operating budget in organizations with heavy investments in machinery and equipment, tracking the performance of maintenance operations in such organizations should be a key management issue. Another reason for linking the measurements to the organization's strategy, according to Tsang, is the influence of the used performance measurements on employee behaviors Tsang, (1998) the performance of the maintenance department needs to be routinely checked to identify and correct poor maintenance practices and to identify areas for improvement. Possible indicators of maintenance performance include: Efficiency measures;

- Equipment-reliability measures ;
- Safety measures;
- Equipment availability;
- Labor availability;
- Quality of work;

2.6.2 Maintenance Performance Benchmarking

Maintenance efficiency and effectiveness tend to be difficult to measure in absolute value. Consequently, performance measures have been defined in relative terms (values), in form of ratios of economic, technical or organizational measures. Therefore there should be performance benchmarking. Benchmarking is critical toward achieving world-class maintenance performance levels Ben-Daya(1995). The implementation of quality improvement programs, modern information systems, continuous improvement programs, and the evolution of performance measurement systems, tended to promote the recent propagation of maintenance performance measures and measurement.

Due to the increase in the number and type of measures, new approaches for maintenance performance measures and measurement are needed Kumar, (2006).There are several approaches to a better systematization and utilization of maintenance performance measures. Traditional approaches tend to establish a hierarchy with two sets of indicators, namely key indicators, to be evaluated periodically, and detailed indicators, which are only used for searching for the causes of deviations observed in the key indicators. However, more recent innovative approaches tends to present a more balanced view of maintenance performance measures, namely,

- Equipment related performance,
- Task related performance,
- Cost related performance,
- Immediate customer impact related performance,
- Learning and growth related performance

Through the framework of the EN 15341 standard, presented the maintenance performance measures' classification in terms of economic, technical, and organizational indicators. More recently, Chen, F. (1994) classified economical and technical measures in four groups,

2.8 Review of Maintenance Strategies

A number of maintenance strategies and concepts have been suggested by intellectuals or implemented by experts. Researching, identification and execution of many inspection, repair and replace decisions (maintenance actions) are involved in the maintenance strategy, and the strategy describes which events trigger which type of maintenance action. Most widely adopted maintenance strategies like run to failure, time based preventive maintenance, condition based maintenance, predictive maintenance, Total productive maintenance, reliability centered maintenance are briefly reviewed next.

2.8.1 Corrective Maintenance

It is also referred as, failure based maintenance, breakdown maintenance or run to failure strategy. It is the original maintenance strategy appeared in industryWaeyenbergh and Pintelon, (2002). In this strategy an item is allowed to fail before maintenance isexecuted. This strategyis appropriate when the consequence of failure is small. It can be used where the failure of equipment do not have a greater impact on availability or service for productive use of an organization. However, such failure based maintenance often may cause serious damage of related facilities, personnel and environment. In this strategy, the task of the repair/ maintenance team is to restore the facility to a state in which it can perform the required function as early as possible.

According to Sharma (2005), this process is called Breakdown Maintenance (BDM). CM maintenance is conducted to restore the functionality of the equipment; no action is taken to comprehend what caused the failure, or what possible actions could be taken to minimize future failures. This form of maintenance strategy is often called action-oriented maintenance or firefighting maintenance strategy. CM is simple and straight forward; “fix it when it breaks” Wheeler (2007), i.e. the things are fixed either after failure or during failure. This maintenance type is emergency repair, unscheduled and remedial tasks Teshome (2012). This method has been a major part of the maintenance operations since the first manufacturing plant was built, and it sounds reasonable on the surface. But it is actually a non-maintenance approach of management. It is also the most expensive one due to high rolling stock downtime, low operational availability; high overtime labor costs and high spare parts inventory cost Prasad (2010). The corrective technique does not take any action until equipment failure. This maintenance management philosophy is rarely used altogether without any preventive tasks (i.e. Lubrication and adjustments).

2.8.2 Condition Based Maintenance

It is a planned maintenance approach where failure or break down of rolling stock and infrastructure is avoided. Basically, this approach tries to forecast or predict the wear and tear or life of equipment by using different approaches and accordingly recommends a corrective action. Fault prediction facilitate maintenance engineers the possibility to plan for the maintenance. In general, the amount of equipment failure can be reduced if the planned maintenance strategies are correctly selected, specially conditioned based maintenance. This form of maintenance strategy as defined by Sharma (2005) maintenance is performed with the assistance of diagnostic tools, on a timely schedule; daily, weekly, or monthly.

CBM maintenance can be performed with the aid of vibration-based tools and diagnostic equipment. The diagnostics equipment measures physical conditions such as temperature, vibration, noise, corrosion, and other revealing signs, which may lead to premature equipment failure. CBM maintenance is considered a more prominent maintenance program designed for mechanical industries, which monitors the performance of rotating or reciprocating equipment. This maintenance strategy does possess an inherent risk. Itlacks the use of a data collection and risk assessment tools used by RCM to assist in identifying potential problematic areas. CBM requires the maintainers receive specialized training that requires additional time, cost, and resources without necessarily receiving the cost savings proposed by RCM Felix (2010).

2.8.3 Preventive Maintenance

The other maintenance strategy described by kamran (2003) is called Preventative Maintenance (PM). Preventative maintenance is a maintenance strategy that reduces the frequency and random failure by performing planned repairs, replacement, overhauling, lubricating, cleaning and inspecting at specific time intervals. The intent of the PM strategy is to minimize the probability of equipment failure prematurely by conducting maintenance before the failure of the equipment. This form of maintenance would be more effective with the support of a computerized system (CMMS). A CMMS generally is not incorporated as part of the maintenance strategy. PM is effective but the maintenance process does possess inherent risk; it lacks the use of a data collection and risk assessment tools used by RCM to assist in identifying potential problematic areas like CBM. This approach to maintenance management is predominantly recurring or time-driven tasks performed to maintain acceptable levels of availability and reliability. The philosophy assumes that the rolling stock component life is predictable, and maintenance is based on hours of run or calendar time elapsed. This is suitable for repeatable degradation modes, e.g. wear process or constant rate corrosion. In this strategy replacement or repair at a fixed time after the installation of facility is carried out which is generally independent of its condition. The time period used to construct a maintenance schedule can be either calendar time or component running time. Component is replaced at a fixed time, or at failure whichever occurs first. In spite of preventive approach some failure may occur because of uncertainty of the failure distribution which is occasionally shorter than the maintenance interval.

2.8.4 Reliability Centered Maintenance (RCM)

It is a methodology that determines what must be done to ensure that the asset continues fulfilling its intended functions in its present operating context defined by Moubray (2000). RCM was initiated in the U.S airline industry in the early 1960s in response to rapidly increasing maintenance costs, poor availability, and concern over the effectiveness of traditional time based preventive maintenance. RCM based program takes into account business requirements and objectives so that the required productivity goal can be achieved. The success of this approach depends on the availability of failure data, analysis methods, and operating experience to achieve its target. RCM has implementation difficulties due to unavailability of plant failure data. This maintenance strategy focuses on optimizing preventative and predictive maintenance, which results in an increase in equipment effectiveness while minimizing maintenance cost. The RCM strategy focuses on maintaining system function rather than both restoring equipment functionality. According to Felix (2010) reliability centered maintenance (RCM) defined "as a process used to determine the maintenance requirements of any physical asset in its operating context and [to] determine what must be done to ensure that the equipment continues to fulfill its function". He also noted that the RCM process combined several well-known risk analysis tools and techniques, including failure modes and effect analysis, as well as decision-tree analysis to identify problematic areas. Wheeler, Paul. (2007) stated that the RCM process is more than just a way of performing maintenance. Wheeler noted "in a nut shell, it's a way at looking at system performance in terms of the impact of a failure and then mitigating those results by design, detection, or effective maintenance".

2.8.5 Total Productive Maintenance (TPM)

The prime objective of total productive maintenance are to maximize equipment effectiveness and productivity Nakajima (1988), and eliminate all machine losses, create a sense of ownership in equipment operators through a program of training and involvement, promote continuous improvement through small group activities involving production, engineering, and maintenance personnel. Each enterprise has its own unique definition and vision for TPM Campbell (1995). But in most cases there are common elements and themes. These are Asset strategy, Empowerment, Resources Planning and scheduling, Systems and Procedures, Measurement, continuous improvement Teams, Processes. This maintenance philosophy requires active participation by all in the organization, including management. Sharma (2005) suggested that the TPM priorities here are to eliminate or minimize the following: loss due to downtime, loss due to setup and adjustments, speed loss, speed reduction, defect loss, and reduced yields. This form of maintenance focuses on increasing the overall equipment effectiveness (OEE).According to

Alsyouf, (2004), this is an excellent indicator of how well TPM is working. Although TPM has been effective and offers advantages over the other maintenance strategies, it does possess an inherent weakness. According to Ben-Daya,(2000), TPM lacks the necessary component for implementing an effective preventative maintenance program that keeps the equipment running optimally.

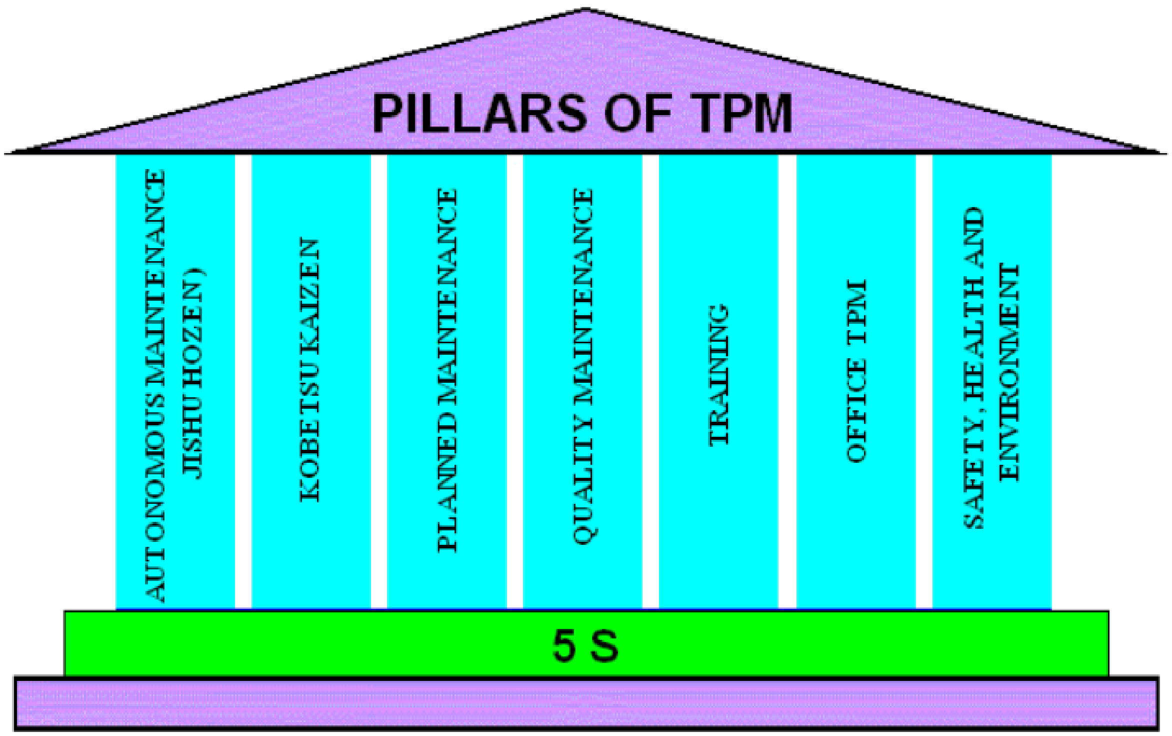

Figure 2-6 Pillars of TPM

2.9 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) methodology, which was developed by Saaty (1980), is a one of MCDM method and it is powerful tool in solving complex decision problems. The AHP helps the researchers organize the critical aspects of a problem into a hierarchical structure similar to a family tree. By reducing complex decisions to a series of simple comparisons and rankings, then synthesizing the results, the AHP not only helps the researchers arrive at the best decision, but also provides a clear justification for the choices made Chin et al., (1999).In the AHP approach, the decision problem is structured hierarchically at different levels with each level consisting of a finite number of decision elements. The upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives; one or more intermediate level embodies the decision criteria and sub-criteria Partovi, (1994).

In this research, the AHP is considered as an ideal systematic approach for several reasons. First, the AHP considers both qualitative and quantitative aspects of research and combines them into a single empirical inquiryCheng, (2001). The AHP is able to adopt a qualitative way in building the decision hierarchy and also uses a quantitative approach in data collection and analysis to test the attributes of the models by using a self-completed questionnaire. The AHP has the capability to combine various types of criteria in a multi-level decision structure to obtain a single score for each alternative to rank the alternatives among the available multi attribute approaches Yurdakul, (2004). Second, the selection of AHP as a method of analysis in this study is also determined by the size of the sample population.

The AHP is an analytical method which permits a small survey group Cheng and Li,(2002). It is thus helpful in collecting and analyzing data from a small group of experts who have real experience in maintenance management. This explains why the AHP is appropriate for use as a method of test. Furthermore, the AHP provides a function of seeking an expert's judgments and provides a consistency check which makes it a reliable way to determine the priorities of a set of factors, which may then be incorporated into other evaluation systems Cheng, (2001)and Chua *et al.*,(1999).By using the AHP approach, different levels of contribution of the selection factors, criteria and sub criteria towards selection of maintenance strategy are identified.

2.10 Literature Summary

In recent years the need to manage the different direction of maintenance more effectively has gained importance magnitude due to changing operational technologies and the changing organizational role of maintenance. As technology has advanced, various maintenance strategies have evolved, including condition based maintenance, predictive maintenance, remote-maintenance, preventive maintenance, e-maintenance and total productive maintenance. The maintenance strategy development process starts with stating the maintenance strategy, which is an expression of the maintenance function's role with in a company and the chosen approach for how to fulfill it. Wireman (1990) proposes a sequential implementation of steps to ensure that all functions for maintenance management are in place. He believes that a basic preventive maintenance (PM) program should be in place before we advance to the next level, the CMMS implementation. He asserts that a suitable work order release system (to schedule and trigger appropriately prioritized tasks) and a maintenance resources management system are required before one considers the implementation of Reliability Centered Maintenance (RCM) and predictive maintenance programs

Now a day's selection of maintenance strategy with multi criteria decision method (MCDM) can be realized. As Zhang *et al.* (2004) pointed out, decision making theorists have applied the MCDM to the preference decision making (i.e., evaluation, prioritization, and selection) on available alternatives in terms of multiple and usually conflicting criteria. Various multi-criteria decision making approaches have been proposed for maintenance strategy selection such as Analytic Hierarchy Process (AHP), fuzzy set theory, Genetic Algorithm (GA), mathematical programming, factor analysis, simple multi-attribute rating technique (SMART). AHP has been used as a multi-criteria tool by most of the authors, either independently or in the combination with other approach. Multi-criteria approach consists of finite set of alternatives among which a decision maker has to select or rank a finite set of criteria weighted according to their importance. In addition, a decision matrix consists of evaluation of each alterative with respect to each criterion using a suitable measure. The evaluation ratings are then, aggregated taking into account the weights of the criteria, to get a global evaluation of each alternative and a total ranking of the alternatives.

Al-najjari (2003) used the combination of AHP and fuzzy method for the prediction of costs in an effective approach to maintenance strategy; however, he did not care about the significance of conditions for maintenance time. Setup costs are also investigated in a report by Dekker, Van Egmond, Frank &Wildeman (1995). It is stated that coordination of age replacement is not possible, since the time of preventive maintenance is dependent on the occurrence of failures, which is unknown. To be able to coordinate the tasks, they suggest using opportunity policies or modified block replacement method. In 2000 Bevilacqua was dealing with analytic hierarchical process and the selection of maintenance strategy. He conducted the analysis of a detailed and complex sensitivity which was imposed on data resulted from paired comparison judgments. The results of this sensitivity analysis showed that the way of locating and the applied weights to different members of the decision group will have an impact on the outcome.

Alsyouf (2003) selected the most efficient maintenance method using fuzzy multi-criteria decision-making. The main problem in this study was the applying of identical definitions of Membership functions for fuzzy numbers and linguistic variables from the viewpoint of different people. Jafari (2008) used Fuzzy Delphi in selecting the best method of maintenance. Dragan et al (1995) selected an optimal maintenance policy in manufacturing factories using a genetic algorithm. Wang et al. (2007) presented a method to evaluate various maintenance strategies including corrective maintenance, time-based preventive maintenance, condition-based maintenance, and predictive maintenance. An efficient maintenance strategy mix is essential for increasing availability and reliability levels of production facilities. The selection of maintenance strategies is a kind of multiple criteria decision-making (MCDM) problem and to deal with the uncertain judgment of decision makers, a fuzzy AHP method was used as an evaluation technique, where uncertain and imprecise judgments of decision makers could be translated into fuzzy numbers. Dekker (1995) describes a method to integrate different maintenance policies into one, and also the grouping of activities to common occasions rather than doing them exactly when they are due. The time shift involves penalties, and one needs to group the activities to minimize the penalties. Dersin et al (2008), selected appropriate inspection and maintenance strategies with the aim of minimizing the costs throughout the product life cycle. Dutta et al, (2011) selected an appropriate maintenance strategy for supporting transmission and vehicle transportation systems using a fuzzy method. Kumar et al (2005) selected a proper repair & maintenance strategy in industrial processes using a fuzzy. As we have seen in the literature part there are considerable amount of researches on selection of maintenance strategy but the author didn't found the selection of maintenance strategy with AHP or other MCDM methods for maintenance of rolling stock transit system.

CHAPTER 3 MODEL FORMULATION AND DATA COLLECTION

3.1 Introduction

Implementation of efficient maintenance system early on the initial establishment of a business organization has good opportunity if it is carefully studied and designed with overall goal of an organization. Usually, the overall maintenance strategy consists of various critical success factors that are necessary to achieve the overall goals for maintenance. The critical success factors include the guidelines for the functions (reliability, safety and quality of service) to be achieved. There should be methods for establishing the relationship between the operational reliability, the condition of the railway vehicle, the associated infrastructure, the maintenance work carried out and for measuring the performance of maintenance strategy.

Therefore, there is a need to develop effective maintenance strategy which can achieve the overall goals of the maintenance activity in a cost effective way. The objectives of formulating maintenance strategy include determining what kind of maintenance philosophy should the LRT use? What are the main maintenance critical factors? How the maintenance strategy selected by using multi criteria expert decision method? Which kind of MCDM method is selected? Which maintenance strategy will meet the LRT objective, what maintenance strategy will secure the safety of the system? Alsyouf *(*2004) showed that most Swedish firms, i.e. about 81%, use the accumulated knowledge and experience within the company as a method for maintenance selection. Besides, about 31% use a method based on modeling the time to failure and optimization. About 10% use failure mode effect and criticality analysis (FMECA) and decision trees and only 2% use multiple criterion decision making (MCDM). Even if in Ethiopia there is no quantified data how maintenance strategy is formulated the researcher's experience concluded that almost all companies use their own experience as a source of maintenance selection method. This research tries to use MCDM as a method for selection of maintenance strategy.

3.2 Identification of criteria

Identification of maintenance strategy key criteria is the most important stage in the formulation of AHP model. According to different researchers finding and maintenance expert suggestion seven selection criteria are considered. These are safety, implementation cost, added value, implementation capability, performance benchmarking, stock and material management and support system integration. Five alternative maintenance strategies are considered, these are; preventive, corrective, reliability centered, condition-based (predictive) and total productive maintenance strategies. Moreover, different sub criteria are added to the model. According to the proposed model goals, criteria, sub criteria and alternatives are found these are described in the steps below.

3.2.1 Safety

According to national rail safety guideline (2008) the safety management system must include systems and procedures for the review of the safety management system at specified periods. The time period for mandatory review is specified in the rail transport operators notice of accreditation. The time period noted in the notice of accreditation may have been prescribed by the legislation or agreed between the rail transport operator and the rail safety regulator. Safety policies, procedures and guidelines maintains healthy working environment. Interruptions in operations due to failure may form a source of hazard to passengers, rail operator worker and the nearby system. Therefore this model outlined passenger safety, worker safety& the system safety as sub criteria.

A. Passenger safety

The primary objective of rail operator is to transport people and freight from one place to another safely. If there is a malfunction in rail vehicle or the infrastructure system there will be accident that will jeopardize the passenger’s safety. Malfunction can be prevented or avoided by formulating proactive type of maintenance strategy. The more safer the maintenance strategy it is the higher the rank.

B. Worker safety

Worker are always exposed for heavy load, pneumatic power driven devices, high pressure hydraulic system, high voltage electric devices, forklifts, cranes, chemicals, noise and many high risk accident will occur. This kind of incident can be mitigated by effective maintenance procedures and guidelines that incorporate safety as a primary goal. The safer the working invironment with theselected maintenance strategy the higher the rank

C. System safety

The LRT system is operating in the center of the city which is exposed to high density population. The electrified system by nature is not fully isolated system; it is highly exposed to peoples, animals, vehicles and other systems. If accident like derailment, fire, collision and other malfunction occurred there is high chance of propagation to the other systems. Here system safety categorized as the vehicle, infrastructure and the external system safety. The safer the system on implementation strategy the better the rank .

3.2.2 Implementation Cost

Maintenance cost usually consists of direct and indirect costs. Direct (visible) costs comprise factors such as direct labor, e.g. manpower, direct material, e.g. spare parts, and overheads, e.g. tools, transportation, training and methods. Indirect (invisible) costs are all the costs that may arise due to planned and unplanned maintenance actions, e.g., lost operations costs, accidents. Those are not the only costs in maintenance organization approaching specific maintenance strategy will cost significant amount of investment. Nevertheless the overall cost effectiveness of the equipment saved by using specific maintenance strategy the implementation cost of maintenance is different for different maintenance system. Therefore this model categorizes the implementation cost of maintenance strategy as hardware cost, software cost, operation and maintenance cost of the implemented system and training & development of personnel to use special tools and methods to perform the maintenance activities. The lower an implementation cost of the strategy the higher the rank.

A. **Hardware cost**

If a LRT system chooses to implement CBM for determining current equipment operating status is accomplished by using sensors and computers that are embedded into the operating equipment and embedded in the railway track. Ultrasound, Infra-Red, Acoustic Gas, laser, Eddy Current Chromatography, Ferro graphic Spectrum Analysis, temperature sensors, pressure sensors, transducers, warning systems and many other non-destructive testing devices (NDT) can be used as a hard ware to predict the maintenance time. Minimized hardware in number and cost the higher the rank.

B. **Software cost**

Some of maintenance strategies work on built around sensor and computer technology that can be embedded on the equipment (train) itself, which is monitored both remotely from a depot and control station and directly at the system by portable equipment. Portable instruments are still used as diagnostic tools, but also are used to collect system health data from sensors and to transfer that data to the networked maintenance workstation environment which interacts with the logistics system. This kind of remote diagnostic system needs sophisticated and reliable software which is developed by internationally recognized software vendors with significant cost. The lower the cost of the software the beter the rank.

C. **System operation & maintenance**

Implementation of high tech maintenance system needs administration of the system which needs highly qualified expertise to operate technology, repair the hardware, to troubleshoot and maintain the software. There are also associated costs incurred from data recording, controlling, interpreting and storage for the future use. Organizations sometimes prefer outsourcing the operation and maintenance of the system to external maintenance and asset care consultants with considerable amount of cost. Generally the cost of system O&M mean the cost incurred by operation, calibration & maintenance of those sophisticated maintenance diagnostic and analysis tools. The lower operation and naintenance cost of the system the better the rank.

D. **<u>Training and personal development</u>**

Maintenance technicians, planners, store keepers, engineers and managers may be required to go through special training for effective use of equipment and software that are used by candidate maintenance strategy. Sometimes the training will include the whole maintenance staff and support organization. The lower the training cost the better the rank.

3.2.3 Value Added

The customer requirement of light rail transit system is having dependable passenger transport. Their satisfaction is measured by factors like reliability, availability and quality of service. In addition to providing mass transit transport for the population the ultimate goal of Transport Corporation like light rail transit is gaining reasonable profit in order to cover the high cost of vehicle and infrastructure operation and management. Proven quality combined with value adding maintenance strategy concepts makes the operator meet the highest standards in terms profit oriented business strategy.

A. <u>Profit</u>

It is the best overall indicator of company performance; it measures the outcome of all management decisions about ticket sales and facility purchase prices. It is the outcome of investment and operation as well as reflecting the essential efficiency with which rail vehicles and its infrastructure are converted into outputs.More profitable the strategy the higher the rank.

B. <u>Reliable service</u>

Reliable service means the probability that a rail vehicle/infrastructure can perform passenger/fright transport operation under the design conditions for a given time interval. Reliable transport service can have an impact on customers, society and the business organization. The LRT operator should give reliable service to capture new customers, satisfy them and retain existing customers by giving them assurance of transport supply on time, which in turn depends on adequate operational capacity with a minimum of disturbances with dependable rail vehicle and infrastructure. Reliability concerns the inherent properties of the rolling stock. It measures the failure frequency of the rolling stock, which is often expressed as the Mean Time between Failure (MTBF) and Mean Time to Failure (MTTF). Equipment on rolling stock often has a failure rate related to the distance the locomotive has traveled. In this case the failure rate is expressed as the Mean Distance between Failure (MDBF) and the Mean Distance to Failure (MDTF). The more reliability is assure with selected strategy the higher the rank.

C. Operational availability

Rolling stock Availability is the ability of the rolling stock to be in a state to perform a required transport function under a designed conditions at a given instant of time or over a given time interval that Assuming that the required external resources Such as no traffic disturbance, no infrastructure damage or obstacle and no power interruption provided.

Operational availability (Ao) is the probability that the system will be ready or train for operation in a real-life environment. This availability measure considers the total maintenance downtime, i.e. both the active maintenance time and the time waiting for maintenance. *Ao* is the preferred availability measure when assessing a system in a realistic operational environment. The operational availability is expressed as:

$Ao = \frac{MTBM}{MTBM + MDT}$; where MDT is the Mean down Time (MDT = MTTR + MWT)

The more available the vehicle with selected strategy the higer the rank.

D. Quality of service

Quality of service is conformal to passenger satisfaction. It can be comfortable interior service with relaxed air-conditioning system, with world class information display, clean interior, aesthetically good interior, low noise level and vibration. That can be achieved by integrated maintenance management system. To consider the quality of services, we analyzed quality metrics directly related to services provided as well as customer satisfaction surveys reflecting the passengers' perception. According to Felix (2010) important indicators measured by train operators are:

- The punctuality of trains
- The share of cancelled trains
- The share of overcrowded trains

Customer satisfaction measurements are based on a European survey:-

- Cleanliness of stations
- Cleanliness of vehicles
- Passenger information

The more quality service achieved by the selected strategy the higher the rank.

3.2.4 Implementation Capability

Once the maintenance strategy is selected there should be a feasibility study should be checked. One factor of feasibility study is the firms' implementation capability. The first indicator will be financial capability to invest on selected strategy. For example strategies like CBM need high investment on initial cost their financial profit will be known overall life cycle profit. The availability of technology with personal capability combined with human and managerial willingness to implement is the main factors to implement world class maintenance strategy.

A. **Budget**

Most of the transport companies other than the airlines (regulation mandatory) invest on acquisition of vehicles and machineries. Their maintenance budget is only recruitment of skilled maintenance personnel and purchasing mechanic tool. There will not be budget for high investment on life cycle profit focused maintenance strategy. Due to the consistent conflict of the budget, maintenance funds can be wrongly cut by reducing needed manpower due to the perception of an idle workforce who may be waiting for their train to arrive, the other point is also negative outcome due the inefficiencies of train to shop movements. Needless to say, the balancing of budgeted funds for maintenance programs, to produce meeting the 'metrics' requirements of operation, namely, availability to meet service demands, to generate ridership revenue is what drives the funding allocation to implement the solutions to contest the interfering constraints. The more the budget allocation capability the better the rank.

B. **Personnel capability**

Human capability in maintenance strategy is not only train maintenance, but also answering for these questions. How the malfunction occurred? What is the cause? Did the case previously happen? How the problem will be solved? What should be done in order to prevent this problem happening? To produce capable multi skilled personnel there should be investment on mechanics, maintenance programmers, maintenance planners, R&D engineers and managers. The skill of the workforce is a key influential critical aspect of rolling stock fleet management and is the most significant ingredient in maintenance practice changes. Though many railroads still foster the avenues of apprenticeship and in-house training for service skills development, the content has been significantly altered as well as their focus from technical information and more towards procedural understanding and workplace safety. There is no argument that all of these training components are necessary for a productive and healthy workforce. In our case in Addis LRT since the company is new in kind in order to have efficient maintenance and support personnel there should be continuous human development program not only in maintenance but also in every department. The higher an availability of qualified human personel to perform the strategy the higher the rank.

C. **Technology availability**

The other factor in maintenance strategy is the availability of the candidate technology. As stated earlier in this globalization age the availability of technology should not be questioned nationally there are plenty of international maintenance and asset care vendors can supply the candidate technology. The question here is how easily those technologies will inherit in workers day to day activity? Simplicity, flexibility and easy to understand should be one of the key criteria regarding to evaluate technology. The more an availability of the technology the greater the rank.

D. **Managerial willingness**

Many researchers believe that the willingness of the managers is the best criteria in every project implementation. What so ever the technology is profitable, available and cheaper the managers should believe its importance. The source of unwillingness of managers could be lack of knowledge, resistance to change, being short sighted (not believing in life cycle profit), frustration of the technology (which will challenge their authority) and the initial investment of cost.Themore acceptable the strategy by maintenance the greater the rank.

3.2.5 Maintenance Performance

Maintenance performance measurement enables a solid basis for establishing where maintenance related improvements are most appropriate at any given time Parida (2006). Performance measures can be classified in a number of ways according to their perspective, namely financial and non-financial measures, outcome measures and performance drivers, internal and external measures.Maintenance Performance measurement system can be used for strategic and day-to-day operations of the organization, control and implementations of improvements, and monitoring of these. Furthermore, establishing the relationship between the internal measures (causes) and the external measures (effects) is a significant objective of a measurement system. Commonly used maintenance performance measures can be divided, depending on what they focus on, into three categories Tsang A. (2000); measures of equipment performance, measures of cost performance and measures of process performance. Based on Tsang A. (1998) finding the maintenance performance indicators will be equipment performance measures, maintenance cost performance measures and maintenance process measures.

A. Equipment performance measures

In LRT system trains, infrastructures, maintenance facility, escalators, power supply stations facilities and operational devices like ticket vendor machines can be equipment. Thisequipment should have their own performance metrics to evaluate their efficiency and overall effectiveness. Measures of performance are used to determine the adequacy of the asset for the intended purpose. Measures are also used to compare actual operation with planned operation. This measure can also be used to determine optimum levels of asset support, functions such as preventative maintenance, spare parts inventory and employee training. There should be SOP (standard operating procedures) for each equipment in the transit system and linked with maintenance strategy. The more the equipment performance measured the better the rank.

B. <u>Maintenance cost performance measures</u>

Maintenance cost in LRT system can be maintenance labor and material costs. Man hour control, level of staffing and assignment of skill for different maintenance work process should have its own standard operating procedure that can be easily controlled and benchmarked in some maintenance strategy. Part cost can be tracked and benchmarked to the desired level of performance metrics. Costs of procurement, implementation, operation, maintenance and disposal (lifecycle) should be tracked and used to identify areas needing attention, as well as a means for evaluating asset strategies. Using net present values, asset strategy scenarios such as renewal versus replacement can be compared relative to available funding to determine the optimum strategy. Cost tracking is also used to set budgets necessary to achieve a desired level of asset performance. The more the cost perfornmance measure the greater the rank.

C. <u>Maintenance process measures</u>

Measuring process performance like the ratio between planned and unplanned maintenance, percent of work order executed, backlog, ratio between corrective to preventive maintenance, MTTR and MTBF are some examples of maintenance process key indicators. Maintenance process measures are related to maintenance strategy. The more process performance measured the better the rank of the alternative

3.2.6 Stock & Material Management

If there is maintenance there is also repair and replacement of parts. The parts and materials (chemicals, lubrications, and additives) are either purchased with the train or to be purchased when the damage occur that is depending on the firm's maintenance philosophy. Stock keeping and material management have significant contribution to the firm's business process but it needs high investment and man power. To have optimized spare part and material purchasing and stock keeping should be integrated with in maintenance strategy formulation.

A. **Part availability**

The necessary parts for which every maintenance program type is being implemented may not have arrived at the right time and location. Materials management is confronted with supplier deliveries that work only to committed forecasts, their long delivery times and their 'just-in time' manufacturing process. Hence if the requirement of the part from the shop floor does not fall in the time frame of the expected planned demand and is not properly communicated to the material management group, will result in a vehicle waiting for its replacement part. Regardless, the train will either leave for required service with uncompleted maintenance tasks or remain parked out-of-service till the part has arrived; this then creates a vehicle availability issue and potentially creates a service bay or yard storage limitation. All parts of train will not be available in stores at same time. The availability of parts can be achieved by manufacturer recommendation, the train usage rate, repair planning and the criticality of parts. Therefore implementing efficient maintenance strategy will guarantee the balance between part availability and high investment of stock keeping.If part availability is maximum with the selected maintenance strategy the higher the rank.

B. **Inventory control**

For highly dynamic business like train maintenance, which has a number of repair and replacement, part control is not easy work. Carefully designed maintenance workflow can have better part control starting from part request for maintenance to report generating and recording to equipment history jacket. Current assets must be inventoried and cataloged. Procedures must be set in place to document the implementation of all asset procurements, implementations and disposals. It is essential for organization to know their assets and how they are being used.If the inventory control is maximum the higher the rank.

C. **<u>Purchase planning</u>**

Purchase planning is based on the equipment maintenance program, part usage rate, fast moving items trend evaluation, maintenance demand, maintenance scheduling replenishment level and engineering modification (major equipment design change). If the strategy is more supportive purchase planning the higher the rank.

3.2.7 Support System Integration

In maintenance and repair organization the main function is maintenance department but that doesn’t mean that it is the only department in organization. There are supports functions like finance, procurement and material management, human resource management, marketing, sales, information technology &communication, research & development and engineering and technical support. Many organizations categorize support function & core functions in a different way in this paper our interest is not categorizing the LRT functions as a support and core function. For this researches every function other than maintenance department; fleet, procurement & material management, Engineering and technical support & IT and communication categorized as important and support function

A. **<u>Fleet operation</u>**

The primary function of light rail transport is fleet operation different researcher and organization argued that the other functions are support functions. Assigning trains for transport of peoples and fright said to be fleet. It has higher relation with maintenance department and highly affected by having efficient maintenance strategy. The more maintenance is integrated with fleet the higher the rank.

B. **Procurement and material management**

The two main inputs of maintenance are labor and spare part. The procurement and administration of spare part is crucial to maintenance functions. The function has a direct impact by delivering and keeping parts in order to perform maintenance timely and as scheduled.The more maintenance is integrated with procurement & material managment the higher the rank.

C. **Engineering and technical support**

Depending to maintenance strategies or programs selection and the organization structure for technical support services to the company management of the operation and maintenance of rolling stock equipment.Technical support service is in fact a critical link between the operating and maintenance groups in terms of understanding the relationship between each other from an issue resolution perspective. By that, the service operation can impact the outcome of the equipment behavior in terms of failures, wear rates and level of performance, likewise, the equipment condition impacts the operation in terms of its' availability for service, passenger comfort and overall safety operation. In some organization engineering and technical support function is part of the maintenance department. The function has a close proximity for maintenance in planning, method writing, and program development, engineering modification, capacity development and controlling maintenance quality management.Depending on where the technical support is provided, or who is responsible and has ownership of an issue, or how they are networked and what departments are involved within the rail operation, (namely: engineering, maintenance facility, workforce/ operator training, suppliers, track and systems groups) will determine the role and contributed value these groups will employ on managing the equipment borne issues and their resolution. The more maintenance is integrated with engineering and technical support the higher the rank.

D. **It & communication**

Now a day this function to maintenance become like a blood vessel to human being. Most maintenance activities uses CMMS to perform a maintenance function, assign work to technicians, know the scheduled train, order and request necessary parts, record and review previous maintenance process and others. Information system technology is a vital tool that transit operators should employ as part of an overarching maintenance management strategy. Computer systems and software used for maintenance management should meet the business needs of an organization. However, caution should be exercised here: Acquisition and installation of CMMS is not sufficient to validate that a transit operator is in fact doing a good job of asset management. Software should be viewed as a tool, much like any other tool used by staff executing physical maintenance.

The range of IT systems applicable to maintenance management is immense and covers a spectrum of subjects from work order processing to inventory control to lifecycle costing. Suitable IT systems for asset management can range from large-scale databases with complex networking and user interfaces at multi-modal organization all the way down to simple, standalone database systems at smaller organization. The management needs of each transit organization should dictate the level of investment. In general, asset management IT tends to focus on materials management practices, and these systems are generally different from financial systems. Integration of such disparate systems would be considered a best practice and should be taken as one of many steps in the overall implementation plan for bringing maintenance management to existence inside a transit organization. Therefore the function closely follows the implemented system in order to avoid interruption. The more maintenance is integrated with IT &communication the higher the rank.

Table 3-1Summary of criteria's and sub criteria with designated symbols on the model

Criteria	Sub criteria	Symbol
Safety	11 Passenger safety	PS
	12 Worker safety	WS
	13 System safety	SS
Implementation cost	21 Hardware cost	HS
	22 Software cost	SC
	23 Operation & maintenance	O&M
	24 training cost	TC
Added value	31 Reliable service	RS
	32 profit	P
	33 vehicle availability	VA
	34 Quality service	QS
Implantation capability	41 Budget	B
	42 Personal capability	PC
	43Technology availability	TA
	44 Manger willingness	MW
Maintenance performance	51 Equipment performance measure	EP

	52 Cost performance measure	CP
	53 Process performance measure	PPM
Stock and material management	61 Part availability	PA
	62 Inventory control	IC
	63 Purchase planning	PP
Support system integration	71 Fleet operation	F
	72 Engineering and technical support	ET
	73 Procurement and material management	PMM
	74 Information technology and communication	IT

Table 3-2 Alternative strategic approaches

Alternatives	**Symbol**
Reliability Centered Maintenance	RCM
Total Productive Maintenance	TPM
Condition Based Maintenance	CBM
Corrective Maintenance	CM
Preventive Maintenance	PM

3.3 AHP Model Representation

Modeling of maintenance strategy selection by AHP is to structure the decision problem into a hierarchical model. This involves the decomposition of the decision problem into elements according to their common characteristics. In this study, the hierarchies illustrate the attribute for selecting efficient maintenance strategy selection for LRT system. The top level is the selection goal (i.e. prioritization of critical selection criteria for efficient maintenance strategy selection), and following this are the selection factors (main criteria) and selection sub-criteria the third level), and finally the alternative maintenance strategy. Using criteria, sub-criteria and alternatives, a hierarchical model is constructed to apply AHP algorithms. Then relationship among criteria and sub-criteria are determined and reflected in the hierarchical model. Maintenance strategy selection criteria were determined based on the review of prior literature, the researchers experience and some maintenance expert recommendation. Figure 3.1 below shows the hierarchical structure of the maintenance strategy selection model, which includes four levels. The top level of the hierarchy represents the strategic goal of the model, while the second level of the hierarchy consists of seven main maintenance strategy selection criteria, the third level of the hierarchy contains twenty two sub criteria to fulfill the strategic goal and the last hierarchy shows the possible alternative strategies.

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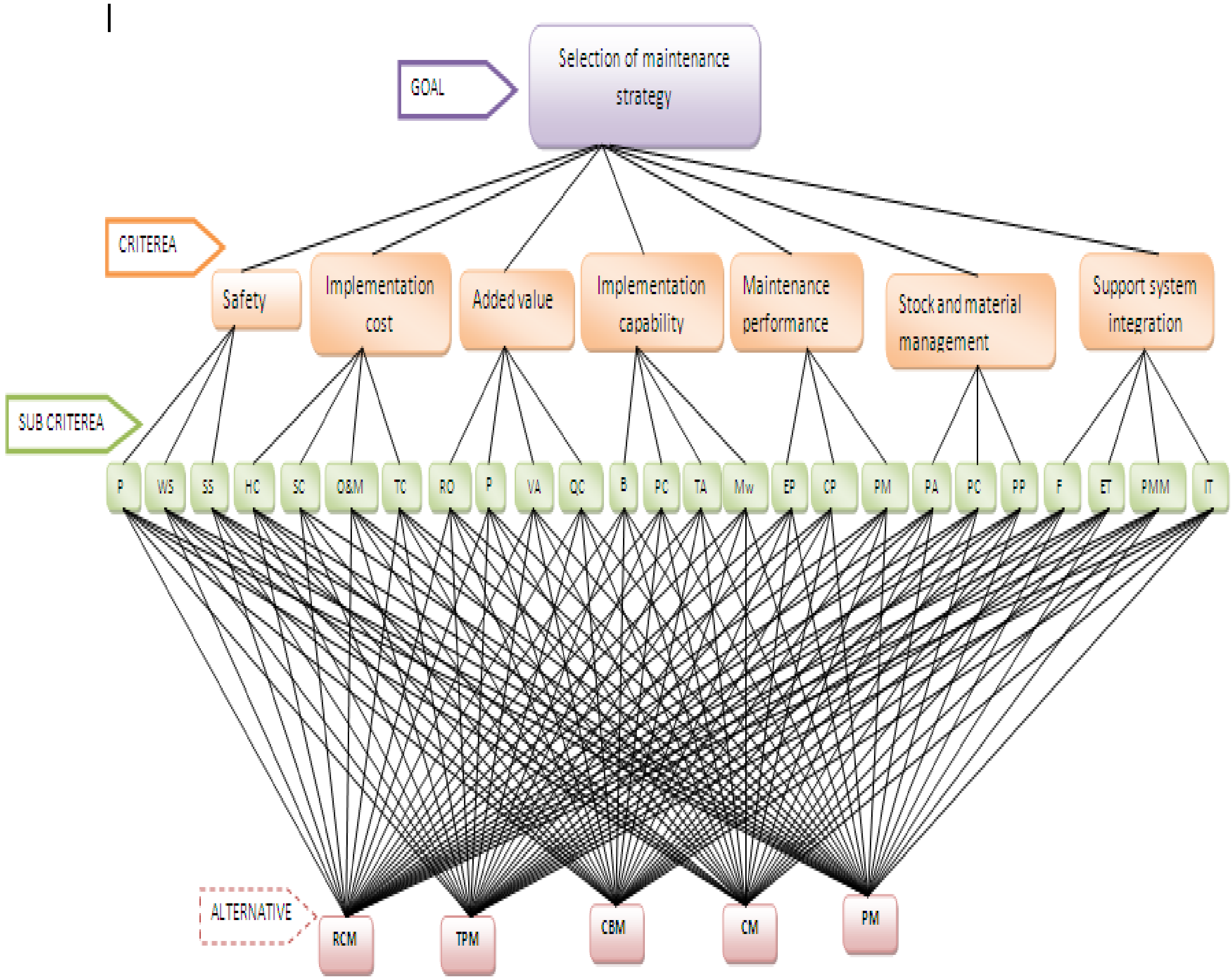

Figure 3-1AHP model for selection of maintenance strategy

3.4 Questionnaire Design

The selection of maintenance strategy in this research has two processes; the first stage is identifying the principal maintenance strategy factors and indicators. Those seven factors and twenty five sub criteria selected from different researchers finding and the researchers prior experience. Then The AHP survey aimed at evaluating the comparison of the identified selection criteria and alternatives. To perform this task a questionnaire was designed for data collection, and the format was synthesized with reference to AHP matrix proposed by Saaty (1980). Since the assignment of the weight requires logical and analytical thinking, only the relevant experts or professionals worked or working in different maintenance organization selected. Initially the target group of experts in this research was the railway managers and delegated maintenance engineers. After preparation of the part I questioner which is a profile checkup and participation willingness assessment questioner the researcher couldn't find the intended target group. In order to select the suitable respondents, part 1 questioner is distributed to different maintenance professionals in different companies. A total of 8 experienced respondents in the general survey replied and expressed their interest in conducting the AHP questionnaire. On the other hand, AHP is a subjective method that is not necessary to involve a large sample, and it is useful for research focusing on a specific issue where a large sample is not mandatory cheng and Li (2002).Cheng and Li (2002) pointed out that AHP method may be impractical for a survey with a large sample size respondents may have a great tendency to provide arbitrary answers, resulting in a very high degree of inconsistency. In this study, seven researchers are selected for the AHP survey.

3.5Data Collection and Analysis

Data collection for AHP method needs formation of a focus group of experts which comprisesixlight rolling stock designers and research and development engineers. The focus group members are from metal technology engineering corporation (METC) locomotive division. After forming the focus group schedule two stage focus group discussion. The first focus group discussion is to comment and evaluate on critical factors, Indicators and alternative maintenance strategies identified by the researcher for the LRT system. The second focus group discussion aimed on completing of the revised questioner with discussion and consensus. The analysis was based on the application of the AHP method. The criteria describing maintenance strategy selection were collected; the appropriate survey questionnaires were prepared and later distributed among the respondent's experts (maintenance professionals) rolling stock related and others. The questionnaire's structure of maintenance strategy is givenin annex I-V. A survey was conducted for both experts from METEC and other expert'snineteen questioners were distributed. However, only the data on7 questionnairescompleted by rolling stock experts (from METEC) were actually used in the survey as the remaining 12 questionnaires were found to be either irrelevant or inconsistentandtherefore, rejected. Finally the completed questioner will be an input for super decision software for pair wise comparison.

Table 3-3 the selected experts profile

No	Title	Education	Age group	Working place
1	Design and development manager	BSc	25-34	METEC locomotive division
2	Design and development engineer	BSc	25-34	METEC locomotive division
3	Design and development engineer	BSc	25-34	METEC locomotive division
4	Maintenance inspection	BSc	Below 25	METEC locomotive division
5	Design and development engineer	BSc	Below 25	METEC locomotive division
6	Maintenance researcher	MSc	25-34	Kaizen institute(ministry of industry)
7	Design and development engineer	BSc	25-34	METEC locomotive division

CHAPTER4 RESULT AND DISCUSSION

4.1 Result

After collection of data by using AHP questioner attached in the annex I-The combined rating of all experts' opinion on selection of maintenance strategy completed in expert decision software and analyzed. Each set of pair wise comparisons was checked for consistency and revised if necessary until the maximum inconsistency was below ten percent, which is considered the minimum standard level Saaty (1980). The results were synthesized throughout the model to yield the overall priorities of the strategic alternatives, shown in Table4.1and the criteria and sub-criteria, shown inTable4.2.

Table 4-1 the priority of alternative maintenance strategy

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP model for selection of maintenance strategy.sdmod

Name	Graphic	Ideals	Normals	Raw
1 RCM		0.648696	0.227619	0.075414
2 TPM		1.000000	0.350888	0.116255
3 CBM		0.618048	0.216865	0.071851
4 CM		0.263946	0.092615	0.030685
5 PM		0.319225	0.112012	0.037112

Table 4-2 priority of criteria and sub criteria

Main Criteria (Inconsistency 0.06418)	Result	Sub criteria	result	Inconsistency
Safety	0.382	PS	0.40	0.00
		WS	0.40	
		SS	0.20	
Implementation cost	0.132	HC	0.346	0.022
		SC	0.346	
		O&M	0.098	
		TC	0.20	
Added value	0.200	RS	0.276	0.045
		P	0.390	
		OA	0.195	
		QS	0.138	
Implementation capability	0.082	B	0.388	0.053
		PC	0.123	
		TA	0.188	

		MW	0.299	
Maintenance performance	0.038	EP	0.549	0.017
		CP	0.240	
		PPM	0.209	
Stock and material management	0.050	PA	0.549	
		IC	0.240	
		PP	0.209	
Support system integration	0.115	F	0.304	0.044
		ET	0.158	
		PMM	0.390	
		IT	0.146	

The Fig 4-1belowshows the priorities of the main criteria in the following order: safety, added value. Implementation cost, support system integration, implementation capability, Stock and material management and performance benchmarking respectively. The priorities of the alternatives maintenance strategy rank as shown in Fig 14 .Total Productive Maintenance, ReliabilityCentered Maintenance, Condition Based Maintenance, Preventive Maintenance & Corrective Maintenance. As we have seen from the result from the stated maintenance factor perspective TPM is highly recommended for LRT maintenance strategy and corrective maintenance is the least to follow.

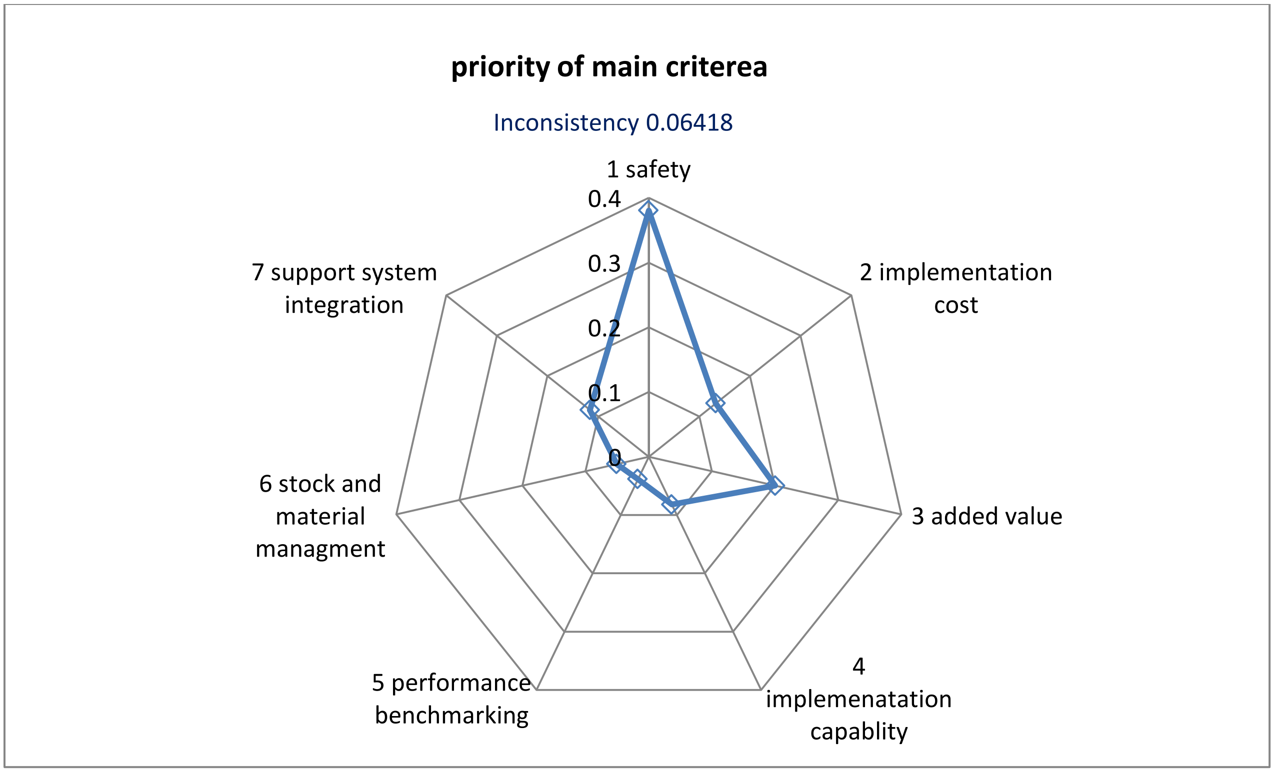

Figure 4-1 Priority of maintenance factors (main criteria)

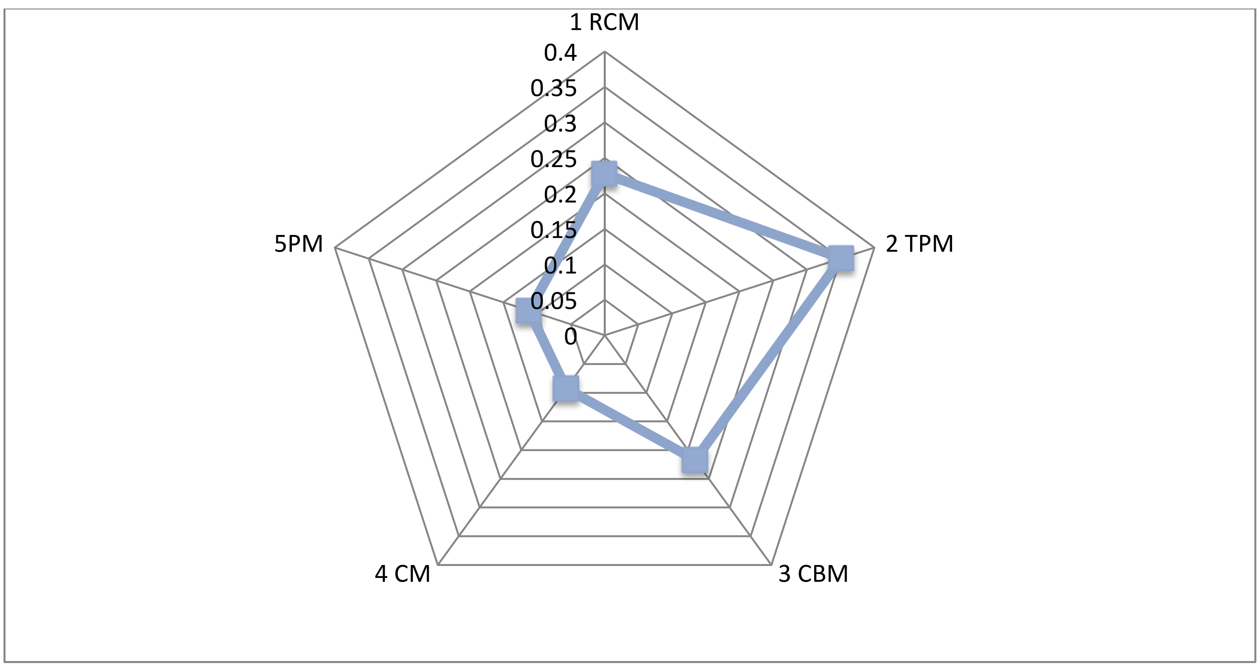

Figure 4-2Priority of alternative maintenance strategy

4.2 Sensitivity analysis

As we have seen in the literature part of the paper one advantage of AHP over other MCDM methods is sensitivity analysis. Sensitivity analysis was carried out by varying the weights of the criteria and sub-criteria to determine the stability of the decision reached by using the decision model proposed in this study. Sensitivity is performed by selecting a criterion (or sub-criterion) and changing its priority, redistributing the change among the other criteria (sub-criteria), and recalculating the priorities of the alternatives to observe if any change occurred in their ranking. A graphical representation of sensitivity for the implementation cost criterion is shown in Fig 15 and Fig 16. Criterion priorities are read from the x-axis; the alternatives' priorities are read from the y-axis. In fig x the priority of the implementation cost indicated by the vertical line, is set to its original priority of 0.50 .The priorities of the alternatives are then read from the y-axis at the points where the vertical line crosses the alternatives' lines (RCM,TPM,CBM,CM &PM are 0.180,0.261,0.150,0.251 and 0.159 respectively). Sensitivity is performed by varying the priority of the implementation cost criterion by moving the vertical line and determining the corresponding alternative priorities. In Figure 4.4, it has been moved to the right to a priority of about 0.70 and the order of the alternatives has changed and shown on table 4.3.

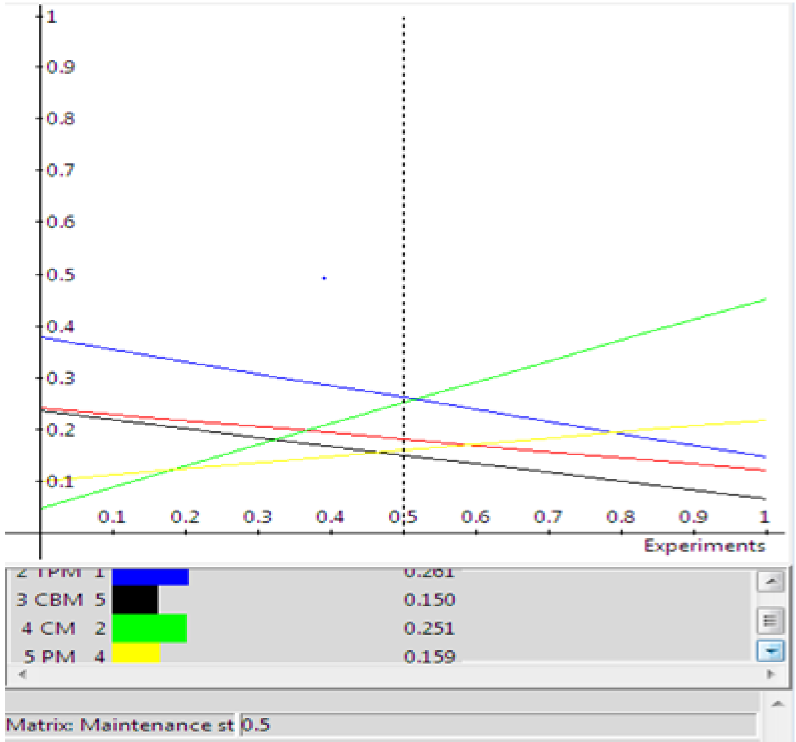

Figure 4-3Sensitivity graph with implementation cost priority set to 0.50

Table 4-3Alternative ranking with implementation cost priority change from 0.5 to 0.7

Alternative	**Sensitivity=0.5**	**Sensitivity=0.7**	**Rank 0.5**	**Rank at 0.7**
RCM	0.180	0.155	3	3
TPM	0.261	0.214	1	2
CBM	0.150	0.115	5	5
CM	0.251	0.333	2	1
PM	0.165	0.183	4	4

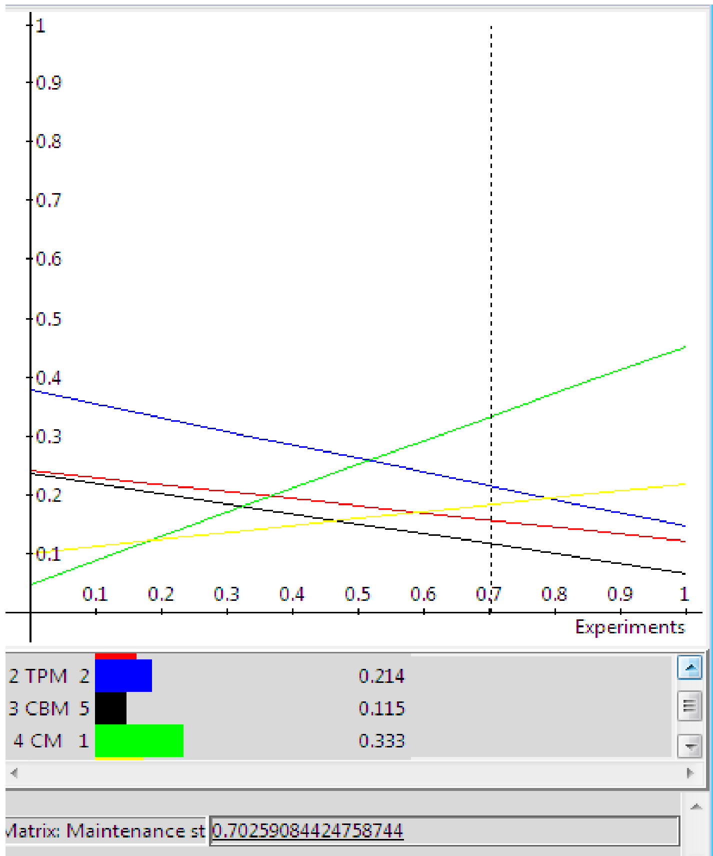

Figure 4-4Sensitivity graph with implementation cost priority set to 0.70

The same procedure as the previous by changing the priority of the performance benchmarking indicated by the vertical line, is set to its original priority of 0.50 in fig 17 priorities of the alternatives are then read from the y-axis at the points where the vertical line crosses the alternatives' lines. In fig 18 the priority of the performance benchmarking indicated by the vertical line is set to 0.9 the rank and values of alternative changed and shown on table 4.4

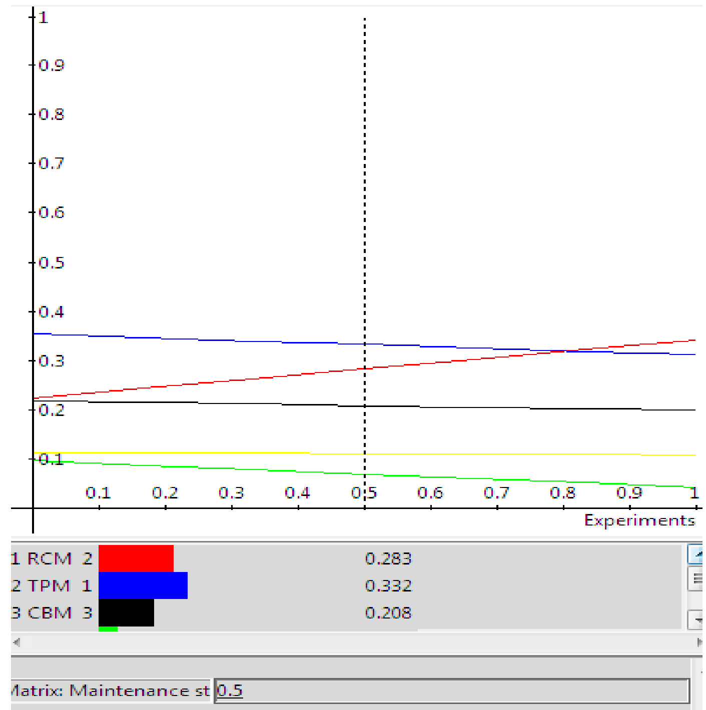

Figure 4-5Sensitivity graph with performance benchmarking priority set to 0.50

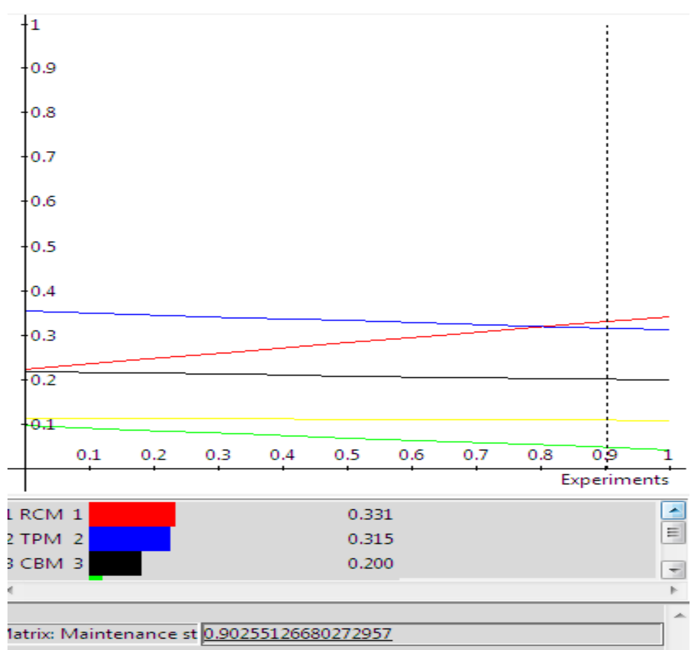

Figure 4-6Sensitivity graph with performance benchmarking priority set to 0.902

Table 4-4 Alternative ranking performance benchmarking priority change from 0.5 to 0.9

Alternative	Sensitivity=0.5	Sensitivity=0.9	Rank 0.5	Rank at 0.9
RCM	0.283	0.331	2	1
TPM	0.332	0.315	1	2
CBM	0.208	0.200	3	3
CM	0.068	0.048	5	5
PM	0.110	0.180	4	4

Performing sensitivity on the criteria of safety, implementation capability, value added, part & material control and support system integration did not affect the first ranked alternative, but in some cases RCM and CBM switched places. Similarly, sensitivity analyses of the sub-criteria was also conducted and showed that the priorities of the first alternative will not change.

4.3 Discussion

From AHP model formulation we discovered that the first stage of selecting efficient maintenance strategy is identifying maintenance key factors and prioritize their importance, but maintenance has infinite factors to consider and those factors will be quantitative or qualitative data. In this paper it has been tried to cover most of the factors which are believe to be core maintenancefactorsby reading different researchers finding and some light rail transit organization experience. The factors which are categorized as maintenance management main criteria are safety, value added, implementation cost, implementation capability, performance measurement, stock &material management and support system integration and there are also 25 sub factors and 5 alternatives to consider. The pair wise comparison andexpertise opinion with their possible explanation is illustrated below.

I. **Safety**

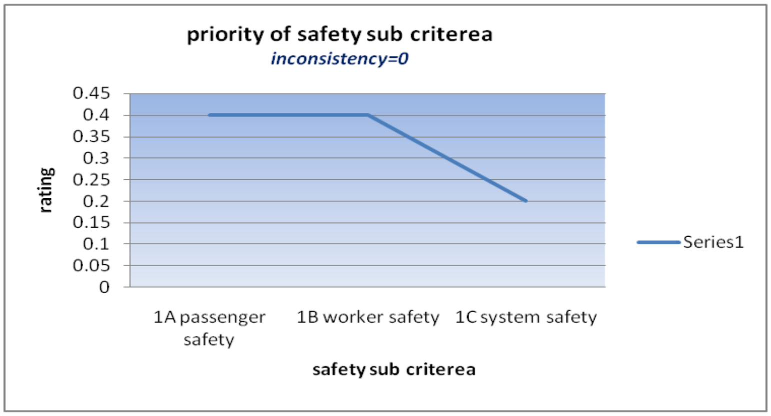

Figure 4-7 Priority of safety criteria

Light rail transit operation is almost 18 hour of service, with this time there is always motion and dynamic incidents. As described earlier in model formulation the key actors in this process are train crews, maintenance personal, operation assistance and external environment. Accidents can happen with or without personal injury. As we know the operation of this transport is not in fully closed infrastructure like metro and other fright operation.So there is time to time sharing of rail infrastructure with road vehicle and pedestrian therefore there is high chance of accident to happen. It is clearly observed that safety got the higher rank in selection of strategy, further more emphasis should be given to achieve 100% personal safety. We see from fig 4-7worker and passenger safety has got 40% attention on implementing maintenance strategy that mean the best maintenance strategy should maximize the personnel safety before the system safety. There should be a failsafe mechanism and alternative procedure on the design and operation management respectively. The other main point this research recommendation is the establishment of national rail safety regulatory agency.

The newly safety management system implemented for LRT system must include systems and procedures for the identification of, and compliance with safety requirements under rail safety and other safety legislation. There should be preliminary step in conducting a risk assessment tools to identify the internal and external context in which rail operation to be conducted. This paper recommend the necessity of independent rail safety regulatory agency under federal ministry of transport to make follow and investigate not only for LRT for overall rail transport and related activity such as to certification of equipment performance standard, personal licensing , the infrastructure condition and capacity ,accident investigation and safety standard and procedure etc. The paper also shows the importance of independent safety office from operation and maintenance inside the organization. Therefore, safety management system requirements in relation to regulatory compliance requirements may be satisfied in part, by clear requirements for identification and documentation of regulatory safety requirements included in the risk management systems and procedures.

II. Implementation cost

Implementation cost has greater value on perspective of organization the reason is most world class maintenance strategy are very costly and dependent on modern high technology sensors and monitoring devices. Not only the mentioned reasons but also familiarization of workers for using thathigh-Tec diagnostic equipment and analyzing the monitored result has got substantial cost.

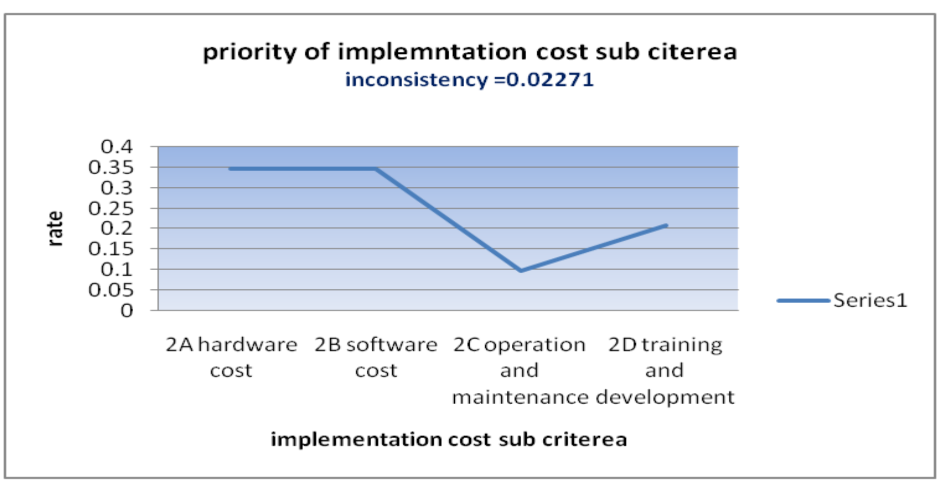

Figure 4-8 Priority of implementation cost criteria

When we observe fig 4.9 above implementation cost prioritize by experts are the cost of hard ware and software which are equally 35%. It is universal fact that hardwarecannotwork without its conjugate software. Training and development 20% and operation and maintenance of implemented maintenance strategy become last 10%. The reason is most of predicting equipment hardware and software costishigh which makes the initial investment cost high .In some maintenance organization experience maintenance strategy implementation cost is higher than yearly maintenance budget of the company. Therefore most firms implement this strategy as a special project approved by the board of directors. Operation and maintenance cost of implemented system is lower in thisresearch. In some organization operation, calibration and maintaining of predicting equipment will be outsourced but due to lack of local companies to outsource the better way is to enhance internal capacity development by allocating more budgets for training and development. That will minimize the cost of O&M. experience shows that well trained technician not only make quality maintenance there is also chance to prolong the hard ware and software cost.

III. **Value added**

Value adding activities in light rail transit operation are quality service, operational availability, reliable service and company profit. Their priority in maintenance experts judgment is profit 39%, reliableservice 27.6%, operational availability19.5% and quality of service13.8%as shown in fig 4-10. There are some expert argue that the main purpose of light rail transit invested by government is mobility of people, quality and availability should become first. The research did not consider the weather light rail transit whether it is financed by government or private. The common consensus here is if it is a business organization there should be necessary profit.

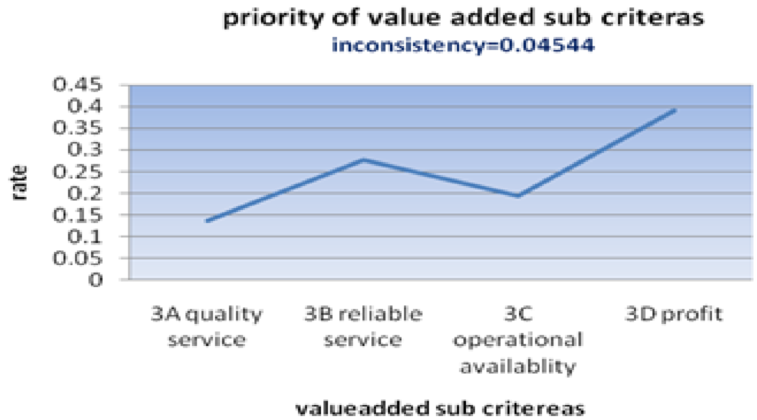

Figure 4-9 Priority of value adding criteria

According to the priority given experts the LRT system as business organization main objective should be making optimum profit with high vehicle and infrastructure reliability and availability with provision of quality service. Service reliability is measured as engineering criteria and passenger criteria. Operational availability the existence of the rolling stock and rail infrastructure in their design parameterQuality of service measured in different manners in rail transport quality of service measured as comfort, cleanliness of vehicle and station, not noisy, availability of seat, entertainment & delivery of information, environmentally controlled (HVAC) and speed. The LRT maintenance strategy selection should analyze optimized overall life cycle profit otherwise the organization willalwaysexpectsubsidy from the government instead of being profit organization. That does not mean that the firm always runs to profit by forgetting other social values.

IV. **Implementation capability**

Implementation capability is further divided to; budget, willingness of managers, availability of technology and personal capability. In fig 4-11 showed that maintenance experts suggest that before implementation of maintenance strategy the company should observe its budget (0.388). The other significantfactor becomes willingness of manager (0.299). Availability of technology (0.188) should be cheeked at national and international level. Personal capability (0.123) can be improved by continues training and performance assessment.

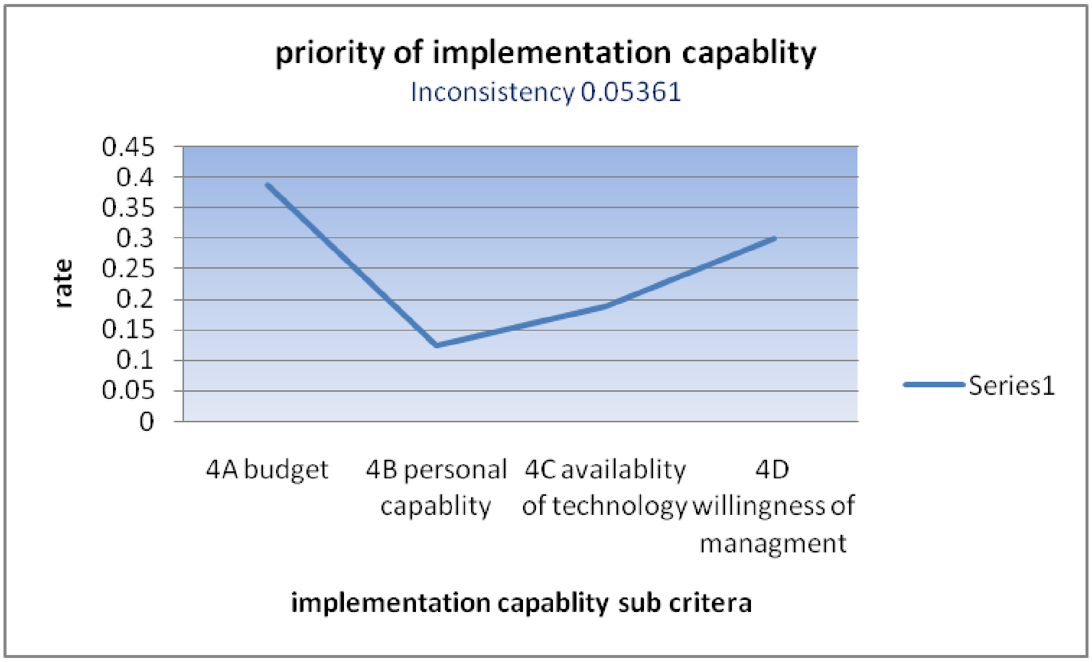

Figure 4-10 priority of implementation capability

V. **<u>Maintenance performance benchmarking</u>**

In railway transit equipmentsmaintenance cost, and maintenance processes performance can be benchmarked and measured in state of art maintenance organization. According to expert decisioninfig 4-12 equipment performance (0.539) should be the first factor on implementing maintenance strategy. The reason is equipment failure is mainly related to passenger and worker safety with bargaining of other value adding activities.Maintenancecost (0.296) and process (0.163)performance are also the other factors carefully observed for strategy formulation. Cost tracking and cost minimization strategy is recommended to maintenance cost factors. Cost tracking is achieved by integration of maintenance and inventory cost with CMMS. Maintenance process performance can be improved by enhancing the maintenance business process and continuous improvement of maintenance function.

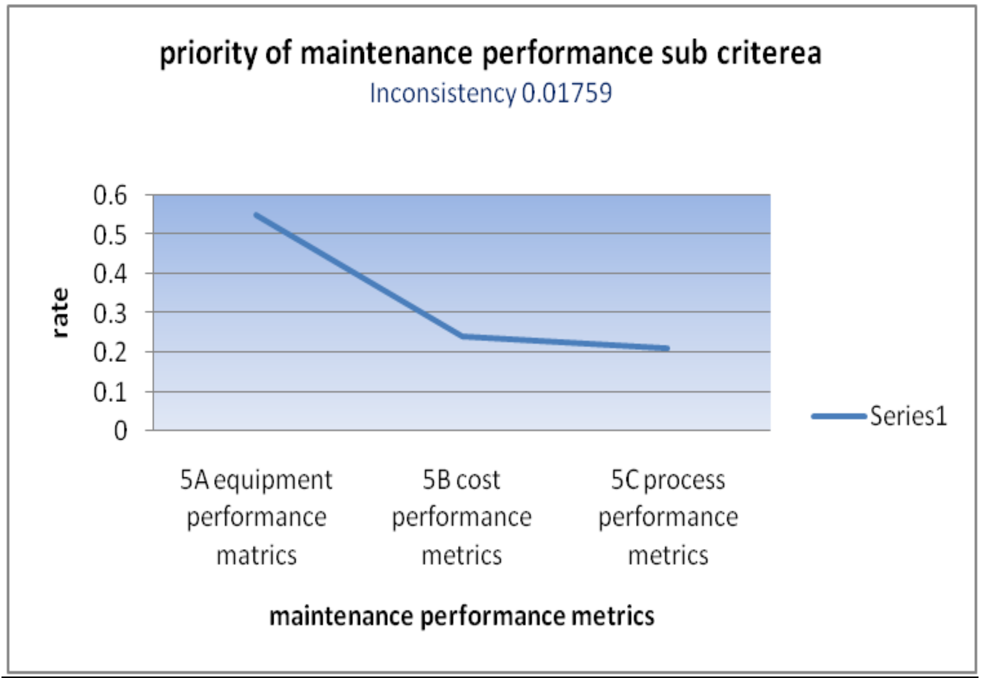

Figure 4-12 priority of maintenance benchmarking

VI. **Procurement and material control**

Includes purchasing, store and delivery of parts.This process is wide and complex which is highly attached to maintenance strategy. Fig 4-13 illustrated that part availability (0.55) is the primary function connected to the selected maintenance strategy; the reason is unavailability of part is directly attached with all of value adding activities. Theotherfactor is inventory control (0.26) and purchase planning (0.209) is attachedwith profit and process performance. All this functions can be improved by integrating with maintenance process and fleet demand by CMMS and application of TPM through companywide thinking of maintenance strategy.

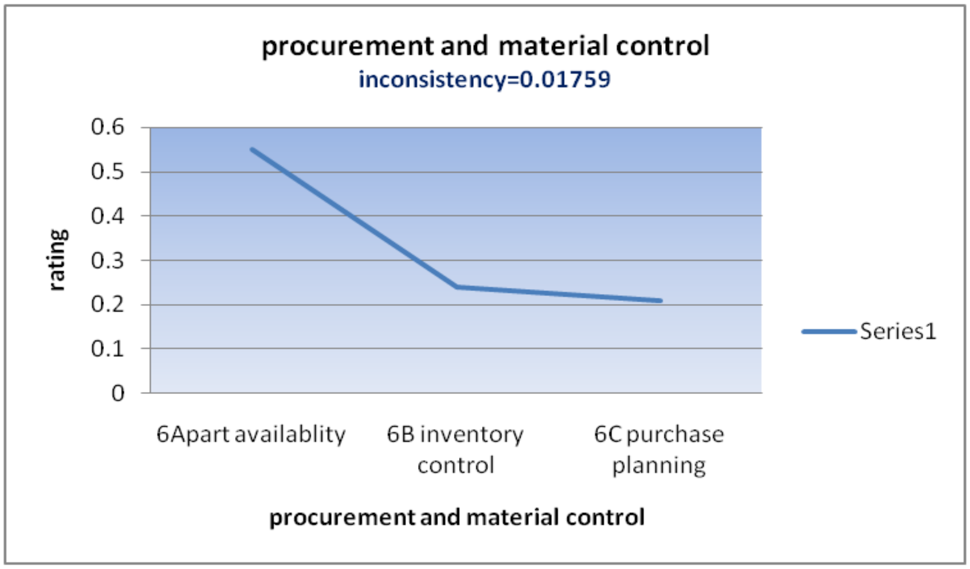

Figure 4-13 priority of procurement and material control

VII. **Support system integration**

Maintenance as a business centered process will interact with different internal departments. Here support system is not intended to classify the functions of light rail transit as support function and core function. The support system means the related functions with maintenance department. In clearly stated maintenance strategy maintenance department has high integration with engineering and technical support (0.390), fleetoperation (0.304), procurement and material control (0.158) andIT (0.146). According to the result there should be non-interfering guidelines, rules, relation, connection with stated departments on implementation of maintenance strategy.

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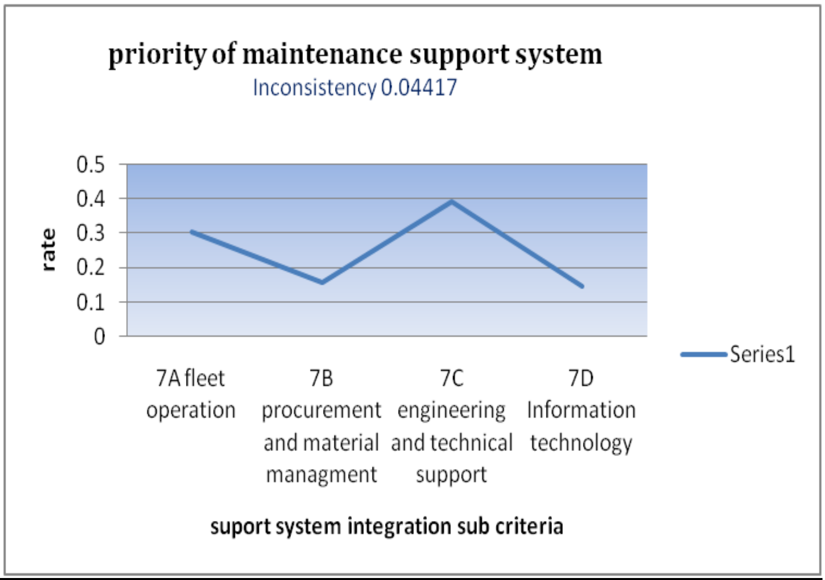

Figure 4-14 Priority of support system integration

CHAPTER 5 INTRODUCTION OF TPM IN LIGHT RAIL TRANSIT

5.1 Introductory Step

As we have seen in previous chapter with the help of expert decision this is paper selected TPM as effective maintenance strategy then the introductory steps of TPM is discussed here for Addis light rail transit. This introductory step can be used as a step by step guide to introduce TPM in workshop and fleet depot and generally in the rail transit. The procedure is adopted from different researchers and customized to light rail transit context.

The introductory step of TPM implementation plan used to make commitment of top management, and to allocate the necessary budget for the implementation. In this step the TPM committee is established and any introductory lesson should be given step by step. Finally the introductory step should be evaluated according to the questions prepared to asses it.

Step one<u>Announce top management of light rail transit about the decision to introduce TPM.</u>

1. Make an announcement the top management of the LRT system to implement TPM.
2. Make announcement to the board of directors of Ethiopian railway corporation meetings.
3. Make an announcement in meeting of light rail transit general manager, finance manager, human resource manager, marketing manager, fleet operation manager, purchasing and procurement manager, store and inventory manager, maintenance manager of Addis LRT system.
4. Plan TPM lectures for business managers such as operation managers, quality control and marketing managers,
5. Promote the top management decision to implement TPM through transit portal and advertisement board.

6. Prepare presentation for the purpose and prospective effects of TPM to board of director and higher government official.
7. Secure decision to spend money & time for achieving improvement of equipment and human psychological establishment through TPM in the transit.
8. Declare an introduction of TPM to operators of the rolling stock?

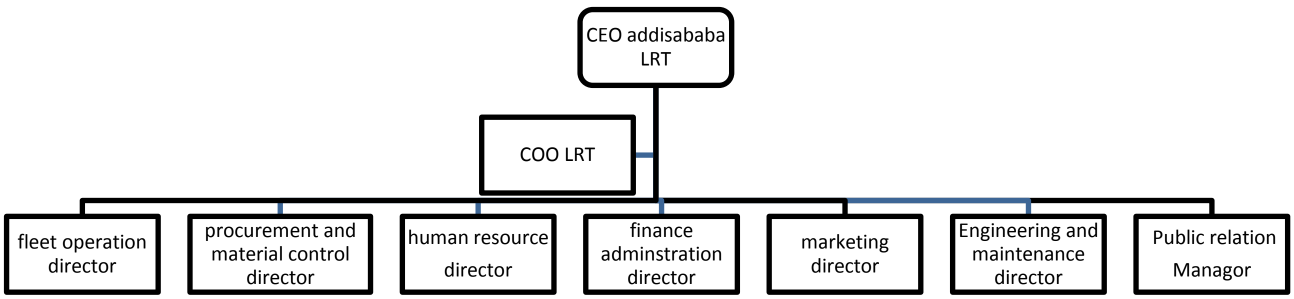

Figure 5-1 Top level manager for light rail transit

Step two<u>Introductory education and campaign of TPM</u>

1. Clearly explain purpose of TPM implementation to all levels of the employees in the transit.
2. Ensure top management, such as fleet operation manager and others Participation in PM achieving completive excellence (ACE) award winner's lecture.
3. Ensure participation of top management of the transit in TPM lectures for the management.
4. Ensure top management participation in TPM management and coaching course.
5. Ensure participation of managers of different departments in the transit in TPM Manager's course.
6. Ensure supervisors and operators, signal man and infrastructure supervisors participation in TPM training courses for the fleet operation of leaders

7. Team leaders participate in TPM training courses for the operation division leaders of the transit.
8. Train the employees by using TPM video and slides.
9. Disseminate education by operation division work leaders to the ordinary employees.
10. Make a Campaign of TPM by using posters, slogans etc in the transit both in workshops and operation work areas.
11. Secure sufficient budget from transit top management for introductory education.
12. Look for initiative from top management of the transit to take in receiving the TPM education.
13. Arrange the education at each level of hierarchy in the transit.
14. Evaluate the progress of education with top management of the transit.

Step 3 Establishing TPM promoting organization and pilot work process in rolling stock.

1. Organize TPM committee to promote TPM throughout the transit.
2. Organize TPM promoting committee to have a promotion office and fulltime personnel.
3. Supervisor and managers of different departments in the transit should be TPM committee members.
4. TPM promotion organization and its personnel allocation should be done by top management of the transit.
5. Do the following committees of the transit held meetings once in a month:

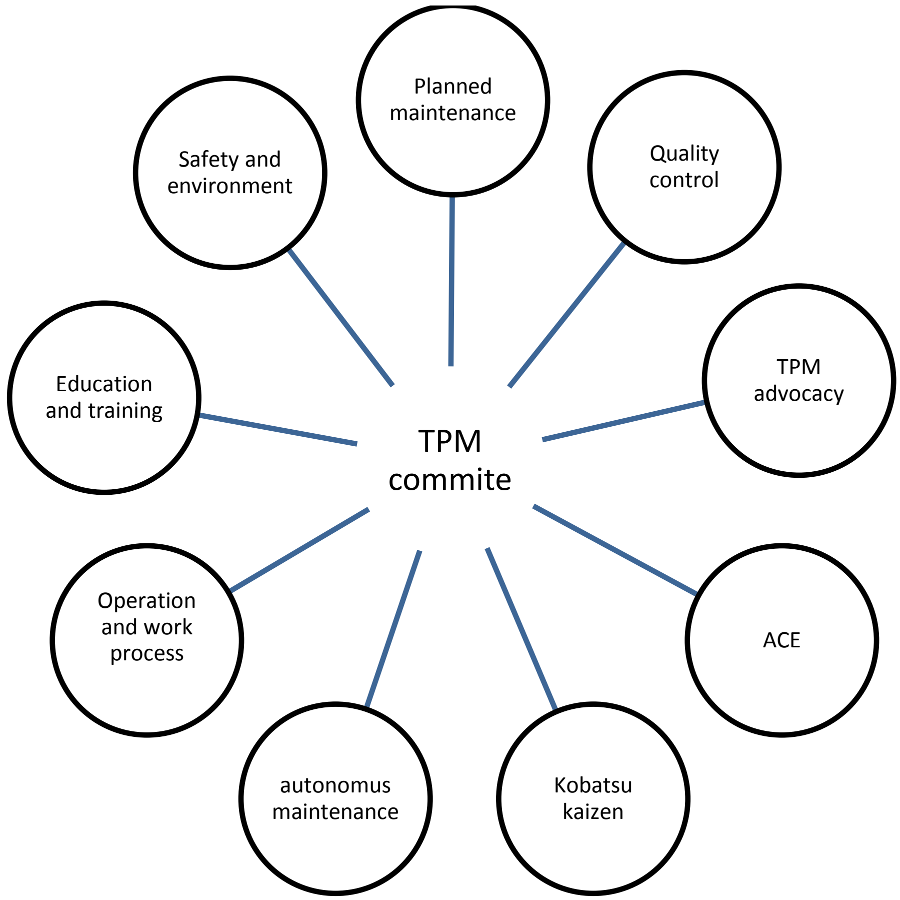

Figure 5-1TPM implemenntation sub-committee

Step four Setting basic policy and Target for TPM

1. Integration TPM into the basic business policy of the light rail transit or corporate mid/long term business plan.
2. The time needed for reaching achieving competitive excellence award been predicted for the transit. This award will consider competition inters departments and employees in the departments to achieve best TPM targets.
3. TPM targets decided for the followings.

- Zero equipment failure and break down.
- Improve reliability and maintainability by 50 %
- Reduce maintenance cost by 20 %
- Ensure availability of spares all the time.

4. ACE award compared with the benchmark to predict the achievement and estimate cost minimization effect for the transit.
5. Adjust TPM activities and targets with the basic business policy or mid/long term business plan, cost management of the transit

Step five **TPM** Master Plan

1. Establish TPM advocacy organization in the transit.
2. Form adequate numbers of over lapping small groups in hierarchical system and advocacy secretariat exist in the organization.
3. Have the policy, targets and achievement goals been set?
4. Are the following activities being exercised in the transit:

- TPM news
- Provide activities status board or if it is possible organization portal.
- Provide presentation of activities.
- Organize of Kaizen teams.
- Selection of Kaizen theme.
- Establishment of planned maintenance system.
- Management of lubricant and spare parts.

- Standardization of process methods establishes Standard operating procedure (SOP) for every process, department and employee.
- 3M (man, machine, material) analysis.
- FMA and PM analysis.
- Simplify accounting related procedures.
- Kaizen of operation management system.
- Development of warehouse and storage management.
- Safety inspection manual.
- Daily safety and human factor management activities.
- Establishing education system if it is possible the corporation will have its own recurrent school for special courses and short refreshment courses.
- Individual capability development program.
- Maintenance skill training, skill level determination and skill allocation of the work.
- Support for quality maintenance activities.

Step sixTPM Kickoff

1. Make an announcement of TPM introduction to all employees in the transit.
2. Celebrate the occasion planned when all the employees in the transit agree with the decision of the top management to completely eliminate 16 major losses of the transit.
3. Create the right environment in the transit where every employee of the rail transit agrees with the top management policy of TPM implementation.
4. Enhancing the morale of all employees in the transit to an extent where they can challenge decisively and energetically.
5. Make presentation made on these topics:

a. The basic of TPM policy to be applied in the transit
b. TPM target for the transit
c. Development of TPM master plan to the transit.
d. Repetition of decision making by top management of the transit.
e. Declaration of ACE Award by the representative of the employees of the transit?

6. Declaration of TPM introduction in the presence of the top management of the transit to reconfirm kickoff.

7. Experience sharing and encouragement speeches by guests from similar railway transit managers.
8. Invitation of higher government officials and customers of the transit, associated companies and cooperative companies to the event
9. Finish the introductory TPM education before kickoff day.
10. Arrange the necessary preparation in advance concerning the events which will be held on the kickoff day.
11. Make a round tour of operation depots to ask the forefront vehicle operators whether end purpose of TPM introduction been fully understood.

Stage 1:<u>Declaration by board of directors and general manager to introduce TPM in the transit</u>

AS we have seen before one of the factor of maintenance strategy selection is the willingness of managers and leaders in organization. Here it has significant outcome to an implementation of TPM since the basics of TPM is achieving continuous small improvement and the change reliant on the overall companies' employees. The commitment of the top management of the company is indispensable for rapid promotion of TPM. In these step activities like Meeting conducted by the board of director of the transit to announce the decision made by the transit to implement TPM and to prepare a schedule for training the managers of the transit.

<u>**Stage 2:** Introductory education & campaign of TPM</u>

After the declarations is made the introductory education to the managers and to all employees of the company conducted according to the plan scheduled by the top managers. Initially, the introductory education is presented to each head divisions of the company that are on the hierarchy and proposed;

1. Operation manager
2. Fleet operation manager
3. Maintenance manager

4. Engineering and technical support manager.
5. Marketing manager
6. Capacity building and development manager
7. Procurement manager
8. material and facility manager
9. Finance manager
10. Human resource manager
11. Recurrent training center manager.

Next, the training will be presented by the section heads, which are already trained, to each of the second level of managers under their section. As example maintenance manager will train those middle level managers under them.

1. Maintenance depot 1 manager
2. Maintenance depot 2 manager
3. Maintenance of way manager
4. Facility maintenance manager
5. Maintenance inspection manager.

The training conducted down the level in the similar manner for example the maintenance depot manager 1 train the lower level managers.

1. Rolling stock maintenance supervisor
2. Body shop supervisor
3. Bogie shop supervisor
4. Brake, hydraulic and pneumatic shop supervisor.
5. Welding and Paint supervisor
6. Component rebuild shop supervisor
7. Vehicle Interior supervisor
8. TVM and electronic appliances supervisor.
9. Cleaning and hygienic environment supervisor.

The supervisors train the personnel under them and finally, a maximum of a three day seminar need to be opened to the entire employee and should teach the employee the future direction of the company. This campaign targets to help the sections head to create some understanding about the TPM and to support them not to have difficulty while implementing TPM. And also, the seminar helps the employee to have some insight about the purpose of TPM.

Stage 3: Establishing TPM promotional organization

For the successful implementation of TPM in light rail transit creating small group from top management to the first line worker or operators of the machines is formed for the transit. Leaders of individual groups are members of a small group at the next higher level of the organization to link the different groups and enhance vertical and horizontal communication. In addition to the small group function, the following team should also be created.TPM office coordinates the TPM program. And will have two functions it the first one is TPM Planning Team which is responsible for planning and prioritizing each activities of the TPM implementation in the transit and the second team is TPM Implementation Team which is responsible for developing and executing each activities of the TPM program in the transit which is already planned.

Stage 4: Setting basic policy & targets for TPM in the transit

Each department in the LRT set the policy and the target for their department for agreed years ahead taking the policy & targets of the LRT as their input as well as based on the condition of the department.

Stage 5:Selecting model equipment for kaizen activity

This is selecting model equipment with the highest priority. The prioritization is based on equipment quality, reliability, maintainability, availability, safety and operational service hour etc. Thisequipment selected from each type of model and function by small group which is formed. The selected model for TPM development with maintenance work flow is presented in figure5.3 below.

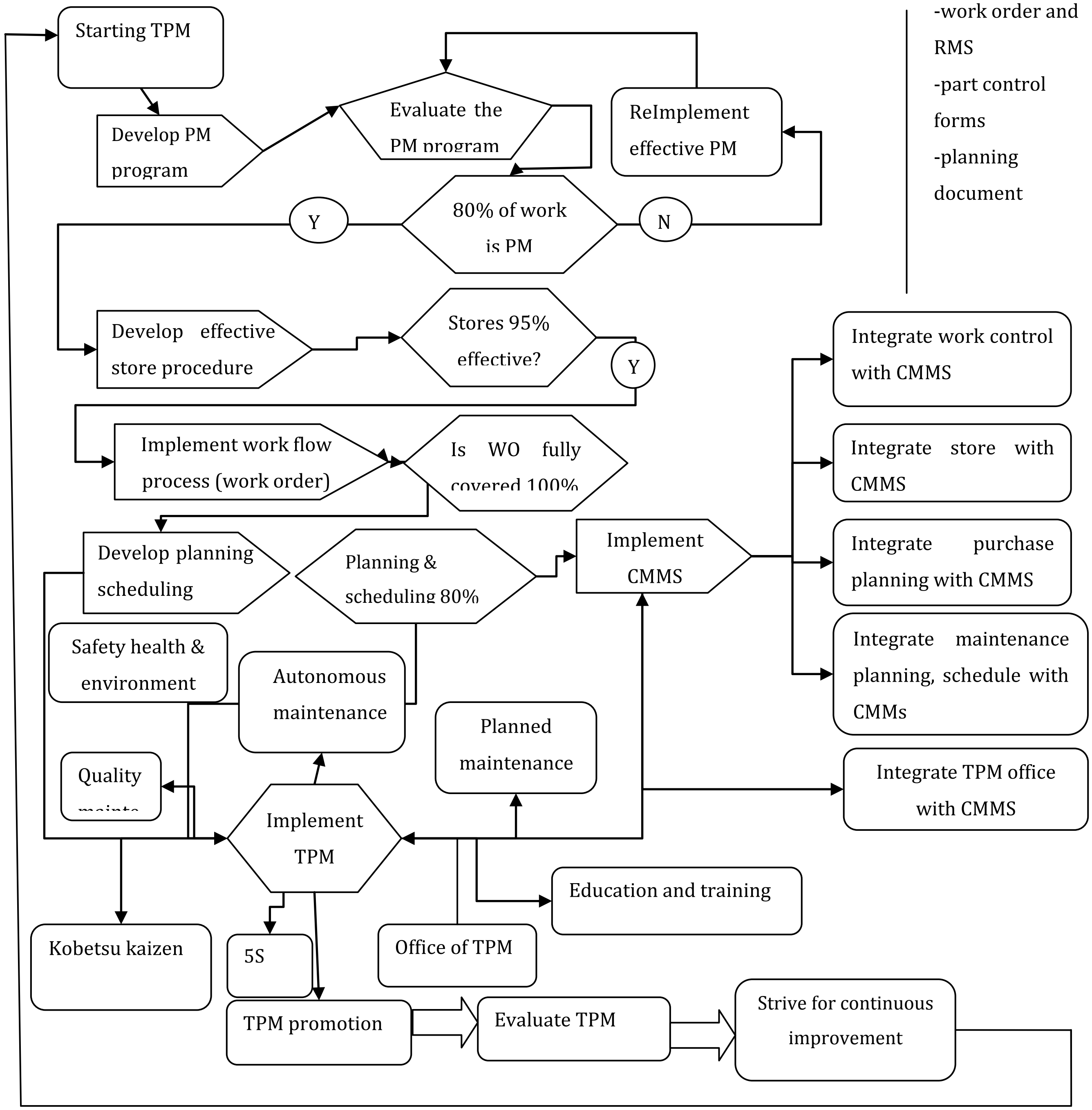

Figure 5-2 Proposed maintainance work process with TPM

Stage 6: Follow up the result

The last part of the introduction step is announcing the implementation of TPM in the LRT in formal procedure in which all employees of the transit participate. In this ceremony supportive organization, focus group of passenger supplier, allied company and regulatory agencies like ministry of transport are invited to create consciousness in their mind that better intimacy is needed based on safety. This stage is a transformation stage where the total implementation of TPM executed and conducted if providing the introductory TPM education to all employees is completed. Based on this recommendation the LRT Company should research on detail implementation plan and procedure of TPM for every section and process of the organization. As specified in the limitation part of this paper the unavailability of data and knowing the proposed company structure, depot facility, level of staffing and many other factors the detail master plan and implementation plan is not included in this thesis.

5.2 Light rail transit depot

i. <u>Depot facility</u>

Depot functions are classified as five categorieswhich define maintenance service requirements, associated service requirements and depot facilities. The specification of depot facilities for light rail transit should direct the classification and typical maintenance program associated with particular classification and the minimum activities that can be carried out through rolling stock servicing.

The LRT System's facilities will consist of the following elements.

- Stations and Parking Facilities
- Light Rail Vehicles
- Tracks, Bridge Structures and Right-of Way
- Shop and Yard Facilities
- Operations Control Facility
- Signals and Communications Systems
- Traction Power Substations and Overhead Catenaries System
- Fare Collection Equipment
- Traffic Controls

The Maintenance depot of LRValso provides the following maintenance crevice

- Carpenter
- Filter cleaning
- Battery maintenance
- Major body work
- Pantograph maintenance
- Bogie, wheel set and brake inspection and maintenance
- Traction motor and testing
- Spray painting and appearance control
- Radio communication maintenance
- Electronic repair maintenance

- non rolling stock facility maintenance
- Welding, small body work and fiber glass.
- Component rebuilding and machine shop

ii. Maintenance shops

It is still common to see workshops for railways provided with tooling and equipment to allow a full range of engineering tasks to be undertaken. This will include milling, boring, grinding, planning and cutting machines as well as part cleaning facilities (including bogie washing and car under frame cleaning or "blow-out" as it is sometimes called), plus electronic and pneumatic testing shops. Good storage and materials management facilities are also needed. Computerizedmaintenance systems are now widely available.

Not only does the rolling stock require maintenance but also track work, traction power equipment, signaling, and communications equipment, and fare collection systems, electronics of all types and buildings maintenance. The main depot of a railway has to be equipped to handle all these works. Storage for hazardous materials and fuel must be in a secure place with proper fire protection facilities. Waste disposal must also be properly managed and waste recoveredpossible.

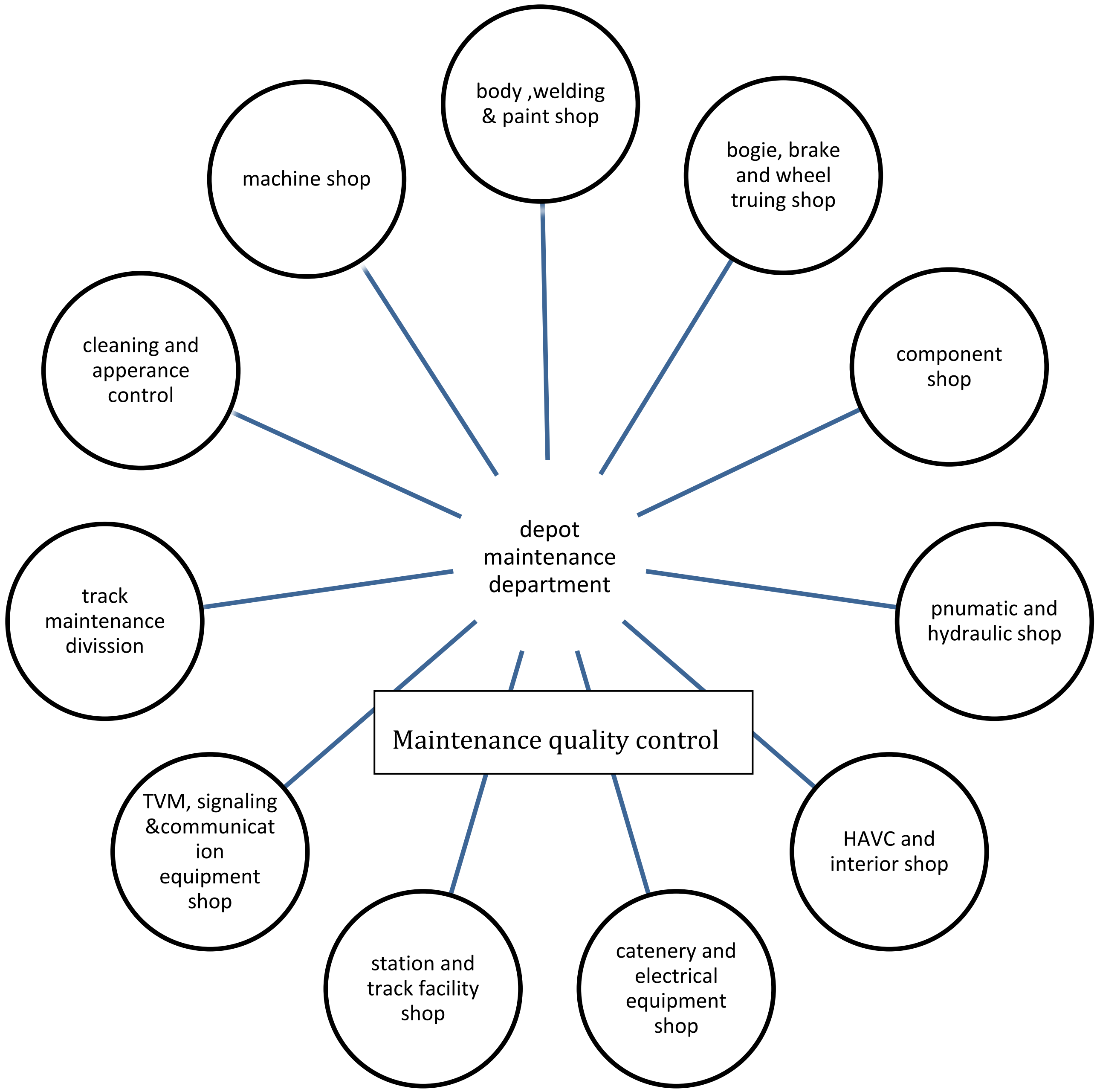

Figure5-3 Depot maintenance staff category shop

iii. Maintenance program in LRT depot

Preventive maintenance includes the development of maintenance rules adapted to component degradation. These maintenance rules are developed in the field by maintenance experts from the actual findings on in-service equipment and RAMS studies (Reliability, Availability, Maintenance, Safety). Preventative maintenance also includes developing a maintenance cycle that can be adapted to the suitable technology, its use and behavior, and take into account the service life of each component. Rolling stock maintenance can be programmed in one of three ways; by mileage, by time or by on conditioning monitoring. Of these three methods, condition monitoring is the most recent.

Traditionally, maintenance was carried out on a time basis, usually related to safety items like braking and wheel condition. Many administrations later adopted a mileage based maintenance system, although this is more difficult to operate as you have to keep records of all LRV mileages and this is time consuming unless you have a modern train control and data gathering system like CBM. There is also the fact that a train will deteriorate just as quickly if it is stored unused somewhere as it would if it was being run in service every day. Only the items which deteriorate will vary. It is impossible to give fixed time or mileage periods here for maintenance as each type of train varies. There are often special rules for high speed trains and for heavy freight. Individual railways have adapted their maintenance to the local conditions and, in many places, certain types of safety inspections are required by law. Most light rail vehicle trains cover about 5,000 kms a week and get an initial inspection every seven days.

Condition monitoring is achieved by checking the operation of the equipment and only changing something if it shows signs of wear beyond preset limits. The checking is often done using on-board monitoring and storing the data gathered in a computer for downloading at the maintenance facility. Of course, it is a recent development made available by the introduction of information technology on trains. Such systems are now becoming so sophisticated that it is possible to have failure predictions of some items of equipment. A combination of on-board data gathering and depot maintenance systems have been developed into complete maintenance management systems on lines where modern rolling stock has been introduced. This cycle comprises five levels of inspection/maintenance efforts, carried out at predetermined intervals

Walk around inspection

This concerns the monitoring actions carried out primarily by the train crews before departure, while en route or after arrival (tests, trials, verifications, etc.), in addition to the automatic on-board and on-ground monitoring devices. In aids LRT case since the route is short and the fleet size is not that much in addition to the train crew it is possible to assign trained technician in maintenance of way department one on each destination of the line. There should be written report form on each fleet which describe the malfunction of the vehicle and associated infrastructure completed by the train crew or the assigned technician. This report should be transferred to maintenance of way division supervisor and according to the emergency level it will be transferred to maintenance planning department to scheduling.

Daily Train Inspection:

Trains are inspected daily as they reach the workshop. The daily train inspection is scheduled to take 90 minutes. The operator checks the repair card list and the work required on the driver's trip log. Any work done is filled in the Rolling Stock Form and a Certificate of rail worthiness is issued if the trains are found to be rail worthy.

A-Examination

This is a general examination done on an entire LRV; both mechanical and electrical components are inspected. This type of examination is done on weekly basis for duration of 4 hours,

B-Examination

This is a monthly inspection that runs for a duration of 8 hours, which includes checks made in A-examination. Additional mechanical checks made during B-examination are those in the compressor/exhauster pressure and oil vapor. Electrical checks include battery compartments, traction motors, main generator and voltage regulator.

C-Examination

Is done every 3 months and includes minor repairs. These services incorporate all services done during A and B Examinations. Additional work done in C-examination.

D-Examination

The D-examination is conducted every 6 months for duration of 4 days. All jobs done in A-Examination to C-Examination are included during D-Examination. The entire locomotive is inspected for loose bolts, nuts and pipe joints and tightened as appropriate. Inspection is also made on the compressor/exhaust where replacement of inlet and discharge valves is done with reconditioned ones.

E-Examination

The E-examination is a yearly examination which runs for 7 days. E-examination activities include all examinations done in A-examination to D-examination. Additional work includes checks made on the battery components for signs of electrolyte leakages and tightness of all wiring connections. Also traction motors are checked and all electrical components are checked and cleaned to clear driver’s trip log.

F-Examination/Overhaul

The F-Examination/overhaul is a major maintenance which is sometimes called refurbishment. The general overhaul or F-Examination for LRV is done every 5 years while for wagons is done every 10 years and this type of maintenance is usually contracted out as it requires heavy plant machinery and big workshops.

iv. Train Washing Machines

Design of train washer work like a very long car wash, where the train stands still and the washer moves during the cleaning cycle but these are rare. Normally, water is used for a daily wash, while a chemical wash is used at less frequent intervals usually several weeks. Many daily washes have a detergent added to assist the process. In referring to a daily wash, this might extend to three days between washes, depending on local practice and degree of pollution and dirt collection. Washing machines require that the track on either side is straight for at least one car's length. This is to ensure that the car goes into the wash straight. There will also be a need for proper drainage facilities, complete with waste water management and, for the chemical wash, waste retrieval using a clarifier or separator.

Washing machines may need a roof under certain conditions and they must be protected from adverse weather, particularly cold.Chemical washes are used for heavy cleaning and the chemicals used will often require the train to stand for some time while the chemical reacts with the dirt on the car body.

v. Cleaning and Stabling

Trains are stabled in depots or sidings when not in use and they need to be cleaned and serviced. Cleaning means a regular exterior water wash and interior sweeping and dusting or vacuuming. At longer intervals, seating upholstery and carpets must becleaned. Exterior washing is usually means a drive through washing machine which will wash the sides and the roof. Suitable facilities must be provided in the stabling areas where trains are stored. Water and power need to be provided in such areas, adjacent to each train to be serviced. Access to trains must be designed so that cleaning staff can reach them safely whilst carrying their equipment. The layout of a stabling area is important. Ideally, each road should have an exit route at each end, so that, if one end gets blocked for any reason, trains can still get out the other end.

There is no reason why two trains should not be stabled on each road if the length is right, again provided an exit is available at each end so that, if one train fails and is not sent out on time, the other is not blocked. Site availability is always an issue and compromises are inevitable. It may even be necessary to stable two trains on a single ended track. Even this is viable if management of the fleet is flexible and allows trains due for entry into service to be swapped at short notice. This is one of the essential skills of a good depot supervisor. Train stabling areas are traditionally outdoors largely because of the expense of constructing large sheds. However, covering the stabling areas with some sort of weather proof structure is always preferable. It protects the trains and the staff working on or around them and reduces contamination by pollutants, frost, and snow and wind damage. A covered area will also provide some benefit in hot conditions and could help to reduce the air conditioning cost.

vi. <u>Maintenance staffing</u>

As we have above in the table selected light rail transit operators has similar maintenance staffing parameter but they have different ratios. The first parameter taken here is employ per the transit operation track kilometer.The other parameter considered with an available data is vehicle operated in maximum service. AddisAbaba light rail transit with current capacity operates 41vehicles on 21.3 mile. If we take the average of the four transit systems parameter we can estimate the level of staffing for Addis light rail transit. But here according to the above cases the difference in calculated no of employ is wide 61 and 203.

Table 5-1.Total maintenance personnel per track mile and per VOMS

LRT operator	employ per track mile	employ per VOMS
San dingo	2.3	2.9
Port land	3.4	4.8
Cleveland	4.2	9.2
Salt lake city	2.2	2.9
Average	2.85	4.95

According to the recommendation the maximum number is taken and 203 maintenance personnel (managers, planners, engineer, technicians and inspectors) with satellite store personnel should be recruited. The number of employ should be optimized according to the work level. The other factor is employ per maintenance clerk and the recommended value is 35 person per clerk therefore addis LRT should have 6 maintenance clerk. Supervisors per maintenance personnel bench marking is 7 in the world class maintenance organization. Therefore 30 personnelwillbe supervisors with a different level. The bench mark of managers per employ is 17 and for proposed maintenance personnel 12personel are different section and department managers.

LRT operator	LRV maintenance	Track maintenance	Traction power and over head maintenance	Signal and communication maintenance	Station maintenance	Facility maintenance	Fare collection maintenance	Store management
Cleveland	17.9	30.2	8.8	36.2	12.2	32.5	N/A	20
Portland	8	19	10.5	8	34	8	6	5
Salt Lake City's	6.7	6	11	4.2	2.4	3	4.8	4
San Diego's	8	7	7.5	8	8.9	6.7	5.2	8

Table 5-2 Managers per maintenance personnel for different section

proposed managers per maintenance personnel for different light rail transit maintenance section

- LRV maintenance 10.15
- Track maintenance 15.5
- Traction power and catenary maintenance 9.45
- Signal and communication maintenance 14.1
- Station maintenance 14.375
- Facility maintenance 5.33
- TVM and electronics maintenance 5.33
- Store management 9.25

CHAPTER 6 CONCLUSION,RECOMMENDATION & FUTURE WORK

6.1 Conclusion

In this paper maintenance strategy selection procedure for LRT system is illustrated by AHP algorithm theory.super decision software is used for analysis.Five alternative maintenance strategies are considered ; total productive maintenance, preventive maintenance,corrective maintenance ,reliablity centered maintenance & condition based maintenanceseven main decision criteria and twenty-five sub criteria have been determined. The criterias and alternatives structured by AHP algorithm. The expert decision software estimates the weights (priorities) of decision criteria using pair wise comparison method. The result indicated that safety is number one priority from maintenance strategic factors followed by value adding factors. In addition, the survey indicated that total productive maintenance is the most suitable strategy to be implemented for LRT system and corrective maintenance is the least one.

6.2 Recommendation

Maintenance strategies change rapidly with new options and practices. Any change in operations requires some adjustment or major change in the adopted maintenance strategy to be compatible with the new requirements. In addition to saving cost maintenance has tangable impact on operational availablity and reliability of the LRT system. Integration of maintenance with other functions will transform the asset management to world class standard. Therefore the LRT system to be compitetive the maintenance and asset care should be compatable with the changing dynamics of maintenance strategy.

6.3 Future work

Thereare plenty of methods to investigate maintenance decission and optimization problem.

- It would be interesting to incorporate the remaintenance cost of labor and spare part to the decision making process when the transit become operational.
- Determining the ratio ofPreventive maintenance with corrective maintenance would be interesting to research.
- In-depth study on the different types of maintenancestrategiesat the repair shop by benchmarking components would also be the right research direction.
- Finally, implementation of the selected maintenance strategy (TPM) with detailed implementation guide and master plan will be highly recommended part of reserch.

APPENDEX

Appendix I Personal Profile

1. Name of respondent:______________________________
2. Your gender:

   Male ☐ Female ☐

3. Your title/ work type:_______________________________
4. Year of experience:
5. What is your highest attainment in education?

   ☐ High school graduate ☐ Diploma Bachelor degree ☐ Master's Degree

   ☐ Doctorate degree ☐ other(s), please specify: ____________________
6. What is your age group?

   ☐ Below 25 ☐ 25 to 34 ☐ 35-44 ☐ 45-55 ☐ 55 or above
7. Have you participated in any types of maintenance function (i.e. rolling stock, vehicle, aircraft, earth moving machineries as an engineer, planner, technician, consultant or managerial) in your current or previous experience?

   ☐ YES ☐ NO

8. If your answer to the above question is 'Yes', would you like to participate our second stage questionnaire survey?

   YES ☐ NO ☐

9. Your contact details:

   Corresponding address:

   ____

   ____

Email account: ____________________________

Thank you so much for your kind participation in this survey.

Appendix II AHPQuestioner Assessment Explanation

Part 2 QUESTIONNAIRES FOR THE AHP SURVEY

Introduction

This research study intends to recommend the best maintenance strategy for light rail transit (LRT) system. The key maintenance management factors and their suitable indicators have been selected from different researches and maintenance expert's opinions to formulate maintenance strategy selection model. In this survey, we aim to prioritize these identified indicators (i.e. by pair-wise comparison), and to investigate the interdependent relationships between the maintenance key factors and their indicators to prioritize the proposed alternative.

Your inputs are tremendously valuable and we do hope that you can participate in this survey. It would be much appreciated if you could spend around 45 minute to complete and return the completed questionnaire in person. Should you have any queries, please feel free to contact Mr. Muluken assefa by email address or phone +251911395019. Thank you again for your time and efforts on this research.

INSTRUCTION:

- Each section in this survey consists of a number of question sets.
- Each question within a question set asks you to compare two factors/criteria at a time (i.e. pair-wise comparisons) with respect to a third factor/criterion.
- Please read each question carefully before giving your opinions/answers, and answer according to the following rating scale:

1 the two factors are **equally important;**

3 on the left (right) = the left (right) factor is **moderately important than** the right (left) factor;

5 on the left (right) = the left (right) factor is **strongly important than** the right (left) factor;

7 on the left (right) = the left (right) factor is **very strongly important** than the right (left) factor;

9 on the left (right) = the left (right) factor is **an absolutely** important than the right (left) factor.
2,4,6,8 are Intermediate values inputs

- The definitions of abbreviation alternative maintenance strategy are provided for your reference: **Corrective Maintenance (CM)): PM (Preventive Maintenance), CBM (Condition Based Maintenance), Reliability Centered Maintenance (RCM) & Total Productive Maintenance (TPM).**

√ Please putxon the selected rating

Appendix III Questioner for main criteria comparison

N⁰	Relative importance point																		
	criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria
	safety																		Implementation cost
	safety																		Value added
	safety																		Implementation capability
	safety																		Maintenance Performance
	safety																		Stock & material control
	safety																		Support system integration
	implementation cost																		Value added
	implementation cost																		Implementation capability
	implementation cost																		Maintenance Performance
	implementation cost																		Stock & material control
	implementation cost																		Support system integration

	Value added																		Implementation capability
	Value added																		Maintenance Performance
	Value added																		Stock & material control
	Value added																		Support system integration
	Implementation capability																		Maintenance Performance
	Implementation capability																		Stock & material control
	Implementation capability																		Support system integration
	Maintenance Performance																		Stock & material control
	Maintenance Performance																		Support system integration
	Stock & material control																		Support system integration

Appendix IV Questioner sub criteria pair wise comparison

Main criteria	Relative importance point																		
	Sub-criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Sub-criteria**
Safety	Passenger safety																		Worker Safety
	Passenger safety																		System safety
	Worker Safety																		System safety
Implementation cost	Hardware Cost																		Software Cost
	Hardware Cost																		Operation &Maintenance Of The System
	Hardware Cost																		Training of the System
	Software Cost																		Operation &Maintenance Of The System
	Software Cost																		Training of the System
	Operation &Maintenance of						v												Training of the System

	System																		
Value adding	Quality service																		service Reliability
	Quality service																		Maximum Operational availability
	Quality service																		Profit
	service Reliability																		operational availability
	service Reliability																		Profit
	Maximum operational availability																		profit
Implementation capability	budget																		Personal capability
	budget																		Technological availability
	budget																		Managerial willingness
	Personal capability																		Technological availability
	Personal capability																		Managerial willingness

	Technological availability																		Managerial willingness
Maintenance performance	Equipment Performance measuring																		Cost performance measures
	Equipment Performance measuring																		Process performance measures
	Cost performance measures																		Process performance measures
Stock & material management	Part availability																		Part cost control
	Part availability																		Purchase planning
	Part cost control																		Purchase planning
Support organization Integration	Fleet operation																		Procurement and material management
	Fleet operation																		Engineering and

																			technical support
	Fleet operation																		IT & communication
	Procurement and material management																		Engineering and technical support
	Procurement and material management																		IT & communication
	Engineering and technical support																		IT & communication

Appendix V Questioner for alternative strategy comparison

	Relative importance point																	
	Sub-criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Sub-criteria**
Passenger Safety	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Worker safety	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
System safety	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Hardware cost	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Software cost	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Operation and maintenance	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Training cost	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
Reliable service	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
profit	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Operational availability	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
	RCM																		TPM
. Quality service	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. budget	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Personal capability	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Technology availability	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Managerial willingness	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Equipment performance	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Cost performance	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Process performance	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
	RCM																		TPM
	RCM																		CBM
. Part availability	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Inventory control	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Purchase planning	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Fleet operation	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Procurement & material management	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
	RCM																		TPM
. Engineering and technical support	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM

	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM
. Information communication technology	RCM																		TPM
	RCM																		CBM
	RCM																		CM
	RCM																		PM
	TPM																		CBM
	TPM																		CM
	TPM																		PM
	CBM																		CM
	CBM																		PM
	CM																		PM

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