A Study on Construction Equipment Planning and Management Problems in Road Construction Project (A Case Study: The Addis Ababa City Roads Authority)

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented in any other university. All sources of material used for the thesis have been duly acknowledged.

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ABSTRACT

Construction equipment is one of the major resources in the construction process for construction companies through the mechanized construction of road projects. Construction equipment planning and management practice lack the necessary policy to meet the standard. As result, many road projects in Ethiopia experienced time overrun, cost overrun and low quality.

In this respect, this study tries to identify the problems of construction equipment planning and management, its causes and negative effects for road projects. The research focuses on construction equipment planning and management policies, like construction equipment selection, acquisition, operation, maintenance and disposal or replacement; leading construction equipment management in general and equipment productivity in particular.

The data collection method is integrated questionnaire, interview and case study. Samples for the study have considered the whole population of Grade one contractors, AACRA own force road construction department and equipment renting companies majorly participating in AACRA road construction projects. In this thesis, a descriptive and inferential statistical data analysis has been used. Interpretations and discussions were made on the basis of result from the analysis.

According to the result from analysis, the research comes up with the following conclusions. Most respondents believe that their companies have no documented construction equipment planning and management policy; the result indicated that idle time, down time, poor equipment maintenance practices are some of major problems that affect construction equipment planning and management in AACRA projects during planning and construction process; huge capital investment during acquisition phase, poor maintenance practices with improper determination of economic life and timing for replacement are the major causes of construction equipment planning and management problems. Cost overrun is the first ranked among the negative effects of construction equipment planning and management problem. As proved by case study, the actual equipment productivity rate is below half of its capacity. This study further provides recommendations like develop equipment planning and management policy to reduce problems on construction equipment planning and management in general and loss on equipment productivity in particular.

Key words: Equipment planning and management; Equipment productivity & OEE

ABREVIATIONS/ACRONYMS

AACRA	Addis Ababa City Road Authority
AR	Availability Rate
CEM	Construction Equipment Management
CEO	Chief Executive Officer
ECWC	Ethiopian Construction Works Corporation
ERCC	Ethiopian Road Construction Corporation
EWWCE	Ethiopian Water Works Construction Enterprise
MoC	Ministry of Construction
MoUDC	Ministry of Urban Development, Housing and Construction
OEE	Overall Equipment Effectiveness
PR	Performance Rate
QR	Quality Rate
RII	Relative Importance Index
SAE	Society of Automotive Engineers
TPM	Total Productive Maintenance
USA	United States of America
U.S GNP	United States Gross National Product
UK	United Kingdom

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CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Currently in Ethiopia, the construction sector plays an important role in short term trends, with more frequent development, not only for the sector itself but also for other economic activities as well. As a result, it is firmly believed that the construction industry needs an effective resource management practice to retain profitability and continue its dynamic contribution to the growth of the country. Before starting any project then, the planning should be done with great care, as the efficiency of the whole project largely depends upon its planning. Planning of a construction project involves deciding about the extent of mechanization, equipment planning, equipment management, and execution planning etc.

Construction is a business sector that relies primarily on high utilization of construction equipment. Equipment is thus one of the key factors for improving contractor‟-s‟ capabilities in performing theirs work more effectively and efficiently (Day, D. A and Benjamin, N.B.H, 1991). By enhancing the effectiveness of utilizing equipment, extensive volume of work can be completed within a shorter period of time and, more importantly, within the project schedule. It was suggested that one of the main reasons for project delays on construction projects in Thailand were equipment management problems, deficiencies in organization, shortages of construction materials, and inefficiencies in site workers (Hinze, J. and Ashton, W.B 1979).

The cost of equipment in a project varies from 10% to 30% of the total cost of the project, depending upon the extent of mechanization (Shama S.c.,2002). In modern fully mechanized projects the cost of equipment goes up to 30%. Proper planning, selection, procurement, installation, operation, maintenance and equipment replacement policy plays an important role in equipment management for the successful completion of the project. With the growing use of machinery it has become necessary for construction engineers to be thoroughly familiar with the construction application and upkeep of the wide range of the modern equipment.

The choice of construction equipment is determined on method of doing the work, the time to complete the work, and the cost of construction (Day, D. A, & Benjamin, N.B.H.,1924). Therefore, when there is shortage in selected plant and equipment force is occurred, it may influence on construction duration as well as the cost. Hence poor management of construction equipment may be considerable reason behind many of the factors. The Equipment Manager should coordinate with various wings of organization in discharging his job of equipment planning, balancing, selection of equipment, its deployment and it‟s utilization, personnel selection and training, financial planning, preventive maintenance and general supervision (Shama S.c., 2007). Thus, equipment management integrates and continuously interacts with human, technical, financial and production system in order to achieve top efficiency and cost effectiveness. Like the other major resources, committed equipment are expected to be fully utilized to complete the project in due time (Uher, T.E., 2003). Hence, proper planning and management of equipment is crucial for the success of a firm, especially for the road project construction sector where profit margin is very low.

1.2. Problem statement

Construction is the mobilization and utilization of capital and specialized personnel, materials, and equipment and to assemble materials and equipment on a specific site in accordance with drawings, specifications, and contract documents prepared to serve the purposes of a client (Rickets, 1999).

Road construction involves a combination of specialized organizations, engineering science, studied guesses, and calculated risks. Since operations must be performed at the site of the project, often affected by planning and management problems, every project is unique. Furthermore, because of exposure to the outdoors, construction is affected by both daily and seasonal weather variations. It is also often influenced significantly by the poor planning, management and utilization of construction equipment. These factors should be addressed and managed in a competent and professional manner to benefit from the industry.

I think a construction company should first study the demand for equipment utilization (Job markets) before ambitiously buying equipment and looking for job markets. It that case, the equipment will be under-utilized, depreciate parked and company will lose its capital and may be forced out of market.

Construction equipment planning and management plays crucial role for the success of construction firms. Inadequate manual processes of equipment planning and selection and the subjective decisions of equipment managers usually result in major losses to construction firms. Moreover, in Ethiopia limited such study have been carried-out, which formulates a method to evaluate construction equipment planning and management problems and its impact on road projects financial performance as compared with the base line schedule. On the other hand, minimizing construction equipment planning and management problems have a significant impact on successful accomplishment of projects. These facts need a detail investigation along with an improving intervention. The aim of this study is therefore, to study the problems and the way in which construction equipment planning and management is used in road construction projects, assess the suitability, to see some construction equipment planning and management practices used in the Ethiopian construction industry and to compare them with internationally used practices and to forward recommendations.

1.3. Significance of study

Construction equipment planning aims at identifying construction equipment for executing project tasks, assessing equipment performance capability, forecasting date-wise requirement of number and type of equipment and finally participating in the selection of equipment to be acquired. To derive full benefits from the equipment, there should be proper selection and good planning and management of its operations. This paper deals with the planning and management procedure for equipment and equipment productivity adopted by a company to achieve its objectives timely in respect of project completion of road construction projects in Addis Ababa.

1.4. Objective of study

1.4.1. General objective

The main objective of the thesis is to study the current practice in construction equipment planning and management practices in road construction projects in Ethiopia in general and in

Addis Ababa particular, to identify the possible problems, explore internationally practiced norms and finally forward recommendations for possible use by pertinent policy makers.

1.4.2. Specific objectives

Based on the problems stated, this study will be undertaken with the following specific objectives:

- To study the current status of construction equipment planning and management practice in general and equipment productivity in particular,
- To identify the main causes of equipment planning and management problems,
- To determine the effects due to poor equipment planning and management problems,
- To determine the extent of equipment productivity reduction due to poor equipment planning and management problems; and
- To recommend possible equipment planning and management methods.

1.5. Research questions

To achieve and address the above stated objectives the study is framed by the following research questions:

- Which type of equipment planning and management policy is used currently by the Addis Ababa City Roads Authority (AACRA) road construction projects?
- How suitable are these policies of equipment planning to increase the productivity of construction equipment?
- Does the current construction equipment planning and management policy affect productivity of equipment? If yes, how much?
- What are the causes and effects of poor equipment planning and management?
- What will be the remedy for the current construction equipment underutilization, if exist?

1.6. Scope of the study

This research focuses on construction equipment planning and management practices currently applicable in selected AACRA road construction projects. The study mainly deals with construction equipment planning policies and its management procedures and their impact on the success of road projects in general and equipment productivity in particular in case of Addis Ababa only.

This study will mainly dwells in the equipment planning and management in contracting firms that are involved with the AACRA road construction projects basically in two phases; Which are Pre-construction and construction. The study will include both national contractors and equipment renting companies who are participating in AACRA road construction projects. In this thesis whether to limit the subject, or to investigate the most frequently used ones, the equipment, which are used in road construction process are aimed.

1.7. Limitation of the research

The study is limited to the construction equipment renting and contracting companies that are classified as first category which have a valid registration by ministry of construction (MoC) in Addis Ababa. The sub-contractors and contracting companies of second and above categories will be excluded, because currently, only grade one general and road contractors are undertaking construction at AACRA projects

1.8. Organization of the thesis

The thesis has been organized as follows

1.8.1. Chapter One- introduction

This chapter depicts the basic research information as an introductory part of the research. In this context, this chapter includes information on the objective of this study, the methodology followed, scope, limitation, problem statement and the disposition of the issuing chapters.

1.8.2. Chapter Two- Literature review

This chapter discusses on the construction equipment planning and management practices as depicted in various literatures, statement by different authors regarding causes, effects and prevention mechanisms of construction equipment planning and management problems from pre-construction to construction phases will be presented.

1.8.3. Chapter three – Methodology

This chapter includes the methodology used in this research and provides information about the research strategy, research design, population, sample size, various approaches for data collection and data analysis. It also identifies the questionnaire design, pilot study, validity content, and reliability.

1.8.4. Chapter Four – Analysis of data

The methodologies to be used for researching purpose like collection of data, development of questionnaires and conducting interview will be discussed. Analysis of all the information gathered will also the part of this chapter.

1.8.5. Chapter Five – Case study

To determine the actual productivity of construction equipment on site, case study is conducted on three AACRA road projects and equipment efficiency is evaluated by overall equipment effectiveness index.

1.8.6. Chapter Six- Conclusions and recommendations

After reviewing the existing construction equipment planning and management practices, having supported by literature from different authors and complying the output of analysis, this chapter will present the conclusions of the research and the subsequent recommendation to the government policy makers, project managers, engineers, consultant designers (architects) and for the contractors and construction equipment renting companies.

1.9. Beneficiaries of the research

The following are the envisaged beneficiary of the research outputs:

- Client
- Consultants;
- Contractor s;
- Construction equipment renting companies;
- Future contractors; and
- Researchers.

CHAPTER TWO

2. Literature review

2.1. General

There are limited researches already conducted on investigation of construction equipment planning and management problems in road construction sector. Existing studies are focused on construction equipment productivity on road construction; therefore it is better to conduct detail study on equipment planning and management problems to mitigate the causes and effects of problems.

Construction equipment is one of the three major inputs of road construction process, together with labor and materials. One of the reasons for the development and use of equipment with in construction is, to enable construction activities to be performed which are beyond the limit of human strength, and to achieve high standards, which is required by current construction technologies and designs. The second one is to make the construction process more economic.

Studying construction equipment is crucial and vital because the share of equipment cost is very significant in construction project. It is also one of the resource areas in construction that can generate profit if it is utilized efficiently and effectively. The cost of equipment in a project varies from 10 to 30% of the total cost of the project, depending upon the extent of mechanization (Shama S.c., 2007). This statistics indicates that focusing on the investigation of the planning and managerial aspect of such a huge investment needs closer follow up. In addition to this, there are arguments in the contemporary engineering development to have a closer look at construction equipment because the extent of mechanization in the new technology appears to be mandatory. According to (Shama S.c., 2007), the extent of mechanization determines the cost of a project in terms of cost of construction equipment.

In general, construction equipment is one of the most important physical assets in a construction industry. It plays a pivotal role in construction operation and constitutes a major portion of construction projects.

2.2. Construction equipment planning and management

Construction equipment management (CEM) is a process, which includes that planning, selection, acquisition, productivity, maintenance, standardization and quality control cycles (Wireman T., 1989). In many cases, however, most of the aspects of this process are either neglected or skipped over. According to researcher‟-s‟ observations, despite the fact that construction equipment is owned and managed by professionals‟, in frequent occasions managerial process seems to follow traditional CEM practices than scientific conventional approaches.

The "equipment managers‟ main task is to reduce downtime of Construction equipment and achieve optimum Construction equipment utilization and increase productivity at minimum cost" (Sharma s.c, 1999). He also reiterates that "proper planning, selection, procurement, installation operation, maintenance, and replacement "process need to be policy driven and, "have important role in CEM".

The purpose of equipment planning is to show the separate size and types of equipment required on rent, lease or outright purchase. Construction equipment and plant refers to the tools, instruments, machinery, and other mechanical implements required in performance of construction work. Construction plant is defined as concrete batch plants, aggregate-processing plants, conveying systems. And any other processing plants, that are erected in place at job site and essentially stationary or fixed in place. Equipment is defined as items that are portable or mobile ranging from small hand tools through tractors, cranes, and trucks.

Modern construction projects are complex in nature and success of a project depends greatly on proper and scientific planning (Sharma s.c, 1997). Before starting any project it‟s planning is done with great care, as the efficiency of the whole project largely depends upon its planning, while planning each and every detail should be worked out in anticipation and should be considered carefully. Planning of a construction project involves deciding about the extent of mechanization, equipment planning, and execution planning etc. while planning a road project, equipment manager should be carefully decided the extent of mechanization so as to minimize the cost of project. On major construction projects mechanization is indispensable; while for middle and minor construction projects a compromise between manual and mechanical means have to be made. In a country, like Ethiopia where man-power is cheap and easily available we can take advantage of this facility especially for the activities which can be easily carried out by the manpower. However, a combination of manual labor and machines is preferred (Sharma s.c, 1997).

Proper selection of equipment for a road construction project is of vital importance for its speedy and economical completion. Problem of equipment selection has become more complicated, because large variety of equipment is being manufactured now-a-days. For selection of equipment, a considerable experience in the operation and maintenance in the field is essential. In fact, selection of equipment for the project is one of the key decisions in planning and executing a construction project, which affects how the work will be done, the time required to complete the work, and the cost that will be accrued. Generally, an equipment manager is responsible of selecting the equipment, whereas it is the responsibility of the construction planning group to select equipment. There are also different factors that affect selection of construction equipment, such as; scope of work, availability of equipment, suitability of job condition, size of equipment, versatility etc.

In fact nearly 50% of the construction firms in Thailand own the equipment they use (Tavakoli, Taye and Erktin, 1989). This data informs how construction equipment is given significant place in the world of construction.

Every construction companies should have policies and processes on equipment control & asset management. Equipment control and asset management involves the management of construction equipment within a company. Equipment control begins with the receipt of a newly acquired equipment item and continues through the item's entire life-cycle. Newly acquired equipment should be inspected by in-house or contracted construction equipment Technicians (CETs), who will receive an established equipment control/asset number from the Equipment/Property Manager. The control method can be used to track and record maintenance activities in the database. Once an equipment control number is established, the device is safely inspected and read for delivery to project areas in the company.

Generally construction equipment planning and management includes pre-construction and construction phases. Therefore in this thesis depending on the reviewed literature and collected data the equipment planning and management problems will be solved with detail investigation.

2.3. Construction equipment planning and management in road construction project

Introduction of proper construction equipment planning and management helps in minimizing the confusion created due to logistics management, horizontal/vertical transportation, material handling, execution methods, interruptions, delays, prolonged duration of projects, finishing trades, and infrastructure requirements (Mohideen, Ramachandran and Narasimmalu.,2011). It is difficult to identify the limit to machine usage in construction site. It is clear however, that as time goes by more machines will be invented or adapted for use in construction sites. Therefore management continually has to make decision about methods of operation and the right mix of human and machines with in working environment. Machines therefore selected, arrive on site, are used and when the project is completed, removed and returned to company plant depot or the hire company. Within this cycle various decisions and assessments are required to be made (Cater, 1993). Therefore if this assessments and decisions are not made in proper manner, it will be difficult to face challenges previously stated. That means proper management of equipment is essential for the successive completion.

Further, construction equipment planning and management can be done in several ways. Various types of construction equipment can be grouped in several ways (Day & Benjamin, 1991). Mainly they could be classified as functional and operational as depicted in figure 1 below.

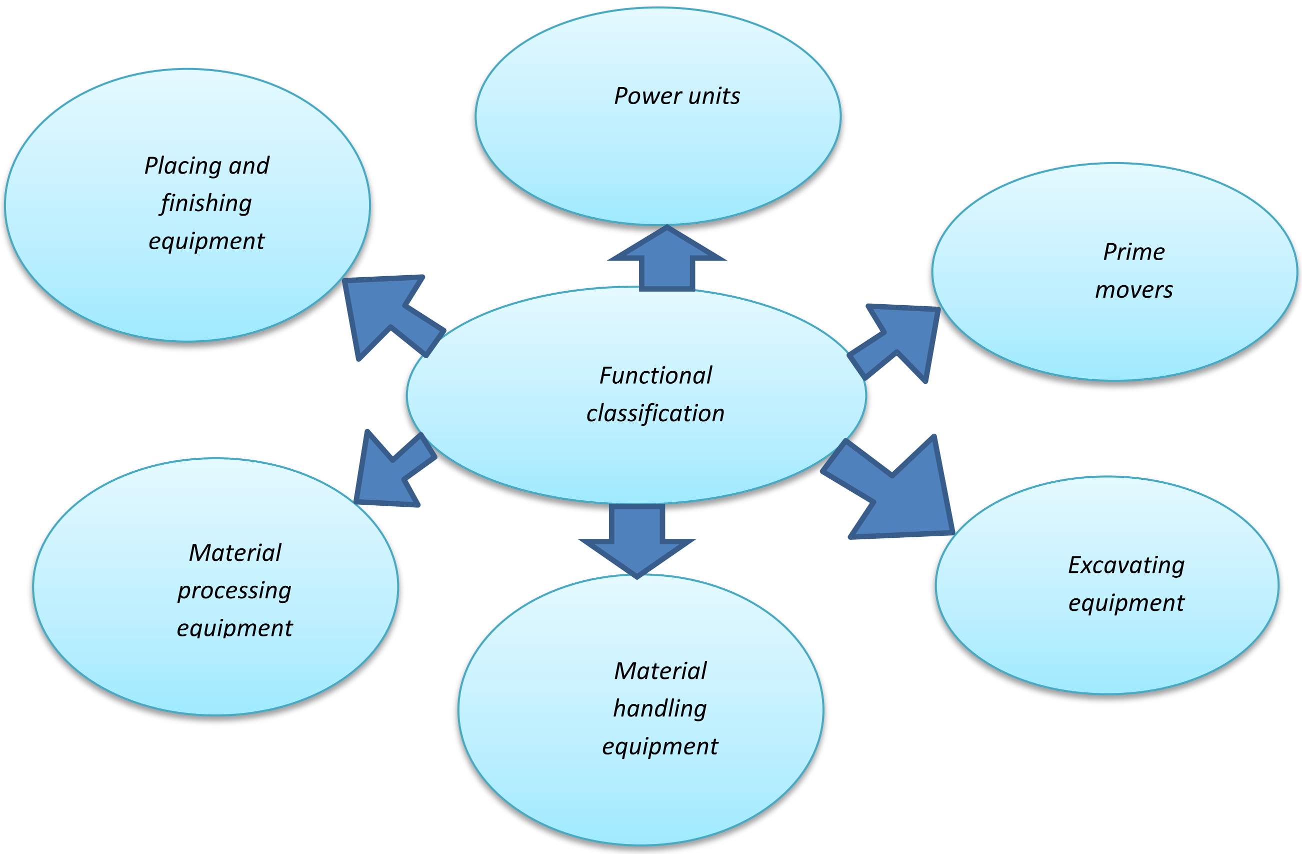


Figure 1: Functional Classification construction equipment. Source: (Day, & Benjamin, 1991)

Operational classification is better in use when functional classification is done according to the functional activity of equipment as above. (Day & Benjamin, 1991)

To construct perfect roads, it is essential that there is adequate equipment for the construction work (Leuva., 2012). Further, effective construction equipment planning and management means being able to draw a definitive line between a losing company and one that is profitable and successful (Campbell, 2011). Construction companies that are finding continued success even in the current economy who finds new ways to lower operating and maintenance costs optimize their utilization and reduce down time and increase profits. Maintenance of construction equipment is crucial as this preserve them for future construction jobs, accident and save contractors from unnecessary expenses (Marvelous, 2012). Maintenance is not only a thing to be aware of in equipment management. Selecting and planning proper equipment on specific construction tasks also one of important portions of the management criteria (Casals, Forcada, and Roca, 2003). Therefore management of construction equipment is directly effects on project cost and duration. All road construction activities comprised with equipment management part are included in critical path of project mostly. Therefore, planning and management of construction equipment directly affects the project duration. Thus, to minimize construction cost and time, it is very important to manage construction equipment in proper manner.

2.3.1. Planning equipment utilization on road project

Each piece of construction equipment is specifically designed by the manufacturer to perform certain mechanical operations. The task of project planner/estimator or engineer on the job is to match the right or combination of machines to the job at hand. Considering individual tasks, the quality of performance is measured by matching equipment‟s spreads production against its cost. Production is work done; it can be the volume or weight of material moved the number of material cut, distance traveled or any similar measurement of progress. To estimate the equipment component of project cost it necessary to first determine machine productivity. Productivity is governed by engineering fundamentals and management ability. (Peurifoy etal. 2006).

Although each major type of equipment has different operational characteristics, it is not always obvious which machine is best for particular project task. After studying the plans and specifications, visiting the project site and performing a quantity takeoff, the planner must visualize how to best employ specific piece of equipment to accomplish the work. Is it less expensive to make an excavation with scraper or to top load trucks with a dragline? Both methods will yield the required end result, but which is the most economical method of attack for the given project condition?

To answer the above question the planner develops an initial plan for employment of the scrapers and then calculates there production rate and subsequent cost. The same process is followed for the top load operation. The type of equipment that has the lowest estimated total cost, including mobilization of the machines to the site, is selected for the job

Most successful construction companies use project preplanning, risk identification, and risk quantification techniques in approaching there work. No two projects are exactly alike; it is important that the planner begins each new project with a completely open mind and reviews all possible options. Additionally, machines are constantly being improved and new equipment being introduced. (Peurifoy etal. 2006).

2.3.2. Construction Equipment planning and management policies

Company‟s standard procedures and policies towards equipment management include factors such as equipment selection strategies, procurement systems, acquisition methods, operation procedures, maintenance and repair policies and replacement decisions. The equipment policies of a construction firm reflect the priorities set by top management and carry significance in terms of resource allocation and strategic planning (Sözen & Giritli, 1987). A company‟s policies may also reflect the corporate level strategy and existing market conditions. Furthermore, maintaining a proper fleet of equipment can be of strategic importance to a company in cases where the award of a contract is based also upon the condition and availability of equipment. Equipment management procedures and policies vary companywide. Thus, some of the major factors that influence policies toward equipment management decision will be discussed next.

2.3.2.1. Selection of equipment

The crux of equipment selection lies in finding the right tool for a given job. It means ensuring that the given piece of equipment is configured in a manner that allows it to maximize its production potential as well as minimize downtime. As such, there are a number of basic considerations for selecting the right piece of equipment for any given task. (Gransberg et al., 2006)

2.3.2.1.1. Basic considerations for equipment selection

Equipment costs rank second to material costs in terms of uncertainty and in their effect on the outcome of anticipated profit for a construction project. Selection of the right piece of equipment, like the right man for the job, affects field productivity. Productivity directly influences profitability. Using a machine that does not have enough capacity will slow down productivity. Using a machine with too large capacity might increase productivity to some extent, but will ultimately negatively affect profitability, because of the cost of operation of the oversized machine. Pairing machines with mismatched capacities are not efficient and will not yield the optimum unit price for the work. Using machines matched to the task will greatly increase the chance of avoiding failures and should be a primary goal of equipment selection. (Gransberg etal.,2006)

One of the most important considerations when selecting a piece of equipment is the availability of the right machine with proper and timely service, maintenance, and repair. The right machine must not only match mechanical functions, but also power, capacity, and control requirements. Dealer or rental agency location proximity and staff competency will influence downtime and turnaround for service. (Gransberg etal.,2006)

The physical properties of clay, gravel, organic matter, rock, sand, or silt to be moved or excavated has a direct influence on the type and capacity of equipment selected for a specific work activity. The ease or difficulty of removing and handling soil or any material directly influences the amount of machine productivity. This will also determine capacities and types of buckets, blades, and attachment or accessories. How the soil breaks apart or sticks together will influence how much can be put in a bucket, blade, bowl, or bed. A front-end loader bucket will hold more slightly wet sandy clay soil than dry sand. The composition of the soil and the amount of moisture in the soil influence the heaped capacity that the bucket can hold or the blade can push. (Gransberg etal.,2006)

The type and condition of the working surface and the distance to be traveled affect the choice of tires or tracks. Desired productivity is also a major influence on earthmoving, excavating, and lifting equipment selection. Meeting the schedule for the quantity of work to be accomplished is the goal. The required hourly production of a piece of machinery is primarily determined by the amount of work to be done and how fast it has to be done. The amount of time the contractor wants to spend or has to spend on excavation or earthmoving will greatly influence the size of machinery chosen for the work. If there is a large volume of dirt that needs to be moved quickly, a large piece of machinery will probably be most efficient. If there is a small amount of dirt to be excavated, a smaller piece of machinery makes more sense. (Gransberg etal.,2006)

The following basic relationships exist for equipment selection: (Gransberg etal., 2006)

- As equipment capacity increases, productivity increases so does the initial purchase price, operating, and maintenance costs.
- As equipment productivity increases, the unit cost (Birr/cubic meter, Birr/square foot, Birr/ton, Birr/load) for the work decreases.

The selection of equipment is affected by economic life of equipment. The owner of construction equipment should be interested in obtaining the lowest possible cost per unit of production. In order to accomplish this objective he must follow an informed program of equipment replacement. When should equipment be replaced? If the owner replaces it too soon, he will experience an unnecessary capital loss, whereas, if he waits too long, the equipment will have passed its period of economic operation. In order to determine the most economical time to replace equipment, accurate records of maintenance and repair costs and downtime must be kept for each machine. The owner must consider all costs related to the ownership and operation of the equipment, and the effect which continued use will have on these costs.

By considering different requirements determined above, the contractor can use the following methods to the select the most appropriate equipment.

- Economic analysis
- Models based on traditional mass haul diagram
- Experiences

2.3.2.2. Acquisition of equipment

Contractors and other users of construction equipment are concerned with a decision as to whether to purchase or rent equipment. Under certain conditions it is financially advantageous to purchase, whereas under other conditions it is more economical and satisfactory to rent it. There are at least three methods under which a contractor may secure the use of construction equipment:

- Purchase the equipment.
- Rent the equipment.
- Rent the equipment with an option to purchase it at a later date.

The method selected should be the one that will provide the use of the equipment at the lowest total cost. Each of the three methods has both advantages and disadvantages which should be considered prior to making a decision. If the cost was the only factor to be considered, then an analysis of the cost under each method should give the answer. If other factors should be considered, they should be evaluated and applied to the cost as a basis on which to reach a decision. The correct decision for one contractor will not necessarily apply for another contractor.

Advantages of purchasing equipment compared to renting it are:

- It is more economical if the equipment is used sufficiently.
- It is more likely to be available for use when needed.
- Because ownership should assure better maintenance and care, purchased equipment should be kept in better mechanical condition.

Disadvantages of owning equipment compared to renting it are:

- It may be more expensive than renting.
- Purchasing may require a substantial investment of money or credit that may be needed for other purposes.
- The ownership of equipment may influence a contractor to continue using obsolete equipment after superior equipment has been introduced.
- The ownership of equipment designed primarily for a given type of work, may induce a contractor to continue doing that type of work, whereas other work requiring different types of equipment might be available at a higher profit.
- The ownership of equipment might influence a contractor using the equipment beyond its economic life, thereby increasing the cost of production unnecessarily.

Once the decision is made whether to purchase or rent, the next decision to be made is whether to simply rent or rent with an option to purchase. The latter alternative will result in a higher rental cost as some of the periodic rental charges will be applicable towards the purchase price of the equipment. This is an attractive alternative if the renter of the equipment believes he may have enough use for the equipment to purchase it, but is not too sure that the utilization will be as high as predicted. This kind of rental agreement results in higher hourly charges than straight rental agreement. If the contractor intends to buy the equipment after renting it for a period of time, then 90% of the rental charges will be discounted from the total actual cost of the equipment.

2.3.2.3. Operation of equipment

After selection of proper equipment for a specific project, operation of equipment takes place based on the equipment planning on road projects. Operation of construction equipment means the equipment is actually in use on specific site in order to complete the intended road construction work according to the schedule. The operation of equipment is dependent on operating cost of equipment.

Operating costs of the construction equipment, which represent a significant cost category and should not be overlooked, are the costs associated with the operation of a piece of equipment. They are incurred only when the equipment is actually used. The operating costs of the equipment are also called „„variable‟‟ costs because they depend on several factors, such as the number of operating hours, the types of equipment used, and the location and working condition of the operation.

The operating costs vary with the amount of equipment used and job-operating conditions. The best basis for estimating the cost of operating construction equipment is the use of historical data from the experience of similar equipment under similar conditions. If such data is not available, recommendations from the equipment manufacturer could be used.

2.3.2.4. Equipment maintenance and replacement practices

2.3.2.4.1. Maintenance practices

The prime objective of maintenance is to keep the equipment in good, serviceable condition. Therefore, equipment maintenance is a vital function in any contracting or equipment hire company. This function includes all the activities such as daily and periodic inspection, lubrication, servicing, repairs and periodic overhauls.

The basic forms of maintenance include (Harris & McCaffer, 1982):

- Planned preventive maintenance.
- Planned corrective maintenance.
- Unscheduled or Unplanned maintenance including repairs.

(i) Planned Preventive Maintenance

The old adage 'Prevention is better than cure', is the first principle of preventive maintenance. Planned preventive maintenance of construction equipment includes inspection, adjustment or tightening routines of equipment components at prescribed intervals in order to prevent any premature failure. These intervals are usually based on previous performance of equipment and experience gained in the past (Tucker, 1980).

Components of construction equipment may fail unexpectedly well before they reach the end of their anticipated life. Inspections at predetermined intervals could, therefore, help to identify such problems and initiate remedial actions before any catastrophic failure occurs. This is important, because damage to a minor component can cause the total failure of a machine. The time interval between inspections could be in days, weeks or even months depending on the type of checks performed in the inspection. For example, daily inspection of equipment may include checking of (Douglas, 1975):

i. air pressure in tires;
ii. Fuel level;
iii. Crank case oil level;
iv. Coolant level;
v. Battery water,
vi. Leaks;
vii. Any obviously broken or defective parts noted by walking around the machine;
viii. Safety items such as brakes, lights and hom.

An example for a longer period inspection is the 'Oil Analysis', which is considered by many equipment owners as an essential part of preventive maintenance (Con. Plant & Equip., 1987-a).

The aim of this is to monitor the rate of wear of certain components such as the Engine, Transmission, Final Drive and Hydraulic system.

This enables the engineers to predict and, to some extent, diagnose the cause of failure before it occurs. Thus, shut-downs can be planned for necessary maintenance at convenient times with the least consequential costs.

The other planned preventive maintenance procedures are the adjustment and tightening routines performed at fixed intervals, and these may include brake adjustment, wheel-nut tightening, track tensioning and the like.

Planned preventive maintenance may also include the following aspects of equipment maintenance:

- Lubrication and Greasing.
- Replenishment of censurable such as Filters.
- Periodic Servicing.
- Periodic Overhauls.

The periodic servicing may be carried out at intervals of machine operating hours such as 100 hr., 250 hr., 500 hr., 1000 hr. and so on. These intervals depend on factors such as the type, make and model of the equipment. Equipment manufacturers usually supply service manuals describing how often their machines should be serviced and procedures to be adopted for each type of service. Very often these services include lubrication, greasing and filter replacement even though they are listed above, as separate maintenance activities. Periodic overhauls are undertaken to improve the mechanical performance of deteriorated equipment. The overhaul could be for an individual component or could be for the whole machine. It is possible to combine some of the preventive maintenance activities together to form an Integrated Maintenance System (Tucker, 1980). (Ibbs and Terveer, 1984) describe such an integrated preventive maintenance system which is being used by a large American quarrying firm. Ibis system is said to have benefits such as reduced unscheduled downtime, increased equipment availability, increased maintenance resources efficiency and more accurate predictability of inventory demand requirements

(ii) Planned Corrective Maintenance

There are certain types of failure of equipment component which may not cause total stoppage of work. For example, a piece of equipment may still function with a failed starter motor or a damaged bucket. Therefore, repairs of this nature can be planned to be performed at convenient times, usually during a service period, after shift hours or when the equipment has no scheduled work. This type of maintenance activities is called planned corrective maintenance.

This type of maintenance may also include repairs resulting from the preventive maintenance system such as the repairs recommended by the 'Oil Analysis'. These could also be the necessary body repairs to components like Hand rails, Foot holds, Operator's cab, and other minor works which are planned in advance to be carried out at convenient times.

A major overhaul on a piece of equipment can also be considered as a planned Corrective maintenance activity, because it is undertaken at a predetermined time, usually after the dudes of the equipment are completed.

(iii) Unscheduled Maintenance (Unplanned Maintenance)

In unscheduled maintenance some maintenance activities such as essential lubrication are performed at unspecified intervals and the repairs are usually undertaken only when a piece of equipment breaks down (Douglas, 1975). However, sometimes

Repairs may also be done on a machine when a component is malfunctioning and the mechanical performance of the machine is unacceptable. An unexpected failure of a machine can occur at any time and unscheduled maintenance in such a case is unavoidable. Therefore, all equipment companies will have to carry out unscheduled maintenance to a certain extent. However, a maintenance policy which is completely unscheduled is not usually recommended. This is particularly so when the machines are key items of a construction process or when there is possible safety hazards arising from unscheduled maintenance.

2.3.2.5. Replacement policies practices

Like any other equipment, a piece of construction equipment deteriorates with use. As a result, the maintenance costs tend to increase and the equipment becomes less reliable. The reliability is a measure of the frequency of unexpected breakdown of the equipment. A less reliable old equipment item would usually have a higher breakdown rate than that of new equipment item. The consequences of these breakdowns are the disruptions to the construction work for which the equipment is being used and these disruptions in turn cause direct or indirect monetary losses to the equipment companies.

Therefore, contracting and plant hire companies usually, replace their old equipment regularly after a number of years of ownership. This ownership or retention period for a particular type of equipment is not fixed and may vary from one owner to another.

(i) Factors Influencing the replacement decision

Maintenance costs and consequential costs due to breakdowns (downtime costs) are not the only factors influencing the replacement decision. Textbooks and research papers on construction equipment replacement suggest that the following factors might also influence the decision concerning the equipment replacement (Douglas, 1975; Harris & McCaffer, 1982; Peurifoy & Ledbetter, 1985).

- Revenue
- Maintenance and Repair costs
- Downtime costs
- Cost of Capital
- Depreciation
- Obsolescence
- Inflation
- Tax considerations and Capital Allowances

Revenue is a very important factor in deciding the replacement age of equipment, provided that there is direct income from the use of the equipment. This factor may be more relevant to plant hire companies and to subsidiary plant companies which operate as profit centers, however, it is of less importance to contracting companies with no direct income from their equipment.

Maintenance costs include expenditure on servicing, replacement of consumables etc. whereas, repair costs are due to labor, spare parts and materials spent on necessary repairs of broken down equipment. As explained earlier downtime costs are the costs such as loss of production, delay in completion of the construction work, extra costs due to substitute equipment and overtime work caused by equipment breakdowns.

The cost of capital is the interest paid on the money used for purchasing the equipment if the money has been borrowed from a bank or any other third party. If the company's own funds have been used for purchasing equipment then the cost of capital would be the profit that could have been made if invested elsewhere in the company's business.

Depreciation is the loss of the resale value of equipment as a result of continued use. For example, if a piece of equipment is retained for one more year, the market value of the item would drop because of the deterioration caused by using it.

Obsolescence is the fact that the newer equipment is superior, usually in productivity to the older equipment, due to technological development. The obsolescence could be measured in terms of cost per unit output. It is believed that newer models of equipment give less cost per unit output than the earlier models. A survey done by Schexnayder and Hancher(1981) shows that in the USA, contractors believe the annual obsolescence rate to be in the range of 1% - 15% with a weighted average of 5.6%.

Inflation is simply the increased price of the new machines (price increase could also be due to technological development). For example, in the USA, the annual growth of rate of inflation of all construction equipment in the period 1971 - 1981 was about 9.8% (Schexnayder and Hancher, 198 1).

Taxes and capital allowances also have some influence on the replacement decision. In the UK, some years ago, there was a tax relief of the taxable profits amounting to 100% of the purchase price (capital allowance) in first year of ownership. This encouraged many contractors" particularly large companies with sizeable turnovers to buy more and more equipment to replace their old equipment. However, the situation has now changed and the maximum annual capital allowance is 25% of the book value; and the corporation tax relief on this is 35% provided that a company has sufficient taxable profits to gain the benefit.

(ii) Determining the Replacement Time of Equipment

Although there are many factors which seem to influence the replacement decision, the actual replacement time of an equipment item is mainly dependent upon the company policy in this regard. This replacement policy may be more influenced by one or more of the factors listed in the previous section. However, the replacement policy of some companies may be based on a completely different criterion.

A survey done in the USA (Hinze and Ashton, 1979) shows that the following criteria are used by contractors in determining the replacement time.

- When the equipment becomes inefficient.
- When the financial picture of the company is good.
- Use economic study to find the economic life.
- When the equipment becomes obsolete.
- Before a new job or a major overhaul.

Another survey undertaken by Tavakoli,Taye and Erktin (1989) gives the following as the methods used by contractors to determine the replacement time of equipment.

- When the cost for necessary repairs are too high.
- Determination of economic life by a quantitative method and replacement and replacement at the end of this life.
- When the equipment costs reach a certain target value.

Both above studies showed that the use of an economic study in determining the life of an equipment item is very low among the contractors. An economic study is usually carried out using a mathematical model. There are mathematical models proposed by researchers like

Douglas (1968), Harris & McCaffer (1982) and Collier & Jacques (1984) for determining the economic life of construction equipment.

However, contractors who undertake replacement analysis may have their own mathematical models to find the economic life of equipment. For example, Tarmac: Construction Plant (Street , 1983) used to have a replacement model which was based on the maximum rate of return of the equipment.

(iii)Selection of the Replacement of Equipment

Textbooks on plant management (Harris & McCaffer, 1982; Douglas, 1975) and investment appraisal recommend various quantitative evaluation techniques to select the most economical equipment from different alternatives available in the market-to replace the existing old equipment items of a company. These techniques use either the costs, or both revenues and costs of different alternatives in the analysis. The most common evaluation techniques are given below.

- Payback period method.
- Accounting return on investment.
- Internal Rate of Return.
- Net Present Worth method.

However, not every company undertakes quantitative analyses to select the replacement equipment. The survey done by Hinze and Ahston (1979) shows that one or more of the following criteria were used by contractors to make decisions as to which equipment to buy:

- Always buy the same brand.
- Take the best purchase price.
- Service record and reputation of the dealer.
- The particular needs of the jobs.
- Availability.
- Best credit terms.

Also, there may be other criteria, different to those mentioned above, used to select the replacement equipment. For example, some companies may look for the dealer's back-up service and good machine performance in addition to the price of equipment (Con. Plant & Equip., 1986-b). Others would prefer to buy the equipment with the longest free warranty period offered by the manufacturer (Mead, 1986).

2.3.3. Construction equipment planning and management practice in Ethiopia

Proper equipment planning and management practice is critical issue, in companies undertaking road construction project most of works are machine intensive. It is the parameter that determines the loosing and gaining company perhaps, construction equipment cost covers about 30% of project cost.

Most construction companies in Ethiopia have no organized equipment planning and management policies. On the other hand some companies have construction equipment planning and management manuals but it is not practically implemented on site performance of equipment. Let discuss construction equipment planning and management practice in some construction companies, which are participated in road construction projects.

(i) Ethiopia construction works corporation(ECWC)

Ethiopian Construction Works Corporation, here after called ECWC was established by council of ministers reg. no. 366/2008 by merging Ethiopian Road Construction Corporation (ERCC) and Ethiopian Water Works Construction Enterprise (EWWCE) on December 18, 2015 G.C.

It is commonly believed that any construction undertaking needed a well maintained, organized and managed equipment to achieve its objective and to foster higher productivity, and be profitable. In the absence of the above accepted facts, it would be hardly possible to think survive in free and competitive market. Accordingly, to cope up with the new situation ECWC top management established the committee to adopt Working Manual from ERCC and EWWCE that can be uniformly implemented in the Corporation.

In accordance with proclamation no. 25/1992 article 16 (1) (g) the Chief Executive Officer prepare and submitted Equipment Management System Manual.

This guide manual applies to ECWC Headquarter including Orma Equipment Maintenance and Production Center, Kality Equipment Maintenance and Production Center, ECWC Projects and any other institutionally accountable, ECWC owned equipment wherever located.

These guidelines serve to achieve the General and Specific policies held within the ECWC Policy Directive relevant to Construction Equipment and Machineries Sector. It offers procedural guidance to ECWC personnel for the acquisition, registration, data record, supply and movement control, utilization, evaluation, inventory, disposal and other responsibilities of ECWC owned equipment.

Even if, ECWC adopted construction equipment planning and management guideline, 93% of equipment owned by a company has completed its economic life. Only 7% of equipment is in its economic life. This shows that most of equipment productivity rate is very low in addition this drives the company to ward loss; therefore serious management decision is needed.

(ii) Sur construction company

Sur Construction Company is one of the front line construction companies participating in road construction project throughout the country. In company organizational structure, there is deputy CEO who is responsible for General Manager. Under deputy CEO there is construction equipment administration department and equipment maintenance department. These two departments plans and manage the movement equipment in the company.

Even if, the company has a good organizational structure in planning and managing construction equipment, they have no documented guidelines which lead the company equipment management towards strategic planning.

(iii) Addis Ababa City Road Authority(AACRA)

AACRA is one the major government organization which is undertaking the road construction in Addis Ababa by its own force and by contractors. Currently the organization is led by director general and there are five departments under director general. Engineering operational deputy general director is one of the main departments that are accountable to the director general. Equipment administration and maintenance director directorate is the department which is responsible for engineering part and operational deputy general director. This department is managing large number of construction equipment for AACRA own force road construction projects. However, department is managing this much of construction equipment they have no standard policy to manage construction equipment.

Lack of proper construction equipment planning and management policy is the critical cause for poor equipment planning and management problems. Most construction equipment owned by the company are completed their economic life. There is no measure taken to replace the outdated equipment which have high maintenance and repair cost than revenue the equipment can generate. Generally, as I have discussed with AACRA top manager and observed practically on site, so many problems are identified on equipment planning and management. Therefore, this paper will conduct detail investigation on heavy duty construction equipment planning and management problems, its cause and effects on AACRA projects. Also possible recommendations will be forwarded for AACRA.

2.4. Heavy- duty equipment in road construction

Heavy-duty construction equipment is of extremely important in earth moving, excavating and finishing operations. This equipment facilitates cutting of earth, finishing and transportation of soil from the point of cutting to the point where it is required or disposed. The main function of heavy-duty construction equipment is moving material, cutting and leveling the ground to meet the primary objectives of the owners (Jose, 2001).

Heavy equipment is usually classified or identified by one of two methods. 1. Functional classification and 2. Operational classification. A bulldozer used to push a stockpile of material, could be identified as a support machine for an aggregate production plant, a grouping could also include front end loaders. The bulldozer could however, be functionally classified as an excavator. (Peurifoy et al, 2006)

In this thesis combination of functional and operational grouping are used. The basic purpose is to explain the critical performance characteristics of particular piece of equipment and then to determine most productive application of machine.

This thesis focuses on excavation and earth moving equipment most frequently used in AACRA road construction sites. Three types of excavating and earthmoving equipment selected for the study: Graders, loader and excavator. The earth moving and excavating equipment was selected for the study because equipment is the major resource used in earth moving and excavating operations, which in turn constitutes a major parts of road construction. In addition the earthmoving operation represents the most rugged operating conditions for equipment in road construction. Therefore, these types of equipment accurately measure the share of the unanticipated factors on loss of productivity.

2.5. Heavy duty construction equipment productivity

2.5.1. Equipment productivity in general

According to Jose (2001) productivity is the ratio of useful work out put to the time spent to complete that work. Productivity in this context represents the volume of earth produced per operator hour and number of work cycles performed per operator minute. To judge the level of performance, the actual productivity must be compared against a desired productivity (estimated). The performance ability ratio (PAR) given as the ratio of estimated productivity to current productivity (Alfeld, 1988). A PAR value close to 1 indicates that the current productivity is relatively good, while a PAR value far greater than 1 indicates a poor productivity.

As Peurifoy et al. (2006) argued there are high degree of interdependency between the size and complexity of the construction projects with equipment utilized. Therefore, this interdependency needs different combination of heavy-duty construction equipment (like loader, grader and excavator) for different activities. In fact, construction work typically requires the right machine for the right job used intensively in road construction projects.

The following sections explain this equipment in detail.

2.5.2. Motor grader production rate

The grader is a long tractor-driven piece of equipment with a blade mounted underneath. The blade is used to push material straight ahead or to the side at a desired level.

Linear grading productivity is estimated using the following basic formula: (Gransberg et al., 2006).

- V, the average grading speed
- W, the effective grading width (width of blade if pushing straight ahead perpendicular to travel direction)
- OF, the operating factor
- N, the number of passes required to cover the area to be graded (width of the road base)

Therefore,

Work hour production of grader = [VxWxOF]/ [N]

When a constructor lacks reliable historical data, most motor grader equipment manufacturers will provide production information. Manufacturer‟s production information is useful in conducting a comparative analysis when developing a conceptual estimate or schedule. Production data provided by manufacturers (or any other source) must be applicable to a particular situation.

For example, Caterpillar (April, 2006) expresses a motor grader‟s production in relation to the area covered by the moldboard as follows:-

A = S x (Le - Lo) x 1000 x E (Metric)

A = S x (Le - Lo) x 5280 x E (English)

Where A: Hourly operating area (m^2/h or ft^2/h)

S: Operating speed (km/h or mph)

Le: Effective blade length (m or ft)

Lo: Width of overlap (m or ft)

E: Job efficiency

Operating speed

Table 2.1. below presents operating speed

Finish Grading	0 – 4km/h (0 – 2.5mph)
Heavy Blading	0 – 9km/h (0 – 6mph)
Ditch Repair	0 – 5km/h (0 – 3mph)
Ripping	0 – 5km/h (0 - 3mph)
Road Maintenance	5 – 16km/h(3 – 9.5mph)
Haul Road Maintenance	5 – 16km/h(3 – 9.5mph)

(Source: Caterpillar Performance Hand book, 2006)

Effective Blade Length

Since the moldboard is usually angled when moving material, an effective blade length must be computed to account for this angle. This is the actual width of material swept by the moldboard. NOTE: Angles are measured as shown in Figure 2.1. The effective length becomes shorter as the angle increases.

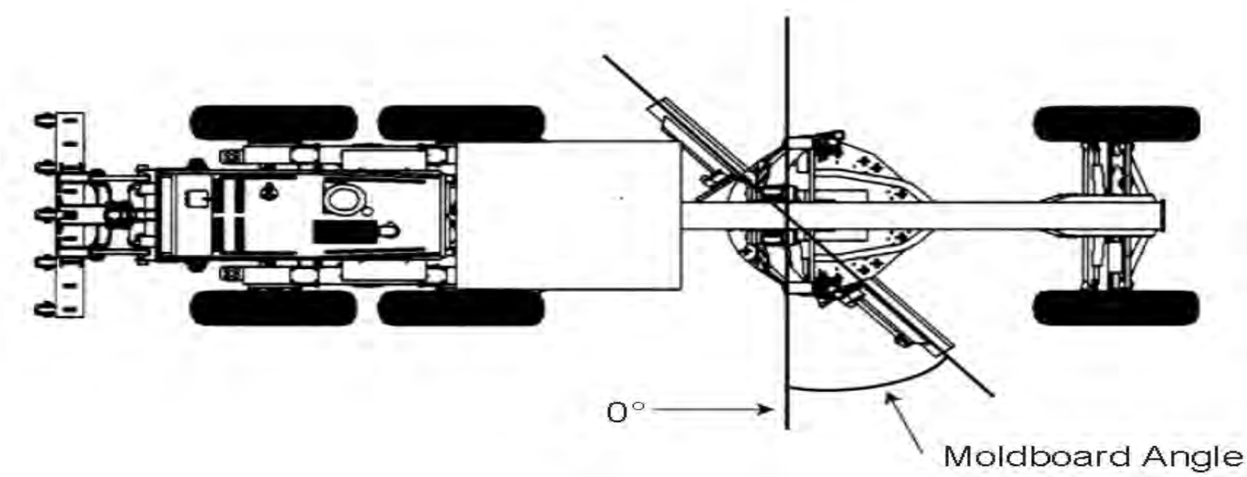


Figure 2.1 moldboard angle when grader moving material (Source: Caterpillar Performance Hand book, 2006)

Table 2.2. below presents effective length for blade angle

Moldboard Length m(ft)	Effective Length m(ft) 30 degree blade angle	Effective length m(ft) 45 degree blade angle
3.658(12)	3.17 (10.4)	2.59 (8.5)
3.962(13)	3.43 (11.3)	2.8 (9.2)
4.267(14)	3.70(12.1)	3.02 (9.9)
4.877(16)	4.22 (13.9)	3.45 (11.3)
7.315(24)	6.33 (20.8)	5.17 (17.0)

(Source: Caterpillar Performance Hand book, 2006)

For other blade lengths and carry angles:

Effective length = Cos [Radians (Blade L)] x Blade Length

Width of Overlap: The width of overlap is generally 0.6 m (2.0 ft). This overlap accounts for the need to keep the tires out of the windrow on the return pass. (Caterpillar Performance Hand book, 2006).

Job Efficiency: Job efficiencies vary based on job conditions, operator skill, etc. A good estimation for efficiency is approximately 0.70 to 0.85, but actual operating conditions should be used to determine the best value.

2.5.3. Excavator production rate

The excavator combines digging and lifting abilities. Excavators come in a wide range of sizes.

Calculate the production rate of excavator using the basic production formula: (Peurifoy et. al., 2006).

Hourly Production = Material carried per load x Cycles per hour

In the case of excavator, the formula can be refined and written as

$$\text{Production} = \frac{3{,}600\text{sec} \times Q \times F \times (AS{:}\ D)}{t} \times \frac{E}{60\text{-min hr}} \times \frac{1}{\text{Volume correction}}$$

Where

Q = Heaped bucket capacity (lcy)

F = bucket fill factor (a numerical value used to adjust rated heaped excavator bucket capacity based on the type of material being handled the type of excavator)

AS: D = Angle of swing and depth (height) of cut correction

t = cycle time in seconds

E = efficiency (min per hour)

$$\text{Volume correction for loose volume to bank volume, } = \frac{1}{1 + \text{swell factor}}$$

2.5.4. Loader production rate

The two critical factors to be considered in choosing loader are 1.The type of material and 2.The volume of material to be handled. Wheel loaders are excellent machines for soft to medium-hard material. However wheel loader production rates decrease rapidly when used in medium to hard material. Another factor to consider is the height that the material must be lifted. When loading trucks, the loader must be able to reach over the side of the trucks cargo container. A wheel loader attains its highest production rate when working on flat smooth surface with sufficient space to maneuver. In poor under-foot condition or when there is a lack of space to maneuver efficiently, other types of equipment may be more effective. (Peurifoy et. al., 2006).

Wheel loaders work in repetitive cycles, constantly reversing direction, loading, turning and dumping. The production rate for a wheel loader will depend on the

1. Fixed cycle time required to load the bucket, maneuver with four reversals of direction and dump the load.
2. Time required traveling from the loading to the dumping position.
3. Time required returning to the loading position.
4. Volume of material hauled each cycle.

Table 2.3 Gives fixed cycle times for both wheel and track loaders. (Peurifoy et. al., 2006).

Loader size, heaped bucket capacity(cy)	Wheel loader cycle time* (sec)	Track loader cycle time* (sec)
1 – 3.75	27 – 30	15 – 21
4 – 5.5	30 – 33	-
6 – 7	33 – 36	-
14 – 23	36 – 42	-

*includes load, maneuver with four reversals direction (minimum travel) and dump

When travel distance is more than minimum, it will be necessary to add travel time to a fixed cycle time. For travel distance is less or greater than 100ft, a wheel loader should be able to travel, with a loaded bucket, at about 80% of its maximum speed in low gear and for return empty speed is less or equals 100ft, at about 60% of its maximum speed in second gear. In the case of distance over 100ft, return travel should be at about 80% of its maximum speed in second gear.

Hauling speed, for all distances = 80% of maximum speed in lower gear

Empty Returning speed, for distance 0 – 100ft = 60% of maximum speed in second gear

Empty returning speed, over 100ft = 80% of maximum speed in second gear.

Table 2.4 Effect of haul distance on production. *(Robert L. peurifoy et. al., 2006).*

Haul distance(ft)	25	50	100	150	200
Fixed time	0.45	0.45	0.45	0.45	0.45
Haul time	0.09	0.18	0.36	0.55	0.73
Return time	0.04	0.09	0.13	0.19	0.26
Cycle time(min)	0.58	0.72	0.94	1.19	1.44
Trips per 50-min hour	86.2	69.4	53.2	42	34.7
Production (tones)*	262	210	161	127	105

The fill factor correction for a loader bucket (see table 2.11) adjusts heaped capacity based on the type of material being handled and the type of loader, wheel or track. Mainly because of the relationship between traction and developed break out forces, the bucket fill factors for the two types of loader are different.

Table 2.5 Bucket fill factors for wheel and track loaders. (Peurifoy et. al., 2006).

Material	Wheel loader fill factor	Track loader fill factor
Loose material		
Mixed moist aggregates	95 – 100	95 – 100
Uniform aggregates		
Up to 1/8 inch	95 – 100	95 – 110
1/8 – 3/8 inch	90 – 95	90 – 110
½ - ¾ inch	85 – 90	90 – 110
1 inch and over	85 – 90	90 – 110
Blasted rock		
Well blasted	80 – 95	80 – 95
Average	75 – 90	75 – 90
Poor	60 – 75	60 – 75
Other		
Rock dirty mixture	100 – 120	100 – 120
Moist loam	100 – 110	100 – 120
Soil	80 – 100	80 – 100
Cemented materials	85 – 95	85 – 100

Once the bucket volumetric load is determined, a check must be made of pay load weight. SAE has established operating load weight limits for loaders. A wheel loader is limited to an operating load, by weight that is less than 50% of rated full-turn static tipping load considering the combined weight of bucket and the load, measured from the center of gravity of the extended bucket at its maximum reach, with standard counterweighs and no ballasted tires. In the case of track loaders, the operating load is limited to less than 35% of static tipping load. Most buckets are sized based on 3000 Ib/lcy material. (Peurifoy et. al., 2006).

$$\text{Production} = \frac{3{,}600\text{sec x Q x F}}{t} \times \frac{E}{60\text{-min hr}} \times \text{Unit weight of material}$$

Where

Q = Heaped bucket capacity (lcy)

F = bucket fill factor (a numerical value used to adjust rated heaped excavator bucket capacity based on the type of material being handled the type of excavator)

t = cycle time in seconds

E = efficiency (min per hour)

2.6. Problems in construction equipment planning and management

When selecting equipment for a given job, the major challenge to be faced is to satisfying several constraints imposed by the job and contractual obligations. This constrains or factors include, specific construction operation, job specification requirement, conditions of job site, location of the job site, time allowed to do the job, balance of inter dependent equipment, mobility required of the equipment and versatility of the equipment (Day & Benjamin,1991). Further in managing construction equipment, contractors are invariably plagued with several difficulties such as huge capital investment in the acquisition phase, which usually constitutes a major financial burden. Procurement of major construction equipment not only costs as high as 36 percent of the total construction project cost, but also causes a high delivery time uncertainty, which may be disrupt the construction schedule (Yeo and Ning, 2006).

In operational phase, contractors are often faced with problems relating to high rate of equipment breakdown and accident resulting from unskilled operator abuse (Prasertrungruang and Hadikusumo and Hadikusumo, 2007). Poor training of equipment operators is often claimed as major causes of equipment related accidents (Gann, and Senkar, 1998). In the maintenance phase, proper maintenance management of construction equipment is never over- emphasized since the cost and time that exceed the designated budget or schedule on projects are often resulted from poor equipment maintenance practice. However, over maintenance of equipment is undesirable as well (Vorster and Garza, 1990). Finally at the disposal phase, determining economic life and timing for replacement is problematic because such decision is influenced by various factors such as equipment obsolescence and efficiency (Vorster and Garza, 1990).

2.7. The main causes of equipment planning and management problems

- Constraints imposed by job and contractual obligation
- Huge capital investment in the acquisition phase
- Poor training of equipment operators
- Poor equipment maintenance practices
- Improper determination of economic life and timing for replacement.

2.7.1. Constraints imposed by job and contractual obligation

In fact, selection of equipment for the project is one of the key decisions in planning and executing a construction project, which affects how the work will be done, the time required to complete the work, and the cost that will be accrued. During selection of equipment for a particular project, the main challenge to be faced is to satisfy several constraints imposed by job and contractual obligation, includes:-

(i) Scope of work to be carried out

(ii) Suitability for job conditions

(iii) Balance interdependent equipment

(iv) Unit cost production

2.7.2. Huge capital investment in the acquisition phase

The primary consideration in the buy, lease, or rent decision is the amount of risk the contractor wishes to assume. This risk is typically associated with financial considerations which are huge capital investment. The evaluation of this risk makes equipment acquisition an important managerial concern. It is advisable to consult an accountant prior to purchase of equipment to evaluate cash flow and tax implications. Along with these financial considerations, how much the equipment is to be utilized is the most important consideration for return on investment.

Future work volume, production needs, project-specific or client requirements, long-term company goals, acquisition time, and equipment availability must be considered when developing a utilization strategy for a piece or fleet of the equipment. The capital investment on purchase and/or rental/lease, and operation of the equipment being very high, it has to be managed so as to ensure maximum return on investment, productivity and minimum operating, maintenance and repair cost. (Gransberg et al., 2006).

For this reason, subcontracting small parts of the work that are equipment intensive minimizes risk and is typically most efficient. Ownership of a particular type or types of equipment, combined with expertise and experience, makes specialty subcontractors cost efficient and minimizes the risk for the contractor. Specialty subcontractors such as dirt work, excavation or demolition and hauling and soil and concrete boring are common today. Subcontracting the work removes most equipment responsibilities from the contractor. (Gransberg et al., 2006).

2.7.3. Poor training of equipment operators

Equipment operator is the last shoting person that determines the productivity of equipment. Misuse of equipment, induced by the negligence of the operator and lack of proper training and know-how on the part of equipment supervisor, may result in increased frequency and cost of down time (Pathmanathan, 1980). An operator‟s skill is one of the most important factors and it affects that operator‟s performance and the direct cost of DT through job efficiency (Arditi et al., 1997; Elazouni & Basha, 1996; Edwards et al., 2000).

2.7.4. Poor equipment maintenance practices

When the machine breaks down, the production drops to zero and the equipment starts costing money to its owner rather than making money. Construction equipment maintenance programs generally consist of three major components: preventive maintenance, routine maintenance, and major repairs. If the first two programs are both aggressively applied and well managed, the major repair program is minimized, and even more importantly, the first two programs occur as scheduled under the owners‟ control whereas major repairs occur randomly and usually at times when they seem to create the most distress to the project. Poor equipment maintenance practices causes the major break on equipment spare parts and increases the down time of equipment, this reduces productivity of equipment and increases project cost. Thus, to understand effective construction equipment management, one must also understand effective construction equipment maintenance. (Gransberg et al., 2006).

Many factors affect the productivity of a machine. Weather, operator efficiency, and operating site conditions all have an impact and are often not possible for the project manager to control. However, the one truly controllable factor is machine availability. For this reason, equipment availability management, which is the primary goal of equipment maintenance, must be aggressively pursued based on a detailed maintenance program developed by the project managers. The specific details of an equipment maintenance program depend on various factors such as the size of the fleet, the type of the project, location, climatic conditions, and other factors, and each program must be customized for the project on which it will be used. However, the absence of a properly implemented maintenance program leads to premature equipment failure, potential cost overruns, and increased crew idle time due to the equipment awaiting repairs. Moreover, the percentage of the total operating cost used for repairs can reach 25% or more (Guralinik, 1979) as quoted on Gransberg et al., 2006. As a consequence, the quality of maintenance management is a significant factor affecting actual construction equipment ownership costs. Implementation of a detailed maintenance program can consistently lower the cost of operating the equipment contemplated in the estimate.

Construction equipment maintenance constitutes a big percentage of the total project cost and as a consequence, the effectiveness of equipment management during project execution is a very important factor in project profitability. (Gransberg et al., 2006).

2.7.5. Improper determination of economic life and timing for replacement

Construction equipment life can be defined in three ways: physical life, profit life, and economic life. Figure 2.2 below shows graphically how these different definitions relate to the life cycle of a typical piece of equipment. (Gransberg et al., 2006).

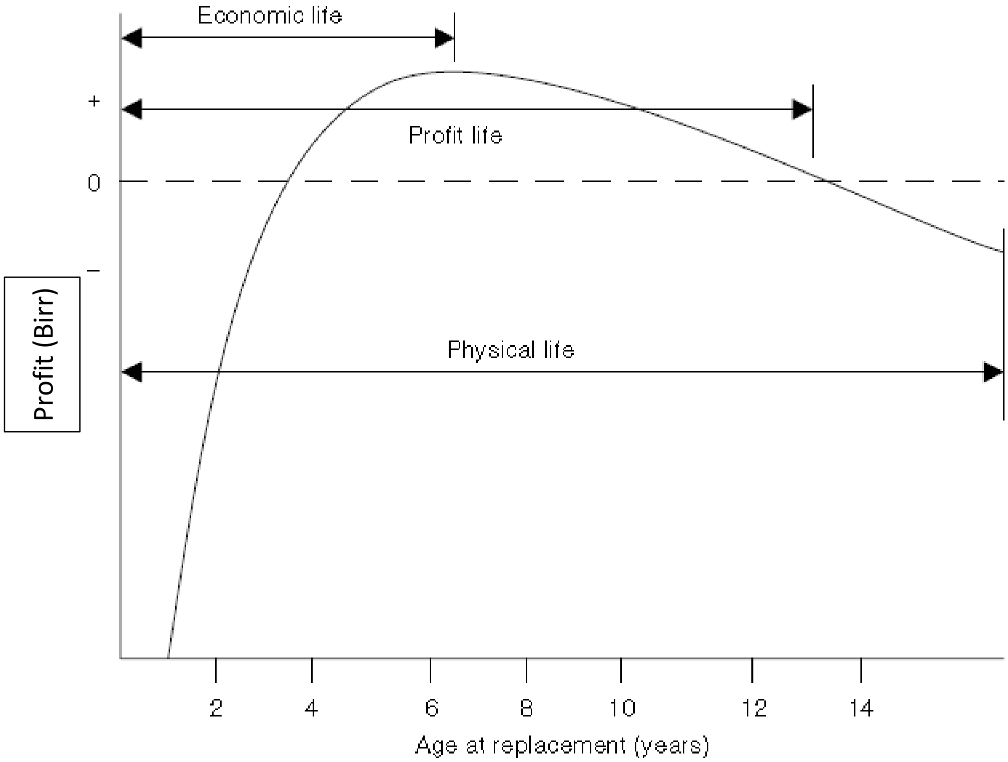


Figure 2.2 Equipment life definitions (Source; Gransberg et al., 2006).

One can see in the graph that over the physical life of the machine, it takes some time for the new machine to earn enough to cover the capital cost of its procurement. It then moves into a phase where the equipment earns more than it costs to own, operate, and maintain, and finishes its life at a stage when the costs of its maintenance are greater than what it earns during the periods when it is in operation.

Physical life is the age at which the machine is worn out and can no longer reliably produce. At this point, it will usually be abandoned or scrapped. As construction equipment ages, maintenance and operating costs increase.

Profit life is the life over which the equipment can earn a profit. The retention beyond that point will create an operating loss. (Guralinik, 1979) as quoted on Gransberg et al., 2006.

Economic life equates to the time period that maximizes profits over the equipment‟s life. Equipment owners constantly strive to maximize production while minimizing the cost of production. Thus, selecting economic life span as the metric to make the equipment replacement decision is in fact optimizing production with respect to profit. Figure 2.10 illustrates how the economic life of equipment is shorter than the physical life and ends when the profit margin associated with a given machine reaches its highest point. Therefore, the improper timing of equipment replacement causes an erosion of profitability by the increased cost of maintenance and operation as the equipment ages beyond its economic life. Owners can determine the most economical time to replace the equipment by keeping precise records of maintenance and repair costs. Determination of the appropriate timing to replace a piece of equipment requires that its owner include not only ownership costs and operating costs, but also other costs that are associated with owning and operating the given piece of equipment (Guralinik, 1979) as quoted on Gransberg et al., 2006. These include depreciation, inflation, investment, maintenance, repair, downtime, and obsolescence costs.

2.8. Effects of poor equipment planning and management

2.8.1. Delay (Time overrun)

Delay is generally acknowledged, as the most common, costly, complex and risky problem encountered in construction projects (Alaghbari, Kadir, Salim and Ernawati 2007). Because of overriding importance of time for both the owner (in terms of performance) and the contractor (in terms of money) it is a source of frequent dispute and claims leading to lawsuits. In construction, delay could be defined as the time overrun either beyond completion date specified in a contract, or beyond the date that the parties agreed upon for delivery of a project. There is a wide range of views on cause of time delays for engineering and construction projects. Different researchers identified that, most causes of delay is directly or indirectly influenced by poor equipment planning and management. Some of causes of delay on road construction project have been severely identified by more than one researcher include:-

- Poor site management and supervision
- Shortage of material availability
- Shortage of material supply
- Shortage of construction equipment
- Delay in site mobilization

- Improper construction methods implemented by contractor
- Equipment breakdowns
- Low productivity and efficiency of equipment
- Lack of high technology mechanicals
- Low level equipment operator skill
- Poor judgment and experience of involved people in estimating time and resources
- Ineffective planning and scheduling project by contractor.
- Accident during construction

2.8.1.1. Relationship between delay cause and poor equipment management

When considering the above studies, although authors have identified construction equipment related delay causes separately, also they have identified more causes under another categories where the cause are indirectly influenced by poor equipment management. For example, in (Assaf‟s, 2005) research, although construction equipment has been taken as separate causes category, there are some causes identified in other categories also related to construction equipment management. In material category, "Delay in material delivery" can be caused by poor management of construction equipment. Also in contractor category, "Delay in site mobilization" is also related to transportation equipment. In some category "Delay in subcontractors work" "Ineffective planning and scheduling of project by contractor" are also influenced by poor equipment planning and management. Because, subcontractors also use construction equipment for their work component and equipment selection is not up to level needed, planning and scheduling goes wrong. Therefore by considering these facts, it is important to identify relationship between all causes of delay and poor equipment planning and management.

2.8.2. Cost overrun

Cost in project comprises money and resources (people, equipment and materials). The client usually wants the project to be finished with the possible lowest cost and timely. However, it is the project manager‟s responsibility to adopt or formulate a performance standard to track cost performance (Rich-man, 2002). Several factors that cause cost overruns in road construction projects have been identified in various places and time. Different problems and challenges may happen for the contractors during the working procedure with the equipment such as life cycle of the machines and different financial risks which may cost a lot for the company (Stewart, Larry., 2002). Different contactors could not finish their projects without enough financial supports. It has been estimated that 36% of the whole construction project cost refers to the equipment costs (Yeo, and Ning,2006). Therefore, poor equipment planning and management is the major cause of project cost overrun.

2.8.3. Loss in productivity of equipment

Productivity is the ratio of useful work out put to the time spent to complete that work (Jose, 2001). The productivity of modern construction equipment has increased with increase in sophistication and modernizations, thus allowing the cost of operations to remain relatively stable. Poor equipment planning and management causes inefficiencies and loss of productive time can result in an increase in cost.

According to (Makulsawatudom and Emsley, 2001) following are main contributing factor for low equipment productivity in the construction industry. In addition, these factors listed out based on their impact on productivity using Relative Importance Index (RII) and their potential for improvement.

i) **Human factor.** Includes:-
   - Lack of construction material.
   - Incompetent supervisor
   - Rework.
   - Operators effectiveness

ii) **Management factor**- Poor coordination between the site and the office is one of the main contributing factors for this problem. Some of management factor includes:-
   - Inspection time frequency.
   - Inspection delays.
   - Poor communication.
   - Lack of equipment
   - Down time

iii) **Work factors**- includes:-

- Incomplete drawings.
- Poor site coordination

2.9. Strategies and best practices for construction equipment planning and management

Construction management is a vast area that considers several components of a project. Direct involvement of equipment management is rare to be seen in these management strategies. However construction equipment planning and management practices can be categorized as follows.

2.9.1. Selection

Contractors consider selection of equipment fleet to be vital for any construction project to be successful. The task of project planner, estimator or the engineer on the job is to select and match the right machine or combination of machines to the job at hand (Peurifoy, Schexnayder and Shapira, 2006).

Equipment selection best practices include:-

- Use models based on traditional mass haul diagrams, artificial intelligence and genetic algorithm and geographic information system to crew optimization. (Mawdesley et al.,2004)
- Mathematics of rough sets and fuzzy sets. (Cirovic and plamenac., 2006)
- Analytical hierarchy process to take account of qualitative factors (Goldenberg and shapira, 2007)

2.9.2. Acquisition

Contractors have two options in acquiring equipment. They may either own their machinery and equipment or hire it. Many contractors prefer to hire only those items of equipment, which are required to meet peak demand or specialized activities. The alternative decision to purchase will have important financial consequence for the contractor, since considerable capital sums will be blocked up in plant, which must be operated at an economic utilization level to produce a profitable rate of return of investment (Construction information services, 2012). Best practices for construction equipment acquisition determined by different researchers includes:-

a) Purchase equipment outright by cash, financing.
    - Purchase equipment in used condition, new condition, based on personal judgment, based on current and future work load, based on life cycle cost(LLC) of equipment, based on company financial status or based on internal rate of return(IRR) of investment. (prasertrungruang and Hadikusumo, 2007)
    - Make decision on acquiring or disposing equipment by president/CEO, by board directors, by equipment managers or by project managers. (Hinze and Ashton, 1979)
    - Purchase equipment based on brand popularity and spare parts availability, functions and its usage.
    - Purchase the same brand that is being used regularly.
    - Purchase equipment from familiar dealers
    - Buy used machines because of cheaper price but still in good condition or need in functions and advanced technology.
    - Buy used machines only the ones that do not have complicated systems, ones that do not have high repair costs once failure, ones that are not frequently utilized or ones that are frequently utilized for long time
b) Acquiring rental or leased equipment.
    - Use rental or leasing strategy for infrequent utilized equipment, to avoid equipment obsolescence, to avoid uncertainty of spare part cost, to avoid initial financial burden to the company, to test newly launched machines, to save spare parts cost, to benefit from mechanics learning curve, to lower operator/labour costs of machine or to enhance safety as operator uses similar machines. (Hinze and Ashton, 1979. Prasertrungruang and Hadikusumo, 2007. Tavakoli et al., 1989)
    - Use standardized policy for better relationship with dealers or for easier equipment administration.(Tavakoli et al., 1989)

2.9.3. Operation

Equipment operator is the person in the construction organization who has the control on equipment costs (Prasertrungruang and Hadikusumo, 2007). Quality output can be partly achieved through skillful operators working with machines that are in good operational condition, thus educating equipment operators is one of the most important policies and that holds great cost saving potentials. Best practices for construction equipment operation determined by different researchers includes:-

- Allow an equipment operator to work with more than one machine
- Provide training by in-house equipment department, equipment dealers or external agencies.
- Consider poor operating procedure as main cause of equipment accident.

2.9.4. Maintenance

Construction equipment is exposed to a huge abuse, dirt and various other elements which can cause damage of equipment, if they are not cared in proper way. Maintenance of construction equipment is crucial as this preserve them for future construction jobs, accident and save contractors from unnecessary expenses and time (Marvelous.,2012). Best practices for construction equipment maintenance determined by different researchers includes:-

- Provide maintenance by equipment operators
- Provide maintenance by in-house equipment department
- Provide maintenance by equipment dealers.
- Provide maintenance by other external mechanics.
- Provide preventive maintenance programs to equipment.
- Seek for substitute equipment once machine suddenly breakdowns.
- Wait until the failed machine is completely repaired and ready for use.
- Transfer crews to other works once machine suddenly breakdowns.
- Accelerate speed of works once machine suddenly breakdowns.
- Modify project activity and schedule once machine suddenly breakdowns
- Consider poor operating procedures as a main cause of machine failure.

- Consider poor maintenance and use of non-original parts as the main cause of machine failure during use

2.9.5. Disposal

The last stage of equipment lifecycle is disposal stage, in which two major decisions concerning equipment have to be made as timing of replacement and equipment economic life expectancy (Prasertrungruang and Hadikusumo and Douglas, 2007). Further, there are various factors affecting the timing of replacement as follows, machine efficiency, capital availability, investment costs, commencement of new projects, profit accrued from use, tax expense, depreciation, economic analysis, obsolescence costs, and down time cost (Hinze and Ashton, 1976).

Best practices for construction equipment disposal determined by different researchers includes:-

- Dispose or replace equipment based on intuition and rules of thumb.
- Dispose or replace equipment based on equipment economic analysis.
- Dispose or replace equipment when it becomes technologically obsolete.
- Dispose or replace equipment when it becomes inefficient.
- Dispose or replace equipment before major overhaul with high repair cost.
- Determine equipment economic life based on investment cost, downtime cost, obsolescence cost, tax advantage, depreciation cost, maintenance and repair cost and profit accrued from use.

2.10. Equipment productivity measure

The extent of equipment productivity is measured by, overall equipment effectiveness index (OEE). Over all equipment effectiveness index is depend on availability rate, performance rate and quality rate.

2.10.1. Overall Equipment Effectiveness(OEE)

By definition, OEE is a measure of value added to the production by a certain machine in a production time. The demand for increasing productivity in the current competitive construction industry led to a need for performance measurement system for the production process. One of such a performance measurement tool which measures different production losses and which indicate area of process improvement is an Overall Equipment Effectiveness (OEE) index. It is a tool designed to distinguish factors contributing for productivity losses. Knowing the three fundamental performance rate Availability Rate (AR), the Performance Rate (PR) and the Quality Rate (QR) will help to compute overall equipment effectiveness index. These rates indicate the degree to which the required output is achieved (Pintelon et al., 2006) as quoted on Abebawu W.(2014). Those equipment production losses stated, in section 2.8.3 measured quantitatively by OEE, which is a function of the three fundamental performance rates.

In order to calculate the OEE index, it is necessary to correlate the major losses described in section 2.8.3., with time (production time).

2.10.2. Relation between major production losses with production time

In every production industries (it may be a factory, a plant, a construction site for which equipment is used) a number of different production time can be defined; from which OEE should be determined (Carlos, 2009) as quoted on Abebawu W. (2014). As pointed out by Carlos, the following procedure shows the relation between production times with basic equipment losses.

Active/ Loading time = Available time – planned down time

The planned down time may be, planned maintenance, precautionary resting time, lack of work and others. However, within the active time, there are downtime losses such as; equipment may breakdown or there may be a set up adjustment.

Due to these downtime losses, the active time reduced to operating time “time during which equipment actually operates”.

Operating time = Active time – Down time losses

This operating time also reduced further by speed losses. These losses may be minor stoppage or some idling. Now the production time left with the net operating time given by:

Net operating time = Operating time – Idling and minor stoppage losses

Again, equipment may not operate at its full capacity within the net operating time.

Therefore, the net operating time further reduced due to production capacity losses, which led to performing time.

Performing time = Net operating time – production capacity losses/ speed losses down time

Finally, the performing time is get affected by yield losses and quality defective losses. What is left is valuable operating time.

Valuable operating time = Performing time – start up yield losses

This is, the "net" time during which the construction equipment actually contributes to add "value" to the construction industry.

Notice: The final time (valuable operating time) and the initial loading time, help as for short cut checkup, in the calculation of OEE index.

$$OEE = \frac{\text{Valuable Operating time}}{\text{Loading time/Active time}} * 100$$ (Pintelon et al., 2006)

This type of overall equipment effectiveness index in fact shows the performance of the construction site. For instance getting 55% OEE index through this calculation, it shows the construction site does not performing well. However, it does not say why it is performing badly or what went wrong (Carlos, 2009). To see where the problem lies or what is wrong within the system, it is better to calculate OEE index using the three - performance rate:

OEE = AR * PR * QR

Where; AR – Availability Rate

PR – Performance rate and

QR – Quality Rate

The following section describes the three main components of the OEE indexes.

(i) Availability Rate

Activity rate

$$\text{Activity rate} = \frac{\text{Available time} - \text{Planned down time}}{\text{Loading time}} * 100$$

This rate is important for the managerial group; this is because theoretically equipment is there to be utilized 100% of the available time. If the activity rate is much less than 100 %, the project manager must ask why. Then, think to reduce the planned down time. Otherwise, this rate is not a primary component of OEE index (Carlos, 2009).

$$\text{Availability/Operativity rate} = \frac{\text{Loading time} - \text{break down losses}}{\text{Loading time}} * 100 = \frac{\text{Operating time}}{\text{loading time}} * 100$$

It is a primary component of OEE

Availability take in to account down time loss at a given production time, which includes any events that stop planned production. An example includes equipment failure, material shortages, and changeover time (set-up losses). In every productive environment, accessory breakdown during the production time is a serious failure for equipment productivity (Kumar et al., 2012).

(ii) Performance rates as a function to determine OEE

Net operating rate:

$$\text{Net operating rate} = \frac{\text{Output actual cycle time} - \text{Planned down time}}{\text{Operating time}} * 100$$

It is also not direct components of the OEE

$$\text{Operating speed coefficient} = \frac{\text{Design cycle time}}{\text{Actual cycle time}},$$

Not expressed as percentage and it is not direct component of OEE but it is used to calculate the third component of OEE index.

Performing rate;

Performing rate = Net operating rate * operating speed coefficient * 100

Performance takes in to account speed loss, which includes any factors that cause the equipment to operate less than the maximum possible operating speed. Examples includes, machine wear, substandard materials, and operator inefficiency (Kumar et al.,2012).

(iii) Quality rate as a function to determine OEE

Quality rate

$$\text{Quality Rate} = \frac{\text{Total executed amount (unit)} - \text{Reworked amount (unit)}}{\text{Total executed amount}} * 100$$

This rate reflects the impact of quality loss and start up yield losses, which accounts for executed amount that do not meet the specification; including activities that require rework (Kumar et al., 2012).

Finally,

$$\text{OEE} = \text{AR} * \text{PR} * \text{QR} = \frac{\text{Valuable operating time}}{\text{Active time}} * 100$$ (Pintelon, et al. 2006)

This OEE calculation quantifies how well the construction equipment performs relative to its designed capacity during the periods where it is scheduled to execute certain activities. OEE defines the expected performance of a machine, measure it, quantifies the extent of equipment productivity and provides a less structure for analysis, which leads to improvement. It can be used as a tracking measure to see if improvement is to be sustained.

The extent of the current productivity of the construction equipment during the valuable operating time noted from the ratio of actual production rate to the theoretical production rate. These results provide solution for the research question.

As OEE is based on three parameters, individual calculation carried out for availability rate, performance rate and quality rate of the three primary components of overall equipment effectiveness index as shown above. Moreover, OEE index is the product of the three primary component rates. Its value can only be equal or less than the lowest rate among the three primary components rates (Suresham, 2012) as quoted on Abebawu W. (2014). From this result, the main contributing factors for productivity loss were identified in their order. The most contributing factors found within the lowest primary component of the OEE index.

The influence of the associated loss on the equipment cost was analyzed using data collected from the organization, such as total project cost, cost allocated for the construction equipment and using the quantified equipment productivity losses. In fact, this study relay on overall equipment effectiveness (OEE) index, as a critical performance indicator. Moreover, the method of productivity loss analysis using OEE index is case sensitive and needs precise data before the office computation. Parameters that have not measured precisely in the field cannot possible to manipulate it in the office. The more accurate equipment performance data is essential to the success of the project and long- term effectiveness of TPM activities (Piter et al., 2010) quoted on Abebawu W. (2014).

2.11. Chapter Summary

It has been learned from the literature proper construction equipment planning and management plays a crucial role on the success of road constructing companies and equipment renting companies.

The reviewed literature indicated also that Company‟s standard procedures and policies towards equipment management include factors such as equipment selection strategies, procurement systems, acquisition methods, operation procedures, maintenance and repair policies and replacement decisions based on international practices. In addition to this some of national companies practice on equipment planning and management policies were reviewed.

Construction equipment Interdependency needs different combination of heavy-duty construction equipment (like loader, grader and excavator) for different activities. In fact, construction work typically requires the right machine for the right job used intensively in road construction projects. Also the above determined each equipment productivity calculation methods are detail discussed in this literature.

The main causes of equipment planning and management problems like Constraints imposed by job and contractual obligation, Huge capital investment in the acquisition phase, Poor training of equipment operators, Poor equipment maintenance practices and Improper determination of economic life and timing for replacement. Also effects like cost overrun, Delays and loss on productivity are discussed in deep and gap is identified. Additionally, strategies and best practices on construction equipment planning and management were reviewed in detail.

At last it"s learned from literature review that the extent of equipment productivity is measured by, overall equipment effectiveness index (OEE). Over all equipment effectiveness index is depend on availability rate, performance rate and quality rate.

CHAPTER THREE

3. Materials and Methodology

3.1. Introduction

The focus of this research is identifying major problems in construction equipment planning and management, and there effect on construction equipment productivity on AACRA projects. Investigating causes and effects of construction equipment planning and management problems within domestic grade one contractors and equipment rental companies participating in AACRA projects. Therefore, the choice of the mixed research method is justified as an appropriate research strategy. The determination of the study sample and the techniques of data collection are also described.

3.2. Fundamental concepts

Progress in almost every field of science depends on the contributions made by systematic research; thus research is often viewed as the basis of scientific progress. Broadly defined, the purpose of research is to answer questions and acquire new knowledge. Research is the primary tool used in practically all areas of science to expand the limits of knowledge ((Marczyk et al., 2005) quoted in Getaneh (2011)). Besides, Kumar (2011) described research as one of the ways to find answers to questions, whereas, Abiy et al (2009) described research methods as specific research tools (surveys, interviews and case studies) that are used in research projects to gain full understanding of phenomena.

On the other hand, research methodology is a way to systematically solve the research problem and it shall identify the research basis, research questions and research analysis (Kothari, 2004). Furthermore, Abiy et al (2009) described research methodology as "the theory of how inquiry should proceed" that "involves analysis of the principles and procedures in a particular field of inquiry." This involves the researcher‟s assumptions about the data collection methods and analysis strategy.

This research was conducted and inquiries were made to identifying major problems in construction equipment planning and management, and their effects on construction equipment productivity on AACRA projects. Accordingly, this chapter covers the applied methodology followed to achieve the ultimate goal of the research to draw up findings in a way to make conclusions and to forward recommendations.

3.3. Research design, approaches and methods

Kumar (2005) described a research design as a procedural plan that is adopted by the researcher to answer questions validly, objectively, accurately and economically. According to (Kumar, 2005), the following two objectives need to be fulfilled in a research design:

- To conceptualize an operational plan and to undertake various procedures and tasks required to complete the study; and
- To ensure that these procedures are adequate to obtain answers to the research questions.

Research strategies can be broadly categorized as either quantitative or qualitative. Quantitative research is objective in nature (Johnson and Harris, 2002). It usually requires respondents to record their attitudes, opinions, or beliefs on different-point scale measured with numbers (Krosnick and presser, 2010). Three main approaches were suggested by Johnson and Harris (2002) to collect data which are the following:

- Asking questions of respondents by means of questionnaires and interviews,
- Undertaking experiments; and
- Performing extensive reviews of the relevant literature.

On the other hand, qualitative research is subjective in nature (Naoum, 2007). It relies on observing people in their own environment, communicating with them in their own language, and on their terms. Case studies are the major types of qualitative study. In addition, a research study using both qualitative and quantitative approaches can be called a “mixed-methods” approach (Creswell, 2009).

3.4. Research methodology employed in this study

3.4.1. Selected research approach type

This research has involved both qualitative and quantitative characteristics, which are explained below;

3.4.1.1. Quantitative aspects of this research

The quantitative aspect of this research was envisaged with identifying the major problems in construction equipment planning and management including their causes and effects on AACRA projects.

3.4.1.2. Qualitative aspects of this research:

The following are the research aspects of this thesis:

- Investigation on construction equipment planning and management problems and its causes and effects on AACRA projects, using a selected case study. These are featured with qualitative elements. Interviews and case studies appear to be more appropriate for capturing such relevant information in this study.
- The major construction equipment planning and management problems and their cause and effects can be identified by using selected case studies of AACRA projects. This again depends on an overall understanding of the major planning and management problems in the planning and construction phase of AACRA road construction projects.

Therefore, in this research, mixed-method research seems to be appropriate and is helpful in gaining a better understanding through an in-depth study of the new phenomenon based on its qualitative and quantitative aspects of the study.

3.4.2. Selected Data collection methods

The approach to data collection should be based primarily on the nature of the investigation and on the type of data and information that are required. The objective of this study is to identify the major construction equipment planning and management problems within the domestic Grade One contractors that are undertaking construction projects under AACRA. This could be met by employing diverse ranges of methods to collect applicable data. This included questionnaires, interviews, and case studies.

3.4.2.1. Survey study

The survey method involves collecting information from the target population, which is selected based on systematic and representative sampling methods by means of a standardized questionnaire administered identically to all the target respondents in the sample population (Creswell, 1994). In this study, the questionnaire survey was used to obtain information about the identification of major construction equipment planning and management problems, its causes and effects among parties which were participating in Addis Ababa City Road Authority projects. This included, AACRA own force construction department, domestic Grade One contractors and equipment rental companies.

Both close and open-ended questions were included in the questionnaire. The close-ended questions had a number of choices of possible answers and the respondents selected whatever they feel was most appropriate. Open-ended questions were incorporated with closed ended questions in places where the response options were relatively wide and not included in the questionnaire to specify their answers in specified data measurement of rating scale as suggested by Krosnick and Presser (,2010).

When designing a survey response rating scale, it is necessary to specify the number of points on the scale. The Study Handbook of Survey Research by Krosnick and Presser (2010) indicated that two-point scales simply require a decision of direction whereas longer scales require decisions of both direction and extremity. Very long scales require people to choose between many options, so these scales may be especially difficult in terms of scale point interpretation and mapping (Krosnick and Presser, 2010).

Thus, in this research, the response of the questionnaire data was prepared based on the scale of five-point rating scale measurement of the agreement towards each statement from 1 to 5, where 1 stands for (very low), 2 (Low), 3(medium), 4(high) and 5(very high). The reason to adopting this simple scale is as to provide simplicity for the respondent to answer and to make evaluation of collected data easier to evaluate; and to rank major integration problems as the objective of this research.

3.4.2.2. Interviews

In the event that a questionnaire survey might not easily allow the researcher to investigate some theme highlighted in response to a certain question on the survey (Fellows and Liu, 2008) quoted in (Getaneh, 2011), interviews were employed to supplement the information required. In this research, face to face interview was conducted to get data related to equipment planning and management problems from the practitioners and professionals(project managers, equipment managers and site engineers) to support the questionnaire in addition to problems obtained in the literature review. Moreover, an interview was employed by questioning a respondent to obtain responses aimed to supplement information required during case study in relation to the identification of major problems in equipment planning and management in AACRA projects.

3.4.2.3. Case study

Gao and Low (2014) quoted by Yin (1994) gave a widely accepted definition of a case study as an empirical inquiry that "investigates a contemporary phenomenon within its real life context, especially where the boundaries between phenomenon and context are not clearly evident". The case study, in contrast to the questionnaire, allows the researcher to uncover how in daily practice the major problems can affect the work of construction firms (Gao and Low, 2014). Generally, in this research, the case studies aimed to give an in-depth understanding of major problems in construction equipment planning and management, causes and effects on performance of contractors within the AACRA projects.

3.5. Research frame work

Figure 3.1 below outlines the research steps considered in this study. The structure of this research has three stages: Literature review; and two-phased data collection and analysis. Based on the literature review, construction equipment planning and management problems were first identified and its cause and effects are reviewed.

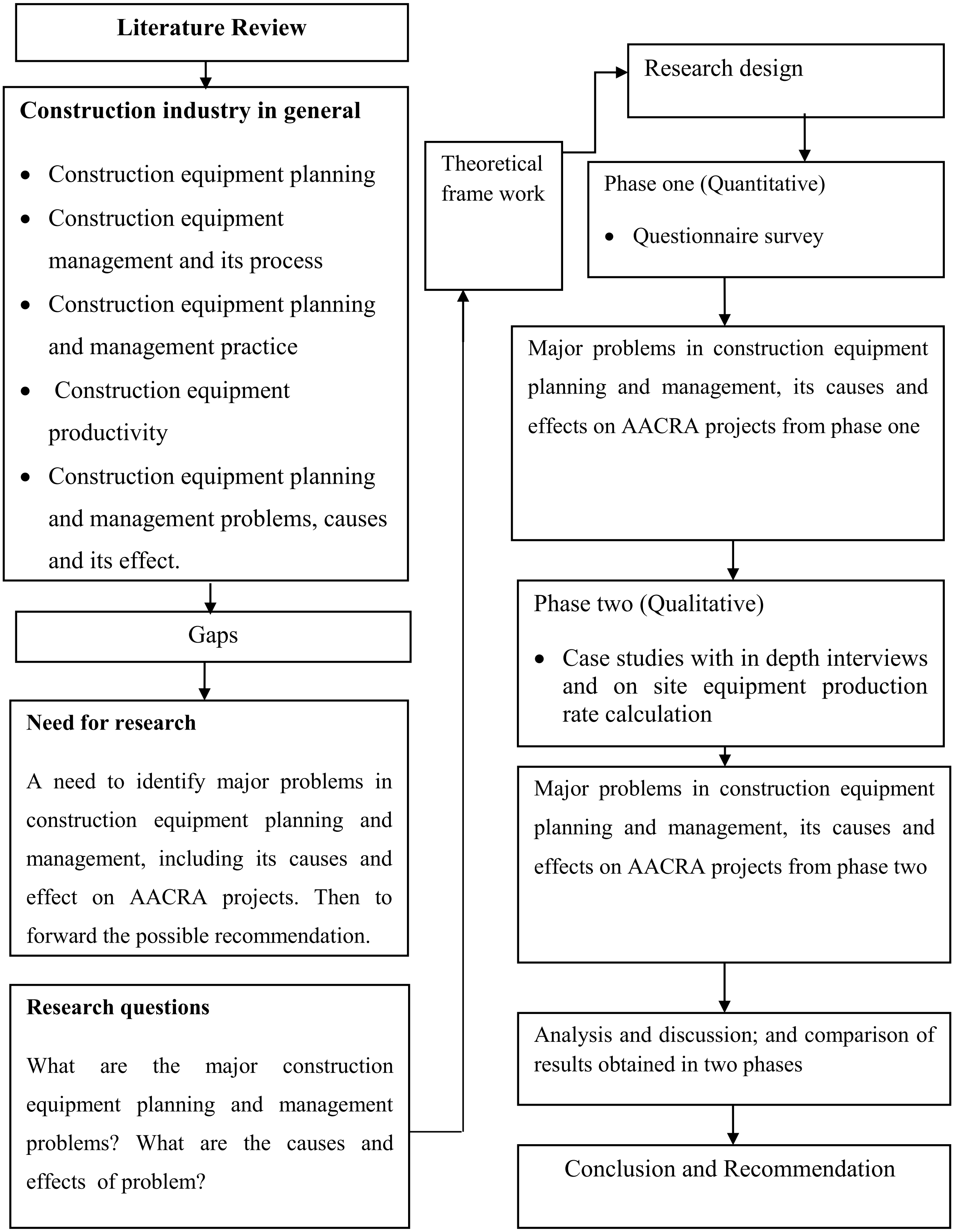


Figure 3. 1: General structure of the research design.

3.5.1. Survey sampling

The population of a research is defined as the units belonging to the category of study (Creswell, 1994). In this study, the population is Grade One contractors, AACRA Own Force construction Department and equipment rental companies which all were participating in the Addis Ababa City Road Authority projects. Using the resource requirement namely "equipment and machinery"; and "manpower", the Ministry of Urban development, housing and construction (MoUDC (2013)) categorized Ethiopian contractors from “Grade One” to “Grade Ten”.

Referring to contract agreement on AACRA, Grade One contractors participating in AACRA projects fall under large category, and thus appear the population of this study. There are two reasons why this study focused on Grade One contractors and they are:

- They play the most important role in Ethiopian‟s construction industry, and thus represent a typical business model in terms of management style, site management practices, human resource management, and equipment management; and
- They have more resource and involved in large AACRA projects and accordingly have wide exposure on different types of construction equipment. Thus, the researcher believes that these contractors have an experience in equipment planning and management issues which may require managerial effort to increase the productivity of equipment.

In this study, Addis Ababa City Road Authority project is the need of this research. In the city governance of Addis Ababa, there are thirty (30) road construction projects including 3 lots (Lot 1, Lot 2 and Lot 3) that construction is currently undertaken by AACRA‟s own force construction brigades. To get more information on subject matter, most of the contractors undertaking the construction have two or more sites and thus they needed to be visited.

In view of the above, there are thirteen (13) Grade one contractors of which twelve (12) are local contractors and one (1) is foreign contractor), of the twelve local contractors, one (1) is the AACRA own force construction department. Companies renting equipment for the private local contractors and AACRA own force construction department are included in the study. Hence, in this study, all the local contractors except the foreign contractor are included in this study and no sampling exercise was required.

3.5.1.1. Data collection

To avoid the constraints regarding direct access to construction companies participated in Addis Ababa City Road Authority construction project, questionnaires were actually distributed to potential respondents and were collected by the researcher directly. Basically, the sample frame for this study were: AACRA own force construction department, Grade One contractors as listed by the Ministry of Construction (MoC) and construction equipment rental companies where; all these entities were participate in AACRA road construction project.

3.5.1.2. Reliability test

Any research based on measurement must be concerned with reliability (Cronbach, 1951). Reliability is concerned with the ability of an instrument to measure consistently whether the test designer was correct in expecting a certain collection of items to yield interpretable statements about individual differences (Kelley, 1942), quoted in Cronbach (1951).

For this, Cronbach"s Alpha (α) was developed by Lee Cronbach in 1951 to provide a measure of the internal consistency of a test or scale; it is expected to always fall between 0 and 1. This system of measurement was originally developed in a context where a set of questions (also called items) are asked to a group of individuals with the objective of measuring a specific concept. Internal consistency is described as the extent to which all questions contribute positively towards measuring the same concept or construct and hence it is connected to the inter-relatedness of the items within the test (Cronbach, 1951).

Accordingly, Cronbach (1951) refers to the internal consistency as the proportion of the test variance that can be attributed to a group of items, which measures the reliability coefficient alpha:

$$\alpha = \frac{I}{I-1}\left(1 - \frac{\sum_{i=1}^{I}\sigma_i^2}{\sigma_X^2}\right) \qquad \text{[Eq. 3.1]}$$

where n = 1, 2 . . . I are the number of items in the scale,

∂_i^2: the variance of item I; and

∂_x^2 is the variance of the observed total test scores.

A high value of the Cronbach"s alpha implies a higher internal consistency of the construct ∂_x^2. The higher the coefficient, the stronger the linear relationship of the items is correlated and the higher the internal consistency (Gao and Low, 2014).

Thus, as Cronbach"s alpha coefficient is the most widely used objective measure of reliability, the internal consistency of the scale of data reliability the data (data collected through questionnaire) were checked using this coefficient before the analysis in this research**.**

3.5.1.3. Data analysis

The relative importance index method was used to determine the relative importance of the major problems in construction equipment planning and management that reflects the causes and effects in AACRA road construction projects. The five-point testing scale of: 1 (very low), 2 (low), 3(medium), 4(high) and 5(very high) were adopted and transformed to relative importance indices (RII) for each integration problem as follows:

$$RII = \sum W / A * N \qquad \text{[Eq. 3.2]}$$

Where;

RII: relative importance indices;

W: the weights given to each equipment planning and management problems by the respondents (Ranging from 1 to 5),

A: The highest weight (i.e. 5 in this case), and

N: the total number of respondents.

The RII value had a range from 0 to 1 (0 not inclusive), the higher the value RII, the more significant the problem on equipment planning and management; similarly on cause and effect. The RII was used to rank the different equipment planning and management problems. These rankings made it possible to cross-compare the importance of the major equipment planning and management problems as perceived by the three groups of respondents (i.e. AACRA own force construction department, contractors and equipment rental companies).

3.5.1.4. Interviews

The design of the semi-structured interviews was based mainly on the research objectives, especially for the one concerning "What are the major problems in equipment planning and management, what are the cause of the problem and its effect on different contractors undertaking road construction in AACRA projects" to include equipment planning and management problems, its causes and effects. Prior to the interviews, their contents were tested with academic experts. Minor alterations were made as a result of this pre-test. Furthermore, during the fieldwork, the interviews were conducted with a selected range of participants at the selected case study projects. These consisted of project managers, equipment managers, site engineers, and foremen from the projects. This was the best opportunity to confirm the findings from questionnaire (phase-1) to identify the major equipment planning and management problems which affect their productivity and to what extent the problems affect at the project sites. The interviews focused on various aspects of major equipment planning and management problems which affect the progress of construction in AACRA projects. In summary, in each interview, the interviewees were asked a subset of the following questions:

- What are the major problems on construction equipment planning and management on parties undertaking construction on AACRA projects?
- What are the causes of equipment planning and management problem?
- What are their effects of equipment planning and management problem?
- What do you recommend to reduce equipment planning and management problems and increase the productivity of construction equipment on AACRA projects?

3.5.2. Case Study

3.5.2.1. Sampling Size Determination

For a given set of available resources, Shang and Low (2014) quoted by Voss *et al.* (2002), highlight that the greater the number of case studies, the greater the opportunities for in-depth observations. This is because, as they highlighted, two limitations exist with a single case: the limit on the generalization of the conclusions drawn, and the presence of biases, such as misjudging the level of representativeness of a single event or exaggerating the importance of easily available data. Furthermore, it can be anticipated that a single case study will not supply enough evidence to validate all the identified equipment planning and management problems and its effect on equipment productivity on the AACRA construction projects in the study. Multiple case studies look at several different construction projects, in order to reach more general conclusions than those provided in a single case study. Besides, multiple case studies give modestly greater amount of comparative data. However, multiple cases may reduce the depth of the study when resources are constrained (Shang and Low, 2014) quoted by (Voss *et al.*, 2002). In this study, the cases are three road projects under AACRA.

3.5.2.2. Selection of case study

(Creswell, 2003) stated the following three conditions that need to considered: during research undertakings:

- Revelatory (when an investigator has an opportunity to observe and analyze a phenomena previously inaccessible to scientific investigation),
- Unique, and
- Critical to testing the theory.

In addition, case study choices should provide opportunity to generalize the study (Shang and Low, 2014). The selection of case studies in this study observed theoretical and practical considerations. Hence, the following three projects have been selected among the overall thirty (30) AACRA road projects.

(i) (Keraniyo Medihanialem – Ambo road Asphalt concrete road project):

This road section is about 2.13km long road and it is at early construction stage. In addition, the researcher hoped different types of construction equipment selected for study will be available on this project and the project is now active. Moreover, it was readily accessible to the researcher.

(ii) **(Shiro meda – Kidane miret asphalt concrete road project):**

This road section is about 2.1km long road and the alignment is uphill and downhill and the construction methodology used needs technical and management skills. The project is at its earliest stage and is currently active. Moreover, it represents a construction at difficult site condition and provides an opportunity to generalize due its work methodology.

(iii) **(AACRA Own Force Construction Project(Lot-1)):**

This is a big construction project consisting number of sub projects and so more number construction equipment are involved in this project. Moreover, it also represents a diverse choice for the case studies, as companies of different natures are covered and provides an opportunity to generalize due to its complexity.

3.5.2. General concept about case study

The reason for employing case study for research is to support the questioner and interview with practical site observation. Through this, the extent of construction equipment productivity will be determined quantitatively and the major factors for equipment productivity loss will be identified.

The extent of equipment productivity is measured by, overall equipment effectiveness index (OEE). Over all equipment effectiveness index is depend on availability rate, performance rate and quality rate. These rates are computed using formulae presented in literature review section 2.10.

CHAPTER FOUR

4. Survey data analysis: Results and Discussions

4.1. Introduction to survey data analysis

This chapter is structured according to research objective and presents the findings. The analysis was carried out using Excel, focusing on: construction equipment planning and management problems, causes of the problem and the effects on AACRA road construction projects. Accordingly, interpretations and discussions were presented on the basis of the findings including the limitations observed. The complete survey questionnaires are provided in Appendix A.

4.1.1. Population characteristics

4.1.1.1. Respondents profile

The study focused on contractors and equipment rent companies that are participating in AACRA road construction projects. These included:-, Grade One local contractors (13 Grade One contractors and AACRA Own Force Construction Department) and major equipment renting companies were considered in the survey. The sum of these individual participants was 24. Accordingly, twenty-four (24) questionnaires were distributed those us: - twenty-one (21) to contractors and three (3) to equipment was renting companies. Out of twenty-four questionnaire, eighteen (18) were responded and collected. The responses were seventy-five (75%) of the total distributed questionnaire which is acceptable.

Table 4.1 shows that 28% of respondents were project managers, 11% were construction managers, 28% were equipment managers, 17% were office engineers and lastly 17% were site engineers. All respondents represented indigenous firms. Sixty percent (60%) of the respondents possessed 0 to 5 years of experience; 17% were 6 to 10 years, 11% were 11 to 15 years, 6% were 16 to 20 years and 6% acquired 21 to 25 years. Eighty percent (80%) of respondents were employees of contraction companies and remainders, 20% were employees of equipment rental company. Table 4.1 below shows the respondents profile.

Table 4.1. Respondents profile

Respondents characteristics	Frequency	Percentage
Designation of respondents		
Project manager	5	28%
Construction manager	2	11%
Office engineer	3	17%
Site engineer	3	17%
Equipment manager	5	28%
Total	**18**	**100%**
Structure of ownership		
Indigenous	13	100%
Foreign	0	0%
Total	13	
Years of experience		
0 – 5	11	60%
6 to 10	3	17%
11 to 15	2	11%
16 to 20	1	6%
21 to 25	1	6%
Total	**18**	**100%**
Types of firm		
Contractors including AACRA own force construction department	12	80%
Equipment renting companies	3	20%
Total	**15**	**100%**

4.1.2. Classification of sample size

Table 4.2 below shows the characteristics of the sample size in respect of contracting and equipment renting companies. The sample consists of 10 respondents from Grade one contractors (56%), 3 respondents from equipment renting company (17%) and 5 respondents AACRA own force construction department (28%). Table 4.2 and Fig. 4.1 below respectively present classification of companies tabularly and graphically.

Table 4.2. Classification of companies

Companies classification	No. of respondent	Percent (%)	Cumulative percent (%)
Grade One contractors	10	56%	56%
Equipment renting Companies	3	17%	72%
AACRA own construction department	5	28%	100%
Total	18	100%	100%

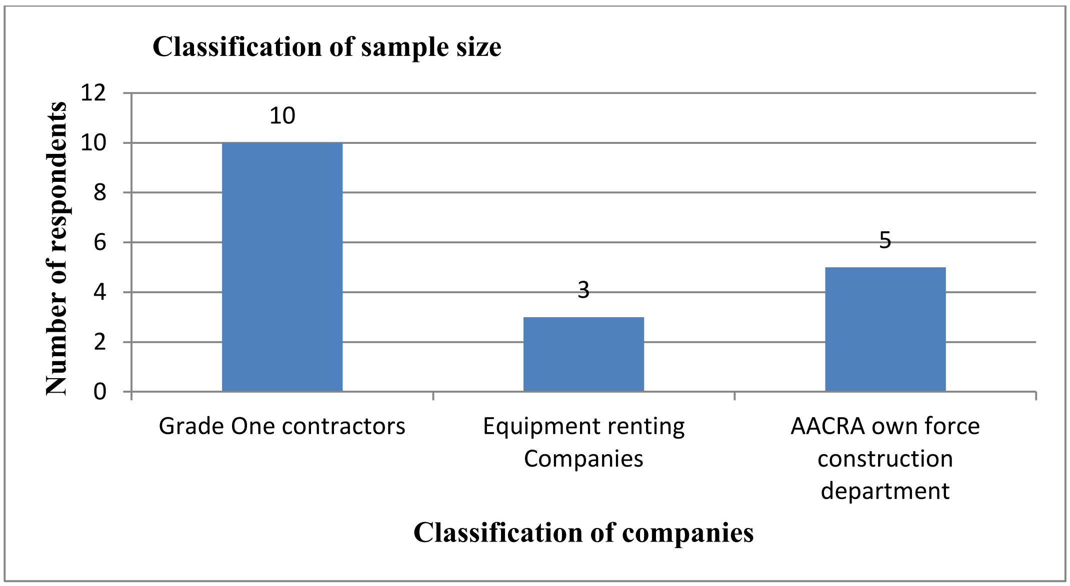


Figure 4.1 Classification of sample size graphically

4.1.3. Response rate

Out of the 24 questionnaires distributed, 18 responses were received which was 75% return rate.

Figure 4.2 below graphically presents response and decline rates.

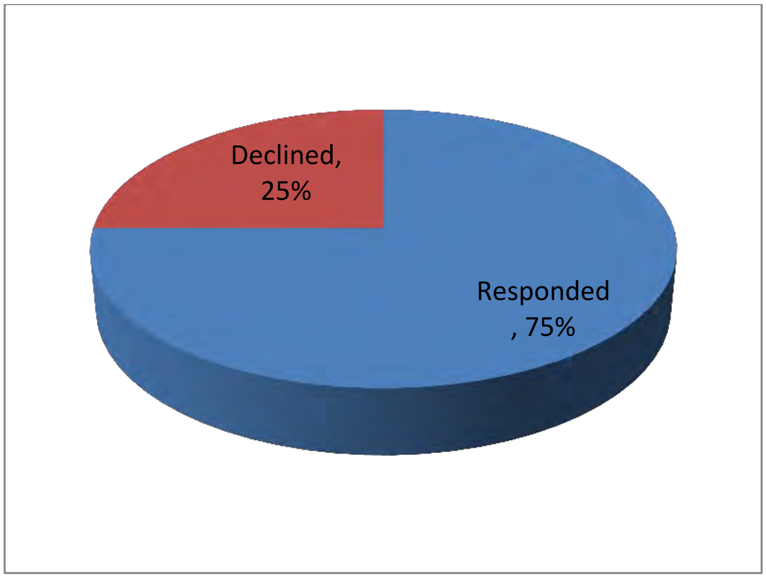


Figure 4.2 Questioner general response rate

Table 4.3 below represents the response rates with 63% off Grade one contractors, 100% of AACRA own force construction department and 100% of construction equipment renting companies.

Table 4.3. Response rates of companies

Companies classification	Distributed questionnaire	Responded questionnaire	Response rate
Grade one contractors	16	10	63%
ACCRA Own Force Construction Department	5	5	100%
Equipment renting companies	3	3	100%
Total	24	18	75%

4.2. Construction equipment planning and management problems

4.2.1. General information

Based on the analysis of data conducted on the questionnaire, 83% of the respondents agreed on the presence construction equipment planning and management policy at head office as well as at project sites. Table 4.3 shows the number of responses corresponding percentages and Figure 4.4 graphically illustrates the same.

Table 4.4 Response regarding presence of construction equipment planning and management policy.

Respondent	Response		Percentage	
	Yes	No	Yes	No
Grade One contractors	10	0	100%	0%
AACRA own construction department	2	3	40%	60%
Construction equipment renting companies	3	0	100%	0%
Total	15	3	83%	17%

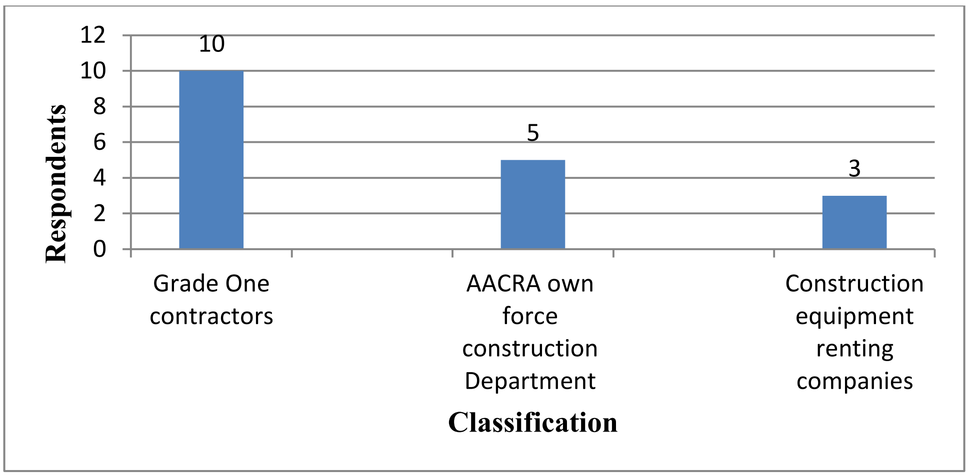


Figure 4.3 Response towards having construction equipment planning and management policy.

When observing the respondents individually, 100% of Grade One contractors and equipment Renting companies agree on having construction equipment planning and management policy but, 60% of respondents from AACRA own force construction department said they have no equipment planning and management policy. However, they believe that AACRA have to adopt documented construction equipment planning and management policy.

Currently, AACRA is undertaking construction of so many roads and bridges, by its own force. Constructing all these projects without equipment planning and management policy is a big failure for AACRA. If great attention is not given, this can lead AACRA to unnecessary wastage of resources and loss since; equipment can cover about 30% of the total project cost.

The researcher also supported the questionnaire by interview. Accordingly, most respondents are agreed on having no documented equipment planning and management policy but, they are using the policies without documentation. This shows that, equipment planning and management is undertaken by personal knowledge. If that employee leaves the company, the company can fall in unexpected loss.

4.2.2. Contractors‟, AACRA Own Force Construction Department‟s and Equipment Renting Companies are implementing Equipment planning and management policy and the types of the policies are stipulated in Table 4.5 below.

Table 4.5 Types of equipment planning and management policy

Item	Policy type
A	Equipment selection policy
B	Equipment acquisition policy
C	Equipment operation procedures
D	Equipment maintenance policy
E	Equipment replacement policy

Table 4.6 shows the types of equipment planning and management policies that contractors, AACRA own construction department and equipment renting companies are to implement regarding the AACRA projects. Based on the analysis 13% of respondents use only the equipment selection policy, 6% of respondents uses equipment operation policy, 13% of the respondents uses equipment maintenance policy, 6% of respondents uses equipment acquisition, operation and maintenance policies jointly, 6% of respondents uses equipment operation and maintenance policies, 6% of respondents uses equipment selection, operation, maintenance and replacement policy and 50% of respondents uses combination of all equipment planning and management policies. Table 4.6 and Figure 4.4 below respectively show tabular and graphical presentation of the same.

Table 4.6 Types of policies and number of responses and percentages

Types of policy	No. of respondents	percent
A	2	13%
C	1	6%
D	2	13%
B, C & D	1	6%
C & D	1	6%
A,C, D& E	1	6%
A, B, C, D & E	8	50%
Total	16	100%

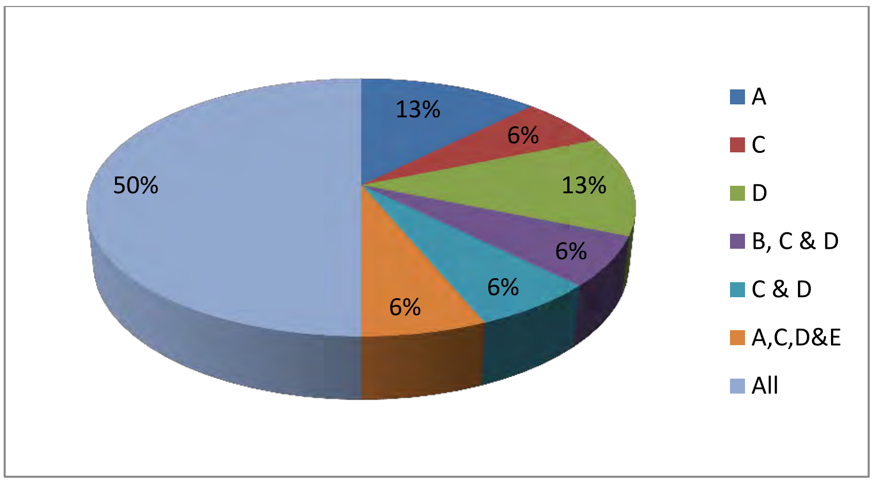


Figure 4.4 Graphical representations of the responses

Accordingly, one respondent uses equipment selection policy, the other uses acquisition policy or operation the remained uses equipment maintenance policy or equipment replacement policy. This practice affects the companies‟ profitability because skipping using one policy affects the implementation of the other policy. Therefore it is better to use all policies consequently.

4.2.3. Construction equipment planning and management problems in AACRA road construction projects.

The reliability of survey data was first checked for accuracy using the Cronbach‟s alpha coefficient formula in order to measure the internal consistency of the collected data. Accordingly, analysis was conducted. The result of the analysis showed that the Cronbach‟s coefficient for the contractors and equipment rental companies were 0.74 and 0.72 respectively. From this, it is clear that the Cronbach‟s coefficient values for all of the individual parties are above 0.70 which showed validity. Accordingly, all the survey data were used for further analysis.

After checking the reliability of the survey data, the relative importance index method was employed to determine the relative importance of the various major equipment planning and management problems that affect productivity of equipment on AACRA construction project. The five-point scale as 1 (very low), 2 (low), 3 (medium) and 4 (high) and (5) very high were adopted and transformed to relative importance indices (RII) for each factor as follows:

$RII= \sum(W)/A*N$.. (4.1))

Where; RII = Relative importance index

W = weights given to each factor by the respondents (ranging from 1 to 5);

A = is the highest weight i.e. 5 in this case;

N = is the total number of respondents (18)

The RII value range from 0 to 1 (0 not inclusive) and, the higher the value of RII the more significant the problem is. The RII was used to rank the different equipment planning and management problems.

These rankings made it possible to cross-compare the importance of the major equipment planning and management problems as perceived by the three groups of respondents. Data collected from 18 respondents were analyzed using the RII method. The calculated RII value of equipment planning and management problems are depicted in Table 4.7 below. These RII values explain how far the construction equipment planning and management problems affect the performance of AACRA road construction projects.

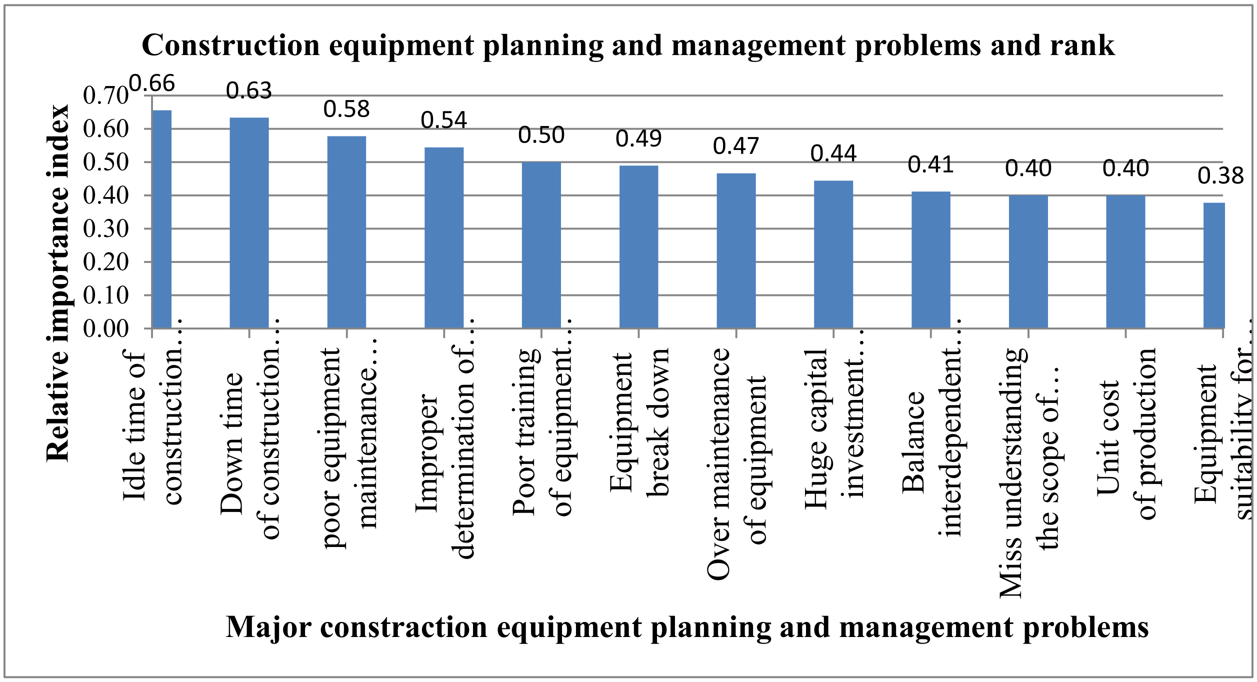
Before, the ranking of major construction equipment planning and management problems, an analysis of importance index of major problems was conducted based on the survey data under the three respondents‟ categories and ranked as shown in Table 4.7 and Figure 4.6 below.

As the Table 4.7 illustrates, it was identified that the perceptions of respondents on 12 equipment planning and management problems affecting the performance of AACRA road construction projects are presented from all parties perspective.

Table 4.7 Indexes of construction equipment planning and management problems and ranks as per the overall respondent's survey data.

No	Major construction equipment planning and management problems that affect the performance of AACRA road construction projects	Extent of problems based on scale of important problems for the sum of all respondents(together)					ΣW	A*N	RII	Rank (from overall respondents perspective)
		1(very low)	2 (low)	3(medium)	4(High)	5(Very high)				
1	Idle time of construction equipment	1		6	5	4	59	90	0.66	1
2	Down time of construction equipment	0	3	4	6	3	57	90	0.63	2
3	poor equipment maintenance practice	0	3	7	5	1	52	90	0.58	3
4	Improper determination of economic life and timing of replacement	2	3	5	4	2	49	90	0.54	4
5	Poor training of equipment operators	1	4	5	4	1	45	90	0.50	5
6	Equipment break down	3	1	5	6	1	44	90	0.49	6
7	Over maintenance of equipment	3	4	5	4	0	42	90	0.47	7
8	Huge capital investment during acquisition	3	1	3	4	2	40	90	0.44	8
9	Balance interdependent equipment	1	3	6	3		37	90	0.41	9
10	Miss understanding the scope of work carried out	3	4	2	1	3	36	90	0.40	10
11	Unit cost of production	3	2	4	3	1	36	90	0.40	10
12	Equipment suitability for job condition	1	5	6	0	1	34	90	0.38	12

As shown in the Table 4.7 above, relative importance of construction equipment planning and management problems in AACRA was computed using the relative importance index equation. The results illustrate the relative importance index and ranking each problem. The survey revealed that the idle time of construction equipment is the major problem with relative importance index (0.66) and highest ranking while the lowest relative importance index (0.38) is equipment suitability for job condition. Figure 4.5 below illustrates the ranked construction equipment planning and management problems based on the survey data.



According to the results of the analysis, idle time is the first major problem that affects the performance of project in respect of time and cost. Idle time is the time construction equipment spent on site without production. If the equipment is rented the contractor will pay for equipment for each time the equipment stayed on site. In this study both Grade One Contractors and AACRA own force construction department incurred unnecessary costs for equipment idle time. This leads the construction companies in to bankruptcy. If the equipment is owned by contractors, the contractor can generate money by renting the equipment at a time when equipment spent on site without work. This is also loss for contractors since idle time is a critical problem that affects proper planning and management of equipment. Some of the major causes of idle time are;

- Material shortage;
- Fuel shortage;
- Operator unavailability;
- Imbalance of interdependent equipment; and
- Weather condition

The second major equipment planning and management problem is poor equipment maintenance practices. Equipment maintenance is vital to keep equipment in good and serviceable condition. In order to be competent, contractors and equipment renting companies have to adopt three types of construction equipment maintenance practices; mainly:

- Planned preventive maintenance
- Corrective maintenance and
- Unplanned or unscheduled maintenance

4.2.4. Effects of construction equipment planning and management problems on AACRA road construction projects

Based on the result of analysis, all the contractors agree on the negative effect of lack equipment planning and management on road construction projects. The results of the survey disclosed that all the respondents agree on the negative effects of lack of proper equipment planning and management.

The results in Table 4.8 below show that "***Cost overrun***" was ranked first with relative importance index of 0.86. It was also ranked first with respect to among four effects of equipment planning and management problems. Loss in productivity of equipment was ranked second with relative importance index 0.84 and delay (time overrun) ranked third with relative importance index of 0.83 and the equipment related accidents has the least effect with relative importance index of 0.59.

Table 4.8 Relative importance indexes for effects regarding lack of construction equipment planning and management.

No	effects of construction equipment planning and management problems in AACRA road construction project	Extent of effects based on scale of important effects for the sum of all respondents(together)					ΣW	A*N	RII	Rank (from overall respondents perspective)
		1(very low)	2(low)	3(medium)	4(High)	5(Very high)				
1	Cost overrun	0	0	3	7	8	77	90	0.86	1
2	Loss in productivity of equipment	0	0	1	12	5	76	90	0.84	2
3	Delay(Time overrun)	1	0	1	9	7	75	90	0.83	3
4	Equipment related accidents	0	5	9	4	0	53	90	0.59	4

As stated by Rich-man, (2002), it is the project manager‟s responsibility to adopt or formulate a performance standard to track cost performance. Several factors that cause cost overruns in road construction projects have been identified in various places and times. Different problems and challenges may happen to contractors during the working procedure with the equipment such as life-cycle of the machines and different financial risks which may cost a lot for the company (Stewart, 2002).

The cost of equipment affects the competitive edge of contractors, making their survival more difficult in a current tight competitive environment. The poor equipment planning and management means loss of profit to road constructors due to extra equipment rental cost, overhead cost and delay in work execution which lead to lower productivity.

The cost of equipment is the critical issue for equipment renting companies since they maximize their profits when the equipment are working the activity effectively and efficiently. If there is poor equipment management, it is difficult to think about efficiency. Poor equipment management means loss on profit due to poor maintenance practices, extra overhead costs and improper determination of economic life of construction equipment. Figure 4.6 below graphically illustrates the negative effects of equipment planning and management problems

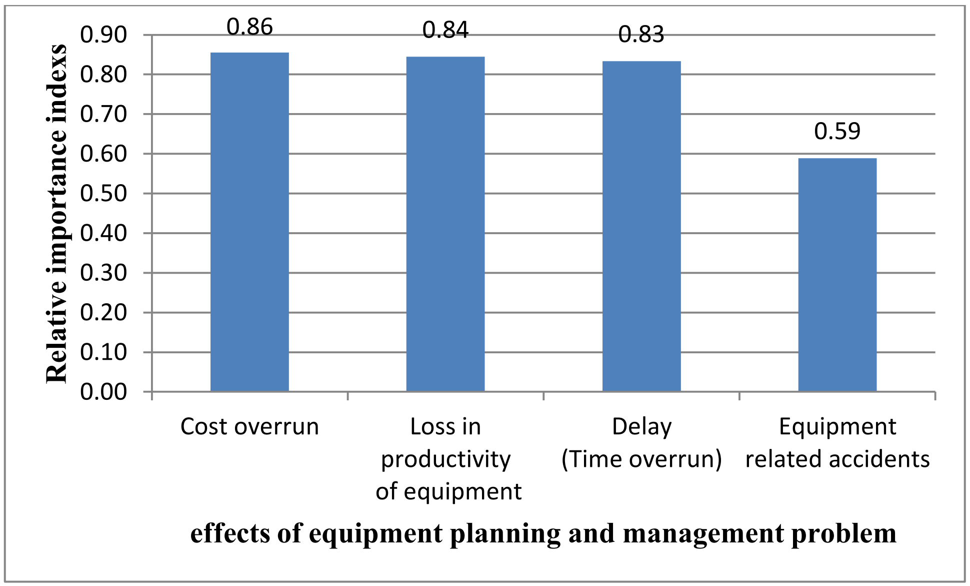


Fig. 4.6 Relative importance indexes of effects of construction equipment planning and management problems.

4.2.5. Planning the selection of construction equipment for the proposed job

Grade One contractors (16) and AACRA Own Force (5) all responded that they plan the selection of construction equipment for the job. Regarding the types of equipment selection policy: economic analysis; models based on traditional mass haul diagram and experiences. Table 4.9 below shows equipment selection policy used on AACRA projects.

Table 4.9 equipment selection policy

Symbols	**Selection methods**
A	Economic analysis
B	Using models based on traditional mass haul diagram
C	Mathematics of rough sets and fuzzy sets
D	Experience

Table 4.10 below shows the equipment selection policy that all the constructors uses during selection of construction equipment. Based on the analysis 40% of the two parties (private contractors and AACRA Own Force) uses economic analysis and experience, 27% uses only economic analysis, 20% uses only experience, 7% use economic analysis, models based on traditional mass haul diagram and experience and 7% uses all the above selection methods to select the right match of equipment to the proposed work task. Table 4.10 below presents the responses by the constructors regarding the engagement of selection policy (ies) and Figure 4.7 graphically represents the same.

Table 4.10 The response of contractors and AACRA own force construction department on types of equipment selection method used on their project.

Types of selection policy	No. of respondent	%	Cumulative (%)
A	4	27	27%
D	3	20	47%
A, B & D	1	7	53%
A &D	6	40	53%
All	1	7	100%
Total	15	100	100%

Figure 4.7 Shows that the percentage of equipment selection policies used by contractors and AACRA own force construction department.

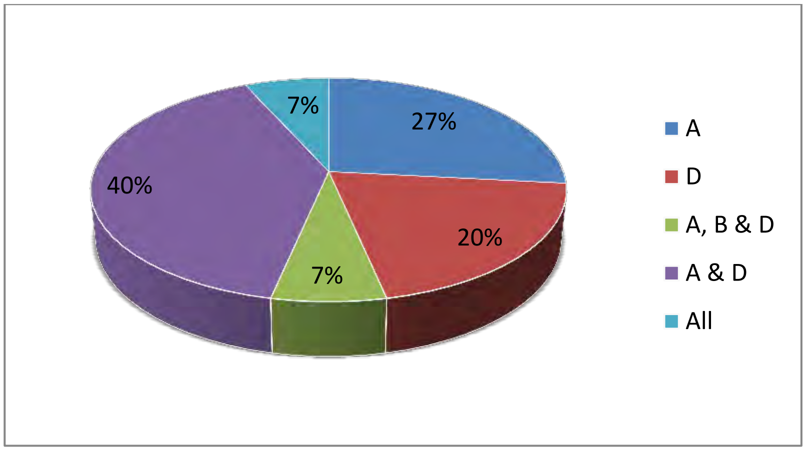
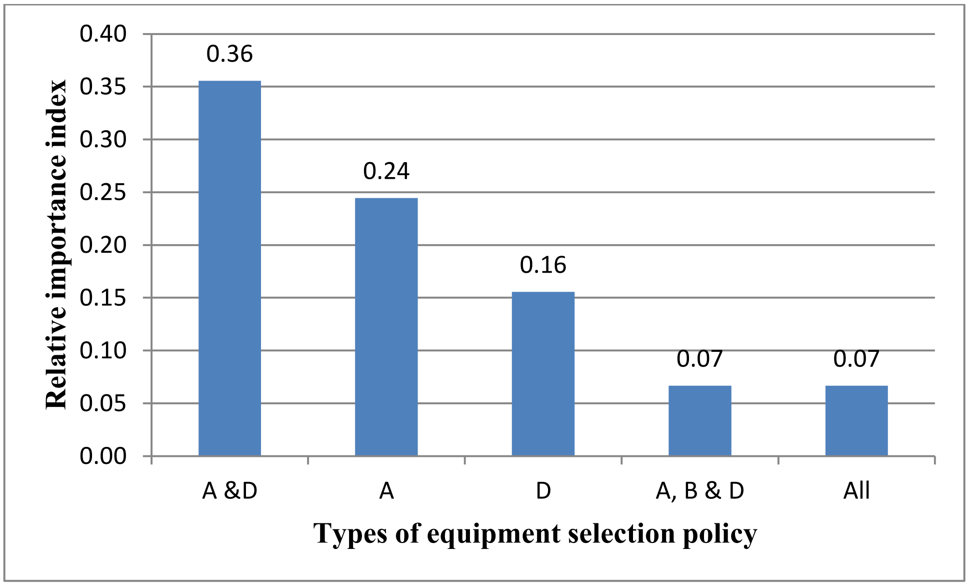


Table 4.11 shows the rank of the above equipment selection policy types based on their degree of accuracy level by using relative importance indexes. The degree of accuracy is expressed in three scales: - 1(Low); 2(Medium); and 3(High). Based on the analysis criteria; economic analysis (A) and experience (D) ranked first with relative importance index (RII) of 0.36, economic analysis ranked second with RII of 0.24, experience ranked third with RII of 0.16 and economic analysis, using models based on traditional mass haul diagrams and experience and all of the selection policy ranked fourth with RII of 0.07. Table 4.10 below shows degree of accuracy of the selection policy and Figure 4.8 graphically presents the same.

Table 4.11 Degree of accuracy of equipment selection policy during selection of leading construction equipment.

Types of equipment selection policy	Degree of accuracy			∑W	A*N	RII	Rank
	Low(1)	Medium(2)	High (3)				
A &D	0	2	4	16	45	0.36	1
A	0	1	3	11	45	0.24	2
D	0	2	1	7	45	0.16	3
A, B & D	0	0	1	3	45	0.07	4
All	0	0	1	3	45	0.07	4

Figure 4.8 RII used to determine degree of accuracy of equipment selection policy during selection.



Most the respondents use economic analysis and experience as the best methods to select the right match of equipment for their site conditions. In order to drive sustainable profits, constructors should select the right of equipment, the right manpower, to enhance productivity. Productivity directly influences profitability. When using economic analysis with practical different site experiences, the contracting companies can reach in a better equipment selection decision. At the same time, they will reduce equipment productivity losses and increases productivity ultimately increasing the profitability of company.

Furthermore, most respondents did not use mass haul diagram as a base to select the right matching equipment. The selection of equipment should consider the characteristics of road profile to optimize the type of equipment and the number of equipment between cut and fill of road sections. So it is better to use economic analysis and experience with traditional mass haul diagram to increase productivity of required equipment.

4.2.6. Acquisition of construction equipment

Table 4.12 below shows the response of contractors and equipment renting companies on determination of construction equipment acquisition method which is the major issue during management with financial implication. Based on the analysis 89% of three parties in aggregate said that determination of the construction equipment acquisition method is the major issue during management with financial implication while 11% of the respondents expressed the opposite.

Table 4.12 Determination of construction equipment acquisition methods

Respondent	Response		Percentage	
	Yes	No	Yes	No
Grade One contractors	9	1	90%	10%
AACRA own force construction department	4	1	80%	20%
Equipment renting companies	3	0	100%	0%
Total	16	2	89%	11%

Table 4.13 below shows types of equipment acquisition methods: - cash, renting and leasing.

Table 4.13 Types of equipment acquisition methods

Item	Acquisition methods
A	Cash
B	Renting
C	Leasing

Table 4.14 below shows percentages of equipment acquisition methods used by the road constructors. Based on the results of the analysis, 27% of the two parties (private contractors and AACRA own force) use renting and combination of cash purchasing and renting, 20% use cash purchasing, renting and leasing, 13% use cash purchasing, 7% use leasing and lastly 7% use a combination of cash purchasing and leasing. Table 4.9 presents responses in the above respect.

Table 4.14 The response of contractors and AACRA own force construction department on types of equipment acquisition method used on their project.

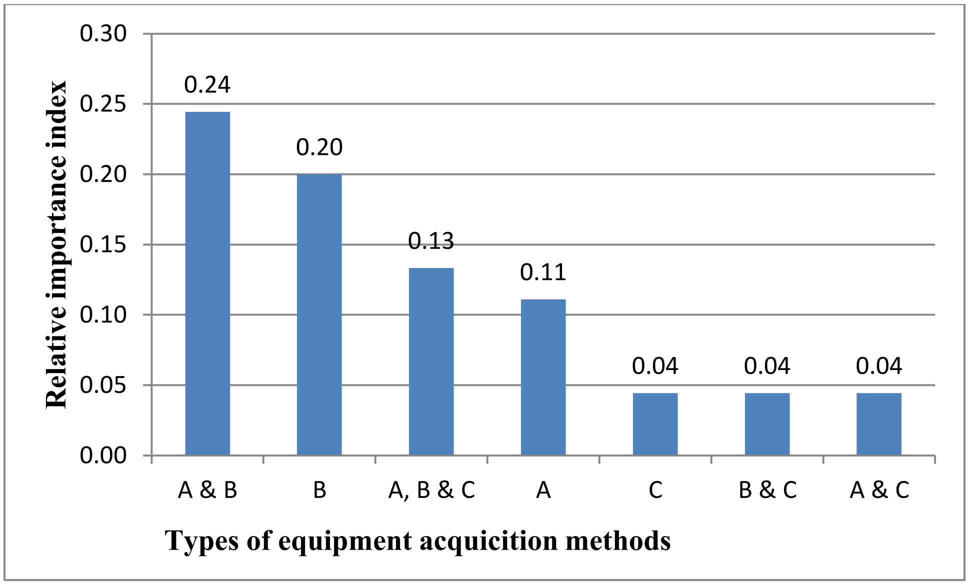
Types of selection policy	No. of respondent	%	Cumulative (%)
A	2	13	13
B	4	27	40
C	1	7	47
A & B	4	27	73
A & C	1	7	80
A, B & C	3	20	100
Total	15	100	100

Table 4.15 below shows the degree of appropriateness of equipment acquisition method used by contractors and AACRA own force construction department. According to the results of analysis, cash purchasing ranked first with RII of 0.24; renting ranked second with RII of 0.2; cash purchasing, renting and leasing ranked third with RII 0.13, cash purchasing takes the fourth rank with RII 0.11 and leasing, combination of renting and leasing and combination of cash purchasing and leasing ranked fifth with RII 0.04. Subsequently, Figure 4.10 represents RII"s in respect of the types of equipment acquisition methods.

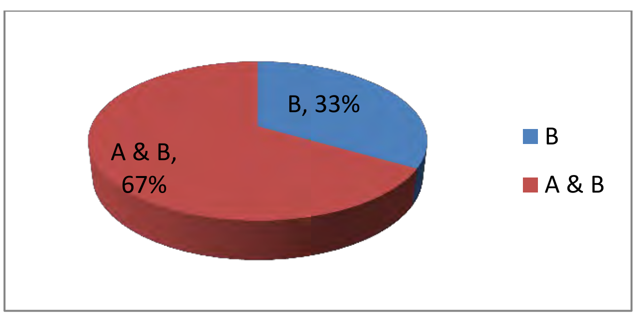
Table 4.15 Degree of appropriateness of equipment acquisition methods.

Types of equipment acquisition methods	Degree of appropriateness			ΣW	A*N	RII	Rank
	Low(1)	Medium(2)	High (3)				
A & B	0	1	3	11	45	0.24	1
B	0	3	1	9	45	0.20	2
A, B & C	0	0	2	6	45	0.13	3
A	0	1	1	5	45	0.11	4
C	0	1	0	2	45	0.04	5
B & C	0	1	0	2	45	0.04	5
A & C	0	1	0	2	45	0.04	5

Figure 4.9 RII"s by types of equipment acquisition methods.



Equipment acquisition methods used by equipment renting companies were analyzed, according to the result of the analysis, 67% of companies provide construction equipment through cash purchasing and renting and 33% of companies provide construction equipment through rental arrangements.



According to respondents" perception, outright cash purchasing and renting are better options. But using two different acquisition methods depend on the scope of work, since it has its own advantages and disadvantages.

Advantages of purchasing equipment compared to renting it are:

- It is more economical if the equipment is utilized sufficiently;

- It is more likely to be available for use when needed; and
- Because ownership should assure better maintenance and care, purchased equipment should be kept in better mechanical condition.

Disadvantages of owning equipment compared to renting are:

- Purchasing may require a substantial investment of money or credit that may be needed for other purposes;
- The ownership of equipment may influence a contractor to continue using obsolete equipment after superior equipment has been introduced.
- The ownership of equipment designed primarily for a given type of work, may induce a contractor to continue doing that type of work; whereas other work requiring different types of equipment might be available at a higher profits.
- The ownership of equipment might influence a contractor using the equipment beyond its economic life, thereby increasing the cost of production unnecessarily.

4.2.7. Operation of heavy duty construction equipment

Surveys were carried out and analysis conducted regarding the operational dependency on operating cost of equipment. During the survey, 15 respondents from road constructors were contacted (10 Grade One Contractors and 5 AACRA Own force). According to the result of the analysis, all the Grade One contractors said that operation of equipment is dependent on operating cost of the equipment whereas, four of the AACRA Own Force responded the same while one responded otherwise. The bases of the types of construction equipment operating cost estimation are three: A. historical data from experience, B. recommendation from equipment manufacturers and C. site production rates.

Table 4.16 presents the percentage of construction equipment operating cost estimation methods used by contractors and AACRA own force construction department. Based on the analysis 29% of the two parties use onsite production rate as a basis to estimate operating cost of equipment, 21% of both parties use recommendation from equipment manufacturers and the combination of all methods, 14% of the two parties uses historical data from experience and onsite production rate, 7% uses historical data from experience and 7% uses combination of historical data from experience and recommendations from manufacturers.

Table 4.16 Response on basis of equipment operating cost estimation methods used on their project.

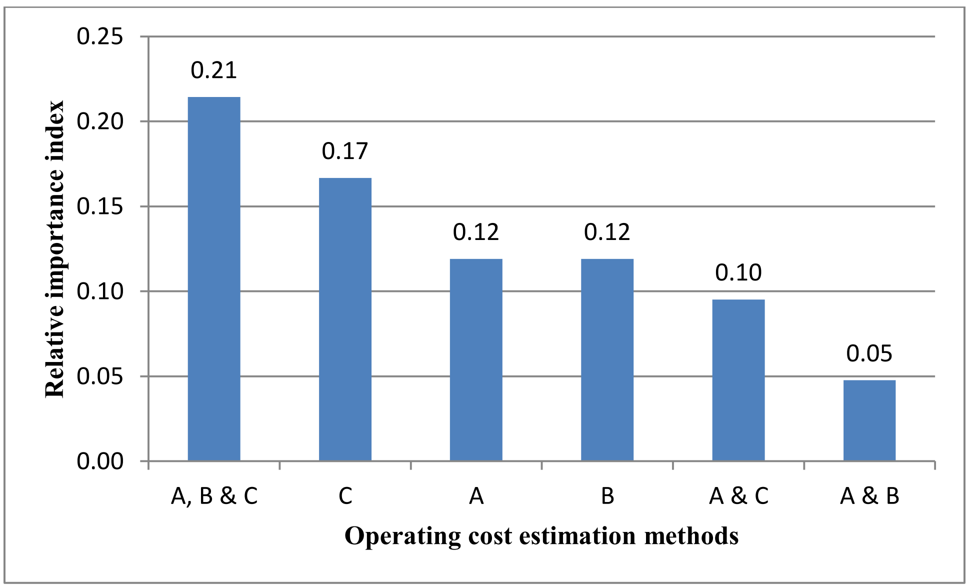
Operating cost estimation methods	No. of respondents	Percentage (%)	Cumulative (%)
A	1	7	7
B	3	21	29
C	4	29	57
A & B	1	7	64
A & C	2	14	79
All	3	21	100
Total	14	100	100

Table 4.17 below shows the degree of accuracy leading to construction equipment operating cost estimation methods used by contractors and AACRA own force construction department. Based on the analysis, combined use of all methods ranked first with RII of 0.21, onsite production rate ranked second with RII of 0.17, historical data from experience and recommendation from equipment manufacturers ranked third with RII of 0.12, historical data from experience and onsite production rate ranked fifth with RII of 0.1 and combined use of historical data from experience and recommendation from manufacturers ranked sixth with RII of 0.05. Table 4.17 below presents the degree of accuracy of equipment operating cost estimation methods on leading construction equipment. Subsequently, Figure 4.16 presents RII is used to determine the degree of accuracy of equipment operating cost estimation methods on leading construction equipment.

Table 4.17 Degree of accuracy of equipment operating cost estimation methods on leading construction equipment.

Operating cost estimation methods	Degree of accuracy			∑W	A*N	RII	Rank
	Low(1)	Medium(2)	High (3)				
A, B & C	0	0	3	9	42	0.21	1
C	1	3	0	7	42	0.17	2
A	0	1	1	5	42	0.12	3
B	0	1	1	5	42	0.12	3
A & C	0	2	0	4	42	0.10	5
A & B	0	1	0	2	42	0.05	6

Figure 4.10 RII used to determine the degree of accuracy of equipment operating cost estimation methods on leading construction equipment.



Surveys were conducted in relation to equipment renting companies, about equipment rental cost dependency on owning and operating cost of equipment. Based on the analysis, 100% of respondents agree on construction equipment rental cost dependency on owning and operating cost of equipment.

A survey was conducted regarding the response of construction equipment renting companies on the basis of equipment operating cost estimation methods used by respective companies. Based on the result of analysis, 67% of equipment renting companies‟ use combination of historical data from experience and recommendations from equipment manufacturers and 33% of equipment renting companies uses historical data from experience as basis to estimate equipment rental rate.

The productivity rate of equipment is depending on operation of construction equipment. So we can consider the operating phase as target shooting phase to achieve all the planned works. Equipment operator is a key person that implements the intended work. Any cost which is spent on operation of construction equipment has direct effect on operating cost of equipment. Therefore, operating cost of equipment is dependent on operation of equipment. In addition rental rate of equipment is highly dependent on operating cost of equipment; because, rental rate is the sum of equipment owning and operating cost.

According to the respondents‟ perspectives, most contracting companies use on site production as a base to estimate operating cost of equipment. Others use the three methods jointly. Using onsite production rate as the only base to estimate operating cost is not relevant to a company that is there for a good profit. Because, most of the time, the equipment hourly production rate is below standard on construction site because of different site condition. It is better to use historical data and compare manufacturers‟ production rate recommendation with onsite production rate to reduce operating cost of equipment and to reduce hourly cost of equipment.

4.2.8. Maintenance of heavy duty construction equipment

Regarding maintenance of heavy duty construction equipment, and based on the analysis, all of respondents agreed that construction equipment maintenance is vital to keep equipment in good and serviceable condition. The types of construction equipment maintenance methods are: A. planned preventive maintenance, B. planned corrective maintenance and C. unscheduled or unplanned maintenance including repair.

Table 4.18 below shows the percentage of responses of the three entities on equipment maintenance methods used in their respective companies and project. Based on the analysis, 67% of the three parties uses planned preventive maintenance method, 17% of the parties uses planned corrective maintenance method, 11% of three parties uses unscheduled or unplanned maintenance including repair and 6% of the three parties uses planned preventive maintenance and planned corrective maintenance jointly.

Table 4.18 Response on equipment maintenance methods.

equipment maintenance methods	No. of respondents	Percentage (%)	Cumulative (%)
A	12	67	67
B	2	11	78
C	3	17	94
A & B	1	6	100
Total	18	100	100

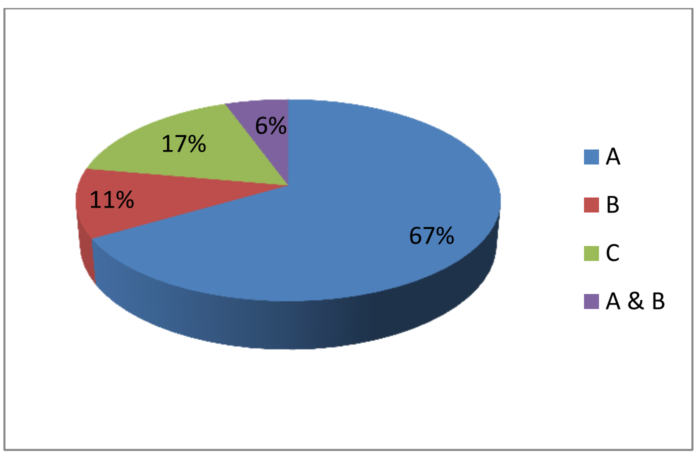


Table 4.19 below shows that degree of appropriateness of construction equipment maintenance methods used by three entities. Based on the analysis, planned preventive maintenance methods ranked first with RII of 0.22, planned corrective maintenance and unscheduled maintenance ranked second with RII of 0.04 and jointly planned preventive maintenance with planned corrective maintenance and unscheduled maintenance ranked third with RII of 0.02.

Table 4.19 Degree of appropriateness of construction equipment maintenance methods used by the three parties.

Equipment maintenance methods	Degree of accuracy			∑W	A*N	RII	Rank
	Low(1)	Medium(2)	High (3)				
A	0	4	8	12	54	0.22	1
B	0	2	0	2	54	0.04	2
C	2	0	0	2	54	0.04	2
A & B	0	0	1	1	54	0.02	4
A & C	0	1	0	1	54	0.02	4

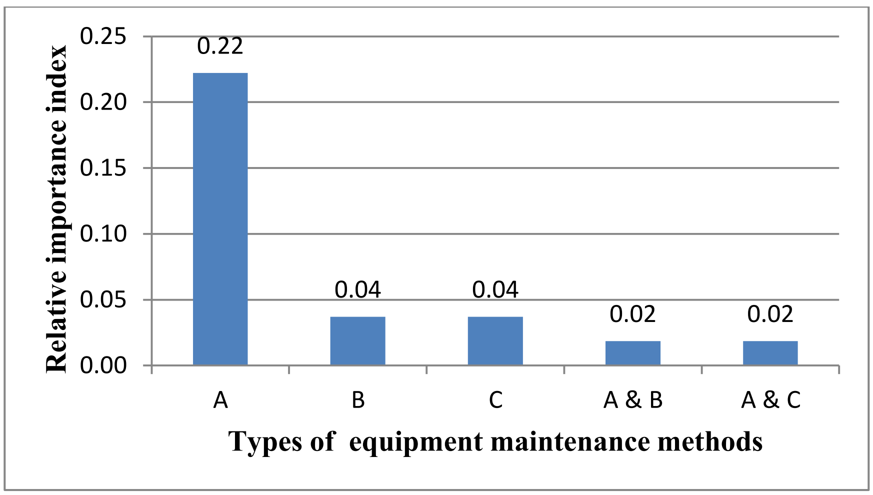


Figure 4.11 Degree of appropriateness of construction equipment maintenance methods used by the three parties.

According to respondent"s perception, most of them use planned preventive maintenance as the only equipment maintenance in their project sites. Some of them use the remained two types of equipment maintenance methods.

All types of equipment maintenances are critically needed to keep equipment in good and serviceable condition. By maintaining equipment periodically on planned preventive maintenance bases, different major failures of equipment can prevented because as said „prevention is better than cure". In addition, it is better to do a corrective maintenance when necessary in order to increase the efficiency of equipment. Furthermore, unplanned or unscheduled maintenance is necessarily needed because, equipment may break down suddenly. Therefore, it is better to use all equipment maintenance methods to make equipment more productive at construction sites.

4.2.9. Replacement or disposal of heavy duty construction equipment

Equipment replacement policy plays a major role in productivity. Based on analysis 89% of the three parties agree that construction equipment replacement plays a major role in productivity of equipment. Accordingly, both AACRA own construction department and Equipment renting companies total agreed while eight of ten Grade One contractors did the same. In respect of the types of equipment replacement policy, they practice four methods and they are: Payback Period; Accounting Return on Investment; Internal Rate of Return and Net Present Worth methods.

Based on analysis, 33% of all use Accounting return on investment and internal rate of return; 17% of them use net present worth method; 8% jointly use payback period method, accounting return on investment method and internal rate of return and 8% of them use combination of all methods.

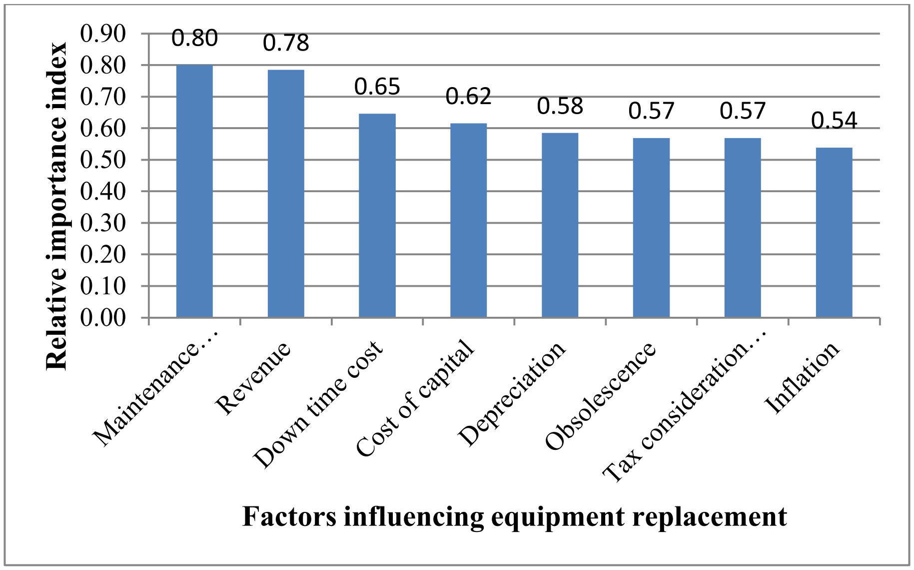
Furthermore, 89% of respondents agree on having factors that influence equipment replacement on their project.

Table 4.20 shows the extent of factors that influence construction equipment replacement criteria used by respondents. Based on the analysis maintenance and repair costs ranked first with RII of 0.8, revenue as an influencing factor ranked second with RII of 0.78, down time cost ranked third with RII of 0.65 and inflation is ranked eighth with RII of 0.54. the rest of ranks are shown in the table below.

Table 4.20 Relative importance indexes for each factor that influence equipment replacement criteria and ranks as per the overall respondent's survey data.

No.	Factors that influence equipment replacement criteria	Extent of influence based on scale of important factors for the sum of all respondents(together)					∑W	A*N	RII	Rank
		1(very low)	2(low)	3(medium)	4(High)	5(Very high)				
1	Maintenance and repair cost	0	2	0	7	4	52	65	0.80	1
2	Revenue	0	1	2	7	3	51	65	0.78	2
3	Down time cost	0	6	1	3	3	42	65	0.65	3
4	Cost of capital	1	3	5	2	2	40	65	0.62	4
5	Depreciation	0	5	5	2	1	38	65	0.58	5
6	Obsolescence	2	2	5	4	0	37	65	0.57	6
7	Tax consideration and capital allowances	2	2	6	2	1	37	65	0.57	6
8	Inflation	2	3	5	3	0	35	65	0.54	8

Figure 4.12 shows RII is used to determine the extent factors influencing equipment replacement criteria



The causes of poor equipment planning and management are; A. constraints imposed by job contractual obligation; B. huge capital investment during the acquisition phase; C. poor training of equipment operators; D. poor maintenance practice and E. improper determination of economic life and timing for replacement.

Table 4.21 below shows the percentages of response of three parties. Based the analysis, 17% of respondents determined huge capital investment during the acquisition phase and poor maintenance practice with improper determination of economic life and timing for replacement were the major causes of poor equipment planning and management problems. In this regard 11% of the respondents agreed that constrains imposed by job condition obligation and improper determination of economic life and timing for replacement were considered as the second major causes of construction equipment planning and management problems.

Table 4.21 the responses on causes of construction equipment planning and management problems.

Causes of poor equipment planning and management problems	No of respondents	Percentage (%)	Percentage cumulative (%)
A	2	11%	11%
B	3	17%	28%
C	1	6%	33%
D	2	11%	44%
E	1	6%	50%
A & B	1	6%	56%
A, B & C	1	6%	61%
D & E	3	17%	78%
C, D & E	1	6%	83%
B, C & E	1	6%	89%
A, B, C, D & E	1	6%	94%
B, C, D & E	1	6%	100%
Total	18	100%	100%

According to respondents" perception, all the above were relatively seen as causes for poor equipment planning and management problems. Some respondents believe that, huge capital investment during acquisition phase and poor maintenance practice with improper determination of economic life and timing for replacement were the major causes of poor equipment planning and management problems. Others believe that, constrains imposed by job condition obligation and improper determination of economic life and timing for replacement were considered as the second major causes of construction equipment planning and management problems. Therefore, it is better to work critically, on areas of identified problems to avoid the causes of construction equipment planning and management problems to increase productivity of equipment.

4.2.10. Best practices and recommendation to minimize construction equipment planning and management problems.

A study on having best practices used to reduce construction equipment planning and management problems was also carried out. Based on analysis, eight (62%) of respondents agreed on having best practices and five (38%) did not agree. These were 50% each of Grade

One contractors and AACRA own construction department and all of the Equipment renting companies

Some of best practices, used by respondents to reduce equipment planning and management problems were:

- Frequently revising equipment planning and management;
- Head office based planning system is experienced;
- The planning is monitored daily and weekly to be summed up monthly;
- Quality management training for equipment administration department staffs and planned preventive maintenance, especially trainings for operators regarding new technologies applied on new equipment.
- Training maintenance crew; and
- Preventive planning and quality control measures.

Table 4.22 below shows the recommendations by the three parties on avoiding construction equipment planning and management problems at equipment selection phase. Based on the analysis and calculating the extent by RII, using models based on traditional mass haul diagram, artificial intelligence and genetic algorithm and geographical information was ranked first RII of 0.45. Using mathematics of rough and fuzzy sets was ranked second with RII of 0.28; and using analytical hierarchy process was ranked third with RII of 0.21. the rests are depicted below.

Table 4.22 Recommendations of by the three parties regarding avoidance of construction equipment planning and managements problems in selection phase.

No.	Description	Extent of recommendation effectiveness					∑W	A*N	RII	Rank
		Very low	Low	Medium	High	Very high				
	Selection phase									
1	Use models based on traditional mass haul diagram, artificial intelligence and genetic algorithm and geographical information system	0	1	4	3	2	36	80	0.45	1
2	Mathematics of rough sets and fuzzy sets	0	2	3	1	1	22	80	0.28	2
3	Analytical hierarchy process	0	0	1	1	2	17	80	0.21	3

Table 4.23 below shows three parties on avoiding construction equipment planning and management problems at equipment acquisition phase. Based on the analysis, using standardized policy for better relationship with dealers or for easier equipment administration was ranked first with RII of 0.85; purchasing equipment based on financial status based on internal rate of return was ranked second with RII of 0.74, using rental or leasing strategy for infrequently utilized equipment ranked third with RII of 0.7; and purchasing the same brand that is being used regularly and purchase used machines only those that do not have complicated systems and those that do not have high repair costs ranked fourth with RII of 0.69 at acquisition phase of equipment.

Table 4.23 Recommendations of three parties to avoid construction equipment and managements problems at acquisition phase

No.	Description	Extent of recommendation effectiveness					∑W	A*N	RII	Rank
		Very low	Low	Medium	High	Very high				
	Acquisition phase									
1	Using standardized policy for better relationship with dealers or for easier equipment administration	1	1	2	11	3	68	80	0.85	1
2	Purchase equipment based on company financial status based on internal rate of return	1	1	4	6	4	59	80	0.74	2
3	Using rental or leasing strategy for infrequently utilized equipment	1		2	11	1	56	80	0.70	3
4	Purchasing the same brand that is being used regularly.		2	4	6	3	55	80	0.69	4
5	Buy used machines only the ones that do not have complicated systems, one that do not have high repair costs once failure	1	1	6	6	2	55	80	0.69	4
6	Make decision on acquiring or disposing by equipment manager or project manager	1	2	2	8	2	53	80	0.66	6
7	Purchase equipment from familiar dealers.	1	3	3	6	1	45	80	0.56	7

Table 4.24 shows that recommendations three parties on avoiding construction equipment planning and management problems at equipment operation phase. Based on analysis, providing training through in-house equipment department, equipment dealer or external agencies ranked first with RII of 0.74; considering poor operating procedure as main cause of equipment accident ranked second with RII of 0.66 and allowing equipment operator to work with more than one machine ranked third with RII of 0.38.

Table 4.24 Recommendations of three parties to avoid construction equipment and managements problems on operation phase.

No.	Description	Extent of recommendation effectiveness					∑W	A*N	RII	Rank
		Very low	Low	Medium	High	Very high				
	Operation phase									
1	Provide training by in-house equipment department, equipment dealer or external agencies	1	1		9	4	59	80	0.74	1
2	Considering poor operating procedure as main cause of equipment accident	1	2	3	6	3	53	80	0.66	2
3	Allow an equipment operator to work with more than one machine.	6	8	1		1	30	80	0.38	3

Table 4.25 shows recommendations given by all parties on avoiding construction equipment planning and management problems during equipment maintenance phase. Based on analysis and calculation for effectiveness of recommendation, providing preventive maintenance program stood first with RII of 0.8, providing maintenance by equipment operators, in-house equipment department,

equipment dealers and external dealers stood second with RII of 0.74, considering poor maintenance and use of non-original parts as the main cause of machine failure during stood third with RII of 0.58; and waiting until the failed machine is completely repaired and ready for use stood fourth rank with RII of 0.49.

Table 4.25 Recommendations by all parties on avoiding construction equipment and managements problems at maintenance phase

No.	Description	Extent of recommendation effectiveness					∑W	A*N	RII	Rank
		Very low	Low	Medium	High	Very high				
	Maintenance phase									
1	Provide preventive maintenance program to equipment.	-	1	-	3	10	64	80	0.80	1
2	Provide maintenance by equipment operators, in-house equipment department, equipment dealers and external dealers.	-	1	4	5	5	59	80	0.74	2
3	Consider poor maintenance and use of non-original parts as the main cause of machine failure during use.	1	1	1	5	4	46	80	0.58	3
4	Wait until the failed machine is completely repaired and ready for use	4	2	3	3	2	39	80	0.49	4

Table 4.26 below shows recommendations by all three parties regarding avoiding construction equipment planning and management problems at the equipment disposal phase. Based on analysis and calculation for effectiveness of recommendation, determining equipment economic life based on maintenance and repair cost ranked first with RII of 0.7, dispose or replace equipment based on equipment economic analysis ranked second with RII of 0.65, dispose or replace equipment when it becomes technologically obsolete and determining equipment economic life based on profit accrued from use ranked third with RII of 0.59, dispose or replace equipment when it becomes inefficient ranked fifth with RII of 0.58, determine equipment economic life based on depreciation cost ranked sixth with RII of 0.51 and determining equipment economic life based on investment cost ranked seventh with RII of 0.3.

Table 4.26 Recommendations by three parties on avoiding construction equipment planning and managements problems on disposal phase

No.	Description	Extent of recommendation effectiveness					∑W	A*N	RII	Rank
		Very low	Low	Medium	High	Very high				
	Disposal phase									
1	Determine equipment economic life based on maintenance and repair cost	1	1	2	8	3	56	80	0.70	1
2	Dispose or replace equipment based on equipment economic analysis	2	1	3	6	3	52	80	0.65	2
3	Dispose or replace equipment when it becomes technologically obsolete	1	3	5	5	1	47	80	0.59	3
4	Determine equipment economic life based on profit accrued from use	2	2	4	6	1	47	80	0.59	3
5	Dispose or replace equipment when it becomes inefficient	1	1	3	6	2	46	80	0.58	5
6	Determine equipment economic life based on depreciation cost	2	2	5	5		41	80	0.51	6
7	Determine equipment economic life based on investment cost	2	5		3		24	80	0.30	7

CHAPTER FIVE

5. CASE STUDY ANALYSIS: RESULTS AND DISCUSSION

5.1. Introduction

In order to get better understandings of what the major construction equipment planning and management problems affect the productivity of equipment in AACRA road construction projects in practice, three case study projects were conducted. The analysis was carried out on the evaluation of construction equipment‟s overall performance. The analysis focused on performance analysis of heavy duty construction equipment productivity on projects to depict the extent of current productivity loss and impact of productivity loss on the financial performance of equipment.

5.2. General information on the three case study projects

This thesis considered three AACRA road projects in Addis Ababa, namely Shiromeda – Kidane Mariam, Keranio medihanialem – Ambo Road and Gofa mazoria – Legahar babur where the constructions of the first two were undertaken by Grade One contractors and the third project by AACRA Own Force construction department.

Although the contractors of the three projects have some other machinery type and model, they all are mostly equipped with caterpillar machineries. In the study, only the productivity of Caterpillars was evaluated. Data in respect of manufacturer‟s specification were used in the computation of ideal production of the machines can be referred in Caterpillar‟s Performance Hand Books or any other standards related to the caterpillar model.

5.3. Performance analysis of heavy duty construction equipment

The performance of heavy-duty construction equipment such as motor graders, loaders and excavators were, assessed based on the percentage of an individual overall equipment effectiveness (OEE) index and the overall performance rate of the individual Equipment. Based on the product of the three primary component rates, the percentage of OEE indexes were calculated. The most significant loss factors are associated with the lowest component rate of

OEE as stated by different authors in the literature part. The performance analyses of heavy duty construction equipment were performed as stated in the following section.

5.4. Keranio Medhanialem – Ambo Road project.

The result analysis and the results in this case provide the rank of factors affecting the performance of the construction equipment and the extent of equipment productivity. Table 5.1 shows the computation of excavator productivity rate and the percentage of individual component rates including the summary of corresponding factors in respect of each independent rate.

Table 5.1: Keranio Medihanialem – Ambo Road project

Data Collection Template Machinery type Excavator Mark; CAT Model: 320C Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines]					
Type of Activity – Excavation					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 92.6%	A	Available time (10hrs. * 60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	10	min	mechanical problem
	D2	Time spent for change in operation condition	30	min	
	D	Major stoppage losses = (D1 + D2)	40	min	
	E	Operating time = C – D	500	min	
	G	Ideal production (from manufacturer specification)	119	m3/hr	
	H	Actual production	74.5	m3/hr	
PR(%) =		Applicable correction factors			

P*R = 42.64		Job efficiency	45	min/hr	
		Heaped bucket capacity	0.75	m3	
		Material type - rock earth mixture			
		Bucket fill factor	1.05		
		height of swing factor			
		swell factor	0.83		
	O	Actual cycle time	33	sec	
	I	Production capacity losses downtime = [1-H/G] x L	142	min	
	K1	Number of minor stoppage	3	min	to change position
	K2	Average duration of minor stoppage	20	min	
	K3	Idle time	60	min	shortage of material
QR(%) = (S-T)/S= 93.7%	K	Minor stoppage/Idle losses = [K1*K2+K3]	120	min	
	L	Net Operating Time = [E-K]	380	min	
	M	Performing Time = [L-I]	238	min	
	N	Valuable operating time = [M-J]	198	min	
	P	Net operating rate = 100*[H*O]/E	82	%	
	Q	Ideal/theoretical/design cycle time	17	sec	
	R	Operating speed coefficient = [Q/O]	0.52		
	J	Time spent for rework and start up yield losses	40	min	
	S	Total executed amount(Unit)	950	m3	
	T	Reworked amount (unit)	60	m3	low standard work
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.37					

Table 5.2 below shows the percentage of productivity rate of the three primary components and OEE in the case of Keranio Medhanialem – Ambo road asphalt concrete road project. According to analysis; the excavator availability rate was calculated 93%, performance rate at 43%, quality rate at 94% and OEE at 37%. Figure 5.1 presents the same graphically.

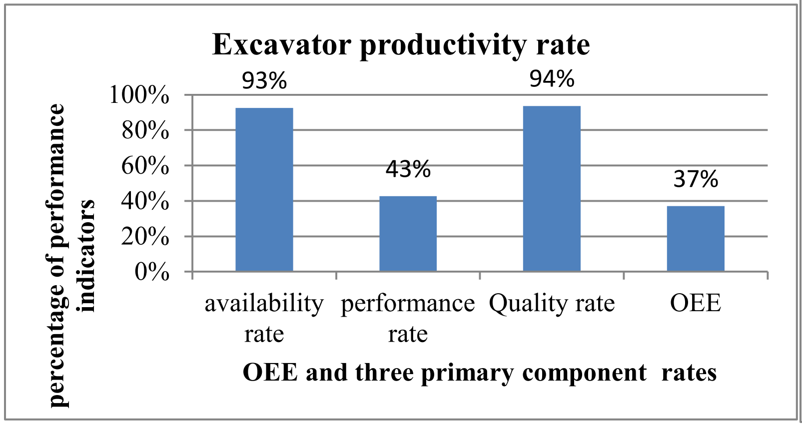
Table 5.2 Summary of average productivity rate at Keranio Medhanialem – Ambo Road project

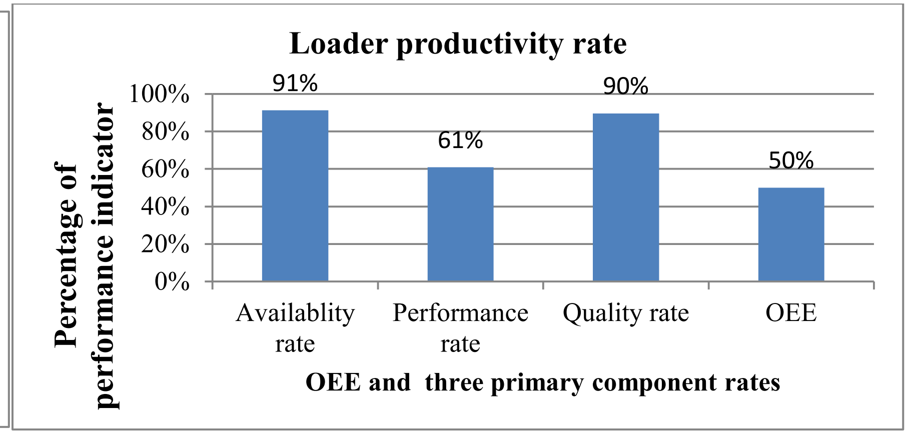
Excavator productivity rate | **Loader productivity rate**

Indexes	percentage	indexes	Percentage
Availability rate	93%	Availability rate	91%
Performance rate	43%	Performance rate	61%
Quality rate	94%	Quality rate	90%
OEE	37%	OEE	50%

Grader productivity rate

Indexes	percentage
Availability rate	83%
Performance rate	46%
Quality rate	99%
OEE	38%





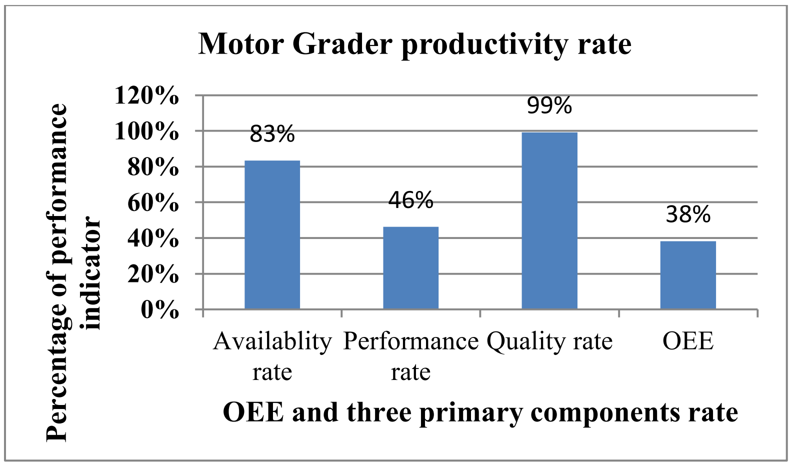


Figure 5.1 Distribution of primary components and OEE index of individual equipment on Keranio Medhanialem – Ambo asphalt concrete road project.

As indicated in Table 5.2 and Figure 5.1, performance rate ranked first on impacting the productivity of equipment, availability rate ranked second; and quality rate has lesser effect on productivity of equipment. Besides, Table 5.2 shows that the extent of overall productivity of excavator, loader and Grader is very poor with OEE of 37%, 50% and 38% respectively (refer independent calculation from Appendix *C-1, C-2* and *C-3*). This is due to improper work management during the utilization of the machine. As noted, insufficient maintenance, shortage of materials, more cycle time and low standard work were the main contributing factor for loss in productivity. Moreover, the result of the analysis showed that, the performance rate for all the machines on road project was most important that needs more attention by the management. In addition, it is the one significantly affecting the overall performance of all the machines.

5.5. Gofa mazoria – Babur Tabiya road project.

The result obtained from this project will represent the productivity rate of equipment on AACRA project. It also provides an indication of the rank of factors affecting the performance of construction equipment on Gofa Mazoria – Babur Tabiya road project. Table 5.3 below presents the performance of motor grader productivity rate on Gofa Mazoria – Babur Tabia Road Project.

Table 5.3: Gofa Mazoria – Babur Tabia road project.

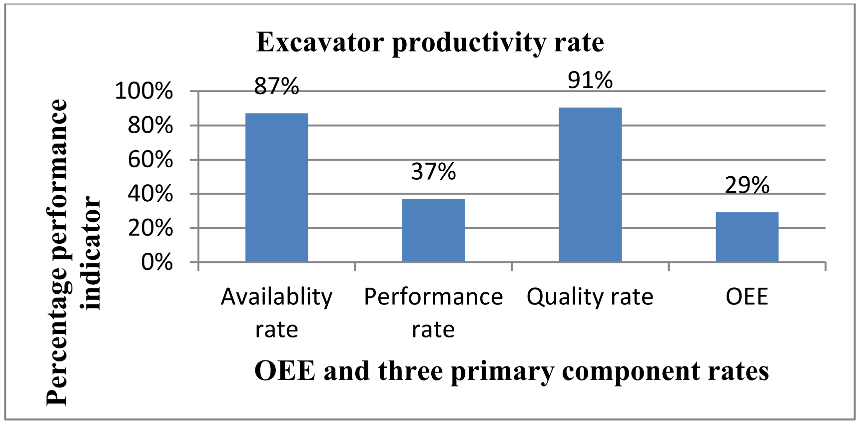
Data Collection Template Machinery type Grader Mark; CAT Model: 140H Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Motor grader productivity in AACRA (Gofa Mazoria - Babur Tabia) Road project					
Type of Activity -					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C)= 88.9%	A	Available time(10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	20	min	Batery change
	D2	Time spent for change in operation condition	40	min	
	D	Major stoppage losses = (D1 + D2)	60	min	
	E	Operating time = C – D	480	min	
	G	Ideal production (from manufacturer specification)	6792	m2/hr	
	H	Actual production	5434	m2/hr	
PR(%) = P*R = 0.46		Applicable correction factors			
		Blade length(L) including overlap	3.96	m	
		Width per trip(B) = L*cos A	3.43	m	
		Tilting angle of the blade	30		
		Lift thickness after compaction	0.25	m	

		Average speed correspond to the work type	2.4	km/hr	
		Cycle time(T) = 0.06∑p/v	1	min	
		operator efficiency	0.8		
	O	Actual cycle time	4	min	
	I	Production capacity losses downtime = [1-H/G] x L	60	min	
	K1	Number of minor stoppage	4		third person communication
	K2	Average duration of minor stoppage	15	min	and tea break
	K3	Idle time	120	min	
QR(%) = (S-T)/S =98.6%	K	Minor stoppage/Idle losses = [K1*K2+K3]	180	min	
	L	Net Operating Time = [E-K]	300	min	
	M	Performing Time = [L-I]	240	min	
	N	Valuable operating time = [M-J]	232	min	
	P	Net operating rate = 100*[H*O]/E	75.8	min	
	Q	Ideal/theoretical/design cycle time	2.45	min	
	R	Operating speed coefficient = [Q/O]	0.61		
	J	Time spent for rework and start up yield losses	8	min	
	S	Total executed amount(Unit)	54336	m2	
	T	Reworked amount (unit)	750	m2	Low quality work
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.40					

Table 5.4 shows that the percentage productivity rate of three primary components and OEE in Gofa Mazoria – Babur Tabia road projects. According to the result of the analysis, motor grader availability rate is 89%, performance rate is 46%, quality rate is 99% and OEE is 40% and Excavator availability rate is 87%, performance rate is 37% and Quality rate is 91%. Figure 5.2 graphically illustrates the result of the analysis of the same.

Table 5.4.Summary average productivity rate at Gofa mazoria - Babur tabia Road project

Excavator productivity rate		**Grader productivity rate**	
Indexes	percentage	indexes	percentage
Availability rate	87%	Availability rate	89%
Performance rate	37%	Performance rate	46%
Quality rate	91%	Quality rate	99%
OEE	29%	OEE	40%



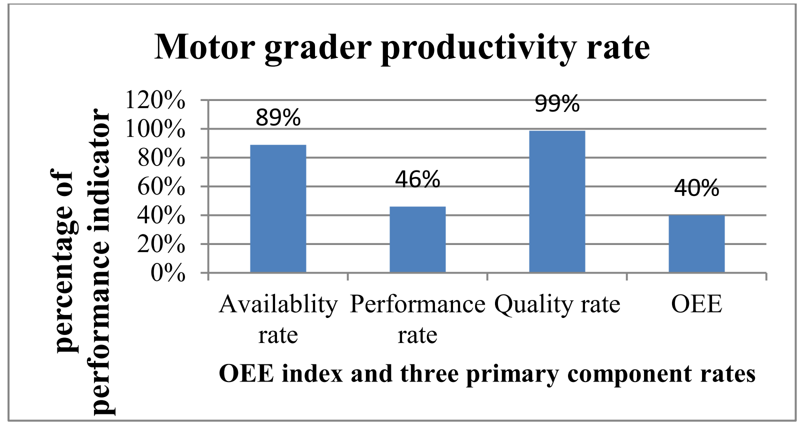


Figure 5.2 shows that the distribution primary components and OEE index of individual equipment on Gofa Mazoria – Babur Tabia road project

As depicted in Table 5.4 and Figure 5.2, performance rate ranked first on affecting the productivity of motor grader and excavator (refer independent calculation on Appendix *C-4* and *C-5)*, availability rate ranked second on affecting the productivity of motor grader and excavator and quality rate had lesser effect on productivity of equipment. Besides, Table 5.4 shows that the extent of overall productivity of Motor grader and Excavator is very poor with OEE of 40% and 29% respectively. This is due to improper work management in the utilization of the machine. Furthermore, inappropriate battery, poor maintenance, shortage of materials, irrelevant communications and low quality work were the main contributing factors for the loss in productivity. Moreover, the result of the analysis showed that, the performance rates for all machines on this road project were that needed more attention by management. In addition, performance rate was the one mainly affecting the overall performance of all the machines.

5.6. Shiromeda – Kidane Mihret Road Project.

The result obtained in the case of this project represent the productivity rate of equipment in Grade One contractor‟s who are working on a road project with difficult terrain. It also provides an indication of the rank of factors affecting the performance of construction equipment. Table 5.5 below presents the loader productivity rate and summary of factors affecting the productivity of the Shiromeda – Kidane Mihret Road project.

Table 5.5 Shiromeda - Kidane Mihret road project.

Data Collection Template Machinery type Loader Mark; CAT Model: 252B					
Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Loader productivity rate on Shiromeda - Kidanemariam road project					
Type of Activity – Caraway work					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	Unit	Contributing factors
AR(%) = (E/C) = 91.2%	A	Available time (10*60')	600	Min	
	B	Scheduled maintenance + scheduled production break	90	Min	Oil check, Lubrication, Lunch break
	C	Loading time = A – B	510	Min	
	D1	Recorded break down time	0		
	D2	Time spent for change in operation condition	45	Min	
	D	Major stoppage losses = (D1 + D2)	45	Min	
	E	Operating time = C – D	465	Min	
	G	Ideal production (from manufacturer specification)	55.45	m3/hr	
	H	Actual production	47.1	m3/hr	
PR(%) = P*R = 60.83%		Job efficiency	50	Min	
		heaped Bucket capacity	0.59	m3	

		Material type – soil			
		Bucket fill factor	0.85		
		swell factor- from table			
		Static tipping load - from table	2342	Kg	
	O	Actual cycle time	34	Sec	
	I	Production capacity losses downtime = [1-H/G] x L	53.46	Min	Lubricant application
	K1	Number of minor stoppage	3	No.	
	K2	Average duration of minor stoppage	20	Min	
	K3	Idle time	50	Min	right of way problem & tea break
	K	Minor stoppage/Idle losses = [K1*K2+K3]	110	Min	
	L	Net Operating Time = [E-K]	355	min	
	M	Performing Time = [L-I]	301.54	min	
	N	Valuable operating time = [M-J]	261.54	min	
	P	Net operating rate = 100*[H*O]/E	77	%	
QR(%) = (S-T)/S =89.6%	Q	Ideal/theoretical/design cycle time	27	sec	
	R	Operating speed coefficient = [Q/O]	0.79		
	J	Time spent for rework and start up yield losses	40	min	
	S	Total executed amount(Unit)	471	m3/hr	
	T	Reworked amount (unit)	49	m3/hr	failure to meet specification
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.50					

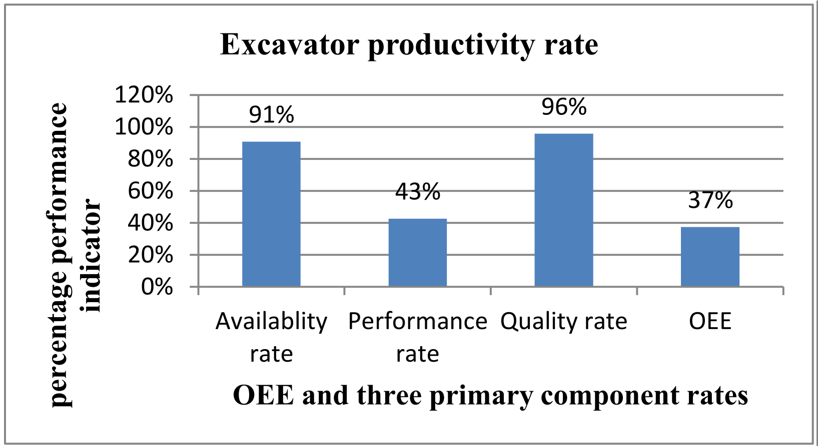
Table 5.5 shows that the percentage productivity rate of three primary components and OEE on Shiro Meda – Kidane Mihret road projects. According to the result of the analysis, Loader availability rate is 91%, performance rate is 61%, quality rate is 90% and OEE is 50%. Subsequently, Figure 5.3 shows the distribution of primary components and OEE indexes of Loader on Shiromeda – Kidane Mihret road project.

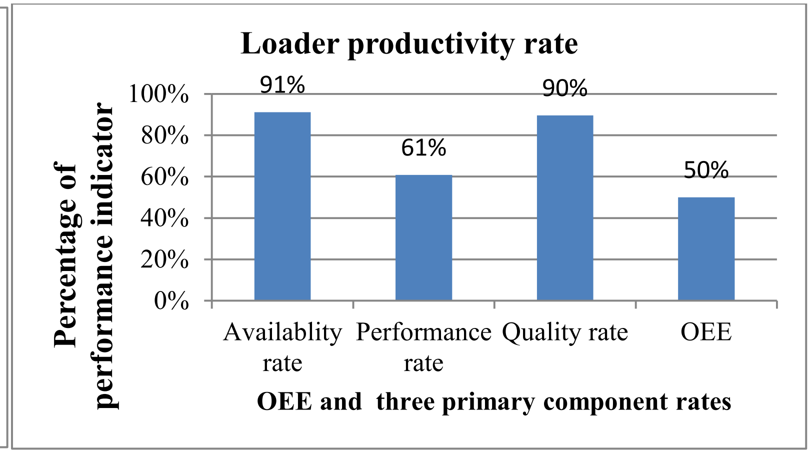
Table 5.6 Summary average productivity rate at Shiromeda - Kidane mihret Road project

Excavator productivity rate		**Loader productivity rate**	
indexes	percentage	indexes	percentage
Availability rate	91%	Availability rate	89%
Performance rate	43%	Performance rate	72%
Quality rate	96%	Quality rate	97%
OEE	37%	OEE	62%

Grader productivity rate

indexes	percentage
Availability rate	93%
Performance rate	43%
Quality rate	99%
OEE	39%





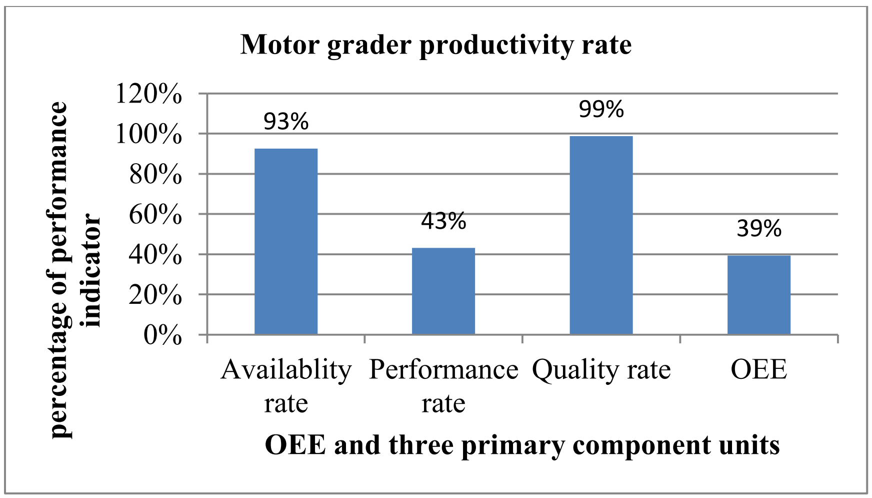


Figure 5.3 Distribution of primary components and OEE indexes of individual equipment at Shiromeda – Kidane Mihret road project

As depicted in Table 5.6 and figure 5.3, performance rate was ranked first on affecting the productivity of excavator, Loader and Grader (refer independent calculation in Appendix *C-6, C-7 and C-8*), quality ranked second on affecting the productivity of three leading equipment and availability rate had lesser effect on productivity of equipment. Besides, Table 5.6 shows that the extent of overall productivity of excavator, Loader and Grader is very poor with OEE of 37%, 50% and 39% respectively. This is due to improper work management during the utilization of the machine. Furthermore, inappropriate lubrication, right of way problem, shortage of materials, irrelevant communications and failure to meet work specifications were the main contributing factor for the productivity loss. Moreover, the the results of the analysis showed that, the performance rate for loader on this road project is the most important rate that needs more attention from the management. In addition, it is the one mainly affecting the overall performance of all the machines.

5.7. Equipment loss comparison among projects

The loss in productivity of equipment is compared by OEE index value. According to analysis result, OEE index at Keranio Medanialem – Ambo road project are 37%, 50% and 38% for excavator, loader and Motor grader respectively. OEE index at Gofa Mazoria – Babur Tabiya road project are 29% and 40% for excavator and Motor grader respectively. OEE index at Shiro meda – Kidane Mihiret Road project are 37%, 50% and 39% for excavator, loader and Motor grader respectively. When comparing OEE index for each equipments; excavator has lowest OEE index value at Gofa Mazoria – Babur Tabia road project, loader has similar OEE index value at all projects and Motor Grader has the least OEE index value at Keranio Medanialem – Ambo road project.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. General

This chapter presents conclusions of the study by combining the research results of both case study and survey study based on the objectives stated in section 1.3 under the introduction chapter. Accordingly, in this chapter the main conclusions for this research are summarized.

Recommendation are also forwarded to minimize construction equipment planning and management problems to improve the performance of the AACRA road construction project which are implemented by contracting companies, AACRA own force construction department and equipment rental companies.

6.2. Conclusions

The road construction sector is one of the major absorber of the country‟s budget. In this regard, the budget of construction equipment consumes about one third of the total road project cost. This study focused on leading construction equipment planning and management problems in road projects in Addis Ababa; it also identified the major causes of construction equipment planning and management problems and presented a comprehensive analysis of this causes. The result indicated that idle time, down time, poor equipment maintenance practices, improper determination of economic life and timing of replacement, poor training of equipment operators, equipment breakdown, over maintenance of equipment, huge capital investment during acquisition, balance of interdependent equipment, misunderstanding the scope of work carried out, unit cost of production and equipment suitability for job condition were found to be the major problems that affect construction equipment planning and management on AACRA projects during the planning and construction process.

At AACRA knowledge about construction equipment planning and management policy is very little. Insufficient training of professional workforces on construction equipment planning and management is the major problem at AACRA road construction projects. So, this study proved that most of sampled respondents majorly use only one or two types of equipment planning and management policy. This trend is not relevant to the motive of the construction companies which is profitability. Lack of knowledge in one policy can result in occurrence of problem on other policy. There is a little use and application of construction equipment planning and management policy in AACRA project. Therefore, if the workers especially site engineers did not have enough knowledge about equipment planning and management policy (selection, acquisition, operation, and maintenance and replacement policies), it is difficult to implement the policy on their project.

Planning to match the right type of construction equipment for the proposed job is the first step to reduce loss in productivity of equipment. As the result of study proved, only 27% of respondents use economic analysis as basis for selection of equipment. In addition to this, only 7% of respondents use combination of economic analysis, models based on traditional mass haul diagram and experience as a basis for selection of equipment. This showed that, most responds fail at the planning stage to select the right match of equipment for proposed job in scientific way.

According to result of study, most contracting companies use on site production as a base to estimate operating cost. Others use three methods (historical data from experience, recommendations from equipment manufacturer and onsite production rate) jointly. Using onsite production rate as the only base to estimate operating cost is not relevant to companies that expect reasonable profits. Most of the time the equipment hourly production rate is below standard at construction sites because of different site condition and management problems.

Proper maintenance of construction equipment is vital to keep construction equipment in good and serviceable condition. As the study revealed, 67% of the respondents use planned preventive maintenance method and only 6% jointly, use planned preventive maintenance and corrective maintenance. All types of maintenances are critically needed to keep equipment in good and serviceable condition. By periodically maintaining equipment using planned preventive maintenance method, different major failures of equipment can be prevented because „prevention is better than cure". Also it is better to do corrective maintenance when necessary to increase the efficiency of equipment. In addition, unplanned or unscheduled maintenance is necessarily needed because, equipment can break down suddenly. Therefore, it is better to use all maintenance methods to make equipment more productive.

Construction equipment replacement policy plays a pivotal role to increase the productivity of equipment and to increase the profitability of construction companies and equipment rental companies. But, equipment replacement is dependent on equipment replacement method that a company selects. In this regard, this study proved that, 33% of the respondents uses accounting return on investment and internal rate of return methods and 17% of the respondents use present worth method for replacement of equipment. It is obvious that the companies working on AACRA projects target a reasonable profit, therefore, it"s better for them to use profit maximization method.

To avoid or reduce construction equipment planning and management problems it is necessary to identify the major causes of the problem. The results of analysis indicated that, huge capital investment at acquisition phase and poor maintenance practice with improper determination of economic life and timing for replacement are the major causes of construction equipment planning and management problems.

This causes of construction equipment planning and management problems reflected negative effects on project performance. loss in productivity of equipment, time overrun, cost overrun and equipment related accidents are some of the major effects of construction equipment planning and management problems. Most effects, like loss in productivity of equipment, time overrun, equipment related accidents are reflected on cost overrun. This is why cost overrun was ranked first with the highest negative effect on performance of road projects.

The performance of equipment effectiveness is evaluated based on actual on site measurement. This actual onsite construction equipment effectiveness is evaluated by overall equipment effectiveness (OEE) indexes. As proved by the case study, actual on site performance of equipment is very poor due to different management problems. All the analyses show that, OEE of construction equipment is 50% and below 50%. This shows that, the equipment productivity rate is below half of its capacity.

6.3.Recommendation

After detail investigation on construction equipment planning and management problems its causes and effects, plausible recommendations can be forwarded to Grade one contractors, AACRA, equipment rental companies and to pertinent government. The recommendation meant to diminish construction equipment planning and management problems on AACRA road construction projects. The following recommendations are forwarded to respective offices.

6.3.1. Addis Ababa Road Authority

- The AACRA established construction equipment administration and maintenance department to plan and manage construction equipment required for each project. This department should employ enough number of qualified engineers. Therefore, the following recommendation are forwarded to the Department;
  - ➢ Develop construction equipment planning and management policy to be used as a guide line to use equipment efficiently.
  - ➢ Should give awareness training for site engineers about equipment planning and management policy and how to manage equipment at project level.
  - ➢ Collect data about the current status of construction equipment and efficiency of equipment at project level.
  - ➢ Develop planned preventive maintenance method to eliminate long down time of equipment.
  - ➢ Develop optimization methods to use available equipment resource effectively and efficiently; and.
- AACRA have to establish a training center, to train unskilled and semi-skilled operators.
- AACRA have to update the equipment management guideline to reconcile with the current working condition and work load.
- AACRA have to implement the currently available technologies regarding equipment.
- AACRA must update equipment crew composition and its production rate.
- AACRA should consider submission of construction equipment planning and management policy as criteria to award contract of road project.

6.3.2. Grade one contractors and Equipment renting companies

Contractors and equipment rental companies play a key role in eliminating construction equipment planning and management problems from planning to construction process. Contractors‟ and equipment rental companies responsibilities vary according to stages of equipment management like selection, acquisition, operation, maintenance and replacement by considering each stage. The following recommendations are forwarded to contractors and equipment rental companies.

- Develop construction equipment planning and management policy to use as a guide line for the road construction work; and.
- Develop equipment management system throughout the company.

- The following are implementation phases:

(i). Selection phase

- Conduct detail planning to select the right match of construction equipment for proposed job condition; and
- Use economic analysis, models based on traditional mass haul diagram and experience jointly to select the economic equipment with high efficiency.

(ii). Acquisition phase

- Use standard policy for better relationship with dealers or for easier equipment administration.
- Avoid huge capital investment during acquisition of construction equipment by using options like rental and leasing of equipment according to the scope of work.
- Use rental or leasing strategy for infrequently utilized equipment.
- Purchasing the same brand that is being used regularly.
- Make decision on acquiring by equipment manager or project manager
- Purchase equipment from familiar dealers.

(iii). Operation phase

- Provide training for equipment operators through in-house equipment department, equipment dealer or external agencies.
- Consider poor operating procedure as a main cause of equipment accidents.
- Allow an equipment operator to work with more than one machine.
- Collect daily based data to measure the overall equipment effectiveness.
- Identify major factors that cause idle time of equipment.

(iv). Maintenance phase

- Implement preventive maintenance, corrective maintenance and unscheduled maintenance program to leading construction equipment.
- Provide maintenance by equipment operators, through in-house equipment department, equipment dealers and external dealers.
- Consider poor maintenance and use of non-original parts as the main cause of machine failure during use.
- Wait until the failed machine is completely repaired and ready for use

(v). Replacement or disposal phase

- Determine equipment economic life based on maintenance and repair cost.
- Dispose or replace equipment based on economic analysis.
- Dispose or replace equipment when it is technologically obsolete
- Determine equipment economic life based on profit accrued from use.
- Dispose or replace equipment when it becomes inefficient.
- Determine equipment economic life based on depreciation cost.
- Determine equipment economic life based on investment cost

6.3.3. Government

The Government is one of major party that can play a pivotal role in the elimination of construction equipment planning and management problems. Accordingly, the following recommendations are forwarded to the Government;

- Develop policy to integrate different parties who have utility lines on areas of road construction project.
- Have to guide AACRA to spend a valuable time in planning phase of road projects.
- Avoid right of way problems before award of contract to road project to contractors.
- Establish special traffic management system on town section road construction projects.

7. FUTURE RESEARCHERS AREAS

Continuous research need to be conducted until construction equipment on site produce at full capacity. Therefore, future researchers are recommended as follows;

- Conduct research on optimization of construction equipment in big cities like Addis Ababa.
- Develop construction equipment management software on road construction project.
- Develop construction equipment productivity calculation software on road project

REFERENCE

Abebawu W. (2014), Loss assessment of construction equipment productivity and its impact on equipment financial performance in federal road projects. MSc. Thesis, Addis Ababa University (AAiT).

Abiy Z., Alemayehu W., Daniel T., Melese G. and Yilma S. (2009). Introduction to research methods. Addis Ababa University 2009.

Alaghbari, W. Kadir, M.R.A, Salim, A. and Ernawati (2007). The significant factors causing delay of building construction projects in malaysia. Engineering, Construction and architectural management, 14(2), 192-206.

An Online International Journal Available at http://www.cibtech.org/jet.htm 2012 vol. (2) April-June, PP. 39-48/Kumar et al.

Arditi, D., Kale, S. & Tangkar, M. (1997) Innovation in construction equipment and its flow into the construction industry. Journal of Construction Engineering and Management, 123 (4), 371-378

Assafs, S.A, and Al-Hejji, S. (2005). Causes of delay in large construction projects, International jornal of project Management 24(2006), 349 – 357. Retrieved from http://ipac kast edu sa/edoc/2006/156957_1.pdf.

Campbell, L. (2011) Essential Guide to construction equipment management retrieved from http://www.articledashboard. Com/Article/Essential-guide-to-construction- equipment – management/2161925.

Casals, M. Forcada,N,. and Roca. X (2003). A methodology to select construction equipment. Barcelona Spain: Polly technic university of Catalonia, Department of construction engineering.

Cater, M.R. (1993). Resource management for construction. London the Macmillan press.

Caterpillar Performance Hand Book, (2006). Caterpillar Inc., Peoria, Illinois, U.S.A

Construction Plant & Equipment. (1986-b). Hire Fleet Expanded. Morgan-Gramplan (Construction Press) Ltd., London, July, 1986, pp 48 - 49.

Construction plant & equipment. (1987-a). Oil Analysis - An Essential Part of Preventive Maintenance. Morgan-Gramplan (Construction Press) Ltd., London, September, 1987, pp 27-32.

Construction information services. (2012). Construction Plant Acquisition & Finanace. Retrieved from http://www.misronet.com/construction plant.htm

Creswell W. (1994): Research design: qualitative & quantitative approaches. London: sage publications.

Creswell W. (2009): Research design: qualitative, quantitative, and mixed methods approaches. London: Sage publications.

Cronibach, L.J. (1951). Coefficient alpha and the internal structure of test. Psychometrica, 16, 297-334.

Crovic, G. and plamenac, D. (2006). Construction machines. Optimal choice of options using mathematical modeling. Kybernets: The internation Jouranal of systems and Cybernetics, 35(9), 1348-68.

Day, D. A, & Benjamin, N.B.H.(1924). Construction equipment guide (1st ed). Canada: John willey and sons.

Day, D.A, & Benjamin, N.B.H.(1991). Construction equipment guide (2nd ed). Canada: John willey and sons.

Douglas, James. (1975). Construction Equipment Policy. McGraw - Hill, Inc., New York.

Edwards, D.J., Holt, G.D. & Harris, F.C. (2000) A model for predicting plant maintenance costs. Construction Management and Economics, 18, 68-75.

Elazouni, A.M. & Basha, I.M. (1996) Evaluating the performance of construction equipment operations in Egypt. Journal of Construction Engineering and Management, **122** (2), 109-114.

Gao S. and Low S. (2014): Lean construction management; the Toyota way, Singapore.

Gann, D. and Senkar, P, (1998). Construction skills training of next mellinium Construction management and economics, 16(5), 569-80.

Getaneh G. (2011): Assessment of Conditions of Contract Problems in Ethiopian Construction industry, Master‟s Thesis, Addis Ababa University, AAiT, Ethiopia.

Goldenberg, M. and Shapira, A. (2007) Systematic evaluation of construction equipment alternatives: case study. Journal of construction Engineering and management, 133(1), 72-85.

Gransberg, Calin M. Popescu, Richard C. Ryan(2006): Construction equipment management for engineers, estimators and owners., CRC press Taylor and Francis Group.

Harris, Frank and McCaffer, Ronald. (1982). Construction Plant - Management and Investment Decisions, Granada Publishing Ltd., London.

Hinze, J.and Ashton, W.B.(1976). Current equipment policies of utility contractors. Journal of the construction Division, 105(C03), 225-37.

Hinze, J. & Ashton, W.B 1979, current equipment policies of utility contractors. „Journal of the construction division, ASCE, 105, No. 3,225-237.

Ibbs, C. William and Terveer, Kenneth R.(1984). Integrated Construction Preventive Maintenance System. Journal of Construction Engineering and Management, ASCE, Vol. 110, No. 1, March, 1984, pp 43 – 59

Johnson P., & Harris D. (2002). Qualitative and quantitative issues in research design. In D. Partington (Ed.), Essential skills for management research (pp. 99–116). London: Sage Publications.

Jose, L. P. (2001). Detailed Haul Units Performance Model. Unpublished Master‟s thesis, Virginia Polytechnic Institute State University, Blacksburg, Virginia.

Kumar R. (2005): Research Methodology: A Step-by-Step Guide for Beginners: 2nd, edition, SAGE Publications.

Krosnick A. and Presser S. (2010): Handbook of Survey Research, Second Edition.

Larry Rich man (2002). Project Management: Step by Step. AMACOM, a division of American Management Association,NY, USA.

Leuva, S. (2012). The importance of road equipment and road construction machinery. Retrieved from http://www.articles/70454/1/ importance – of – road equipment – road - construction machinery/page 1.html

Makulsawatudom, A and Emsley, M (2001) Factors affecting the productivity of the construction industry in Thailand: The project manager‟s perception. In: Akintoye, A (ED.), 17th Annual ARCOM conference, 5-7 September 2001, University of Salford. Association of research in construction Management, Vo.1, 281- 290.

Marvelous. (2012), the importance of maintaining construction equipment. Retrieved from http://www.edbs.com/ the-importance-of-maintaining-construction-equipment.

Mawdelsey, M.J., Askew, W.H. and Al-Jibouri, S.H. (2004). Site layout for earthwork in road projects. Engineering Construction and Architectural Management, 11(2), 83-89

Mead, Geoff. (1986). A Thriving Contractor. Construction Plant and Equipment, April, 1986, pp 10 - 11.

Mohideen, P.B.A., Ramachandran, M., and Narasimmalu. R.R.(2011) constraction plant breakdown criticality analysis- part-1: UAE perspective. Emerald, 18(4), 472-489.

Naoum S. (2007): Dissertation Research and Writing for Construction Students (2nd edn.), Elsevier Butterworth-Heinemann, Oxford, UK.

Pathmanathan, V. (1980) Construction equipment downtime costs. Journal of Construction Division, 106(4), 604-607.

Peurifoy, R.L., Schexnayder, C.J., and Shapira, A.(2006). Construction planning, equipment, and methods(7th ed). New York: Suzanne Jeans.

Pintelon, Lilian, Muchiry and peter. Performance measurement using over all equipment effectiveness (OEE): literature review and practical application discussion. International journal of production research. 2006. Found in http://mc.manuscriptcentral.com/tpr

Prasertrungruang and Hadikusumo T. and Hadikusumo, (2007) B.H.W. Heavy equipment management practice and problems in Thai highway contractors Emerald, 14(3), 228-241.

Rickets, 1999 Heavy equipment management practice and problems in Thai highway contractors Emerald, 14(3), 228-241.

Schexnayder, C. J. and Hancher, Don E. (1981). Contractor Equipment- Management Practices. Journal of the Construction Division, ASCE, Vol. 107 (C03), December, 1981, pp 619 - 626.

Sharma S.c,1997.construction equipment and its management, New Delhi,Khanna publication.

Sharma S.c,1999.construction equipment and its management, New Delhi,Khanna publication.

Shama S.c., 2002. Construction equipment and its management New Delhi,khanna publishers,

Shama S.c., 2007. Construction equipment and its management New Delhi,khanna publishers,

Stewart, L.A.R.R.Y., 2002. Buyers juggle more rentals and leasing. Construct. Equip., 105(7): 44.

Sözen, Z. & Giritli H. (1987). Equipment policy as one of the factors affecting construction productivity: a comparative study. In: Managing Construction Worldwide: Productivity and Human Factors in Construction, (eds P.R. Lansley, & P.A. Harlow), pp. 691-696. 5th International Symposium, CIOB, CIB, London.

Street, D. (1983). Aim is to avoid Conflict. Construction Plant and Equipment, March, 1983, pp 14 - 16.

Tavakoli,A., Taye, E.D. and Erktin, M. (1989), „‟equipment policy of top contractors: A survey." Journal of construction engineering and management. ASCE, 115,No.2 317-329.

Tucker, V. V. (1980). Earthmoving Plant - An Introduction To Its Selection, Operation and Costing. Woodhead - Faulkner Ltd., Cambridge.

Uher, T.E. (2003), programing and scheduling techniques. Sydney : University of new south wales press.

Vorster, M.C. and Garza, J.M.D.L. (1990) consequential equipment cost associated with lack of availability and down time. Journal of construction Engineering and management, 116(4), 656-69. Voster, M. (2005). A machine replacement strategy. Construction equipment, 108(7), 51-2.

Yeo, K.T. and Ning, J.H. (2006) managing uncertainty of major equipment procurement in engineering project. European journal of operational research, 171(1), 123-34.

Appendix A – Questioner

STUDY ON CONSTRUCTION EQUIPMENT PLANNING AND MANAGEMENT PROBLEMS IN ROAD CONSTRUCTION PROJECTS IN ADDIS ABABA.

Dear Sir/Madam:

I am currently doing a research on Construction Equipment planning and Management problems on Road Construction Projects in the city of Addis Ababa for M.Sc. degree in Construction Technology and Management. In this regard, this questionnaire has been developed to acquire the required data from pertinent construction companies. Accordingly, your company has been selected with full confidence that realistic data will be obtained to reflect the quality of the thesis. Therefore, your cooperation is highly necessary and I thank you in advance for assistance. I want to assure you that the information provided by you is confidential and specifically used in the research indicated above.

Sincerely yours;

Mekdim Mathewos

Mobile phone number: +251-910-287-161

Email: mekdimanjo@gmail.com

QUESTIONNAIRE

Profile

Profession--

Company---

Year of Experience in the Company---------------------------------------

Position---

1. Does your company have construction equipment planning and management policy?

   Yes ☐ No ☐

2. If yes, which equipment planning and management policy is applicable in your Company? Please circle the policy implemented on your project.
   A. Equipment selection policy
   B. Equipment acquisition policy
   C. Equipment operation procedures
   D. Equipment maintenance policy
   E. Equipment replacement policy

   If any other, please specify

   ----

3. Is there any construction equipment planning and management problem in AACRA road construction projects and in your construction site?

   Yes ☐ No ☐

4. If your answer is yes, please indicate their influence by marking the appropriate box.

No.	Description	Very low	Low	Medium	High	Very high
1.	Miss understanding the scope of work carried out					
2.	Equipment suitability for job condition					
3.	Balance interdependent equipment					
4.	Unit cost of production					

5.	Huge capital investment during acquisition					
6.	Poor training of equipment operators					
7.	Poor equipment maintenance practices					
8.	Improper determination of economic life and timing of replacement					
9.	Equipment break down					
10.	Over maintenance of equipment					
11.	Down time of construction equipment					
12.	Idle time of construction equipment					

If other, indicate and mark their influence in the appropriate box.

No.	Description	Very low	Low	Medium	High	Very high
1.						
2.						
3.						
4.						
5.						

5. Do you think construction equipment planning and management problems have negative effect on road construction performance?

   Yes ☐ No ☐

6. If your answer is yes, please indicate the influence by making on the appropriate box.

No.	Description	Very low	Low	Medium	High	Very high
1.	Delay (Time overrun)					
2.	Cost overrun					
3.	Loss in productivity of equipment					
4.	Equipment related accidents					

7. Planning to find the right match of construction equipment for the proposed job is the first step to reduce loss in production rate of equipment. Do you think this is correct?

   Yes ☐ No ☐

8. If yes, how do you select the right match of equipment to the proposed work task? Please circle the method which applies to your practice.
   A. Economic analysis
   B. Using models based on traditional mass haul diagrams
   C. Mathematics of rough sets and fuzzy sets
   D. Experience.

   If there is other method, please specify.

   ----

9. How accurate is this method of the equipment selection?

   High ☐

   Medium ☐

   Low ☐

10. Determination of construction equipment acquisition method is the major issue during management with financial implication. Do you think this is correct?

    Yes ☐ No ☐

11. If yes, which method do you use? Please circle the method from the following.

    A. Cash
    B. Renting
    C. Leasing

    If there is any other method, please specify

    ----

12. How appropriate is this construction equipment acquisition is to reduce loss in production rate of construction equipment?

    High ☐

    Medium ☐

    Low ☐

13. Do you consider operation of equipment is highly dependent on operating cost of equipment?

    Yes ☐ No ☐

14. If your answer is yes, what basis do you use for estimating the cost of operating construction equipment? Please circle the basis used for your project.
    A. Historical data from experience
    B. Recommendations from equipment manufacturers
    C. On site production rate

    If any other basis, please specify

----

15. How accurate this base to estimate operating cost of construction is to determine the level of loss in equipment production rate?
    High ☐
    Medium ☐
    Low ☐
16. Proper Construction equipment maintenance is vital to keep equipment in good and serviceable conditions. Do you think this is true?

    Yes ☐ No ☐

17. If your answer is yes, which basic form of maintenance method is used in your Company? Please circle the method used in your company.
    A. Planned preventive maintenance
    B. Planned corrective maintenance
    C. Unscheduled or unplanned maintenance including repairs

    If any other method, please specify

----

18. How proper the equipment maintenance method used in your project to reduce loss in equipment production rate?

    High ☐

    Medium ☐

    Low ☐

19. Construction equipment replacement policy plays a major role in productivity? Do you think this Correct?

    Yes ☐ No ☐

20. If your answer is yes, which parameter is used in your company? Please circle the parameter used in your project.

    A. Payback period method
    B. Accounting return on investment
    C. Internal rate of return
    D. Net present worth method

    If any other policy, please specify

    ----

21. Is there any factor that influences the equipment replacement criteria in your company?

    Yes ☐ No ☐

22. If your answer is yes, please indicate the influence(s) by indicating in the appropriate box.

No.	Description	Very low	Low	Medium	High	Very high
1.	Revenue					
2.	Maintenance and repair costs					
3.	Down time costs					
4.	Cost of capital					
5.	Depreciation					
6.	Obsolescence					
7.	Inflation					
8.	Tax considerations and Capital allowances					

23. What do you consider the causes are for poor equipment planning and management problem in your company? Please circle the major condition, that causes poor equipment planning and management problems in your company.
    A. Constraints imposed by job and contractual obligation.
    B. Huge capital investment during the acquisition phase.
    C. Poor training of equipment operators.
    D. Poor equipment maintenance practices.
    E. Improper determination of economic life and timing for replacement.

    If any other causes, please specify

    ----

24. What do you consider the effects of poor equipment planning and management in your company? Please circle the major effect from the following:-
    A. Loss in productivity rate of equipment
    B. Time overrun

C. Cost overrun

If any other effects, please specify

----

25. Is there any kind of best practice you are used to reduce construction equipment planning and management problems during construction phase?

Yes ☐ No ☐

If yes, please list some of them

----

26. What is your recommendation to avoid construction equipment planning and management problems regarding road construction projects?

No.	Description	Very low	Low	Medium	High	Very high
	Selection of equipment					
1.	Use models based on traditional mass haul diagram, artificial intelligence and genetic algorithm and geographical information system					
2.	Mathematics of rough sets and fuzzy sets					
3.	Analytical hierarchy process					
	Acquisition phase					
4.	Purchase equipment based on company financial status based on internal rate of					

	return					
5.	Make decision on acquiring or disposing by equipment manager or project manager					
6.	Purchasing the same brand that is being used regularly.					
7.	Purchase equipment from familiar dealers.					
8.	Buy used machines only the ones that do not have complicated systems, one that do not have high repair costs once failure					
9.	Using rental or leasing strategy for infrequently utilized equipment					
10.	Using standardized policy for better relationship with dealers or for easier equipment administration					
	Operation phase					
11.	Allow an equipment operator to work with more than one machine.					
12.	Provide training by in-house equipment department, equipment dealer or external agencies					
13.	Considering poor operating procedure as main cause of equipment accident					
	Maintenance phase					
14.	Provide maintenance by equipment operators, in-house equipment department, equipment dealers and external dealers.					
15.	Provide preventive maintenance program to equipment.					
16.	Wait until the failed machine is completely repaired and ready for use					
17.	Consider poor maintenance and use of non-original parts as the main cause of machine failure during use.					
	Disposal phase					
18.	Dispose or replace equipment based on equipment economic analysis					
19.	Dispose or replace equipment when it becomes technologically obsolete					

20.	Dispose or replace equipment when it becomes inefficient					
21.	Determine equipment economic life based on investment cost					
22.	Determine equipment economic life based on depreciation cost					
23.	Determine equipment economic life based on maintenance and repair cost					
24.	Determine equipment economic life based on profit accrued from use					

Appendix B – Case study interview

STUDY ON CONSTRUCTION EQUIPMENT PLANNING AND MANAGEMENT PROBLEMS IN ROAD CONSTRUCTION PROJECTS IN ADDIS ABABA.

Dear Sir/Madam:

I am currently doing a research on Construction Equipment planning and Management problems on Road Construction Projects in the city of Addis Ababa for M.Sc. degree in Construction Technology and Management. In this regard, this Interview has been developed to acquire the required data from pertinent construction companies. Accordingly, your company has been selected with full confidence that realistic data will be obtained to reflect the quality of the thesis. Therefore, your cooperation is highly necessary and I thank you in advance for assistance. I want to assure you that the information provided by you is confidential and specifically used in the research indicated above.

Sincerely yours;

Mekdim Mathewos

Mobile phone number: +251-910-287-161

Email: mekdimanjo@gmail.com

INTERVIEW

Profile

Profession---

Company---

Year of Experience in the Company--------------------------------------

Position--

1. Do you feel there is proper construction equipment planning and management policy in your company and AACRA project you involved?

   Yes ☐ No ☐

2. Please identify the existing equipment planning and management problem in your company. For the identified problems, please indicate the reason for problem and the effect on project performance.

No.	Major problems which affect construction equipment planning and management in AACRA	Check (Yes/No)	Critical cause of the problem	In which phase occurred	Possible effects (Time, cost, productiy etc.)	How it could be managed
1.	Miss understanding Scope of work carried out					
2.	Equipment suitability for job condition					
3.	Balance of interdependent equipment					
4.	Unit cost of production					
5.	Huge capital investment in the acquisition phase.					
6.	Poor training of equipment operators					
7.	Poor equipment maintenance practices					
8.	Improper determination of economic life and timing of replacement					
9.	Equipment break down					
10.	Over maintenance of equipment					
11.	Down time					
12.	Idle time					

3. Is there any measure taken in your company to improve problems towards equipment planning and management during planning or construction phase?

   Yes ☐ No ☐

   If yes, please discuss some of them.

   ----

4. Do you have other opinions about construction equipment planning and management problems and possible recommendations in your company or AACRA road construction project and your project site? (if any)

Appendix C – Average OEE index of selected construction Equipment

C-1: OEE Index for Excavator on Keranio Medhanialem – Ambo road project

Data Collection Template Machinery type Excavator Mark; CAT Model: 320C Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines]					
Type of Activity – Excavation					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 92.6%	A	Available time (10hrs. * 60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	10	min	mechanical problem
	D2	Time spent for change in operation condition	30	min	
	D	Major stoppage losses = (D1 + D2)	40	min	
	E	Operating time = C – D	500	min	
	G	Ideal production (from manufacturer specification)	118.73	m3/hr	
	H	Actual production	74.5	m3/hr	
PR(%) = P*R = 42.64		Applicable correction factors			
		Job efficiency	45	min/hr	
		Heaped bucket capacity	0.75	m3	
		Material type - rock earth mixture			

		Bucket fill factor	1.05		
		height of swing factor			
		swell factor	0.83		
	O	Actual cycle time	33	sec	
	I	Production capacity losses downtime = [1-H/G] x L	141.5598	min	
	K1	Number of minor stoppage	3	min	to change position
	K2	Average duration of minor stoppage	20	min	
	K3	Idle time	60	min	shortage of material
QR(%) = (S-T)/S= 93.7%	K	Minor stoppage/Idle losses = [K1*K2+K3]	120	min	
	L	Net Operating Time = [E-K]	380	min	
	M	Performing Time = [L-I]	238.4402	min	
	N	Valuable operating time = [M-J]	198.4402	min	
	P	Net operating rate = 100*[H*O]/E	82	%	
	Q	Ideal/theoretical/design cycle time	17	sec	
	R	Operating speed coefficient = [Q/O]	0.52		
	J	Time spent for rework and start up yield losses	40	min	
	S	Total executed amount(Unit)	950	m3	
	T	Reworked amount (unit)	60	m3	low standard work
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.37					

C-2: OEE Index for Motor Grader on Keranio Medhanialem – Ambo road project

Data Collection Template Machinery type Grader Mark; CAT Model: 143H Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Motor grader productivity in AACRA (keranio medihanialem - Ambo road) Road project					
Type of Activity - Sub base laying					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C)= 83.3%	A	Available time(10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	40	min	Batery problem
	D2	Time spent for change in operation condition	50	min	
	D	Major stoppage losses = (D1 + D2)	90	min	
	E	Operating time = C – D	450	min	
	G	Ideal production (from manufacturer specification)	8995	m2/hr	
	H	Actual production	4895.85	m2/hr	
PR(%) = P*R = 46.2%		Applicable correction factors			
		Blade length(L) including overlap	3.66	m	
		Width per trip(B) = L*cos A	3.17	m	
		Tilting angle of the blade	30		
		Lift thickness after compaction	0.2	m	
		Average speed corrospond to the work type	2.54	km/hr	

		Cycle time(T) = 0.06∑p/v	1	min	
		operator efficiency	0.75		
	O	Actual cycle time	4	min	
	I	Production capacity losses downtime = [1-H/G] x L	136.71	min	
	K1	Number of minor stoppage	3		third person communication
	K2	Average duration of minor stoppage	10	min	and tea break
	K3	Idle time	120	min	Material shortage
QR(%) = (S-T)/S =99.2%	K	Minor stoppage/Idle losses = [K1*K2+K3]	150	min	
	L	Net Operating Time = [E-K]	300	min	
	M	Performing Time = [L-I]	163.29	min	
	N	Valuable operating time = [M-J]	155.29	min	
	P	Net operating rate = 100*[H*O]/E	75.7	min	
	Q	Ideal/theoretical/design cycle time	2.45	min	
	R	Operating speed coefficient = [Q/O]	0.61		
	J	Time spent for rework and start up yield losses	8	min	
	S	Total executed amount(Unit)	48958.5	m2	
	T	Reworked amount (unit)	350	m2	Low quality work
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.382					

C-3: OEE Index for Loader on Keranio Medhanialem – Ambo road project

Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Loader productivity rate on keranio medihanialem - Ambo road project					
Type of Activity -					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 91.2%	A	Available time (10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	90	min	Oil check, Lubrication Lunch break
	C	Loading time = A – B	510	min	
	D1	Recorded break down time	0		
	D2	Time spent for change in operation condition	45	min	
	D	Major stoppage losses = (D1 + D2)	45	min	
	E	Operating time = C – D	465	min	
	G	Ideal production (from manufacturer specification)	55.45	m3/hr	
	H	Actual production	47.1	m3/hr	
PR(%) = P*R = 60.83%		Job efficiency	50	min	
		heaped Bucket capacity	0.59	m3	
		Material type – soil			
		Bucket fill factor	0.85		
		swell factor- from table			
		Static tipping load - from table	2342	kg	
	O	Actual cycle time	34	sec	
	I	Production capacity losses downtime = [1-H/G] x L	53.46	min	Lubricant application
	K1	Number of minor stoppage	3	No.	

	K2	Average duration of minor stoppage	20	min	
	K3	Idle time	50	min	right of way problem & tea break
QR(%) = (S-T)/S =89.6%	K	Minor stoppage/Idle losses = [K1*K2+K3]	110	min	
	L	Net Operating Time = [E-K]	355	min	
	M	Performing Time = [L-I]	301.54	min	
	N	Valuable operating time = [M-J]	261.54	min	
	P	Net operating rate = 100*[H*O]/E	77	%	
	Q	Ideal/theoretical/design cycle time	27	sec	
	R	Operating speed coefficient = [Q/O]	0.79		
	J	Time spent for rework and start up yield losses	40	min	
	S	Total executed amount(Unit)	471	m3/hr	
	T	Reworked amount (unit)	49	m3/hr	failure to meet specification
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.50					

C-4: OEE Index for Excavator on Gofa Mazoria – Babur Tabia road project

Data Collection Template Machinery type Excavator Mark; CAT Model: 318CL Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Excavator productivity on Gofa Mazoria - Babur Tabia Road project					
Type of Activity – Excavation					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 87%	A	Available time (10hrs. * 60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	30	min	Mechanical problem
	D2	Time spent for change in operation condition	40	min	
	D	Major stoppage losses = (D1 + D2)	70	min	
	E	Operating time = C – D	470	min	
	G	Ideal production (from manufacturer specification)	79	m3/hr	
	H	Actual production	34.83	m3/hr	
PR(%) = P*R = 37.1%		Applicable correction factors			
		Job efficiency	40	min/hr	
		Heaped bucket capacity	0.45	m3	
		Material type - rock earth mixture			
		Bucket fill factor	1		
		height of swing factor			
		swell factor	0.83		

	O	Actual cycle time	35	sec	
	I	Production capacity losses downtime = [1-H/G] x L	173.33	min	
	K1	Number of minor stoppage	4	min	to change position
	K2	Average duration of minor stoppage	20	min	
	K3	Idle time	80	min	shortage of material
QR(%) = (S-T)/S= 90.5%	K	Minor stoppage/Idle losses = [K1*K2+K3]	160	min	
	L	Net Operating Time = [E-K]	310	min	
	M	Performing Time = [L-I]	136.67	min	
	N	Valuable operating time = [M-J]	116.67	min	
	P	Net operating rate = 100*[H*O]/E	75.7	%	
	Q	Ideal/theoretical/design cycle time	17	sec	
	R	Operating speed coefficient = [Q/O]	0.49		
	J	Time spent for rework and start up yield losses	20	min	
	S	Total executed amount(Unit)	632	m3	
	T	Reworked amount (unit)	60	m3	Not fullfill specification
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.292					

C-5: OEE Index for Motor Grader on Gofa Mazoria – Babur Tabia road project

Data Collection Template Machinery type Grader Mark; CAT Model: 140H Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Motor grader productivity in AACRA (Gofa Mazoria - Babur Tabia) Road project					
Type of Activity -					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
	A	Available time(10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	20	min	Batery change
AR(%) = (E/C)= 88.9%	D2	Time spent for change in operation condition	40	min	
	D	Major stoppage losses = (D1 + D2)	60	min	
	E	Operating time = C – D	480	min	
	G	Ideal production (from manufacturer specification)	6792	m2/hr	
	H	Actual production	5433.6	m2/hr	
		Applicable correction factors			
		Blade length(L) including overlap	3.96	m	
		Width per trip(B) = L*cos A	3.43	m	
PR(%) = P*R = 0.46		Tilting angle of the blade	30		
		Lift thickness after compaction	0.25	m	
		Average speed corrospond to the work type	2.4	km/hr	
		Cycle time(T) = 0.06∑p/v	1	min	

		operator efficiency	0.8		
	O	Actual cycle time	4	min	
	I	Production capacity losses downtime = [1-H/G] x L	60	min	
	K1	Number of minor stoppage	4		third person communication
	K2	Average duration of minor stoppage	15	min	and tea break
	K3	Idle time	120	min	Material shortage
QR(%) = (S-T)/S =98.6%	K	Minor stoppage/Idle losses = [K1*K2+K3]	180	min	
	L	Net Operating Time = [E-K]	300	min	
	M	Performing Time = [L-I]	240	min	
	N	Valuable operating time = [M-J]	232	min	
	P	Net operating rate = 100*[H*O]/E	75.8	min	
	Q	Ideal/theoretical/design cycle time	2.45	min	
	R	Operating speed coefficient = [Q/O]	0.61		
	J	Time spent for rework and start up yield losses	8	min	
	S	Total executed amount(Unit)	54336	m2	
	T	Reworked amount (unit)	750	m2	Low quality work
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.40					

C-6: OEE Index for Excavator on Shiromeda - Kidanemihret road project

Data Collection Template Machinery type Excavator Mark; CAT Model: M318C Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] on Shiromeda Kidane Mihret road project					
Type of Activity – Excavation					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 90.7%	A	Available time (10hrs. * 60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	20	min	Tire change
	D2	Time spent for change in operation condition	30	min	
	D	Major stoppage losses = (D1 + D2)	50	min	
	E	Operating time = C – D	490	min	
	G	Ideal production (from manufacturer specification)	64.5	m3/hr	
	H	Actual production	28.35	m3/hr	
PR(%) = P*R = 43%		Applicable correction factors			
		Job efficiency	45	min/hr	
		Heaped bucket capacity	0.35	m3	
		Material type - rock earth mixture			
		Bucket fill factor	1.05		
		height of swing factor			
		swell factor	0.83		

	O	Actual cycle time	35	sec	
	I	Production capacity losses downtime = [1-H/G] x L	212.98	min	
	K1	Number of minor stoppage	2	min	to change position
	K2	Average duration of minor stoppage	15	min	
	K3	Idle time	80	min	shortage of material
QR(%) = (S-T)/S= 95.65%	K	Minor stoppage/Idle losses = [K1*K2+K3]	110	min	
	L	Net Operating Time = [E-K]	380	min	
	M	Performing Time = [L-I]	167.02	min	
	N	Valuable operating time = [M-J]	147.02	min	
	P	Net operating rate = 100*[H*O]/E	88	%	
	Q	Ideal/theoretical/design cycle time	17	sec	
	R	Operating speed coefficient = [Q/O]	0.49		
	J	Time spent for rework and start up yield losses	20	min	
	S	Total executed amount(Unit)	920	m3	
	T	Reworked amount (unit)	40	m3	Not fullfill specification
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.373					

C-7: OEE Index for Motor Grader on Shiromeda - Kidanemihret road project

Data Collection Template Machinery type Grader Mark; CAT Model: 160H Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Motor grader productivity on shiromeda - kidane mihret road project.) Road project					
Type of Activity - Base coarse spreading					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C)= 92.6%	A	Available time(10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch break
	C	Loading time = A – B	540	min	
	D1	Recorded break down time	20	min	Batery problem
	D2	Time spent for change in operation condition	20	min	
	D	Major stoppage losses = (D1 + D2)	40	min	
	E	Operating time = C – D	500	min	
	G	Ideal production (from manufacturer specification)	7905	m2/hr	
	H	Actual production	4991	m2/hr	
PR(%) = P*R = 43.1%		Applicable correction factors			
		Blade length(L) including overlap	4.27	m	
		Width per trip(B) = L*cos A	3.7	m	
		Tilting angle of the blade	30		
		Lift thickness after compaction	0.2	m	
		Average speed corrospond to the work type	2.3	km/hr	
		Cycle time(T) = 0.06∑p/v	1	min	

		operator efficiency	0.7		
	O	Actual cycle time	5	Min	
	I	Production capacity losses downtime = [1-H/G] x L	129.02	Min	
	K1	Number of minor stoppage	3		third person communication
	K2	Average duration of minor stoppage	10	Min	and tea break
	K3	Idle time	120	Min	Material shortage
QR(%) = (S-T)/S =98.7%	K	Minor stoppage/Idle losses = [K1*K2+K3]	150	Min	
	L	Net Operating Time = [E-K]	350	Min	
	M	Performing Time = [L-I]	220.98	Min	
	N	Valuable operating time = [M-J]	205.98	Min	
	P	Net operating rate = 100*[H*O]/E	88	%	
	Q	Ideal/theoretical/design cycle time	2.45	Min	
	R	Operating speed coefficient = [Q/O]	0.49		
	J	Time spent for rework and start up yield losses	15	Min	
	S	Total executed amount(Unit)	49910	m2	
	T	Reworked amount (unit)	650	m2	poor workmanship
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.394					

C-8: OEE Index for Loader on Shiromeda - Kidanemihret road project

Data Collection Template Machinery type Loader Mark; CAT Model: 268B Average of Five Days with 10 working hour per day [Construction equipment with Cyclic Operating Machines] Loader productivity rate on shiromeda - kidanemariam road project					
Type of Activity -					
Productivity Rate(Dependent variables)	Symbol	Independent variables	Values	unit	Contributing factors
AR(%) = (E/C) = 89.2%	A	Available time (10*60')	600	min	
	B	Scheduled maintenance + scheduled production break	90	min	Oil check, Lubrication Lunch break
	C	Loading time = A – B	510	min	
	D1	Recorded break down time	10		bucket teeth damage
	D2	Time spent for change in operation condition	45	min	
	D	Major stoppage losses = (D1 + D2)	55	min	
	E	Operating time = C – D	455	min	
	G	Ideal production (from manufacturer specification)	371.7	m3/hr	
	H	Actual production	239.35	m3/hr	
PR(%) = P*R = 72.2%		Job efficiency	50	min	
		heaped Bucket capacity	3	m3	
		Material type – aggregate			
		Bucket fill factor	0.85		
		swell factor- from table			

		Static tipping load - from table	2342	kg	
	O	Actual cycle time	33	sec	
	I	Production capacity losses downtime = [1-H/G] x L	124.62	min	Lubricant application
	K1	Number of minor stoppage	3	No.	
	K2	Average duration of minor stoppage	15	min	
	K3	Idle time	60	min	right of way problem & tea break
QR(%) = (S-T)/S =97.1%	K	Minor stoppage/Idle losses = [K1*K2+K3]	105	min	
	L	Net Operating Time = [E-K]	350	min	
	M	Performing Time = [L-I]	225.38	min	
	N	Valuable operating time = [M-J]	185.38	min	
	P	Net operating rate = 100*[H*O]/E	88	%	
	Q	Ideal/theoretical/design cycle time	27	sec	
	R	Operating speed coefficient = [Q/O]	0.82		
	J	Time spent for rework and start up yield losses	40	min	
	S	Total executed amount(Unit)	1914.8	m3/hr	
	T	Reworked amount (unit)	55	m3/hr	failure to meet specification
Overall Equipment Effectiveness index (OEE) = AR*PR*QR = 0.62					