



**ANALYSIS OF MAINTENANCE PRACTICE, IN THE  
CASE OF RIES ENGINEERING SHARE COMPANY  
IN COMPONENT REBUILDING CENTER**

**ADDIS ABABA**

**DERES MEZGEBU**

**MASTERS OF BUSINESS ADMINISTRATION**

**ADDIS ABABA SCIENCE & TECHNOLOGY**

**UNIVERSITY**

**MAY 2018**



**ANALYSIS OF MAINTENANCE PRACTICE, IN THE CASE OF RIES  
ENGINEERING SHARE COMPANY IN COMPONENT  
REBUILDING CENTER ADDIS ABABA.**

A Thesis submitted to

Addis Ababa Science and Technology University College of Natural and Social  
science Department of Management as Partial Fulfillment of the Requirements

of Masters of Business Administration (MBA)

Degree in industrial management.

**DERES MEZGEBU**

**MASTERS OF BUSINESS ADMINISTRATION**

**ADDIS ABABA SCIENCE & TECHNOLOGY UNIVERSITY**

**MAY 2018**

## *Abstract*

*This thesis is concerned with maintenance practice at Component Rebuilding Center in the case of ries engineering share company in Addis Ababa head quarter located at akaki- kality sub city , it analysis the maintenance practice activities within the organization. The specific objectives are derived to provide focus for the research activities, In order to achieve these objectives; descriptive research design and a combination of quantitative and a qualitative approach was used. since some features of the maintenance practice is expressed by numerical; and the quantitative approach helps the researcher to examine to know frequency of maintenance failures, cost of spare part and the like and also some features of the maintenance practice are also expressed qualitatively like work procedures employed, types of maintenance exercised, and goodness of maintenance plan. Qualitative data was collected by non structured interview (from different levels of management and supervisors) , and the secondary data found from the review of different machinery history file are presented by frequency, percentage and tables to show (examine), frequency of machine failures, downtime amount , spare and maintenance cost and the like. In the study both stratified random sampling and convenient sampling are used to select representative of the population for the study period with a total population of 36. The key findings of the research indicate that the case study organizations preventive maintenance strategy is not being performed as per the schedules of the manufacturer recommendations. Frequent failure problem and stretched downtime are also some of the findings. The case company is recommended to create strong integration among departments and ownership of their work. By taking into considerations these and other factors which can be addressed by effective and efficient implementation of optimum and modern proved maintenance strategies; RESCO will be granted to the improvement of availability by about 26.1% from the existing availability which estimated in the data collection and analysis phase of this work.*

***Key words:*** *Maintainability; maintenance strategy; availability; total productive maintenance;*

## CHAPTER ONE

### INTRODUCTION

Many scholars have defined the word maintenance with respect to their specific field of study in different period. For instance, the researchers whose field of study is life science can define the word “Maintenance” as the process of repairing lively body of living things where as a construction professionals can define as the repairing or preserving original conditions and functions of buildings or roads. Likewise, mechanical engineers can define it in the context of machines, production processes and any other equipment or tools, etc. However, the basic or the central ideas of their definitions are converged to the same idea.

In a similar context, according to the definition of (Al-Najja, 1995), it is a means to maintain and improve the quality of the elements involved in a production process, continuously and cost-effectively through detecting and controlling the deviations in the condition of a production process that is decided by production costs, working environment and product quality in order to interfere when it is possible to arrest or reduce component/equipment deterioration rate before the process condition and product characteristics are intolerably affected and to perform the required action to restore the equipment process or a part to as good as new . In further optimistic view, maintenance is a science since its implementation trusts, sooner or later, on most or all of the sciences.

It is an art because apparently identical problems regularly demand and receive varying approaches and actions and because some managers, supervisors, and maintenance technicians display greater aptitude for it than others show or even attain. It is above all a philosophy because it is a discipline that can be applied intensively, modestly, or not at all, depending upon a wide range of variables that frequently transcend more immediate and

obvious solutions (Mobley, Lindley, & Darrin, 2008). A more general definition, by (Stapelberg, 2009) is maintenance can be defined as “the continuous action of caring for the condition of equipment”. Equipment condition is the operational and physical state of equipment on which the functions of the equipment depend on the work and properties that the equipment is designed to perform. In a similar principle maintenance is combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function (British Glossary Standard institution, 1974).

Therefore, the overall concept of the definitions is a set of organized technical activities that are carried out in order to keep equipment or system or process in its best operational condition with minimum cost acquired by using the acquired and available technology. In other word, Maintenance is the combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function.

### **1.1 Background of the study**

Even though human being have long history of maintenance from the beginning of using instrument as tools from the era of stone age, the evolution of maintenance can be traced from the days prior to world war II .the attitude of managers then was "to fix the equipment when it breaks" corrective maintenance trends which was predominant. The period after World War II saw the introduction of the word "technology"; which was initially defined by the committee on technology as “a combination of management, financial, engineering and other practice applied to physical assets in pursuit of economic life cycle costs”. Due to rising costs and inflation, focus was on reducing downtime of equipment and hence preventive maintenance

came into being as an important activity gradually. Besides high cost of maintenance, environmental concerns, safety issues, warranty and reliability factors, regulatory matters, ageing plant and equipment, drive for cost reduction ...etc. are some of factors that change the attitude of managers toward maintenance department. Therefore, many researchers worked on operation research models for preventive maintenance. Moreover, Importance of planning maintenance activities also grew during this period (Timothy & Bruce, 2006).

However, until recently middle- and corporate level management have ignored the impact of the maintenance operation on product/service quality and production costs. And maintenance was considered as on bottom-line profit, necessary evil or nothing can be done to improve maintenance costs. Perhaps these statements were true until very few decades before, but the development of microprocessor or computer based instrumentation that can be used to monitor the operating condition of plant equipment, machinery, and systems has provided the means to manage the maintenance operation. This instrumentation has provided the means to reduce or eliminate unnecessary repairs, prevent catastrophic machine failures, and reduce the negative impact of the maintenance operation on the profitability of manufacturing and production plants (Mobley R., 2002). Therefore, the process of developing and exercising a smart framework or methodology which include planning, organizing ,directing and controlling to the maintenance functions has counted few decades that provided a structure for the efficient exercise of maintenance activity. Because of realizing that maintenance activity extremely affects the useful life of the equipment, product quality, direct costs of maintenance and consequently production/servicing cost and at the end the profits of an institute or factory (Bhadury B, 2000).

In general, usually the evolution of maintenance is categorized into three different generations, the period of 1930's -1940's which usually referred as the first generation, between 1950's to 1970's often recognized as the second generation, and the 1980's till recent which commonly accepted as the third generation. The evolution in the maintenance processes also rooted from the changing complexity of the industry itself. The first generation is the earlier days of industrialization where mechanization is low. Most equipment in the factory is basic and repairing and restoration process is done in a very short time. Thus the term downtime did not matter much and there was no need for managers to put maintenance as a high priority issue.

The second generation emerged as the result of growing complexity in equipment and plant design. This had led to increase mechanization and industry was beginning to depend on these complex machines. Repairing and restoration has become more difficult and special skill and more time is needed to mend the machinery. At this dependence grew, downtime became more apparent a problem and getting a sharper focus from the management. People are beginning to think that these failures should be prevented which led to the concept of preventive maintenance. As maintenance cost started to rise sharply relative to other operating cost, interest in the field of maintenance planning and control systems is raised up. Beginning in the 1980's, the growth of mechanization and automation has becoming more complex and some small breakdowns in equipment could affect the operation of the whole plant. This has meant that reliability and availability have become key issues since any failure can have a serious consequence to the whole division. Fundamental differences between the second and third generation's maintenance are: -

1. Focus is now not only concentrated on availability but also reliability

2. There is a push towards zero downtime or zero in-service breakdowns, and
3. Improved maintenance tools such as Reliability centered maintenance (RCM), Total Productive Maintenance (TPM), and root cause failure analysis (RCFA), Failure Modes and Effects Analysis (FMEA) and others are being applied to achieve maintenance objectives.

Under the third generation maintenance principles in many organizations have stated zero breakdowns/zero in-service failures as their maintenance goals. However, since no amount of maintenance can guarantee the total elimination of failures. Since, there is always probability of failure. But may be very close to zero is a more realistic approach. Hence, it is no longer a realistic objective that is achievable. The realistic approach is reducing the consequences and frequency of failures. With these changes, maybe the focus of maintenance will change and perhaps the new mission of maintenance department is more towards providing an excellent support for their customers by reducing the loss of maintenance failures (Dekker, 1996). Hence one of the core activities in RESCo is provision of maintenance service for its customers and its machinery; as the result this study is investigating the level of maintenance practice which is conducted at RESCo and computing from theoretical perspective and showing the strength and weakness found in their maintenance practice; since maintenance service provision is the back bone of the company which is attached to its sales volume and the biggest revenue generated next to machinery rental service.

## **1.2 Background of the organization**

Ries Engineering share company (RESCo) started operation in 1961 as an engineering department at one of its sister companies, Paulries and Sons (Eth.Ltd.). It became an independent company in 1965. Since then it has been developing continuously and today it represents well known and reputable companies supporting the development of the country in

construction, mining, power and Agriculture sectors. The reputed companies represented by RESCo include, among others:-caterpillar-Agriculture Company (AGCO)-Massey Ferguson, Valtra and challenger, Ford, Berthoud, Marini. Mc Closkey, Schneider Electric. Ries Engineering Share Company has opened four main branches in the areas of Bahir Dar, Dire Dawa, Hawassa, Mekelle ([www.riesethiopia.com](http://www.riesethiopia.com)) These branch enables the company's service reachable by the customers at their working site. It gives after sales customer support such as; Maintenance, Training, Warranty and Parts delivery. Recently due to the government's mega projects and foreign direct investments; the construction, mining, power and agriculture sectors are highly in demand of the RESCo's after sales support. So the motive of this research is to investigate the maintenance practice of the component rebuilding center; so that to deliver best maintenance practices at the head office and the four branches of the company. The frequent failure of machinery is one of the major reasons that inhibits the company maximum provision of service and play its expected role in customer satisfaction.

### **1.3. Statement of the problem**

Since RESCo is one of the private sector that provide and rent different machinery with full after sales service to different customer (private and government) in Addis Ababa and outside Addis Ababa, effective and efficient uses of existing resources will have significant role in improving the company income and good will. Maintenance provision as a competitive advantage and business strategy becomes an essential element of many organizations to triumph in the competition. Ries engineering is a sole dealer for caterpillar machineries and has a reputed name with this brand; following the transfer of ownership with the unknown reason; the activity and performance of the company is decreasing.Lack to meet specifications, Pre- mature component failure, Delay in service delivery, customer compliant

and dissatisfaction is some of the problems that are seen in the last 5years period at CRC (Company annual report 2009) and hence CRC is one of the back bone of RESCo revenue it should be studied properly its practices. Therefore the research addressed the following basic research questions:

1. Which maintenance practices are used in CRC at Ries Engineering Share Company?
2. What is the extent of availability of the existing machinery for rental at Ries Engineering Share Company?
3. What kinds of failures are frequently happening that are responsible for the current availability of existing machinery in Ries Engineering Share Company?
4. What are maintenance strategies that results for current availability of machinery at Ries Engineering Share Company?

#### **1.4 Objectives of the research**

##### **1.4.1 General Objective**

The general objective of this research is to analysis the maintenance practice at CRC of Ries Engineering sh.co.

##### **1.4.2 Specific Objective**

In line with the above general objective the researcher addressed the following specific objectives:-

- ✓ To investigate frequent failure problems of machinery at the Ries Engineering Share Company
- ✓ To figuring out failure rate of machinery at Ries Engineering Share Company
- ✓ To study what kind of maintenance practice existed at CRC of Ries Engineering Share Company.

### **1.5. Significance of the study**

I conduct the research with the intension that the company should remain competitive in the industry; therefore, the company is expected to be benefited from the suggestions and recommendations of the investigation. Besides, it will use as additional reference and documentation for other researchers who wish to study the maintenance practice of related company.

### **1.6 Scope of the Study**

The scope of this study is embraced for the period of 2008 – 2009 E.C. the head office in Ries engineering Share Company at Addis Ababa.

### **1.7. Limitation of the study**

The study is focusing only at the component rebuilding center (CRC) of the company, which is located at its head office in Addis Ababa.

### **1.8. Organization of the thesis**

The thesis consists of five chapters. Chapter one will be introduction, including the statement of the problem, objectives of the study, significance of the study, scope of the study, limitation of the study, and the organization of the thesis. The literature related to the subject matter will be presented in chapter two. Chapter three will focus on the research methodology and approach used. The presentation and analysis of the data collected will be presented in chapter four. Summary of major findings, conclusion, recommendation about the problem and limitation of the study will be in chapter five.

## **CHAPTER TWO**

### **REVIEW OF RELATED LITERATURE**

#### **2.1 Literature review**

##### **2.1.1 Definition of Maintenance**

Corder (1976) defines five key objectives of maintenance as follows:

1. To extend the useful life of assets
2. To assure the optimum availability of installed equipment for production and/or services, and obtain the maximum possible return on investment;
3. To ensure readiness of equipment needed for emergency use at all times;
4. To ensure the safety of personnel using facilities; and
5. To guarantee customer satisfaction.

Patton (1988) lists major work tasks to be accomplished in any maintenance environment as including: inspection, replenishing consumables, troubleshooting, removal and replacement, repair, adjustment, calibration, functional testing, refurbishing, and conditioning. Maintenance is the major part of the total operating costs of all manufacturing or production plants. Depending on the specific industries, maintenance costs can represent between 15 and 60 percent of goods produced and according to the recent surveys of maintenance management effectiveness one-third (33%) out of every dollar of all maintenance costs is wasted as the result of unnecessary or improperly carried out maintenance activities. For instance; delays, product rejects, scheduled maintenance downtime, and traditional maintenance costs- such as labor, overtime, and repair parts are generally the major contributors to irrelevant maintenance costs. Moreover, it significantly affects the ability to manufacture/deliver quality products/services that has vigorous impact on customer satisfaction. Hence, it results in losses

of service and product quality and affords irrelevant costs in return high loss of profit simply because of the inefficient uses of existing assets and resources (Mobley, R, 2002). Moreover, the tendency reason for this ineffective management is the lack of factual or correct data that quantify the actual and exact need for repair or maintenance of plant machinery, equipment, and system. Maintenance scheduling has been and in many instances still is predicted on statistical trend data or on the actual failure of plant equipment. However, the developments of microprocessor or computer- based instrumentation that can be used to monitor the operating condition of plant equipment, machinery, and systems have provided the means to reduce or eliminate unnecessary repairs, prevent catastrophic machine failures, and reduce the negative impact of the maintenance operation on the profitability of manufacturing and production plants (Mobley, 2004). The negative effect of Maintenance activity in any plant or enterprise especially in the developing country those have traditional failure diagnosis, information collection, analysis, interpretation, and poor maintenance management will result catastrophic cost or loss of profits. Hence, faced cash trapped problems. But now a day managers or companies especially in the developed country gave equal emphasis to maintenance activities by understanding that the impossibility of exceeding customer satisfaction without efficient and effective maintenance activities especially within these late few decades. Maintenance is defined as a combination of all technical and associated administrative activities required to keep equipment, installations and other physical assets in the desired operating condition or restore them to this condition (BSI 1984; Pintelon et al. 1997; Pintelon and Van Puyvelde 2006 cited in Muchiri et al. 2010). Heiser and Render (2006:660) list maintenance management as one of the most important contributors to effective and efficient operations.

Good maintenance assumes that maintenance objectives and strategies are not determined in isolation, but are in some way derived from factors such as company policy, manufacturing policy and other potentially conflicting demands and constraints in the company (Swanson 1997, pp. 191-207; Johnsson and Lesshamar 1999, pp. 55-78; Swanson 2001, pp. 237-244; Pinjala et al. 2006, pp.214-229).Maintenance of production equipment, assets and facilities is another important aspect of controlling costs and quality. Adendorff et a/. (1999:315) state that the mismanagement of maintenance can lead to catastrophic consequences for an enterprise. This includes threats to safety, to plant, lower quality products and services, lower customer satisfaction, and more. Gaither and Frazier (2001:743) make a distinction between the costs of repair and preventive maintenance (PM) activities. They list repair as work done after breakdown or after a machine has failed. It is reactive, and PM is the regular scheduled work done to avoid breakdown (down time) of production assets like production machinery and equipment before failure. This schedule can be after one month, one year, three years or five years, or after so many operations. As Coetzee (2000) describes different practices and strategies such as; Preventative maintenance is maintenance of an item performed to prevent failure of an item; corrective maintenance or failure (wait for failure) maintenance is reactive in nature and is maintenance of equipment after it has failed, the run-to-failure strategy is used in equipment that is cost effective to let to fail before taking any action, for example, light bulb replacement, breakdown maintenance is corrective maintenance of a failed item normally subject to, or which should have been subject to, preventative maintenance, condition-based maintenance is preventative maintenance of an item performed when a measurable condition of that item indicates that maintenance is necessary to prevent failure of the item and scheduled maintenance is preventative maintenance of an item performed at

fixed time intervals, or at intervals determined by the extent to which the item has worked. Generally, best maintenance process and well-adjusted predictive, preventive, proactive, and corrective maintenance strategies are essential to minimize the operational and technical down time of a system and to maximize the availability of system. Because, it allows the system's maintenance program to move from a reactive approach to planned approach (Achermann, 2008). Therefore, the importance of the maintenance function has been greater than before, due to its role in maintaining and improving availability, performance efficiency, quality products, on-time deliveries, the environment, safety requirements and overall company productivity at high levels, Al-Najjar (1997), Riiset al. (1997), Mckone and Weiss (1998) and Bevilacqua and Braglia (2000).

### **2.1.2 Maintainability**

The other concept that is related to the concept of maintenance is maintainability. The word "maintainability" as defined in simple language is the simplicity and quickness with which a failed item can be repaired and brought back to service. Maintainability has a detailed definition as stated below. "Maintainability is the probability that a unit or system will be restored to operational efficiency within a given period of time when the maintenance action is performed in accordance with prescribed procedures" ( Kaduna Polytechnic, 2001).

Maintainability can be defined as the degree of facility with which an equipment or system is capable of being retained in, or restored to serviceable operations. It is a function of parts' accessibility, interval configurations, use and repair environment and the time, tools and training required to affect maintenance. the U.S. department defines maintainability as "a characteristic of design and installations which is expressed as probability that an item will imitate to specified conditions within a given period of time when maintenance action is

performed in accordance with prescribed procedures and resources”. Maintainability is the ability of an item to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair (Department of Defense United Stat of America, August 3, 2005).

### **2.1.3 Maintenance Strategies**

Bearing in mind of the above objectives, companies, Enterprises, original equipment manufacturer firm etc. implemented different types maintenance strategies by learning through experience about the natural characteristics /strength of materials/ in working condition, and duty of device, handling condition, and etc. since nothing is in this world is ever lasting, equipment’s have their own life span and failure rate, reliability, and availability. But, after realization of maintenance effect of on these variables of equipment/system users of equipment and manufacturers has prompted increased attention to the maintenance area as an integral part of productivity improvement through the deployment of various maintenance strategies. Therefore, many companies are being implementing different strategies and styles of maintenance for taking their best advantage from the maintenance strategies and activities.

The following are the commonly known types of maintenance strategies:

1. Breakdown Maintenance
2. Preventive Maintenance
3. Predictive Maintenance
4. Proactive Maintenance

### **2.1.3.1 Breakdown Maintenance**

In these types of maintenance activity, the required repair, replacement, or restore action performed on a machine or a facility after the occurrence of a failure. This is to bring failed machine or facility to at least its minimum acceptable condition. It is the oldest type of maintenance. In this phase, machines or machine components are serviced only when repair is drastically required. This concept has the disadvantage of unplanned stoppages, excessive damage, spare parts problems, high repair costs, excessive waiting and maintenance time and high trouble shooting problems (Telang, February 14, 1998).

### **2.1.3.2 Preventive Maintenance**

This is a time based maintenance strategy where on a predetermined periodic basis, equipment is taken off line, opened up and inspected. It is a set of activities that are performed on plant equipment, machinery, and systems before the occurrence of a failure in order to protect them and to prevent or eliminate any degradation in their operating conditions. The aim of preventive maintenance is to reduce failure probabilities by maintenance before failure or significant degradation has occurred (SS\_EN 13306, 2001). British Standard 3811:1993 Glossary of terms defined preventive maintenance as the maintenance .carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning and the effects limited (British Standard Institution, 1993). Advantage of applying preventive maintenance activities is to satisfy most of maintenance objectives. It is good for those machines and facilities which their failure would cause serious production/service losses. Its aim is to maintain machines and facilities in such a condition that breakdowns and emergency repairs are minimized. Its activities include replacements, adjustments, major overhauls, inspections and lubrications.

### **2.1.3.3 Predictive Maintenance**

Predictive maintenance is a more condition-based approach to maintenance. It is a set of activities that detect changes in the physical condition of equipment (signs of failure) in order to carry out the appropriate maintenance work for maximizing the service life of equipment without increasing the risk of failure. Predictive maintenance involves performing maintenance on a machine in advance of the time a failure would occur if the maintenance were not performed. It is classified into two kinds according to the methods of detecting the signs of failure.

- ✓ Condition-based predictive maintenance
- ✓ Statistical-based predictive maintenance

Condition-based predictive maintenance depends on continuous or periodic condition monitoring equipment to detect the signs of failure. Statistical-based predictive maintenance depends on statistical data from the careful recording of the stoppages of the in-plant items and components in order to develop models for predicting failures. The drawback of predictive maintenance is that it depends heavily on information and the correct interpretation of the information. Some researchers classified predictive maintenance as a type of preventive maintenance. The main difference between preventive maintenance and predictive maintenance is that predictive maintenance uses monitoring the condition of machines or equipment to determine the actual mean time to failure whereas preventive maintenance depends on industrial average life statistics (Dunn & Johnson, 1991).

### **2.1.3.4 Proactive maintenance**

Unlike the three type of maintenance strategies which have been discussed earlier, proactive maintenance can be considered as another new approach to maintenance strategy. Unlike to

preventive maintenance that is based on time intervals or predictive maintenance that is based on condition monitoring, proactive maintenance concentrate on the monitoring and correction of root causes to equipment failures. The proactive maintenance strategy is also designed to extend the useful age of the equipment to reach the wear-out stage by adaptation a high mastery level of operating precision (Jabar, 2003).

Table 2-1 below summarizes the four different strategies of maintenance which are being commonly practiced in the industry. Despite of this, the need for maintenance is established on actual or impending failure – ideally as such, the practical operation of a component is time-based function.

Table 2.1. Contrast of Common Maintenance Strategy

Strategy Maintenance	Maintenance Approach	Signification
Breakdown Maintenance	Fix-it when broke	Large maintenance budget
Preventive Maintenance	Scheduled Maintenance	Periodic component replacement
Predictive Maintenance	Condition-based Monitoring	Maintenance decision based on equipment condition
Proactive Maintenance	Detection of Sources of Failures	Monitoring and correcting failing root causes

#### 2.1.4 Maintenance Theory

To optimize these maintenance strategies many theories and models have been developed by different researchers at different periods in the past and continued yet. The probability-of-survival distributions most commonly used in the practical analysis of reliability data are

among those distributions which have been most intensively studied by theoreticians. Such as exponential failure distribution, Weibull failure distributions, Normal or called Gaussian distribution, log normal distribution and Gamma Distributions are the most commonly and extensively used theory of structures. Even though there is a slight difference in shape of the graph for mechanical and electrical components, if one were to graph the failure rate a component population versus time, it is likely the graph would take the “bathtub” shape. It describes a particular form of the hazard function which comprises three parts. Wear in (The first part is decreasing failure rate, known as early failure). Normal operation (The second part is a constant failure rate, known as random failures). Failures in this period are indicted by the Poisson and Weibull distributions. Wear out (The third part is an increasing failure rate known as wear-out failure). Failures during the wear-out period are described by the normal and Weibull distribution. The bathtub curve is generated by mapping the rate of “infant mortality” failures. When first introduced, the rate of random failures with constant failure rate during its “useful life”. And finally the rate of “wear out” failures as the product exceeding its design life time. This curve originates from actual statistics. Therefore, failure characteristics examination supported by the above maintenance trend representation will help to take relevant maintenance strategies to reduce the early/ infant and wear- out failure rate. Because, evidently taking proper maintenance strategies actions supported by relatively better failure trend model or theories are expected to reduce the risk of failure further and extend or stretches the horizontally constant failure rate of the machines or equipment’s. Figure 2.1 reflects this idea. As it is indicated in the figure 2.1, Proper maintenance activities are expected to drop down the failure rate at the two extreme ends and stretches and reduce the shape of the middle part of figure 2.1.it implies the reliability and availability of the

equipment will be improved and at least its service life of an equipment or system will be sustained.

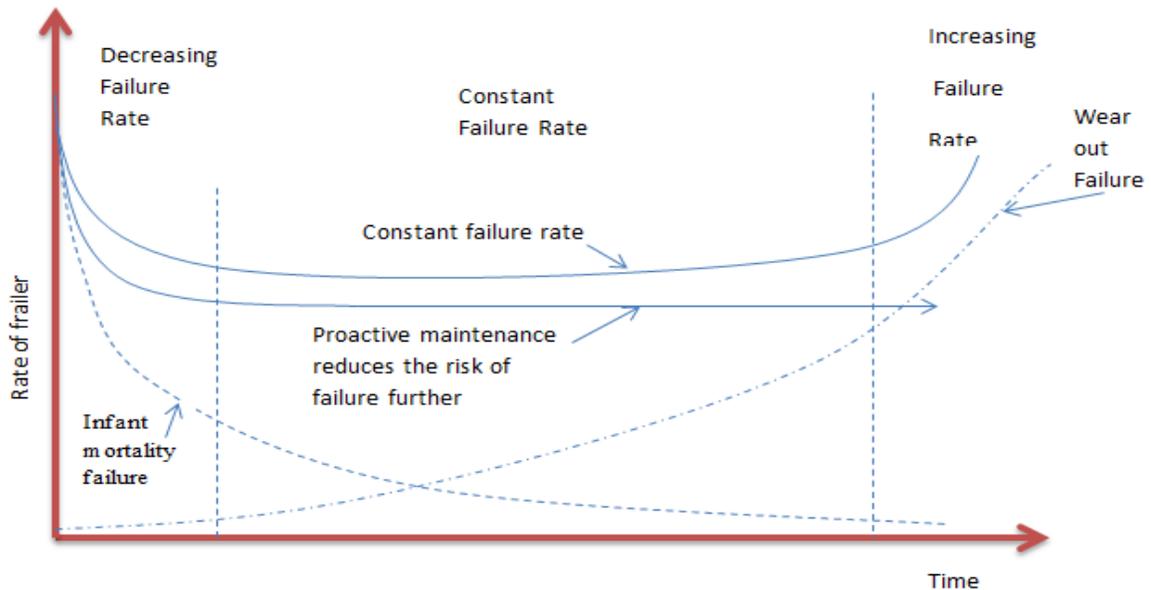


Figure 2.1. The Bathtub Curve Generated by Mapping the Rate of Failures

Source: Methodologies & techniques for advanced maintenance (Fedele L. 2011)

The notion of aging, which describes how a unit improves or deteriorates with its age, plays a role in reliability theory. Aging is usually measured based on the term of failure rate function. That failure rate is the most important quantity in maintenance theory, and important in many different fields .e.g., statistics, social sciences, biomedical sciences, and finance.

### 2.1.5 Availability

Availability has various meanings and ways of being computed depending upon its use. Availability is defined as “a percentage measure of the degree to which machinery is in an operable and committable state at the point in time when it is needed. In the same perspective is the degree to which a system or component is operational and accessible when required for

use (IEEE, 1990). This definition includes operable and committable factors that are contributed to an equipment/machine itself, the process being performed, and the surrounding facilities and operations. Moreover, availability has given various meanings and ways of being computed depending upon its use (Nicholas, 2010). Commonly known types of availability are: - Instantaneous (or point) availability is the probability that a system (or component) will be operational (up and running) at any random time,  $t$ . This is very similar to the reliability function in that it gives a probability that a system will function at the given time,  $t$ . Unlike reliability, Instantaneous (or point) availability is the probability that a system (or component) will be operational (up and running) at any random time,  $t$ . instantaneous availability measure incorporates maintainability information. This availability is given by probabilistically (Hosford, 1960).

#### **2.1.5.1 Inherent Availability**

Inherent availability is the steady state availability when considering only the corrective downtime of the system. It is defined as the expected level of availability for the performance of corrective maintenance only. Inherent availability is determined purely by the design of the equipment. It assumes that spare parts and manpower are 100 percent available with no delays. It excludes logistics time, waiting or administrative downtime, and preventive maintenance downtime. It includes corrective maintenance downtime. Inherent availability is generally derived from analysis of an engineering design. Inherent availability fulfills the need to distinguish expected performance between planned shutdowns.

#### **2.1.5.2 Achieved Availability**

The probability that an item will operate satisfactorily at a given point in time when used under stated conditions in an ideal support environment (i.e., that personnel, tools, spares, etc.

are instantaneously available). It excludes logistics time and waiting or administrative downtime. It includes active preventive and corrective maintenance downtime. Achieved availability is defined as the achieved level of availability for the performance of corrective and preventive maintenance. Achieved availability is determined by the hard design of the equipment and the facility. Also assumes that spare parts and manpower are 100 percent available with no delays. Achieved availability is very similar to inherent availability with the exception that preventive maintenance (PM) downtimes are also included. Specifically, it is the steady state availability when considering corrective and preventive downtime of the system. It can be computed by looking at the mean time between maintenance actions, MTBM and the mean maintenance downtime

### **2.1.5.3 Operational Availability**

Operational availability is a measure of the average availability over a period of time and it includes all experienced sources of downtime, such as administrative downtime, logistic downtime, etc. It is the probability that an item will operate satisfactorily at a given point in time when used in an actual or realistic operating and support environment. It includes logistics time, ready time, and waiting or administrative downtime, and both preventive and corrective maintenance downtime. The operational availability is the availability that the customer actually experiences. Where the operating cycle is the overall time period of operation being investigated and uptime is the total time the system was functioning during the operating cycle. The difference between achievable and operational availability is the inclusion of maintenance support. Achieved availability assumes that resources are 100 percent available and no administrative delays occur in their application (Nicholas, 2010).

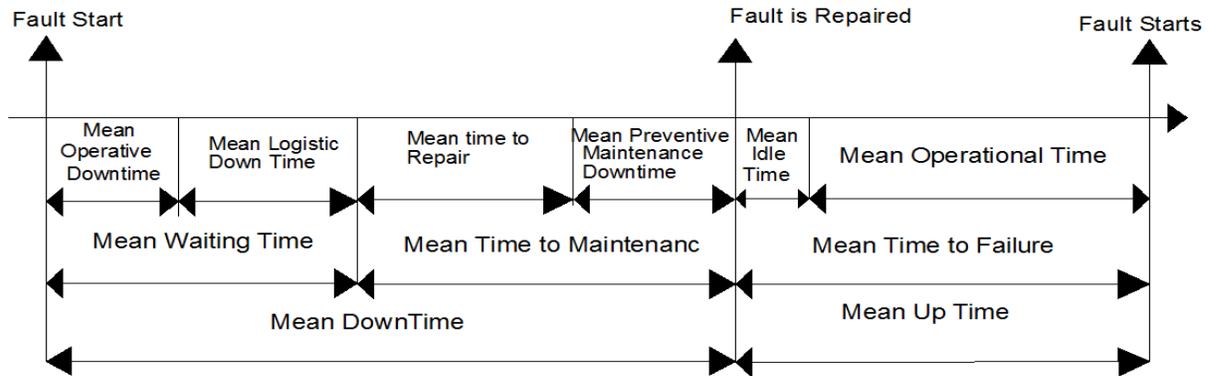


Figure 2.2. Mean up Time and Mean down Time of System or Machine

Source: Physical Asset Management (Nicholas, A. 2010).

Figure 2.2 clearly break through the immediate influencing factors for reduction of mean down time of equipment or a system and for the improvement mean up time of a system or equipment for the optimum availability of a quality product/service. Hence, as it is indicated mean down time is the outcomes of operational down time / such as operators, unhealthy bureaucratic process which comes from poor time and resource management etc. /, logistic down time /i.e. waiting for spare parts, lubricant oil, etc. /, the skills and knowledge of failure diagnosis in corrective action, productivity of maintenance crews and the optimum interval and duration of preventive maintenance (Nicholas, 2010).

In general the optimum availability of equipment is the cumulative effects of the maintenance effectiveness of an enterprise or a company. Hence, human factors/ labor skill, and commitment/, administration factors /job planning, work load management, time management, cost control/ and technical factors / equipment reliability, maintainability logistic support/ are key contributing factor for maintenance effectiveness. Consequently, guaranteeing maintenance effectiveness in an enterprise or company results optimum availability of product/services of a company or enterprise and take over the desired out

comes or profit in provision of quality service or product through in satisfying or exceeding customer satisfaction. Therefore, maintenance effectiveness cannot be realized in satisfactory level by optimizing only one of or some of these factors. Factors such as reliability optimization, routine maintenance optimization, job planning optimization, emergency response optimization, operator and maintenance training skill and commitments optimization, redundancy and parallel stand by repair pool equipment optimization, improved maintainability, spare part inventory optimization, etc. indeed, better commitment in one or some of the above factors will improve maintenance effectiveness and will resulted better availability of equipment or system. But integrated and inclusive improvements of all factors by taking into considerations of the existing conditions will results sustainable maintenance effectiveness. The final output from this is optimized availability of a system or systems (Nicholas, 2010). Therefore, the work of this paper is to study in filling gaps in the case company that is RESCo by careful or thorough investigation of the maintenance culture and actual availability performance in the maintenance trend of RESCo. Moreover, almost all researchers that have raised the above issues in their investigation are concentrated to only manufacturing or processes industries or institute. Consequently, the modern, proved optimized maintenance strategies that optimized all the above factors for maintenance effectiveness inclusively, which brought paradigm shifting about maintenance role in the overall effectiveness of a company are suggested investigated and implemented in many production industries and results salivating prize from the efficient and effective implementation of TPM and RCM.

### **2.1.6 Tools and systems used for maintenance management**

The use of the Computerized Maintenance Management System (CMMS) which is a computerized maintenance work execution system helping companies /enterprises to manage work orders, material and purchasing, has made the maintenance management easier, as companies Endeavour to improve its operations. The newer versions of CMMS also calculate the costs and repair history. The process, as a work order module, receives maintenance input, creates work orders and tracks work in progress (process). It also generates reports, like work status and equipment availability (Vineyard & Meredith, 1992:2649). The inventory module ensures that spares are kept sufficient and cost effective. It automatically generates reports and issues requisitions whenever quantities drop below a predetermined level (re-order point). A material reservation function additionally ensures sufficient stock is on hand for scheduled projects. The purchasing module generates purchase orders (POs) for stocked and non-stocked items, special orders and services. It tracks open POs and generates a list of those past due date. If buyers wish, they can access complete supplier and item order histories on demand (Stagnaro, 2001 :105). According to Singer (2002:34), organizations had to make a choice between the best breed CMMS or software packages that address a multiplicity of business functions such as an ERP system. According to a survey conducted by the Aberdeen group found demonstrated cost savings by 80 percent of organizations that switched to fleet management systems to Commercial maintenance management (MM) software is now widely used by machine fleets and truck fleets in the US and Europe. Furthermore, the investigation discovered that 13 percent improvement in machine utilization due to reduced breakdown rates, 11 percent reduction in maintenance costs, 12 percent increase in service organization

profitability; and improvements in operator compliance with defect reporting (Energy Sector Management Assistance Program, The World Bank, 2011).

## **2.2 Empirical Study**

Lukacs (2003) through his research argues that organizations with proactive attitudes to planning represent the world top organizations in terms of profits margin and return on equity. Research conducted by Shen Qiping (1997) in Hong Kong and UK revealed that public sectors in many countries have been experiencing a problem of not prioritizing maintenance issues, such as budgeting and resource allocation.

Maintenance has been considered as a non-productive support function and not as a core function, i.e. as a necessary evil, Bamber et al. (1999), Ralph (2000), Sherwin (2000), (Al-Najjar,2000a,2001). Maintenance cost usually consists of direct and indirect costs. Direct (visible) costs comprise factors such as man power, material, e.g. spare parts, Indirect (invisible) costs are all the costs that may arise due to planned and unplanned maintenance actions, e.g., lost production costs, accidents, etc., This is because the impact of the maintenance function can be found in many areas in the company such as production, quality, logistics, etc.(Al-Najjar, 2000a,2001). Dunn (1998) illustrated that when a breakdown happens, it is often easy to show that a lack of maintenance was responsible. But when breakdowns do not happen, it is not easy to demonstrate that maintenance had prevented them. It is easy to say that maintenance costs so much per year but not what is the gain of that maintenance, and how it can be measured.

Equipment maintenance and system reliability are important factors that affect the organization's ability to provide quality and timely services to customers and be ahead of competition, see Cooke (2000), and Madu (1999 and 2000). Coetzee (1999) showed that the

increased use of various methodologies, techniques, or philosophies to improve the effectiveness and efficiency of the maintenance function in the organization is a very important step to enable it to cope with the increased importance of the function. But since maintenance is a service function for production, neither the merits nor the shortcomings of the service rendered are immediately apparent, Pintelon and Van Puyvelde (1997). Dwight (1995) showed that it has not been made scientifically credible that there exists a link between the inputs to the maintenance process and the outcomes for the organization, due to the difficulties of establishing a causal link between actions and outcomes and the determination of organizational goals.

The importance of maintenance to a business strategy can be paradoxical, Dunn (1998) and McGrath (1999). On the one hand, the more maintenance contributes positively to the overall strategic goals of an organization the less noticeable as a value adding activity it becomes to top management. On the other hand, poor maintenance programs can obstruct the addition of value, retard the advantage of a capital resource, and destroy a business strategy. Appropriate performance measurement systems are crucial to ensure the successful implementation and execution of strategies, since measurement provides the link between strategy and action, Neely et al. (1995) and Schalkwyh (1998). Therefore maintenance plays an important role specially those industries like RESCo which engaged in rental and sales of different machinery in present market; since those company uses after sales service as a strategy for computation.

## **CHAPTER THREE**

### **RESEARCH DESIGN AND METHODS**

#### **3.1. Research design**

Descriptive type of research design is adopted to describe the maintenance practices of the company through an interview to CRC manager and General Managers of RESCo, and through observation and review of secondary data.

#### **3.2. Research Approach**

According to (Crompton and Jones, 1988, Bryman, 1988) it is difficult to study organizations without using both quantitative and qualitative approach. I found that a combination of quantitative and qualitative approach is appropriate, since some features of the maintenance practice is expressed by numerical; and the quantitative approach helps the researcher to examine to know frequency of maintenance failures, cost of spare part and the like and also some features of the maintenance practice are also expressed qualitatively like work procedures employed, types of maintenance exercised, and goodness of maintenance plan.

#### **3.3 Population and Sampling**

##### **3.3.1 Target population**

The population of the study is General Managers of RESCo, supervisor of CRC, senior technician of CRC and rental service users (customers) in Addis Ababa head office employees & repetitive customers which represent the population of CRC staff which are 28 and 8 repetitive customers.

##### **3.3.2 Sampling Technique**

For the purpose of this study, both stratified random sampling & purposive samplings are used. Purposive sampling used to select people with desired qualities and experience. General

Manager of RESCo and CRC Supervisor will purposively sampled due to the information they have by the virtue of the positions they hold. The study use stratified random sampling techniques for CRC staff and repetitive customers. Stratified sampling will use to achieve representation of the respondents. The respondents' stratify on the basis of their position. It is believed that the sample taken is representative of target population. I believe the sample plan to take is representative of target population.

### 3.3.3 Sample size determination

According to Muganda (2003), a sample of 10-30% is good enough, if samples are well chosen and the elements in the sample are more than 30%. I take 16 respondents i.e. near to 39% which is indicated below in table 3.1 from the total population of 28 CRC employees and 8 repetitive customers. Therefore, in this study the sample size are 10 employees and 4 repetitive customers are proportionally selected from the five strata and 2 top management officials with total of 16 respondents in the survey.

Table 3.1 Stratified proportional sample size

<b>Group</b>	<b>Population Size</b>	<b>Sample size</b>
Top Management	2	2
Senior Technician	8	2
Technician	9	4
Junior Technician	9	4
Repetitive customers	8	2
<b>Total</b>	<b>36</b>	<b>16</b>

Source: Staff and customer profile

### **3.4. Data Collection Tools and Procedures**

#### **3.4.1 Data Collection Procedures**

Approval of the study and request letter to get necessary support from the respected sample company will be first obtained from AASTU; Dean Office. Permission to collect relevant data from the RESCo through the General Manager to component rebuilding center department head. After the permission get the researcher then distribute questioner based on strata and randomly

#### **3.4.2 Data Collection Tools**

This study conduct through the collection of both primary and secondary data. With regard to primary data, the data collected through semi- structured interview and observation with top management of RESCo, Technique staff and CRC repetitive customers to get in depth understanding of the organizations maintenance working principles, procedures and methods and it involves oral verbal communication to understand the working practices of maintenance Strategies employed in RESCo and Secondary data are obtained through review of the organization's, maintained machine history, annual and quarterly report, income statement, books, articles, literatures, journals, staff and customer profile, websites and other available sources to answer frequent Failure of machinery.

### **3.5 Data Analysis and Presentation**

Data found from the primary sources (interview and observation) is analyzed against the theory and describe in details and the secondary data found from the review of different documents are presented by frequency, percentage and tables to show (examine), frequency of machine failures, downtime amount , spare and maintenance cost and the like.

### **3.6. Validity and reliability**

The validity of instrument is the extent to which it does measure what it is supposed to measure. According to Mugenda and Mugenda (1999), Validity is the accuracy and meaningfulness of inferences, which are based on the research results. To increase the validity and reliability of the data collected using secondary data, interview and observation; I seek the data based on the objectives of the research. In addition, the researcher ensured that the interview questions were not leading. The interview question is viewed by peers and supervisors who offered objective suggestions on areas to improve on.

### **3.7 Ethical consideration**

I explains to the respondents about the research study and it is used only for academic purposes. I made clear that the participation is voluntary and that the respondents are free to decline or withdraw any time during the research period. Respondents would not coerce into participating in the study. The participants would have informed consent to make the choice to participate or not. They would be guaranteed that their privacy are protected by strict standard of anonymity.

## **CHAPTER-FOUR**

### **DATA PRESENTATION, ANALYSIS, AND INTERPRETATION**

#### **4.1. Introduction**

This chapter presented and discussed the main findings of the study. Under this topic, the RESCo maintenance practice of weakens and strength of the company would describe.

#### **4.2 Maintenance Strategies of RESCo**

According to the case supervisor at CRC both preventive and corrective maintenance are being exercised. Preventive maintenance is performed for the purpose of reduction catastrophic failures of the machines which results higher direct and indirect maintenance cost. Corrective maintenance activities are performed for failures that are related to unplanned failures, accidental failures. There are different phases of preventive maintenance activities in RESCo based on the manufacturer's recommendations. As it is depicted in the figure 4.1, Machinery can be drawn out from the regular work service either for corrective maintenance or preventive maintenance. If the machinery are rending the regular service whiles its failure (site call) first servicing or restoring will be done by field mechanics. If failure is minor and can be restored by field mechanics it will be returned to its regular service. But if field mechanics is not successful and the failure is series it will be brought to the CRC.

In the case of preventive maintenance, after the predictive testing and inspections, if no failure is observed it will return to regular service. On criticality of observed failure, either it will recalled after giving service of its peak hour or it will be maintained immediately.

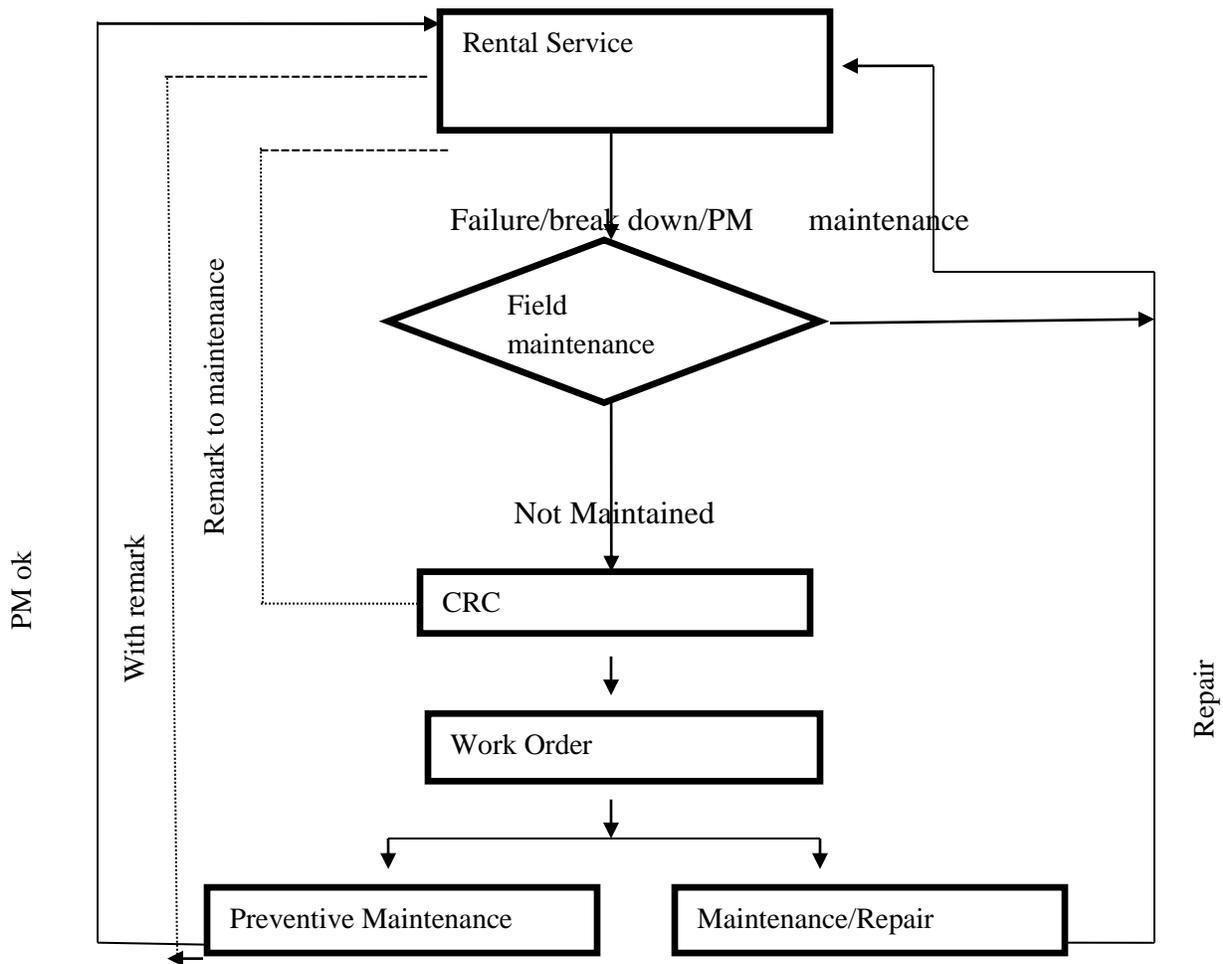


Figure 4.1. General Maintenance Work Flow of RESCO

Source: RESCO Maintenance work flow procedures

Since the objectives of this paper is to investigate maintenance practice of RESCO; Data that reflects the maintenance practice and availability of machinery, such as frequent failure problems, failure rate, technical and operational availability, actual preventive maintenance in time based, the ratio of corrective maintenance and preventive maintenance, site calls, direct and indirect maintenance cost are kept in touch for the data collection, analysis and presentation to figure out maintenance practice and availability of machinery.

Hence, data analysis and presentation started by examining availability performance of machinery. The purpose of this data is to figure out the availability and go through the causes for this availability of machinery in present conditions such as the maintenance policies and strategies, present maintenance crews and available resources. In other word it is to illustrate how the availability of the machinery with the time unit measurement of days and hours in a year of 2009 E.C.

### 4.3. Frequency of Machines' Working Date/ Month

Machinery “ monthly performance report of RESCo gives breakthrough of the following information that is helpful to figure out performances of machineries Such as, service date of each machinery per month, average working hours of Machinery per month, revenue generated by each machinery per month etc. Average working hour of machinery per month is derived by multiplying the number of days working per month multiplied by average working hours per day. Therefore; the intention in this phase of the overall availability of all functional machinery is in the time measurement unit of date. This is by using the maximum available and reachable performance report. It is observed that, the mean working days of the machinery are approximately 16.8 days per month, with the standard deviation 10.9 and the range 30 days.

Table 4.1. Sample machine availability per month

Machine Model	Machine Working Date per Month												
	Jan.	Feb.	Mar.	Apr.	Ma.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec	
D8R Dozer		5	4	1	1	4	2	0	5	3	7	9	8
140H Grader	1	3	1	8	9	5	6	0	4	7	8	0	
324D Excavator	5	5	5	6	1	4	8	7	4	6	5	3	
Working date	0	1	2	3	4	5	6	7	8	9	10	11	

Frequency	3	5	1	2	5	6	3	3	4	2	0	0
-----------	---	---	---	---	---	---	---	---	---	---	---	---

Source: RESCo machine follow up data sheet sample

This means majority of the machinery do not give continues service even for acceptable period or length in comparison with planned time. In other word, if a machinery give rental service let's say 28 days in the first month, 3 days in the second month, 1 day in the third month, 10 days in the fourth month, 1 day in the fifth month etc. then it merely implies that the machinery has frequent failure problem may be because of poor design of its components or its systems, operators problem, poor maintenance strategies or maintenance qualities and so on that should be minimized. Whereas, if machinery give rental service continuously let us say 28, 29, 30, 27, 30, 28, 29 days in a respective months in the year, then it shows there is a healthy conditions of quality maintenances and strategies/policies, good operators, convenient working condition quality design of machine components or systems and so on that should be encouraged and took as bench marking for others to improve their performance. Table 4.1 indicates machineries failure frequency and prolonged down time or slowed maintenance reactions to improve their availability. The reason might be factors that are mentioned earlier and many others. For that reason, direct implication of this table is majority or almost all machinery are performing very lower than that of their designed performance level. Even though machinery are in the infant mortality phase, they are not available in reasonably.

#### **4.4 Availability performance of machinery**

Figure 4.2 is developed by taking the mean availability date of the machinery from the monthly reports. The mean availability is derived by summing the whole machinery working day/month of all machinery and then dividing by the number of functional machinery in each

monthly report. Hence, it did not include machinery which has zero working days in each monthly report.

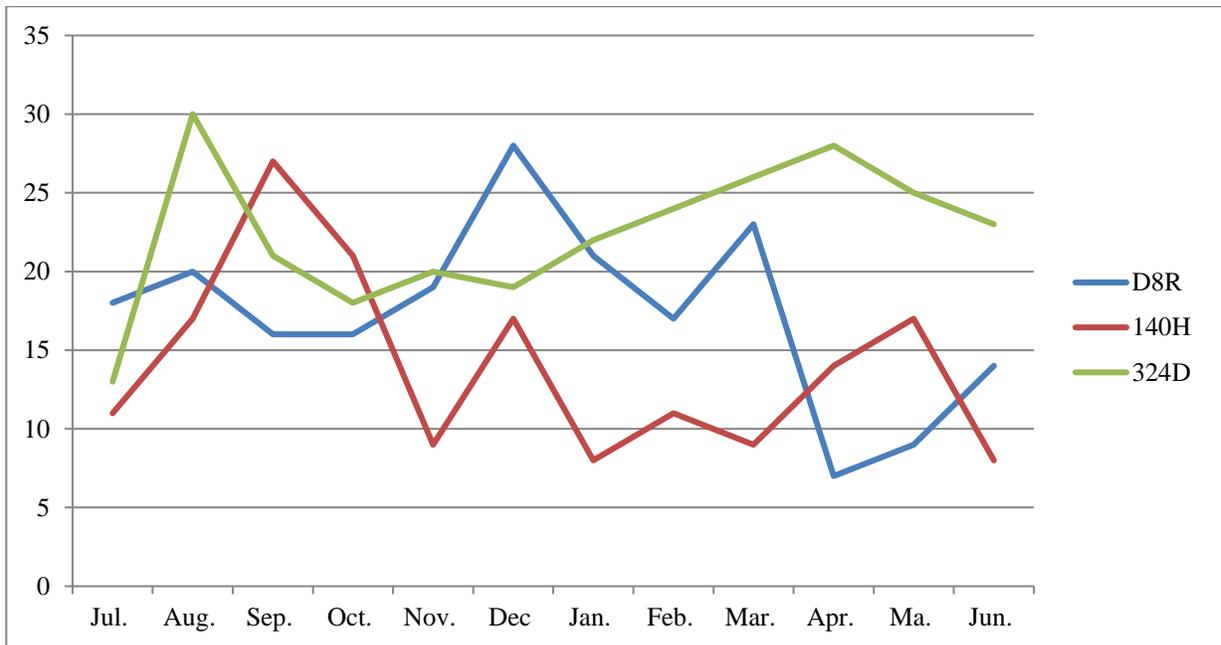


Figure 4.2 Average availability Working Date of machinery for company in 2009 E.C

Source: RESCo machine follow up data sheet compiled for the period of 2009 E.C

In general, figure 4-2 indicates that the mean availability date of machinery is slightly higher than half availability from full availability. The implications of this availability figure is the enterprise is losing slightly less than half of its revenue that could be generated by the machinery if machinery were 100 % available in the current situation. In addition, figure 4-2 indicates inclination or propensity of the availability. It is dropping down rather than improving throughout the year.

#### 4.5 Average Downtime and availability

To measure and analyze downtime and availability the following method are used: RESCo has nearly 75 functional different categories of machinery (mining, construction and power

generation). Since data recording method is manual and there is no summarized data which shows key performance indicator, it is very difficult to include all machinery in the analysis of each machine's downtime for a long period. Therefore, taking a sample is found as the only alternative choice. Yet, taking samples for a long period more than a month is also found very awkward because of their manual recording system of daily downtime by control sheet. I took machinery which is assigned to one maintenance crew (group/team) as a sample for my measurement of the availability. The maintenance crews are grouped into case teams. Each team is consisted of senior mechanic, mechanic, junior mechanics and trainee mechanics.

Concerning to the machinery assignment, all machinery are assigned equally, since each maintenance team are considered to have equal knowledge and skills. Based on the strength or the status of machinery, all machinery are generally grouped into three groups: the first stage or group includes all machinery those are weak in strength and the daily working hour is up to 6 hours, nearly 40 machinery, are in this stage. The second stage includes machinery those have medium strength, full time functional 8 hours per day. The third stage includes all machinery that is fully strong and work in anywhere and in full time coverage. The third group has 5 machines. Based on these factors all machinery is assigned equally from each groups to each maintenance teams. Therefore in this sample team like all other maintenance case team, all machinery from all the three stages is assigned. Furthermore, the daily control sheet that is used by all maintenance team is not in such a way that is mentioned above but it is grouped in the models of the machines. The aim of this activity is to estimate the current availability status of the machinery and to visualize how the availability of the machinery just at maintenance level. To do this observing the daily control sheet of machinery at maintenance level is helpful. the daily control sheet is used as report for controlling what

activities are done by the maintenance crews in each day and it also tells the time of entry for maintenance and the time of exit and ready for service delivery of each machinery which are in the maintenance team control.



Figure 4.3 Down time demonstration

Source: RESCo down time recording Chart

Figure 4.3 total down time of machinery into technical downtime /maintenance, set up, logistic down time and any preparation activities for maintenance action / and operational downtime /such as idle time of machinery because of operators, discrepancy of designed performance and actual performance down time or all down times after machinery maintenance works completion. Whereas technical down time includes all down times related with maintenance works. And it can be divided into two major groups. Such as, maintenance time spent for all restoring activities and maintenance time for rework of restoring of the function of machinery.

Hence, availability can be computed in two different stages for the purpose of this work. Availability at the end which is operational availability shown and availability which include only technical down time. This is to find out performance losses by operational loss/idling by

machinery operators, etc. Because operational availability is less than availability of machinery just after the technical level the difference of these two availabilities gives the percentage of losses by operational loss. That is called performance losses in overall equipment effectiveness measurement. Operational availability is measured by taking machinery monthly hours from the monthly performance report. Average daily working hour per month in 2009 E.C is tabulated in the annex. Although the average planned daily working hour of machinery is 13 hour and probable (acceptable) down time is an hour in daily operating hour of machinery which is 11 hour, from monthly working hour reports of machinery for 2009 E.C, the average actual working hour of machinery/date is 7.2 hours.

Operational Availability =  $\frac{\text{up time}}{\text{operating cycle time}}$

Therefore, based on this result operational availability is 55.4%. So far it has been computed that availability of machine just after maintenance work completed is about 63.9%. This implies that the difference of the two availabilities is about 8.5% which is lost availability by operational down time. Performance is measured as the ratio of actual service time of machinery to the planned service time of machinery. Therefore, performance is about 91.5%. Moreover, maintenance quality is computed from the machine history card of sample machinery. The result is tabulated in the annex table 4 indicates that maintenance quality is about 82.63%. Therefore, the overall equipment efficiency (hereafter OEE) measurement of RESCo is computed as follows:

OEE= Availability x Performance x Quality

OEE = 61.9 % x 91.5% x 82.63%

OEE = 48.05%

However the acceptable world class values of availability is greater than 90%, performance is greater than 95% and rate of quality is greater than 99% (Sharma, Vishwas, Dr.H.B.Khurasia, & Shikarl, 2007). Thus OEE should be greater than 85%. This shows OEE of machinery is about half of universally standard value of OEE. Table 4.2 depicts, how much time is average down time, average operational time and average availability of the sample machinery for all the three models of machinery that are assigned to the sample team per day in May 2009 E.C. Similarly, results obtained from the samples which are presented briefly in table in table 4.1 shows numerical measurement results which are well-matched to the previous presentations in the performance analysis.

Table 4.2 Average down Time and Availability of the Sample machinery /Day in May 2009

Performance indicators	324DExcavator(40 machine)	140HGrader(30 machine)	D8RDozer(5 machine)	Average
Average Down time / day	161	173	255	196.3
Av. Operation Time / Day	241.88	281.72	590.33	371.31
Availability	60.02%	61.92%	69.86%	63.9%

Source: RESCo Down time & operation time recording sheet for May 2009 E.c

Table 4.2 shows the average operation time, average down time and the average availability of the sample machine which is almost similar to the average availability derived from the monthly report displayed in figure 4.2 in the above. Again based on this observation of the daily control sheets of machine for a month, the daily downtime of those sample machines is computed by taking the time difference of the entry to the maintenance service and exit from the maintenance service for repairing of failures or for preventive maintenance. However, the

time of waiting for maintenance during the night shift is not considered as downtime because it is planned shutdown time of machines. The waiting time is considered as downtime only if the machines are out of service. The standard working hours for each machine is 13 hours per day. Therefore, if machines are waiting in the maintenance section/site for maintenance service in this time interval, the waiting time is considered as down time for maintenance service /technical down time/.

Most Japanese equipment system are designed and manufactured for more than 90% availability. Which means any system or equipment must be available at least for 90 % in its life cycle. But, the average availability on the sample machine is 60.02 % for 324D Excavators, 61.92 % for 140H Grader and D8R Dozer 69.86% for construction machine which is lower than the stated standard earlier ( $\geq 90\%$ ). Then the average availability is about 63.9% by taking the average of these three models “ availability results. Table 4-3 is developed from machine that have 30 working date from the monthly performance report of machine in 2009 E.C.

Table 4-3 Average Daily Revenues per machine that have 30 working date/month.

Types of machinery	Average Daily Working hr	Average Daily revenue/ machine
D8R Dozer	8	14,400.00
140H Grader	8	10,400.00
324D Excavator	8	10,400.00
<b>Average</b>	<b>8</b>	<b>11,733.33</b>

Source: RESCo machinery rental price list sheet

From the monthly report of machinery performance, by considering machinery that have 30 working days per month, table 4.3 shows the average daily revenue and table 4.2 shows the

average daily down time of the sample machine is converted to the number of machine based on standard daily working hours which is 8 hour per day.

The average downtime of the three models (75 machines) = 196.3 hours / day.....R<sub>1</sub>

A single machine working hours per day which = 13hours.....R<sub>2</sub>

The average revenue/machine/day = 11,733.33 Birr.....R<sub>3</sub>

From R<sub>2</sub> & R<sub>4</sub> of down time machinery = 196.3hours/13hours=15/day.R<sub>4</sub>

Normal working hours =8 hours.....R<sub>5</sub>

Financial loss from a single sample machine = (15 X 1733.33)/8 hour = 21,999.94birr

(from R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub> & R<sub>5</sub>).

Then if we assume that the same down time for all teams, since all teams are under the same circumstance, to predict the daily loss of revenue multiplying this result by the number of teams in RESCo will result the estimated daily loss. Obviously, there is no demand problem for the rental of machine, but the very visible problem in this company to give optimum service and generate optimum revenues by all machines. Therefore, unpleasantly integrated maintenances activities are forced RESCo to pay values every day and resulted cash trapped problem. It's very low availability of machine because of the frequent failures of machine and delayed maintenance service. Therefore for optimum utilization of available of machines, improving the preventive maintenance culture is indispensable. Hence, maximization of the up time or mean time between failure and minimization of meantime between failures or down time of a system are the two alternatives. Therefore, considering all the factors that are related to these two alternatives in the study of the maximizations of availability is very important.

The first alternative is maximization or stretching the mean time between failures. Obviously, this could be achieved through different methods like studying the failure mode effect analysis, identifying the vital few trivial many failure problems, then cause and effect analysis and taking optimum preventive maintenance interval are some of the major solutions. The second alternative for the maximization of availability is reducing the mean time to repair or down time to the optimum level. This could be also achieved by avoiding unnecessary delay of maintenance work by removing unnecessary wastage of time, resource, energy, logistic delays minimizing diagnosis period for finding the exact failure of machines, poor management delays, quality of maintenance/i.e. minimizing the number of rework because of poor diagnosis of failure and improper maintenance which is related to the skills of the maintenance crew/ ...etc. and shortage of relevant resource also could be factor for prolonged of down time or mean time to repair. It also related to the emphasis given the roles of maintenance and their commitment by the top and middle managers.

Therefore, to take the first alternative to maximize or improve the availability of machines, it is better to go through in the investigation of failures problems thoroughly. To stretch the mean time between failures( MTBF) of machines and to gain the designed performance, in reduction of direct and indirect maintenance cost, clearly it is prerequisite to understand the functions and failure mode and consequent of failures then to implement preventive maintenance activities effectively. A stretched objective of maintenance department and other related departments should be to minimize loss in strong commitment and motivation. To do this again it is very imperative to have proper skilled and continuously trained and motivated staff members beside the availability of relevant tools and management in the working environment. Because, obviously the optimum integration of all this results to optimize the

productivity of machines, equipment, employee, management and RESCo as a whole. Hence, to look for maximization of mean time between failures (MTBF), the first step is filtering out the frequent failure problems of components or systems of machines and through analysis with proper solution is mandatory.

#### **4.6 Identifying frequent failure problem using ABC analysis and pareto chart**

Figure 4.2 and 4.3 in the analysis of availability date and average downtime, and its indirect cost, It is clearly shown that the mean availability date is 19 date per month in 2009 E.C. this is because of frequent failure problem and delayed response to restore its functionality. Based on this observation one may ask, are there failures which occur frequently that holds 80% of the cost of spare part but 20% in causes of failure? The best commonly known tool for answering this question are ABC analysis or Pareto or 80/20 rule analysis. This section worked out on filtering out failures that are responsible for 80% of downtime and consequently for 80% of spare part cost by the aid of Pareto Analysis. Moreover, it went through an ABC analysis to classify failures that are in charged for labor and spare part cost. Pareto Analysis /sometimes referred to as the 80/20 rule and as ABC analysis/ is a method of classifying items, events, or activities according to their relative importance. It is frequently used in inventory management where it is used to classify stock items into groups based on the total annual expenditure for, or total stockholding cost of, each item. Group A usually represents 10-20% of number of items and 50-70% of the projected cost birr volume. Group B represents 20% of items and 20 of the birr volume. Group C is 60-70 of the items and 10-30% of the birr volume. For ABC analysis the following activities are performed; types of failures, date of failures, direct cost /labor and spare part cost/ and durations for maintenance of sample machine are recorded from the machine history file. Then each failure is grouped to

their major groups or sub section of a machine body. Finally from ABC analysis the following result is obtained; figure 4.4. Represents as 10-20% failure items are projected 50-70% labor and spare part costs; which are under A class. 20% of frequent failure worth 20% labor and spare part cost volume that is B class; and Group C; which are 60-70% frequent failures that effect for 10-30% of labor and spare part cost volume.

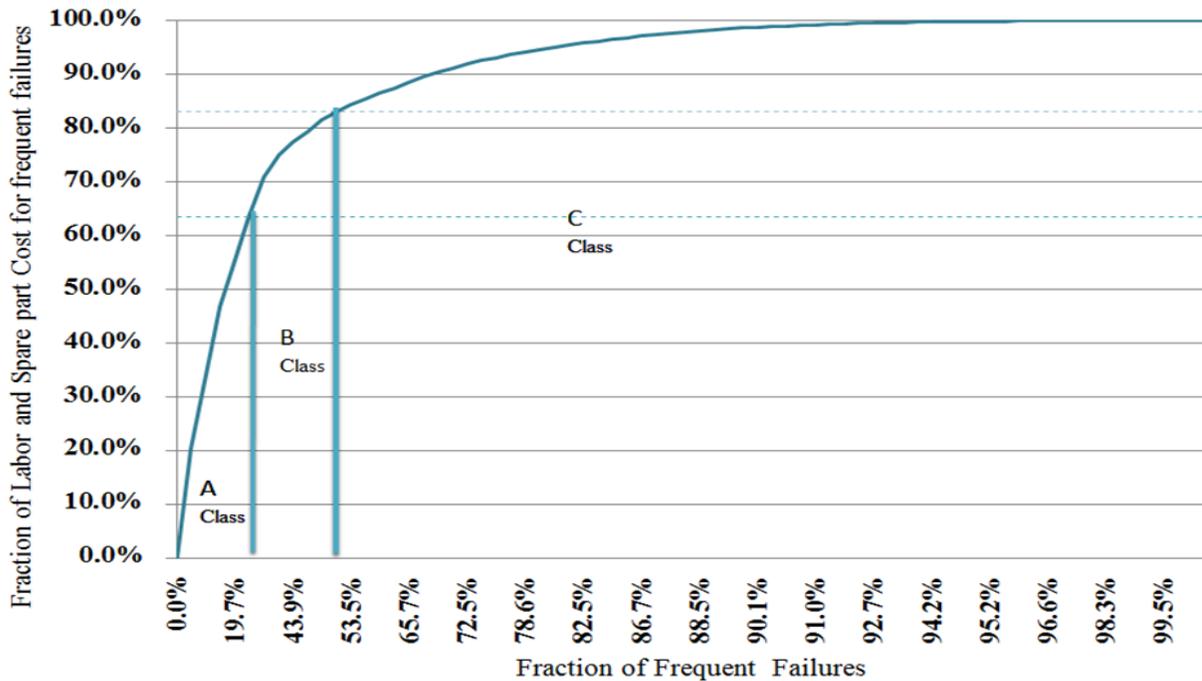


Figure 4.4 ABC Chart for Frequent Failures Versus Labor and Spare Part Cost volume

Source: RESCo maintenance failure, labour and spare part cost data sheet

Figure 4.4 presents that 63.52 % of the labor and spare part cost of sample machines are caused by 19.85 % of frequent failure items which are under A-class and 19.53% of the total labor and spare part cost is resulted from 30.02% of frequent failure items that is under B-class. Likewise, 16.95% of cost volume is caused by 49.95% of frequent failure items that is under C-class. Based on the data report in the Annex table 1 failure which are failed in group

A is engine failures, starter failures and crank shaft failures. Group B failures are Brake system, compressor, clutch system, friction disc and bearing failures. Group C failures are hydraulic system, door, lever switch, etc. failures.

Based on sample machinery history and from ABC analysis, in current maintenance working conditions failures which effects for higher downtime of machines and frequent failures are failures which are grouped in the above explanation of ABC analysis based on their frequency of failure and birr volume. So far it has been displayed the results of ABC analysis for the sample machines. In more broader sense, failures which occur frequently that holds 80% of the cost of spare part but 20% in causes of failure categories is shown in the Pareto analysis.

Pareto Chart of spare part Cost versus Failure Categories

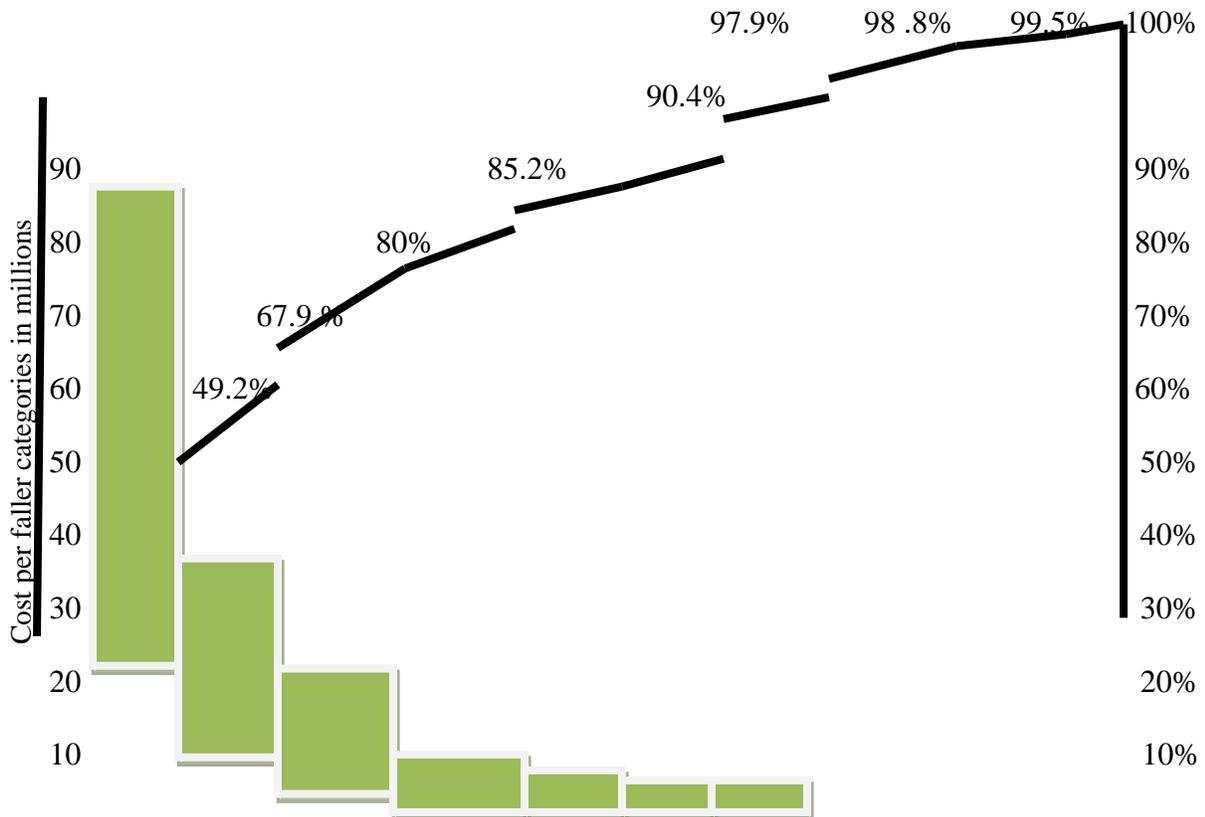




Figure 4.5 Pareto Chart for Failure Categories and Spare Part Cost Consumed in 2008-2009E.C

Source: Failure recording data sheet & spare part consumption data sheet for the period of 2006-08 E.C. Each spare part that are consumed for maintenance of machinery are grouped into their major sub class of machinery parts by the aid of the components part number and manual of machinery with their corresponding cost of spare parts. As it is indicated by figure 4.5, failures that are accessory components, Engine components and electrical system components holds the vital few trivial many contributors of for the frequent failures and consequent cost or un productivity of machinery. Fuel system components, hydraulic system components, front and rear axle components and gear box components hold the next contributing stage in existing maintenance environment of RESCO.

#### 4.7 Examining Preventive Maintenance intervals

So far it has been figured out vital few and trivial many failure problems which resulted poor availability of machines. Once it has been identified in such manner the next phase was detail analysis for such major contributing factors of machines frequent failure separately. But Cause and effect analysis and failure mode effect critical analysis /FMECA/ of each failure requires efficient and efficient data collection and automatic restorations. In other word computerized maintenance management system /CMMS/ and qualified workers that have a

capacity of predicting the rationalized prediction for the causes of such failure is essential. Unfortunately, the existing staff is embraced by the traditional method of maintenance and even there is no proper data generation and handling system. Therefore, further study on these failure is blocked by this stage.

However, preventive maintenance is also one contributing factor for such conditions of machinery. Hence, examining the maintenance working habit is very important to give an answer for the question, does all this failure happen in the proper preventive maintenance as recommended by machine manufacturer or not?. Because maintenance activities, are one of the major contributors for elongation or shortening of mean time between failure (MTBF) beside operation environment and operator skills, attitude or the feeling of motivation and ownership for the machines. In other words, control of maintenance quality, preventive maintenance and type of maintenance is compulsory rather than simply implementing machine manufacturer recommendation. And availability of optimum spare parts which is the result of strong integration of maintenance department and finance and purchasing department based on reliable and appropriate information flow is some of the most contributing factors to this failure propensity and prolonged down time.

Hence, to go through preventive maintenance, as it is mentioned in the chapter of organization profile, RESCO maintenance department is being implementing two types of maintenance policies or strategies. The first is breakdown maintenance and the second is preventive maintenance. Here the focus is given to the preventive maintenance activities. There are two classes of preventive maintenance inspections which are time based & manufacturer recommendation; 250 hr (1 month), 500 hr (2 month), 750 hr (3 month), 1000 hr (4 month), 2000 hr (1 year), 4000 hr (2 years), 6000 hr (3 years) and 10000 hr (7 years).

To observe how the preventive maintenance is being exercised according to the time and manufacturers recommendation and to answer questions such as what is preventive maintenance cycle? In other word after how many activities one preventive maintenance activities is repeated itself. And is there a trial to optimize these preventive maintenance intervals? The sample machines history file has been used to track maintenance activities time interval performed in the years from 2008-2009 E.C. Based on the actual versus scheduling preventive maintenance comparisons as it is clearly indicated in figure 4.4, there are two major types of faults regarding respecting scheduled preventive maintenances. Firstly, it is not respected the prescheduled time and manufacturers recommendation. Secondly it is not respected the cyclic sequence of each preventive maintenance type. In RESCO every 250 hours preventive maintenance is represented by P, every 1000 hours by A, every 2000 hours by B. But if all preventive maintenances were being exercised in respecting their scheduled time or manufacturer's recommendation, the cyclic and the interval would be P P P A P P P A P P P B for new machines or in other words every 3P inspection A inspection will follow and every 2A inspection B follows; then the cycle repeats in such a way. Obviously, preventive maintenance must be performed in optimal regular intervals and must be scheduled for optimization by modification of preventive maintenance intervals in thoroughly investigating the failure trends of machinery's component to minimize abrupt and frequent failures. Consequently, improve down time and availability of machines. Taking as reference the first preventive maintenance performed in the considered years (2008-2009 E.C), and tracking when the next preventive maintenance had been performed based on the time and manufacturer recommendations; Preventive maintenance in RESCO is not being exercised in proper way. This is by assuming that maintenance works recorded in the history file of each

machines are presented the failure rate of each machines per month. Hence, with this assumption the failure trend or failure rate per month looks like shown in the figure 4.5. Moreover table 4.4 can be also a witness or confirmation for the higher failure rate of machines which came from uncontrolled preventive maintenance activity in the RESCo. According to monthly reports, as it is leap forward maintenance department is congested or machines in corrective maintenance rather than preventive maintenance, and the average site call is about 596 per month in this time period which is very recent.

According to (Wireman, 2005) the effectiveness of the preventive maintenance program is measured by the level of reactive maintenance that is performed. An effective preventive maintenance program will reduce the amount of corrective maintenance work to less than 80% of the total labor expended for all equipment maintenance activities. In other word the ratio of reactive maintenance will be 20% and then 80 % maintenance work will be corrective maintenance. if more time is being spent on unplanned activities, then a re evaluation of the preventive maintenance program is required. Because, the level of reaction maintenance has an immediate impact on the availability of equipment, spare parts and purchasing capacity of the enterprise. Unless maintenance activities are proactive (less than 20% unplanned weekly), the stores and purchasing groups cannot be cost effective in meeting equipment maintenance spare parts demands. Thus, for spare parts to be on hand at least 95% of the time for the stores and purchasing systems to support equipment maintenance activities effective preventive maintenance is essential. Table 4.4 show average monthly corrective maintenance percentage is about 57.2 % excluding field maintenance work which is too far from the recommended; hence the current preventive maintenance is not effective at all.

Table 4.4 Corrective Maintenance versus Preventive Maintenance and Monthly site Calls

Months	Correctives Maintenance per month	Preventive Maintenance per month	Total	Percentage of Corrective maintenance	Monthly site calls
July,2009	1108	767	1875	59%	575
August, 2009	1053	756	1809	58%	595
September,2009	1081	785	1866	58%	597
October, 2009	1098	847	1945	56%	596
November,2009	1123	910	2033	55%	615
<b>Average</b>	<b>1092.6</b>	<b>813</b>	<b>1905.6</b>	<b>57.2</b>	<b>595.6</b>

Source: Monthly Troubleshooting report format

Up to now, it has been demonstrated that RESCO is running in poor availability and very high down time as result of frequent failure rate and delayed maintenance reaction. This makes to miss machine design performance advantages and less productivity of the machines and manpower resources. The existence of RESCO in this situation, forced to pay values like running in less profit relatively as showed in figure 4.6. As it has been presented in the figure the role of maintenance in running cost is about 36 %, gas oil /fuel cost hold nearly 42 % while administrative general expense embraces 7% the remaining 15% of running cost RESCO is expense for operators and other supportive staff members. Figure 4.6 presents detail annual running cost of RESCO in 2009 E.C .There are two major points that are clearly visible from the figure. The first point is the company is running in relatively less profit. The second point is maintenance cost is the second largest cost of the company running cost which agrees with idea mentioned in the literature review part of maintenance role for overall running cost of the company. Moreover, maintenance cost percentage is in the estimated percentage cost range of maintenance which is 15-60 % depending on the type of industries. Therefore, RESCO facing cash trapped problem because of its inefficient utilizations of its assets/ machines.

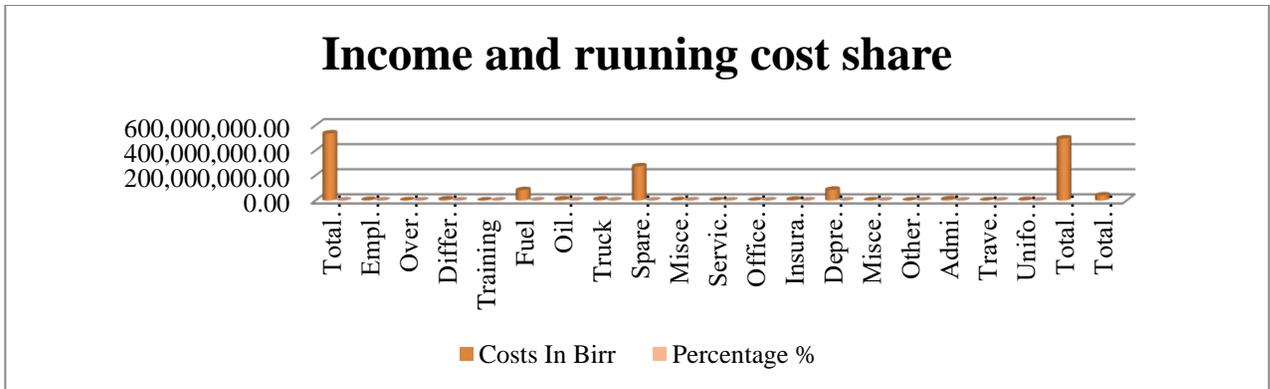


Figure 4.6 Income and Running Cost Share In 2009 E.C

Source: Income statement of RESCO 2009 E.C annual report

As it is illustrated in this section, RESCO is performing a traditional way of managing the maintenance department, it looks that relevant emphasis is not given to the maintenance sections, as it is the back bone for the sustainable existence of the company; the company is not snatching the right advantages from the proper maintenance roles. Hence, there should be paradigm shifting in working culture, data collection, generation, handling and data retrieving for analysis. As it is illustrated in the previous sections of this work, this frequent failure of machines and delayed maintenance responses which resulted low availability of machines is not because of one section or division weakness or failures in horizontal or vertical hierarchy of the company. It is cumulative effect of all factors which have traditional nature of performing direct or indirect value adding tasks for contribution of productivity of RESCO. Therefore, to achieve the established targets in the mission and visions of RESCO, there should be modern maintenance cultures that are laid on strong foundations. Because, this make RESCO cop up in the current problem and before the computations become strive.

#### **4.8 Finding of data collected analysis**

So far it has been gone through the quantitative and qualitative analysis of secondary data. In addition non-structured interview with maintenance professionals and middle managers are implemented to extract data about motivation of the maintenance staff members/human factors/. Moreover, observation of the working environment and the working culture /technical factors/ which they are being implemented. Therefore, finally reached to the following findings which are summarized as follows:

- ✓ From the working date frequency of RESCO in months, about 45.8% are less than 17 working date per month, 27.8% are between 17-27 including and the remaining 26.4% are 28-35 working dates. Moreover, working date frequency pattern shows machines have faced two major problems: frequent failure problem and stretched downtime which are resulted from ineffective and efficient preventive maintenance culture.
- ✓ Consequently, the frequent failure problem and prolonged down time resulted for machines availability about 63.9% at technical level and 55.6 % at the end or operational level.
- ✓ According to the failure rate analysis of sample machine, the average failure rate is about 4.11 times per month.
- ✓ From the preventive maintenance pattern analysis, preventive maintenance is not being performed as per the schedules of the manufacturer recommendation, it looks implementing randomly.
- ✓ The main contributing factor for running in shortage of spare part which is the common claim of the company is ineffective preventive maintenance; the prove of this statement is the observation of the ratio of preventive maintenance and corrective

maintenance in the monthly maintenance reports which shows mechanics are being busy by corrective maintenance rather than being busy by preventive maintenance work.

- ✓ However, maintenance cost holds the second place from the running cost of RESCO.

All this are very essential for the effective preventive maintenance activities. As it is indicated preventive maintenance is not effective. Excluding, corrective maintenance works performed at field, the ratio of corrective maintenance from the total monthly maintenance work at the branch is 57.2 percent. But to say preventive maintenance is effective, the corrective maintenance work should be less than 20 percent. In other words, had it been effective 80% would be preventive and 20% would be corrective maintenance from the total monthly maintenance work. Achieving this state will help for more than 95% availability of spare parts.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

- From the research finding of this thesis it can be concluded that RESCo, CRC maintenance section is not given deserved stress for the better improvement and to play its role in reduction of machinery shortage problem. Hence, the maintenance department is embedded in many problems resulted from traditional maintenance activities. From the working date frequency of CRC in month's date interval, about 45.8% are less than 17 working date per month, 27.8% are between 17-27 including and the remaining 26.4% are 28-35 working dates. Moreover, working date frequency pattern shows CRC has faced two major problems: frequent failure problem and stretched downtime.
- Consequently, the frequent failure problem and prolonged down time resulted for a machine at maintenance level availability is about 63.9% and 55.6 % at operational availability level. According to the failure rate analysis of sample machine, the failure rate is about 4.11 times per month. From the preventive maintenance pattern analysis, preventive maintenance is not being performed as per the schedules of the manufacturer recommendation, it looks implementing randomly. Therefore, the main contributing factor for running in shortage of spare part which is the common claim of the enterprise is in effective preventive maintenance. The prove of this statement is from the observation of the ratio of preventive maintenance and corrective

maintenance in the monthly maintenance reports which shows mechanics are being busy by corrective maintenance rather than being busy by preventive maintenance work. However, maintenance cost holds the second place from the running cost of RESCo.

- In efficient integration and coordination in the department and other related department are some of the oxidizers for the problems. This condition also caused for absence of systematic method of solving problems by breaking down big problem into smaller pieces and identifies the bigger contributors for down time, frequent failures, and maintenance costs which helps to get the most improvement in problem solving effort by showing where to focus in available resource by using 80/20 rule or pareto charts.
- The absence of motivation diminishes autonomous maintenance, results maximize the load for technicians; so that hinders for effective preventive maintenance quality of corrective maintenance.
- Therefore, all this factors makes RESCo to have low availability of machine. So, most machines spent their time in the maintenances floor of CRC or field site rather than spending their time in offering service to customers. However, huge amount of many is expended to buy them to make profitable the company. But, because of improper handling and ignoring the maintenance section, the target is not being achieved.

## **5.2 Recommendation**

- In order to solve the existing problems of RESCo CRC, it is recommended to give proper weight for the maintenance section to integrate it with other related department optimally. It is helpful in snatching over its role for over all achievement of the stated

objectives. Since, maintenance department is the back bone for RESCo; it should not be overlooked as any supportive departments. Its consequence probably will be priceless for RESCo, if it continued in such manner. Therefore, RESCo needs to take very quick action in avoiding these awkward problems for maintenance effectiveness. Therefore, based on the finding of the research the following recommendations are forwarded:

- RESCo should develop computerized maintenance management that can fill the gap data collection, handling and retrieving problem for the efficient, effective, continuous improvement researches.
- RESCo should has continuous training program at the right time for the right staffs
- Autonomous maintenance; this is to minimize the burden on the mechanics assurance of maintenance quality create opportunity for further researcher
- RESCo should have relevant incentive programs for their better performance in repair standard time, maintenance quality, etc.
- Once RESCO take action on deploy CMMS the remaining step is optimizing its strategy by deploying integrated total productive maintenance and reliability centered maintenance to use its ample human resource and assets.
- Meanwhile total productive maintenance looks give more emphasis to the management side aimed at maximizing equipment effectiveness by optimizing equipment availability, performance, and efficiency and service quality; Therefore, total productive maintenance and Reliability centered maintenance are two of a multitude of maintenance management approaches focused on establishing, servicing

and optimizing a maintenance concept. Hence RCM is to set preventive and predictive maintenance standard and letting TPM to manage the overall improvement of RESCo. Therefore, it is time for RESCo to change maintenance culture by implementing Integrated TPM and RCM to take the strength (intended benefit) from both Systems.

- RESCO should create strong integration in among department and ownership of their work. By taking into considerations these and other factors which can be addressed by effective and efficient implementation of optimum and modern proved maintenance strategies which are TPM and RCM. RESCo recommended for implementing integrated or merged TPM and RCM. Return from the effective implementation of these strategies are achieving overall efficiency more than and equal to 85% which is standard of TPM. This implies having availability more than 90%, having 95% performance and 99% of quality which are the standards of TPM. Therefore, if RESCo is able to release and implement effectively and efficiently, RESCo will be granted to the improvement of availability by about 26.1% from the existing availability which is about 63.9% as estimated in the data collection and analysis phase of this work.

## References

- Achermann, D. (2008). Modeling, simulation and optimization of maintenance strategies under consideration of logistic processes. Zurich: Swiss federal institute of technology.
- Adendorff, S.A., Botes, P.S. De wlt, P.W.C., Van loggerenberg, B.J., Coetzee, J.L. 2000. Maintenance strategy setting: a dangerous affair. South African paper presented at the IFRIM World Trends in Maintenance Conference, Pretoria, South Africa
- Al-Najja, B. (1995). *Total Quality Maintenance: Cost-Effective & Continuous Improvement Of Company's Profitability & Competitiveness*. Växjö, Sweden: School Of Technology And Design, Växjö University Lückligs.
- Anthony, K. (2006). *Product Development, A Structured Approach To Consumer Product Development Design and Manufacture*.
- Basim, A.-N. (2012). *Maintenance Management and Modeling*. (A.-N. Basim, Ed.) Quality In Maintenance Engineering.
- Bhadury, B. (1988). *Total Productive Maintenance*, New Delhi: Allied Publishers Limited.
- Bhadury, B. (2000). *Management of Productivity Through TPM* (Vol. Vol41).
- British Standard Institution.(1993).*Glossary of Maintenance Terms In Technology*. Londen: British Standards Institution.
- Coetzee, J.L. 2000. Maintenance strategy setting: a dangerous affair. South African paper presented at the IFRIM World Trends in Maintenance Conference, Pretoria, South Africa
- Corder, AS. 1976. Maintenance management techniques. New York, N.Y.:McGraw-Hill.

- Damilare, T. O., & Akinyemi, O. O. (May 2010). *Development of Equipment Maintenance Strategy for Critical Equipment*. The Pacific Journal Of Science And Technology, 11(1).
- David, A. (2008). *Modeling, Simulation and Optimization of Maintenance Strategies Under Consideration Of Logistic Processes*.
- Dekker, R. (1996). *Application of maintenance optimization models: A review and analysis*. Vol.51. Reliability engineering and system safety.
- Department of Defense United State of America. (August 3, 2005). Reliability, availability, and maintainability.
- Dhillon, B. (1999). *Engineering Maintainability*. Texas: Gulf Publishing Company,.
- Dunn, R., & Johnson, D. (1991). *Getting Started In Computerised Maintenance Management* (Vol. Vol.45 No.). Plant Engineering.
- Energy Sector Management Assistance Program, The World Bank. (2011). *Best Operational And Maintenance Practices; For City Bus Fleets To Maximize Fuel Economy*. Guidance Note.
- Fedele, L. (2011). *Methodologies and techniques for advanced maintenance*. London: Springer-Verlag.
- Gaither, N. & frazier, G. 2001 . *Operations management*. 9th ed. Nashville, TN.: South Western
- Graziano, P. (N.D.). *Maintenance integrated system: The Right Recipe of TPM and RCM*.
- Gulati, R. (2009). *Maintenance and reliability best practice*. New York: Industrial Press Inc.
- Hecht, H. (2004). *System reliability and failure prevention*. USA: Arch House Inc.
- Heiser, J. & Render, B. 2006. *Operations management*. 8th ed. New Jersey, N.J.: Prentice Hall
- Higgins, L., Brautigam, D., & Mobley, R. (1995). *Maintenance Engineering Hand book* (5th ed. ed.). New York: McGraw-Hill Inc.

- Johnsson, Patrik and Less hamar, Magnus.(1999).Evaluation and improvement of manufacturing performance measurement systems—the role of OEE. *International Journal of Operations & Production Management*, 19(1), pp. 55–78.
- Jabar, H. B. (2003). <http://www.maintenanceresources.com>. Retrieved 2012, from <http://www.maintenanceresources.com>.
- Jerry. B. (1989). “Principles of quality control”, Wiley, New York.
- Juran, J.M., and Godfrey, A.B. 1998. *Juran’s Quality Handbook*. McGraw hill.
- Kabak, I. (1969). *System availability and some design implications*.
- Keith, M. R. (2004). *Maintenance fundamentals* (Second Edition ed.). UK,USA: Elsevier Inc.
- Kutucuoglu, K.Y. J. Hamali, Z. Irani, J.M. Sharp.(2001).A framework for managing maintenance using performance measurement systems, *International Journal of Operations & Production Management*, 21(1/2), pp. 173 – 195.
- Labib, A. (2008). Computerized maintenance management systems. In: *Complex systems. Springer series in reliability engineering*.
- Liker, J. & Meier, D. 2006. *The "Toyota Way" fieldbook*. New York, N.Y.: McGrawHil
- Litman, T. (26 July 2012). *Evaluating Public Transport Benefits and Costs: Best Practices Guidebook*. Victory: Victoria Transport Policy Institute.
- Mobley, R. (2002). *An introduction to Predictive Maintenance* (Second Edition ed.). Elsevier Science.
- Mobley, R., Lindley, R., & Darrin, J. (2008). *Maintenance Engineering Handbook* (Seventh Edition ed.). New York: McRraw Hill.
- Mugenda, Mo.and Mugenda, G.A(2003),*research methods*, Nairobi,Acts press.

- Nakagawa T, G. A. (1973). *A note on availability for a finite interval*. IEEE Trans Reliab.
- Nakagawa, T. (2005). *Maintenance Theory of Reliability*. (P. H. Pham, Ed.) London: Springer-Verlag Liited.
- Nakajima, S. (1988). Introduction to TPM. *Productivity Press*.
- NASA. (September 2008). *Reliability Centerd Maintenace Guid for Facilities and Collatral Equipment*. National Aeronautics and Space Administration.
- Nicholas, A. (2010). *Physical Asset Management*. London: Springer-verlag Limited.
- Nicholas, J. (1998). *Competitive Manufacturing Management*. USA: McgGraw-Hill.
- Patton, J.D. 1988. Maintainability and maintenance management. Instrument Society of America. Triangle Park, N.C.: Services
- Pinjala, K.S., Pintelon, L. and Verreecke, A. (2006).An empirical investigation on the relationship between business and maintenance strategies. *International Journal of Production Economics*, 104,pp. 214–229.
- P.Hilber. (2003). *State of the art, maintenance optimaization of electrical networks, with respect to reliability and costs*. KTH, Stockholm.
- Pham, H. (2006). *Reliability Modeling, Analysis and Optimization* (Vol. Vol. 9). World Scientific Publishing Co. Pte. Ltd.
- R.Keith, M., Lindley, R., & Darrin, J. (2008). *Maintenance Engineering Handbook* (Seventh Edition ed.).
- Rausand, M. (1998). Reliability Centerd Maintenance . *Reliability Engineering and System Safety*.
- ROLLINS, T. 2003. Human capital index. (Web]: [www.watsonwyatt.com](http://www.watsonwyatt.com) Date of access: 15 June 2009.

Saraph, J.V. Benson, P.G. and Schroeder, R.G. (1989) An instrument for measuring the critical barriers of quality management. *Decision Sciences*, 20( 4) 81 0-29

Swanson, Laura. (1997). An empirical study of the relationship between production technology and maintenance management. *International Journal of Production Economics*, 53(2),pp. 191–207

Swanson, Laura. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics*, 70(3),pp. 237–244

SS\_EN 13306. (2001). *Maintenance terminology* (1st Edition ed.). Swedish Standard.

Stapelberg, R. (2009). *Handbook of Reliability, Availability, Maintainability and Safety in Engineering Design*. Queensland, London, Australia: Springer-Verlag.

Steinbacher, H., & Steinbacher, N.(1993). *TPM for America, Productivity Press Portland*,. Portland: OR.

Telang, A. (February 14,1998). *Proceeding of National conference on maintenance and condition monitoring*. Vijayakumar,K: Government Engineering College.

Timothy, C., & Bruce, H. (2006). *Maintenance planning and Scheduling*. Elsevier Inc.

Transport Cooperative Research Program. (2004). *Maintenance Productivity Practices*. Washington D.C: Transportation Research Board.

UITP; UATP. (April 2010). *Public Transport in Sub-Saharan Africa: Major Trends and Case Studies*. *Trans Africa*.

VILLEMEUR, A. 1991 . Reliability, availability, maintainability and safety assessment. Vol.2. New York, N.Y.: Wiley

Wakaru, Y. (1988). *TPM for Every Operator*. Portland: Productivity Press, OR.

Wireman, T. (2005). *Developing Performance Indicators for Managing Maintenance*.

# APPENDIX

**Annex –A**  
ADDIS ABABA SCIENCE & TECHNOLOGY UNIVERSITY  
COLLEGE OF NATURAL AND SOCIAL SCIENCE  
DEPARTMENT OF MANAGEMENT

Interview question with the General Manager, Product service Support Manager and CRC supervisor and technician at head office, Addis Ababa akaki-kality Sub City.

**Purpose**

The purpose of this research is to analysis maintenance practice at CRC in the case of RESCo, Addis Ababa head office; akaki-kality sub-city woreda 7 for the requirement of completion of Masters of Business Administration (MBA) degree. The outcome of the study will be used in order to suggest possible solutions for problems identified while conducting the study.

**Statement of Confidentiality:**

The responses you provide will be strictly confidential. No reference will be made to any individual(s) in the report of the study. Therefore, your genuine, frank and timely responses are quite vital to determine the success of this study. So, I kindly request your contribution in conducting the interviewee questionnaire honestly and responsibly.

**Interview Questions**

1. Does your company have Maintenance policy, strategy & procedures? If yes; Are You reviewed on time? If not, why?
2. Do your company have planned and programmed Maintenance scheduling?
3. Could you explain the maintenance practice of CRC at head office?

4. How do you evaluate the effectiveness and efficiency of maintenance practice exercised in the CRC? What kind of tools you will use to measure?
5. Could you explain the maintenance practice strength and challenges of CRC section?

**Thank you in advance for your honest cooperation!**

**Annex - B**

ADDIS ABABA SCIENCE & TECHNOLOGY UNIVERSITY

COLLEGE OF NATURAL AND SOCIAL SCIENCE

DEPARTMENT OF MANAGEMENT

Interview question with the repetitive customers of RESCo rental service at head office, Addis Ababa akaki-kality Sub City.

**Purpose**

The purpose of this research is to analysis maintenance practice at CRC in the case of RESCo, Addis Ababa head office; akaki-kality sub-city woreda 7 for the requirement of completion of Masters of Business Administration (MBA) degree. The outcome of the study will be used in order to suggest possible solutions for problems identified while conducting the study.

**Statement of Confidentiality:**

The responses you provide will be strictly confidential. No reference will be made to any individual(s) in the report of the study. Therefore, your genuine, frank and timely responses are quite vital to determine the success of this study. So, I kindly request your contribution in conducting the interviewee questionnaire honestly and responsibly.

**Interview Questions**

1. Does RESCo furnish the maintenance service what you intend to get at expected quality? If yes how do you explain? If no in what area you dissatisfy?
2. Does RESCo delivered your machinery as per the agreed schedule?

3. How do you evaluate the effectiveness and efficiency of maintenance service given by CRC RESCo ? What kind of tools you will use to measure?

4. Could you explain the maintenance service strength and challenges of CRC section?

4. How do you explain RESCo the availability of machinery for rental service whenever you need?

Thank you in advance for your honest cooperation!

#### Annex –C

Table 4.2 Frequency of Failures Vs costs

Description	Frequency of Failures	Frequent Failures%	Cumulative %	labor cost (Birr)	Spare Part Cost (Birr)	sub Total Cost(Birr)
Hydraulic Failures	150	13.60%	13.60%	1938.925	862950.6	864889.525
Engine Overhaul	6	0.54%	14.14%	3987.26	567036.12	571023.38
Starter Failure	33	2.99%	17.14%	1289.76	533877.78	535167.54
Track failure	28	2.54%	19.67%	188.69	373697.64	373886.33
Crank Shaft failure	2	0.18%	19.85%	101.11	344792.52	344893.63
Brake system failures	134	12.15%	32.00%	2918.52	292499.34	295417.86
Compressor Failures	53	4.81%	36.81%	9467.11	128445.54	137912.65
clutch System failure	78	7.07%	43.88%	4293.397	70593.36	74886.757
Friction Disc	50	4.53%	48.41%	1275.67	80856.36	82132.03
Bearing Failure	9	0.82%	49.23%	1523.88	78964.8	80488.68
Battery Failure	9	0.82%	50.05%	203.79	69467.34	69671.13
Air System Failure	38	3.45%	53.49%	1006.801	51817.98	52824.781
Lever Switch Failure	21	1.90%	61.92%	728.74	39950.94	40679.68
Fly Wheel Failure	10	0.91%	62.83%	456.46	39588.9	40045.36
Pressure Plate	32	2.90%	65.73%	797.3915	37479	38276.3915

Propeller Shaft Failure	20	1.81%	67.54%	797.3915	37479	38276.3915
Transmission	11	1.00%	68.54%	774.48	33089.22	33863.7
Relay valve Failure	33	2.99%	72.53%	325.2	30103.92	30429.12
leaf Spring	5	0.45%	72.98%	45.62	28369.32	28414.94
Servo Failures	36	3.26%	76.25%	340.1615	22438.14	22778.3015
Gear Box failure	22	1.99%	78.24%	2275.065	9648.324	11923.389
Cooling System Failure	12	1.09%	79.69%	424.2	16237.98	16662.18

Annex -D

Table 4.2 Dawn Time for May 2009 for Sample Team

Date	Down Time for D8R	Expected working hr	Down Time for 140H	Expected Working hr	Down Time for 324D	Expected working hr
1/9/2009	137.05	320	200.27	240	239.3	240
2/9/2009	134.4	320	172.58	240	237.4	240
3/9/2009	159.92	320	170	240	237.45	240
4/9/2009	158.5	320	150.1	240	209.3	240
5/9/2009	143.58	320	138	240	232.5	240
6/9/2009	172.33	320	143.5	240	234.25	240
7/9/2009	148.4	320	130.15	240	221.36	240
8/9/2009	168	320	202.25	240	251.55	240
9/9/2009	168.05	320	180.15	240	240.15	240
10/9/2009	163	320	148.4	240	285.25	240
11/9/2009	179.1	320	132.5	240	256.5	240
12/9/2009	132.45	320	165.5	240	260.1	240
13/09/2009	189.25	320	165.1	240	245.55	240
14/09/2009	162.15	320	172.03	240	265.35	240
15/09/2009	137	320	208.5	240	264.3	240
16/09/2009	124.45	320	217.1	240	242.05	240
17/09/2009	154.38	320	105.55	240	228.4	240
18/09/2009	153.3	320	234.2	240	248.35	240
19/09/2009	149.5	320	210.3	240	243.4	240
20/09/2009	122.5	320	154.4	240	232.2	240
21/09/2009	153.2	320	162.35	240	261.4	240
22/09/2009	163.45	320	171	240	241.05	240
23/09/2009	138	320	160.1	240	303.05	240

24/09/2009	158.15	320	190	240	272.15	240
25/09/2009	200.39	320	167.05	240	275.45	240
26/09/2009	201.52	320	158.25	240	282.45	240
27/09/2009	190.05	320	178.3	240	289.45	240
28/09/2009	176	320	233.1	240	286	240
29/09/2009	180.47	320	192.1	240	262.25	240
30/09/2009	215.04	320	185.5	240	292	240
Total	4833.58	9600	5198.33	7200	7639.96	7200

### Annex - E

Table 4.3 Income Summary in 2009 E.C

Type Of Costs	Costs In Birr	Percentage %
Total Revenue	535,764,000.00	100%
Employees' Salaries and Over Time	4,212,000.00	0.85%
Over Time	1,404,000.00	0.28%
Different Benefits	8,130,000.00	1.64%
Training	577,000.00	0.12%
Fuel	83,252,000.00	16.81%
Oil And Lubricant	8,059,000.00	1.63%
Truck	6,777,000.00	1.37%
Spare Parts	273,094,000.00	55.15%
Miscellaneous Garage Materials	2,040,000.00	0.41%
Service Car Repair	664,000.00	0.13%
Office Equipment Maintenance	571,000.00	0.12%
Insurance	6,033,000.00	1.22%
Depreciation	86,295,000.00	17.43%
Miscellaneous Stationery Materials	848,000.00	0.17%
Other Printed Materials	181,000.00	0.04%
Administrative Expense	9,362,000.00	1.89%
Travel Per dium	264,000.00	0.05%

Uniform And Safety Materials	3,412,000.00	0.69%
Total Expense of RESCo	495,175,000.00	
Total Profit of RESCo	40,589,000.00	

#### Annex - F

Table 4. Maintenance Quality of sample machine for 2008 and 2009 E.C

Mac. No.	Maintenance Quality/4 months				Annual Average 2008 & 2009 E.C		
D8R	81.25	75	83.3	85.71	88.57	80	82.3
140H	81.25	79.07	86.7	77.5	80.64	91.67	82.8
324D	93.75	76.47	87.5	83.3	84.61	82.35	84.7
329D2	66.7	76.9	83.3	87.5	91.7	78.3	80.7
Average	80.7375	76.86	85.2	83.5025	86.38	83.08	82.6

