Adama Science and Technology University

School Of Civil Engineering and Architecture

Construction Technology and Management Program

ASSESSMENT OF CONSTRUCTION EQUIPMENTS PRODUCTIVITY ON UPGRADED CONCRETE ASPHALT ROAD PROJECTS: A CASE STUDY IN ADDIS ABABA.

By

Tewodros Demissie Kibret

March 2017

Adama,Ethiopia

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Management)

By :- Tewodros Demissie Advisor:- Girmay Kahssay (Dr. Ing.)

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Approved By Board of Examiners

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DECLARATION

I declare that this thesis entitled "ASSESSMENT OF CONSTRUCTION EQUIPMENTS PRODUCTIVITY ON UPGRADED CONCRETE ASPHALT ROAD PROJECTS: A CASE STUDY IN ADDIS ABABA**.**" is my original work. This thesis has not been presented for any other university and is not concurrently submitted in candidature of any other degree, and that all sources of material used for the thesis have been duly acknowledged.

Candidate:

Name: ________________________

Signature: _____________________

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LIST OF ABBREVIATIONS

AR - Availability Rate

PR - Performance Rate

QR - Quality Rate

OEE - Overall Equipment Efficiency

Wt – Weight

AC – Asphalt Concrete

AACRA- Addis Ababa City Roads Authority

PM- Project Managers

SE- Site Engineers

OP- Operators

H_O- Null Hypothesis

HA- Alternative Hypothesis

MS- mean score

WA MS- Weighted average means score

MF – Management Factor

WF- Work Factor

EF- Equipment Factor

HF- Human Factor

ABSTRACT

In Concrete Asphalt Road Projects, Heavy duty construction equipments are very important factors for successful construction implementation. Generally, the construction industry is looking for the most acceptable equipment productivity base line for different project types. Because the construction industry has been on progress through time, the productivity of equipments should also be revised so as to minimize loss of productivity which is dependent on different working conditions. Being so, assessing the productivity of the equipment in an upgraded concrete asphalt road project was a matter of achieving a better equipment productivity base line in general in Town section and in particular in the study area on roads in Addis Ababa. The objective of this research was to assess the actual productivity of heavy duty equipments in the selected upgraded concrete asphalt road projects, to identify factors affecting construction productivity and to understand about all the problems occurring in the project because of improper utilization of equipments and to put a better recommendation. Therefore a case study and questionnaire survey were used to diagnose and evaluate the utilization process involved in the equipment management. In construction project operation, often there is a project cost variance in terms of the, equipments, material, manpower, subcontractor, overhead cost, and general conditions. Equipment is the main component in construction projects. If the equipment's productivity is not properly managed it will create a project cost variance. Project cost can be controlled by taking corrective actions towards the cost variance. Therefore, it is crucial that the equipment productivity on upgraded concrete asphalt road projects in town section should be assessed in order not to face loss of productivity which leads to increase in cost of the project.

Key Words: - Asphalt Concrete, Heavy duty construction equipment, Equipment productivity

Chapter One

1. Introduction

1.1. Background

Heavy equipment is a very important factor for successful construction implementation. Construction Equipment of whatever type, may be heavy or Simple, cheap or expensive, is liable to breakdown/failure when they are used continuously to perform construction activities or when they are used without repair or preventive maintenance for a long time. Beside, construction equipment may not available for work as scheduled due to various factors. (Jose, 2001)

Construction heavy duty equipment is of extreme importance in earth moving operations. This equipment facilitates the transportation of soil from point of cutting to the point where it will be used as fill or to the point where it will be wasted or stockpiled. Moving materials and leveling the ground to meet the needs of the owner are the primary functions of heavy equipment. The productivity of this modern equipment has increased with the increase in sophistication and modernization allowing the cost of the operations to remain relatively stable. Inefficiencies and loss of productive time can result in increases in cost because of high cost associated with such equipment. (Nunally, 1997)

In order to make a profit in any earth moving operation it is important to plan the operation, select the appropriate equipment and use the equipments efficiently in order to obtain the maximum productivity. Maximizing productivity is one of the construction project management personnel's primary objectives, but can also be one of their greatest challenges. The need for effective productivity planning is obvious since productivity ultimately translates into profit. (Jose, 2001)

Equipment productivity is a relative measure of equipment efficiency, either good or bad, when compared to an established base line as determined from an area of great experience. In Concrete Asphalt Road Projects, Heavy duty construction equipments for the earth work and asphalt work have been utilized.

According to (Abebaw, 2014), as construction is a risky business and requires substantial amount of money for its work accomplishment, increasing the productivity of heavy-duty construction equipment will play a role to minimize problem in money transaction. Moreover, increasing machine productivity is very crucial for successful project management. Therefore, knowing the impact and the extent of loss of construction equipment productivity will safeguard the contractors and the client of the projects from time and cost overrun resulted from poor overall performance of the construction equipment. With this perspective, the primary benefit of such study is to provide additional scientific knowledge and tools that enables the stakeholders to quantify loss of construction equipment productivity and to detect area of improvement. Hence, it promotes the success of the client by producing good quality of work through proper utilization of the existing machines with appropriate time and cost.

Therefore, the estimation of equipment cost is a critical job in the construction planning phase. A formula for production rates has been used to estimate construction equipment capability per hour and cost. By doing proper production rate estimates and making improvements achieve high cost savings with minimal effort. According to (Dozzi and Abourizk, 1993), productivity improvement in construction is best understood when the construction process is visualized as a complete system. Control of the system is achieved by collecting and processing information about the rates at which production is attained. If the actual productivity doesn't compare favorably with the estimated values, the input categories affecting productivity in the system-namely material timeliness, labour effectiveness and management practices – need to be examined. According to (Michael, 1988), an accurate measurement of productivity gives the owner or contractor the confidence and ability to plan, organize, and control the manpower and resources available. Without an accurate measurement of productivity the owner or contractor could easily flounder in their attempt to control the construction contract.

Moreover, stakeholders of the construction industry have to know the extent of their construction equipment productivity, associated losses during the production, factors contributing to the equipment productivity loss and its impact on the project performance. (Abebaw, 2014)

According to (Abebaw, 2014), maximizing heavy-duty construction equipment productivity in relation to contractor's perception, productivity loss and associated cost and the technical conditions in machine management have been analyzed and recommended.

But it is opened for future study to assess about equipment productivity in relation to other factors. Being so, there had been a lack of research in our country in respect of assessment of equipment productivity in relation to working site condition. In this study, assessing the actual productivity of machineries mainly involved in upgrading concrete asphalt road projects in town section and recommending better way of enhancing the productivity were carried out so as to fill the gap.

1.2. Statement of the Problem

Identifying key factors that bring cost variance due to deviation between the actual productivity and the standard performance of heavy-duty construction equipment was the concern of this study. Because equipments productivity in relation to the working area condition has not been assessed, the productivity of equipments in the Addis Ababa City was measured, compared and factors that cause difference was identified as a typical model for upgraded asphalt concrete road projects in cities. This was therefore to identify key factors that are leading to equipment productivity loss using work-study method helps to take corrective actions towards the cost variance.

1.3. The Research Questions/Expected Findings

This study addressed the following research questions:

- What is the level of the actual equipment productivity on the upgraded asphalt road projects in Addis Ababa?
- How much is the difference of the actual productivity from the standards?
- What are the factors that cause the difference from the standards?
- What corrective actions should be taken to reduce the equipment productivity loss?

1.4. The Purpose of the study

The purpose of this research was to know the extent of the deviation of the actual equipment productivity from the standard performance and to identify the key factors that cause the gap so as to minimize the loss due to the performance gap by taking corrective actions.

1.5. Objectives

1.5.1 General Objective

Assessment of the current situation of construction equipment productivity on upgraded concrete asphalt road projects in Addis Ababa.

1.5.2 Specific Objectives

1. To measure the current actual productivity of heavy-duty construction equipment
2. To compare the actual with the standard performance of the construction equipment productivity based on performance charts
3. To identify the key problems that causes the deviation
4. To recommend corrective actions for improving the performance of the equipment

1.6. Significance of the Study

In construction project operation, Equipment is the main component in construction projects. Because of poor management and different factors, often there is a project cost variance in terms of equipment utilization. If the equipment's productivity is not properly managed it will create a project cost variance. Therefore, it is crucial that the equipment productivity on upgraded concrete asphalt road projects in town section should be assessed in order not to face loss of productivity which leads to increase in cost of the project. Therefore, knowing the consequence and the extent of the loss will benefit more contractors to be more competitive by estimating their equipment performance considering actual parameters of the equipment and working site condition and ultimately improve the operation and make a profit through the successful completion of the project in cost and in time and the Client has got a better engineering estimate before offer and has also a benefit to finalize the project without additional cost and time.

1.7. The Scope of the Study

1. This study mainly focused on assessment of the new and the model heavy-duty construction equipment productivity that are highly involved on upgrading Concrete Asphalt Road Projects in Town Section namely, Asphalt Paver, motor- grader, Loader, excavator and Dump Trucks on the selected Projects.

2. The assessment of the productivity rate for other construction equipment like Dozer that are not mostly used in upgrading asphalt project and Rollers that have less effective operational hour was not covered in this study.
3. All charts, graphs, tables or standard values incorporated in the determination of the design/ideal production rates were referred from manufacturer's technical specification corresponding to each particular mark and models of the construction equipment.
4. The case study for the actual measurement of productivity for each equipment type and similar model were carried out on three selected projects from the active ongoing upgraded concrete asphalt road projects. The questionnaire survey will be focused on the all active ongoing projects.
5. Because of the Design change on Mexico Round About- Amistegna Polis Tabiya Road Project, the Asphalt paving work was postponed at the time of the study. Being so, the OEE index for the Asphalt Paver was not carried out.

1.8. The operational Definitions

Standby time: The time when a given construction equipment is able to do work, but no work is available

Non-Productive time: the time in which a given construction equipment is not capable of doing any activities. This is may be the case of accessory breakdown, doing unnecessary or non-value adding activities.

Production time: The total scheduled time for the production.

Non-scheduled time: the time when the construction equipment not scheduled to perform a certain activities.

Operation time: the total available time minus non- scheduled time

Downtime is the time when the construction equipment is not in a working condition for its intended function or equipment not available for work due to repair or mechanical adjustment. "It does not include any portion of non-schedule time".

Planned down time: "during the available time, equipment may not be operating for a number of reasons; planned breaks in production schedule, planned maintenance, precautionary resting time, lack of works and others"

Active Time/Loading Time is the time when the construction equipment is actually available for work. That is available time minus planned downtime.

Net operating time: is the time during which the equipment operates under stable condition

Performance time is the time during which construction equipment operates under stable conditions at its design speed or capacity.

Valuable operating time is time during which equipment actually operates, under stable Conditions, at optimal speed, and producing acceptable out puts.

Productivity state is the state at which the equipment is performing its intended function.

Theoretical production time is the time that theoretically scheduled to complete the intended activities.

Job efficiency: the actual number on minutes worked by the machines during an hour

Availability Rate is the ratio of the Operating time with the planned production time or the active time actually available for the work.

Performance rate is the ratio of the net operating time within the total available run time or operating time.

Quality Rate is the ratio of the difference between the total executed amount and the rework amount to the total executed amount.

Overall Equipment Effectiveness is a measure of value added to the production by a certain machine in a production time.

Chapter Two

2. Literature Review

2.1. Heavy Duty Construction Equipments

Heavy duty construction equipments are very important factors for successful construction implementation. Heavy duty construction equipments for the earth work and asphalt work have been utilized.

Earth moving Operations are part of almost every construction job. They are needed for leveling the surface by cutting or filling, in order to shape the ground to serve the needs of the parties involved in the project. In most projects earth moving operations constitute a large portion of the project. Construction equipment assists in moving materials from one point to another. The price of most of this heavy equipment is considerable, thus the purchase of any construction equipment constitutes a particularly large investment. The purpose of being in the construction industry is to make a profit in every job. Construction Managers need to plan the operation and select the most appropriate equipment in order to maximize productivity. Maximization of productivity is the goal of every construction manager. In order to make profit in any earth moving operation it is important to plan the operation, select the appropriate equipment and use the equipment efficiently in order to obtain the maximum productivity. The need for effective productivity ultimately translates into profit. (Jose, 2001)

Construction heavy equipment is of extreme importance in earth moving operations. This equipment facilitates the transportation of soil from point of cutting to the point where it will be wasted or stockpiled. Moving materials and leveling the ground to meet the needs of the owner are the primary functions of the heavy equipment. The productivity of this modern equipment has increased with the increase in sophistication and modernization, thus allowing the cost of the operations to remain relatively stable. Inefficiencies and loss of productive time can result in increases in cost, because of the high cost associated with such equipment. (Nunally, 1977)

2.2. Measuring and Estimating of Equipments productivity

2.2.1. Definition of Productivity.

There are many definitions used to define productivity. The term productivity is generally used to denote a relationship between output and the associated inputs used in the production process. The simplest definition of productivity is the ratio of outputs of goods or services to inputs of resources. The common expression of productivity is shown as follows:

PRODUCTIVITY = OUTPUT/INPUT (Michael, 1988)

It is important to specify the input and output to be measured when comparing productivities. Efficiency is simply the ratio of actual productivity divided by the estimated productivity. The main use of efficiency is in comparing productivities of different factors or of the same factors at different times. This ratio allows the project manager to compare the estimated productivity with the actual productivity. (Michael, 1988)

2.2.2. Equipment Productivity

Once the equipment needs for an activity have been identified, the next step is to conduct an equipment productivity analysis to select the optimum size. The objective is to determine the number of units and the size of equipment that would permit the constructor to accomplish the activity with a duration resulting in the lowest cost. (Tom and Sanjiv, 2003)

Understanding the performance of heavy equipment is the key to adequate planning. Tools to estimate equipment performance could enable more contractors to be more competitive by estimating their equipment performance considering actual parameters of the machine and field and ultimately improve the operation and make a profit through the successful completion of the project. (Jose, 2001)

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 grader, loader, paver, excavator and Dump Trucks) for different activities.

In upgrading concrete Asphalt Road Projects especially in Cities, the above mentioned heavy duty construction equipments are highly engaged. The following sections review these equipments productivity in detail.

2.2.2.1. Dump Truck Productivity

According to Peurifoy (2006), the productivity of a truck depends on the size of its load and the number of trip it can make in a unit of time.

The number of trips completed per hour is a function of cycle time. Truck cycle time has four components: (1) load time, (2) haul time, (3) dump time, and (4) return time. Examining a match between truck cargo body size and excavator bucket size yields the size of the load and load time.

The haul and return cycle times will depend on the weight of the truck, the horsepower of the engine, the haul and return distances, and the condition of the roads traversed.

A practical rule of thumb frequently used in selecting the size of the trucks is to use trucks with the capacity of four to five times the capacity of the excavator bucket. The following is the format that can be used to calculate truck production.

Number of Bucket Loads

The first step in analyzing truck production is to determine the number of excavator bucket loads it takes to load the truck.

Balanced number of bucket loads= Truck Capacity (lcy)/Bucket capacity (lcy)

Load Time and Truckload Volume

The actual number of bucket loads placed on the truck must be an integer number. It is possible to not completely fill the bucket (light load)to match the bucket volume to the truck volume, but the practice is usually inefficient as it results in wasted loading time.

Next Lower Integer For the case where the number of bucket loads is rounded down to an integer lower than the balance number of loads or reduced because of job conditions:

Load Time= Number of bucket loads x Bucket cycle time

Truck Load (volumetric) $_{LI}$ = Number of bucket loads x Bucket Volume

Next Higher Integer, Load time = Number of bucket loads x Bucket cycle time

Truck load (volumetric) $_{HI}$ = Truck volumetric capacity

Gravimetric Check Always check the load weight against the gravimetric capacity of the truck, Truck load (Gravimetric) = Volumetric load (lcy) x Unit weight (loose vol. lb/icy)

Truckload (gravimetric) < Rated gravimetric payload?

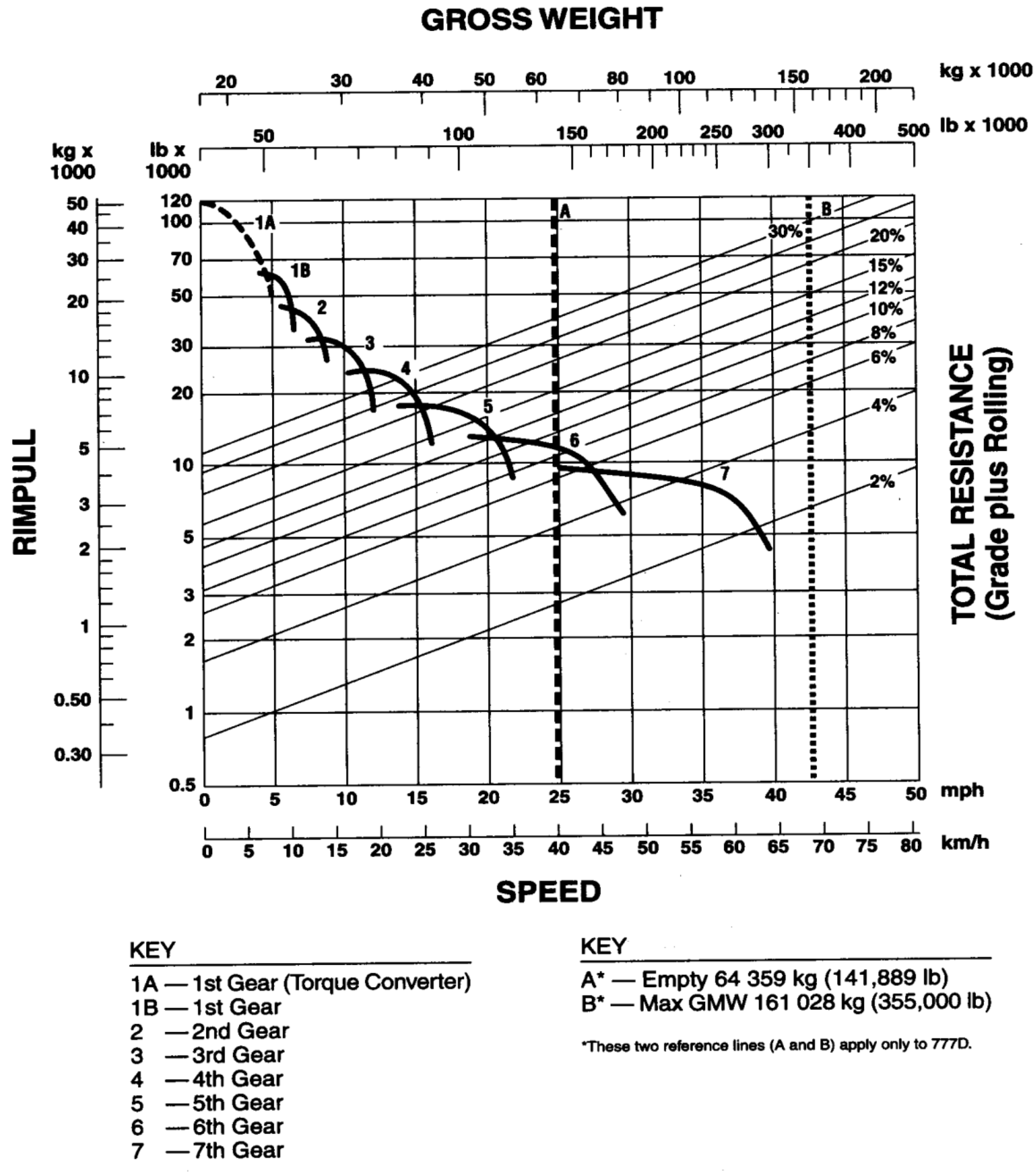

Figure 2.1 Performance Chart for Dumping Truck

Source: Caterpillar performance handbook (2012)

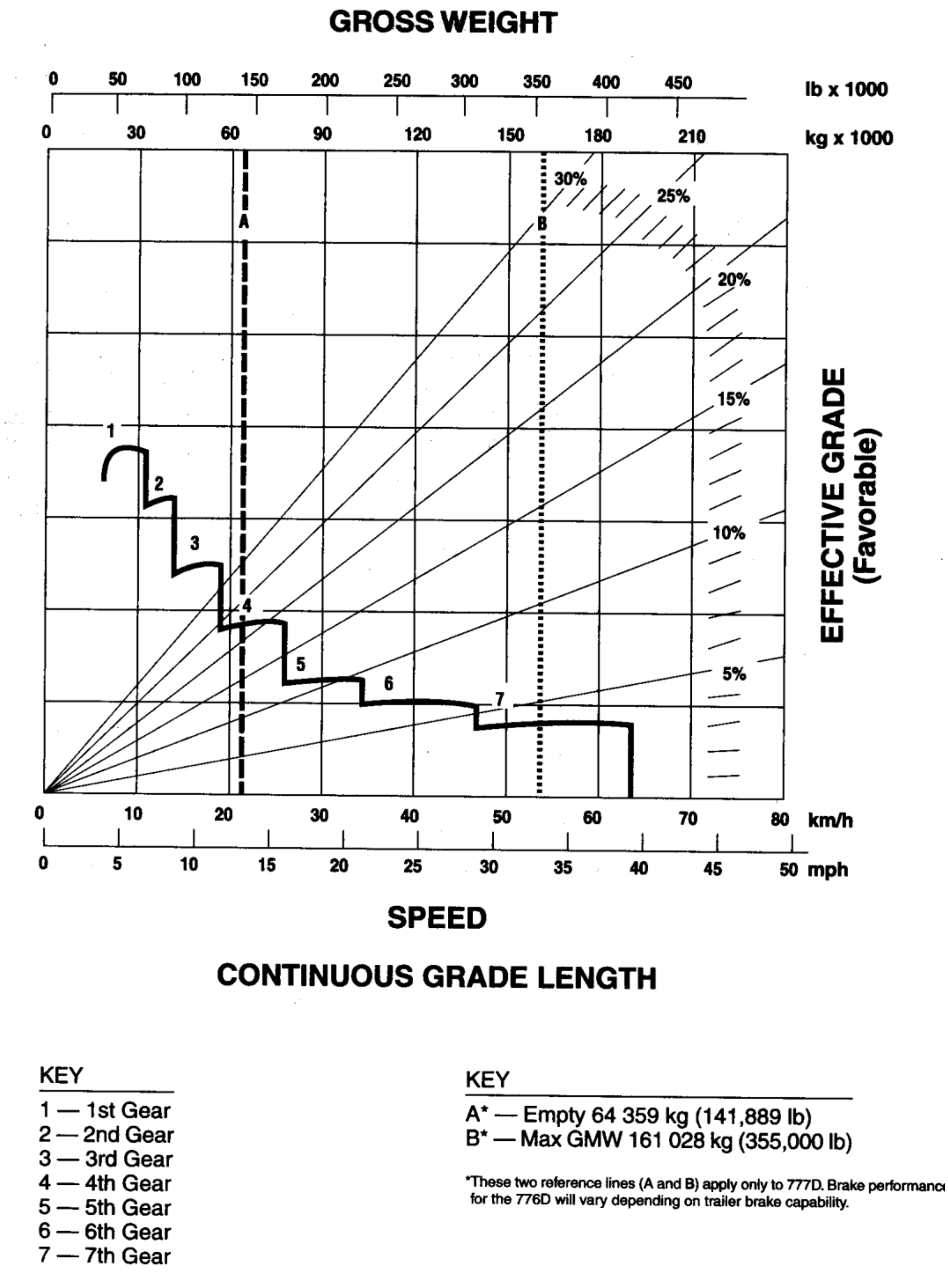

Figure 2.2 Retarder Curve for Dumping Truck

Source: Caterpillar performance handbook (2012)

Haul Time

Hauling should be at the highest safe speed and in the proper gear. To increase efficiency, use one way traffic patterns.

Haul time (min) = Haul distance (ft)/(88fpm/mph x Haul speed(mph))

Based on the gross weight of the truck with load, and considering the rolling and grade resistance from the loading area to the dump point, haul travel speeds can be estimated using the truck manufacturer's performance chart (see fig 2.1)

The truck's performance chart should be used to determine the maximum speed for each section of the haul road having a significant difference in grade or rolling resistance.

While a performance chart indicates the maximum speed at which a vehicle can travel, the vehicle will not necessarily travel at this speed. A performance chart makes no allowance for acceleration or deceleration. Additionally, other travel route conditions and safety can control travel speed. Before using a performance chart speed in an analysis, always consider such factors as congestion, narrow haul roads, or traffic signals when hauling on public roads, because these can limit the speed to less than the value given in the chart. The anticipated effective speed is what should be used in calculating the travel time.

Return Time

Based on the empty vehicle weight, and the rolling and grade resistance from the dump point to the loading area, return travel speeds can be estimated using the truck manufacturer's performance chart.

Return time (min)= Return distance(ft)/(88fpm/mph) x Haul speed(mph))

Dump Time

Dump time will depend on the type of hauling unit and congestion in the dump area. Consider that the dumping area is usually crowded with support equipment. Rear-dumps must be spotted before dumping.

This usually means that the truck must come to a complete stop and then back up some distance. Total dumping time in such cases can exceed 2 min. Bottom-dumps will customarily dump while moving. After dumping, the truck normally turns and returns to the loading area. Under favorable conditions, a rear-dump can dump and turn in 0.7 min but an average unfavorable time is about 1.5 min. Bottom-dumps can dump in 0.3 min under favorable conditions, but they too may average 1.5 min when conditions are unfavorable. Always try to visualize the conditions in the dump area when estimating dump time.

Truck Cycle Time

The cycle time of a truck is the sum of the load time, the haul time, the dump time, and the return time:

Truck cycle time = Load time + Haul time + Dump time + Return time

Number of Trucks Required

The nubmer of trucks required to keep the loading equipment working at capacity is

Balanced number of trucks = Truck cycle time(min)/Excavator cycle time(min)

Production

The number of trucks must be an integer number.

Integer lower than Balance Number If an integer number of trucks lower than the result is chosen, then the trucks will control the production.

Production(lcy/hr) = Truck load(lcy) x Number of Trucks x (60 min/Truck cycle time(min))

Integer Greater than Balance Number When an integer number of trucks greater than the result is selected, production is controlled by the loading equipment.

Production(lcy/hr) = Truck load(lcy) x (60 min/Excavator cycle time(min))

Effeciency

Driver efficiency increases as haul distances increase out to about 8000 ft,after which efficiency remains constant. Other critical elements affecting efficiency are bunching and equipment condition.

Adjusted production = Production x Working time(min/hr)/60min

2.2.2.2. Excavator Productivity

Excavators are a common and versatile type of heavy construction equipment. As in the project, excavators are used to accomplish many activities, such as lifting objects, excavating for trenches and mass excavation, loading trucks and scrapers, and digging out stumps and other buried objects.

The production of an excavator is a function of the digging cycle, which can be divided into the following segments:

1. Time required loading the bucket
2. Time required swinging with a loaded bucket
3. Time to dump the bucket
4. Time to swing with an empty bucket

This cycle time depends on machine size and job conditions. For example, a small excavator can usually cycle faster than a large one, but it will handle fewer payloads per cycle. As the job conditions become more severe, the excavator will slow. As the soil gets harder and as the trench gets deeper, it takes longer to fill the bucket. (Tom and Sanjiv, 2003)

Digging depth is the other factor considered in estimating excavator production. The optimum depth of cut is mainly depending on the type of material excavated and the type and bucket size.

"As a rule, the optimum depth of cut for a hoe is usually in the range of 30-60% of the machines maximum digging depth" (Peurifoy, 2006) and its production rate is given by:

Production rate=

$$= \frac{3600sec*Heaped\ bucket\ capacity(Lm3)*fill\ factor}{Cycle\ time\ (sec)}*\frac{Efficiency(min/hr)}{60min/hr}*\frac{1}{volume\ correction}$$

Volume correction for loose volume to bank volume = 1/(1+swell factor)

For loose volumes of tons = Loose unit weight, lb/ (2000lb/ton)

To perform this calculation, the following data are required and it is necessary to refer standard bucket fill factor (based on the type of machine and class of material being excavated) from standard tables and total cycle time (loading, swing, dump and swing empty) was noted out in the site.

In calculating the ideal production rate of excavator, it is also necessary to consider the manufacturer specification for bucket capacity/Heaped bucket capacity and a 60 min job efficiency factor.

2.2.2.3. Wheel Loader Productivity

Loader is versatile construction equipment used extensively in construction work to excavate earth, handling and transporting a bulk material to load the transportation truck, and for back filling purpose. The maximum production rate using wheel loader obtained when it is working on a flat surface that gives sufficient space to manipulate it properly. This is because wheel loader works repetitive cycle in loading, turning, and dumping (Peurifoy, 2006). According to Gashaw (2009), the following formula helps to compute loader production rate.

The Production of a loader can be estimated by:

$Q_o= V_L*60*f_F*f_L/T_c$

Where

V_L= bucket capacity in Bm3 per hour, f_F= Bucket fill factor, f_L=load factor, T_c= cycle time

$$T_c = t_l + t_{sl} + t_{hl} + t_d + t_{he} + t_{se}$$

Where: t_l = Load time , t_d = dump, t_{sl} = Swing loaded , t_{he} = haul empty (optional) , t_{hl} = haul loaded (optional) , t_{se} = swing empty

The actual productivity Qa can be computed by giving due consideration to the different affecting parameters as follows.

$Q_a = Q_o * f_N * f_Z$, Where: Q_o = theoretical productivity as given above in Bm3/hour

Q_a = Actual productivity in Bm3/hour

f_N = Factor to take care of:

Operators' effectiveness

Table 2.1 Factor to take care of Operators effectiveness

Qualification and motivation of operator	very good	Good	average	Bad
Human factor	1.0	0.9	0.7	0.5

Source: Gashaw (2009) In Fundamentals of Earth Moving Equipment

Machine influence (condition and appropriateness)

Table 2.2 Factor to take care of Machine Influence

Condition and appropriateness of machine	very good	good	average	bad
Machine factor	1.0	0.9	0.75	0.6

Source: Gashaw (2009) In Fundamentals of Earth Moving Equipment

Management conditions

Table 2.3 Factor to take care of Management Conditions

Management conditions	very good	good	average	bad
Construction site factor	0.85	0.75	0.65	0.55

Source: Gashaw (2009) In Fundamentals of Earth Moving Equipment

f_Z = time factor to take care of the length of operation

Table 2.4 Factor to take care of the Length of Operation

Length of operation	An hour	A week	A month	A year
Human factor	0.95	0.8	0.75	0.7

Source: Gashaw (2009) In Fundamentals of Earth Moving Equipment

To perform this calculation, bucket fill factor and fixed cycle time data are required from Caterpillar performance handbook (2012)

2.2.2.4. Motor Grader Productivity

Grader is multi-purpose construction equipment used for finishing, shaping, grading or grade-leveling, spreading, side cutting and earth trimming, ditching and backfilling/back sloping. Since grader has many applications, the calculation of production rate of a motor grader is somewhat complicated. However, case-by-case computation is possible (Gashaw, 2009). The average actual productivity of motor grader by leveling and spreading is:

Q a (m2/h) = S x (Le - Lo) x 1000 x E (caterpillar performance handbook, 2012)

Where: Qa: Hourly operating area (m2/h), S: Operating speed (km/h) Lo: Width of overlap (m), Le: Effective blade length (m) E: Job efficiency

Alternatively, it is possible to use this relation:

Q a = B * L* f N* f z * 60/T [m2/ h] (Gashaw, 2009), B = l * Cos A

For this Computation the following data are required: the width per trip (B) with due consideration of overlapping, length of the blade(l), Angle of the blade(A) with respect to the axis, lift thickness after compaction(L), factor to taker of site conditions, operator effectiveness (f_N) , the time factor (f_Z) and cycle time(T) = 0.06∑P/V [min/meter]. If the blade is parallel to the axis, A = zero and cosine of A = one and P = number of pass and V= forward and backward average speed in Km/h.

Note: “the width of overlap is generally 0.6m” (caterpillar performance handbook, 2012)

The following tables have all parameters required for the calculation.

Table 2.5: Angle of Response

Type of earth or operations	Angle A in degrees
Normal	30
Hard earth	45
Loose and light material	20
Scarify, mix and spreading across	30 - 50
Fine leveling, and spreading along	0 - 30

Source: Caterpillar performance hand book (2012)

2.2.2.5. Paver production

According to peurifoy 2006, continuous paving operation depends on balancing the paver production with plant production. The critical shock points in the operation, which must be analyzed and managed, are loading of haul units at the plant and the haul unit- paver link.

Product demand per paving length (m3/m)= thickness(cm)x width(m)/100

Wt. of AC per paving length = Product demand per length x Unit weight of AC

Average paver speed = Average plant production (ton/min)/(Weight of AC (ton/m))

Adjusted truck capacity per truck = Truck capacity per truck x (60min/hr)/total haul cycle time (min)

$$\text{Number of truck required per paver} = \frac{\text{Average plant production(ton/hr)}}{\text{Adjusted truck capacity per truck}}$$

2.3. How to evaluate the performance of an equipment

In order to evaluate the performance of equipment, overall equipment effectiveness index can be used. According to Pintelon et al., 2006, 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.

OEE= valuable operating time/(active time)*100= **AR x PR x QR** ,where AR= Availability Rate, PR= Performance Rate and QR = Quality Rate.

Loading Time /Active time = Available time - Planned Downtime

Operating Time = Loading Time - Inactivity losses(break down & setup losses)

Net Operating Time = Operating time- Idle minor stoppage

Performing Time= Net operating time - Production capacity loss

Valuable Operating Time (Time during which effective output are produced)

Performing time- Rework and Start up yield losses =Valuable operating time

Availability Rate = Operating time*100/Loading time

Performance Rate = Net Operating rate x Operating speed coefficient

Net operating rate = (Output x Actual cycle time-planned down time)*100/operating time

Operating speed coefficient = Design cycle time/Actual cycle time

According to Kumar et al., 2012, the Quality rate can be calculated as follows,

Quality Rate = (Total executed amount-Rework amount)*100/Total Executed amount

2.4. Contributing Factors for the loss of Equipment Productivity

According to (Dozzi and Abourizk, 1993), productivity improvement in construction is best understood when the construction process is visualized as a complete system. Control of the system is achieved by collecting and processing information about the rates at which production is attained. If the actual productivity doesn't compare favorably with the estimated values, the input categories affecting productivity in the system-namely material timeliness, labour effectiveness and management practices – need to be examined. The following main contributing factors for low equipment productivity that can be categorized into four main factor groups was identified.(Makulsawatudom and Emsley,2001). According to (Abebaw,2014), it was concluded that the management factors(MF) were the key factors in affecting equipment productivity among the main contributing factors for equipment productivity loss such as human factor(HF), equipment factor(EF) and work factor(WF). The second critical factor that affects equipment productivity was the equipment factor. The human factor and work factor were ranked third and last in contributing for equipment productivity loss.

Table 2.6 Factors affecting productivity (Makulsawatudom and Emsley, 2001)

Contributing factors	Factor group
Lack of material	MF
Incomplete drawing	WF
Inspection delay	MF
Incompetent supervisor	HF
Instruction time	MF
Lack of tools & equipment	MF
Poor communication	MF
Poor site condition	WF
Change order	MF
Poor site layout	WF
Rework	HF

Absenteeism	HF
Occasional working Overtime	HF
Tools/equipment breakdown	EF
Interference from other trades	WF
Overcrowding	WF
Worker turnover & changing crewmember	HF
Specification and Standardization	WF
Schedule working overtime	WF
Weather	WF
Changing of foremen	HF
Safety(accident)	MF
Shift work	WF

Chapter Three

3. Research Methodology

3.1. Methods and Procedures

In order to conduct such research, the following methods and procedures were implemented. The methodology consists of four parts. The first part focused on the measurement of the actual productivity of the equipments based on productivity principles. The second part focused on the comparison of the actual equipment productivity from the standard performance. The third part focused on the contributing factors that cause the difference and the last part was about the corrective actions that should be taken to reduce the equipment productivity loss. The procedures that were included are research design, sampling techniques, data collection tools/research instrument and method of data analysis and evaluation.

3.2. Research Design

The research methodology was a case study on three selected upgrading Asphalt Road projects because of the fact that making observation and actual measurement in all projects throughout the Addis Ababa City is very tedious. The factors that cause the difference were analyzed by questionnaire survey on all active ongoing asphalt road projects.

3.3. Sampling Techniques

The City was selected purposively that currently several city section roads are on upgrading to concrete Asphalt. Projects that have all the targeted equipments are actively on operation were selected as representative sample projects based on their statistically significance by cluster sampling technique from the list of the existing ongoing asphalt concrete upgrading projects within the city.

3.4. Data collection tools/Research Instrument

This study utilized the two types of data sources for investigating the actual productivity of equipments and the factors that contribute for the productivity loss. These are questionnaires and actual observation and measurement as primary data sources and literature review as secondary data sources.

On the field the actual productivity was measured and recorded when the equipments were assigned to do certain activities in order to compare with the expected base line.

Questionnaire survey was used as data collection tools for this study so as to get information about factors that contribute for the reduction of the equipments productivity.

3.5. Methods of Data Analysis and Evaluation

3.5.1. Methods of Performance Analysis and Evaluation

So as to achieve the objectives of the research, the observed and measured data were analyzed by calculating the overall equipments effectiveness based on the availability, Performance and quality rates. Manufacturer's specifications provide the ideal/theoretical production rates as a base line for comparison.

The OEE was computed by formulae given in the literature reviewing section of this research such as:

OEE= valuable operating time/(active time)*100= AR x PR x QR ,where AR= Availability Rate, PR= Performance Rate and QR = Quality Rate.

From the actual observation on the selected projects, the contributing factors were identified and the percentages of the factor groups were compared.

3.5.2. Methods of Contributing factors Analysis and Evaluation

The second methodology used for this study was questionnaire. A questionnaire that contains contributing factors for all targeted equipments was carefully designed from literatures, internet and materials around heavy duty construction equipments. It was organized in the form of a priority scaling (1 = not significant, 2 = slightly significant, 3 = moderately significant, 4 = very significant, and 5 = extremely significant).

There were five Active upgrading concrete Asphalt Road Projects in the City at the period of the study. The questionnaires were distributed for the all the five the under mentioned active ongoing Upgraded Asphalt Road Projects in Addis Ababa; Jhosansen-Mola Maru Upgrading Asphalt Road Project, Huletegna Polis Tabiya-Kidiste Mariyam-Minilik Hospital Upgrading Asphalt Road Project, Mexico Round About- Amistegna Polis Tabiya Upgrading Asphalt Road Project, Shiromeda -Kidane Mihrete Upgrading Asphalt Road Project and Lideta Tsebel-Africa Hibret- Bulgaria- Meskel Flower Upgrading Asphalt Road Project.

The procedure used in analyzing the results aimed at establishing the mean score of the various factors responsible for loss of productivity. The score for each factor is calculated by summing up scores assigned to it by respondents.

Therefore, the level of importance as indicated by the Project Managers, Site Engineers and Operators were used to measure the mean score of each factor.

The mean score (MS) for each variables of the contributing factors was computed by using the following formula;

$$MSi = \frac{\Sigma (f \times s)}{N} \qquad \text{Equation 3.1}$$

Where; S = score given to each contributing factors by the respondents;

F = frequency of responses to each score for each contributing factors;

N = total number of responses in the respective contributing factors.

Weighted Average is calculated by using the following formula;

$$\text{Weighted Avg.} = w_a x_a + w_b x_b + w_c x_c \qquad \text{Equation 3.2}$$

Where; w= relative weight (%)

x= mean score

a, b & c represent Project Managers, Site Engineers and Operators respectively.

The Spearman (rho) rank correlation coefficient is used for measuring the differences in ranking between two groups of respondents scoring for various factors (i.e. project managers versus Site Engineers, Project managers versus Operators, and Site Engineers versus Operators).

The Spearman (rho) rank correlation coefficient for any two groups of ranking is given by the following formula.

$$\text{Rho } (\rho cal) = 1 - \frac{6 \times (\Sigma di2)}{N \times (N2 - 1)} \qquad \text{Equation 3.3}$$

Where:

Rho (ρcal) – Spearman rank correlation coefficient

di– The difference in ranking between each pair of factors

N– Number of factors (variables)

Procedure for hypothesis testing:

1. Define the null hypothesis (H0) and the alternative hypothesis (HA)
2. Choose a value for ρ. (i.e. choose the significance level)
3. Calculate the value of the test statistic, Rho (ρcal).
4. Compare the calculated value with a table of the critical values of the test statistic.
5. If the calculated value of the test statistic is less than the critical value from the table, accept the null hypothesis (H_0). If the absolute (calculated) value of the test statistic is greater than or equal to the critical value from the table, reject the null hypothesis (H_0) and accept the alternative hypothesis (HA).

3.5.2.1. Questionnaire approach

A questionnaire was developed to assess the perceptions of Project Managers, Site Engineers and Operators due to the importance index for the loss of productivity on equipments engaged on upgrading Concrete Asphalt road projects in Addis Ababa. Factors contributing for the loss of productivity in all active ongoing upgrading Concrete Asphalt Road Construction Projects in Addis Ababa were first identified and analyzed.

3.5.2.2. Questionnaire design and content

The draft questionnaire was discussed with the supervisor of the thesis. The final questionnaire contains contributing factors for all targeted equipments. The respondents were asked to fill the questionnaire and they had assured that the information will be confidential and only for research purpose. The questionnaire included two parts; these parts are general organization information, factors influencing the equipments productivity. Due to the fact that there was no Asphalt paver Operation on three projects, the respondents couldn't reply their perception. So, the questionnaires to be distributed were not the multiple of the no. of projects and the no. of targeted equipments. The questionnaires to be distributed, distributed and returned are shown on table 3.1.

Table 3.1 Questionnaires to be distributed, distributed and returned

No. of respondents	To be distributed	Actually distributed	returned
Project Manager	25	22	22
Site Engineer	25	23	23
Operators	25	22	22

3.5.2.3. Questionnaire General Information

Four items were prepared for asking information about organization such as the name of Organization, Grade of the contractor, respondent's designation and his/her experience. (The questionnaire is included in Appendix B)

3.5.2.4. Contributing factors for the loss of productivity

This part of questionnaire consist of 5 equipments questionnaire included 50 contributing factors for Grader , 34 contributing factors for Excavator, 32 contributing factors for Loader, 28 contributing factors for Dump truck and 54 contributing factors for Asphalt Paver. (The questionnaire is included Appendix B).

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

This chapter describes the results of the computation carried out on the analysis of the construction equipment productivity. The assessment result contains three main sections, i.e. Performance analysis of heavy duty construction equipments involved in the selected upgrading concrete asphalt road projects to compare the actual with the standard performance, analysis of main contributing factors for the loss of productivity on all active ongoing upgraded asphalt road projects and comparing the performance analysis result with the contributing factors analysis result on the selected active projects.

4.2. Basic Information about the three projects

From projects launched for execution by AACRA on the time of the study, there were five active ongoing upgraded concrete Asphalt Road Projects.

The contributing factors analysis is done for all active upgraded concrete Asphalt road projects and the projects considered as case study is selected which are statistically significant. The selected projects had almost all the equipments and their activities actively on operation than the other remaining two projects.

Although the Same Grade Contractors of the selected projects had different machineries and equipments type and model, the similar equipment types and models were selected for the study. The comparison for the productivity of the equipments is done based on Caterpillar Performance Hand Books or any other Standards related to the equipments.

The models that are selected for the case study are Caterpillar model for the Grader and the Excavator, ZL50G China Loader and Sino Truck and Dynapac Asphalt Paver.

4.3 Performance analysis of Heavy Duty Construction Equipments

The performance of heavy duty construction equipment like Motor Grader, Excavator, Loader, Asphalt Paver and Dump Trucks was assessed based on the percentage of an individual OEE index and the overall performance rate of the individual equipment. From the product of the three primary component rates, the percentage of OEE index was calculated.

4.3.1 Performance Analysis for Jhosansen- Mola Maru Upgrading Asphalt Road Project

The computation of the equipments productivity rate and the percentage of individual components rate are summarized on Table 4.1

The performance of the equipments and their OEE index calculation sheets are attached on the Appendix A

Table 4.1 Summary of Average Productivity rates on Jhosansen- Mola Maru Upgrading Asphalt Road Project

Equipment	Indexes			
	Availability Rate	Performance Rate	Quality Rate	OEE
Grader	76.23	50.22	90.57	34.67
Excavator	92.86	44.53	78.65	32.52
Loader	91.46	66.56	46.14	28.09
Asp. Paver	90.27	80.00	100	72.21
Dump Trucks	96.67	88.17	100	85.23

All the summary of all primary component rates and OEE indexes are contained in Table 4.1. It shows that the performance rate ranked first, availability rate next and the quality rate the last for all the equipments except for the loader.

Moreover, the calculation in the table shows the extent of the overall productivity of the equipment is very poor especially for Motor Grader, Excavator and Loader. (below 50%).

This is the result that shows the equipments are not performing well. For the loader, even if it has low performance rate, the quality rate is highly affected because of the assignments given here and there for rework and start up yield losses.

4.3.2 Performance analysis for Huletegna Polis Tabiya-Kidiste Mariyam- Minilik Hospital Upgrading Asphalt Road Project

The computation of the equipments productivity rate and the percentage of individual components rate are summarized on table 4.2

The performance of the equipments and their OEE index calculation sheets are attached on the Appendix A

Table 4.2 Summary of Average Productivity rates on Summary of Average Productivity rates on Huletegna Polis Tabiya-Kidiste Mariyam- Minilik Hospital Upgrading Asphalt Road Project

Equipment	Indexes			
	Availability Rate	Performance Rate	Quality Rate	OEE
Grader	78.93	49.33	80.41	31.31
Excavator	85.79	69.58	100	59.70
Loader	71.14	61.23	63.77	27.78
Asp. Paver	97.12	75.56	100	73.38
Dump Trucks	97.13	91.04	100	88.61

All the summary of all primary component rates and OEE indexes are contained in Table 4.2. It shows that the performance rate ranked first, availability rate next and the quality rate the last for all the equipments except for the loader.

Moreover, the calculation in the table shows the extent of the overall productivity of the equipment is very poor especially for Motor Grader, Excavator and Loader.(below 60%). This is the result that shows the equipments are not performing well. For the loader, even if it has low performance rate, the quality rate is also affected by its engagement on unproductive works.

4.3.3 Performance analysis for Mexico Round About- Amistegna Polis Tabiya Upgrading Asphalt Road Project

The computation of the equipments productivity rate and the percentage of individual components rate are summarized on table 4.3.

The performance of the equipments and their OEE index calculation sheets are attached on the Appendix A.

Table 4.3 Summary of Average Productivity rates on Mexico Round About- Amistegna Polis Tabiya Upgrading Asphalt Road Project

Equipment	Indexes			
	Availability Rate	Performance Rate	Quality Rate	OEE
Grader	94.78	62.69	74.40	44.21
Excavator	94.59	55.19	86.02	44.91
Loader	94.36	67.50	56.87	36.22
Dump Trucks	96.00	77.92	100	74.80

All the summary of all primary component rates and OEE indexes are contained in Table 4.3. It shows that the performance rate ranked first, availability rate next and the quality rate the last for all the equipments except for the loader. Moreover, the calculation in the table shows the extent of the overall productivity of the equipment is very poor especially for Motor Grader, Excavator and Loader.(below 50%).

This is the result that shows the equipments are not performing well. For the loader, even if it has low performance rate, the quality rate is also affected by its engagement on unproductive works.

4.4. Analysis of main Contributing factors for the loss of productivity from the Actual Observation

1. **Observed loss contributing factors for Grader**

The performance rate is low in all the three cases for the Grader. The main observed factors for low performance rate and low OEE index on average less than 37% were summarized in Table 4.4.It is possible to conclude that the management problems were the key factors in affecting the equipment productivity in all projects and it was ranked first (i.e. 42.86%) among the main contributing factors for equipment productivity loss such as human factor, equipment factor and work factor. The second critical factor that affects equipment productivity on the three projects was the Human factor with the percentage of 28.57. The work factor and equipment factor with a percentage of 21.43 and 7.14 respectively ranked third and the last in contributing for the Grader productivity loss. This result is in line with Makulsawatudom et al. (2001) as lack of material, instruction time, poor communication, change order and the like affects the productivity of the equipment.

2. **Observed loss contributing factors for Excavator**

The performance rate is low in all the three cases for the Excavator. The main observed factors for low performance rate and low OEE index on average less than 46% were summarized in Table 4.4.It is possible to conclude that the management problems were the key factors in affecting equipment productivity in all projects and it was ranked first (i.e. 44.44%) among the main contributing factors. The second critical factor that affects equipment productivity on the three projects was the Work factor with the percentage of 33.33. The human factor and equipment factor ranked as the third with a percentage of 11.11 in contributing for the Excavator productivity loss. This result is in line with Makulsawatudom et al. (2001) as poor communication, Poor site condition, change order and the like affects the productivity of the equipment.

3. Observed loss contributing factors for Loader

The quality rate is low on average in all the cases for the Loader. The main observed factors for low quality rate and low OEE index less than 31% were summarized in Table 4.4.It is possible to conclude that the work factors were the key factors in affecting equipment productivity in all projects and it was ranked first (i.e. 42.86%) among the main contributing factors for equipment productivity loss such as human factor, equipment factor and management factor. The second critical factors that affect equipment productivity on the three projects were the management factor and human factor with the percentage of 28.57. The equipment factor ranked as the third with a percentage of 14.28 in contributing for productivity loss. This result is in line with Makulsawatudom et al. (2001) as Overcrowding, Rework, Poor site condition and the like affects the productivity of the equipment.

4. Observed loss contributing factors for Asphalt Paver

The performance rate is lower than the other rates for the two cases for the Asphalt Paver. The main observed factors for lower performance rate and OEE index less than 73% were summarized in Table 4.4.It is possible to conclude that the equipment factors were the key factors in affecting equipment productivity in the two projects and it was ranked first (i.e. 66.67%) among the main contributing factors. The second critical factor that affects equipment productivity on the two projects was the management factor with the percentage of 33.33 in contributing for the Asphalt paver productivity loss. This result is in line with Makulsawatudom et al. (2001) as lack of material, Tools/equipment breakdown and the like affects the productivity of the equipment.

5. Observed loss contributing factors for Dump Trucks

The performance rate is low in all the three cases for the Dump Truck. The main observed factors for lower performance rate and OEE index less than 83% were summarized in Table 4.4.It is possible to conclude that the work factors were the key factors in affecting the equipment productivity in all projects and it was ranked first (i.e. 50%) among the main contributing factors. The second critical factors that affect equipment productivity on the three projects were the Equipment factor and the Management factor with the percentage of 25.00 in contributing for the Dump Truck productivity loss. This result is in line with Makulsawatudom et al. (2001) as Tools/equipment breakdown, Interference from other trades instruction time, Overcrowding, Poor site condition and the like affects the productivity of the equipment.

Table 4.4 Summary of Factors for the loss of productivity on the study projects

Equipment	Contributing factors observed	Factor group
Grader	Delay of fuel boy	HF
	Mobilization within the site	MF
	Interference of other trades	WF
	Maintenance	EF
	Operation not given	MF
	Activity dependency	WF
	Improper work order	MF
	Traffic jam	WF
	Rework	HF
	Operator delay	HF
	Service delay	MF
	Absenteeism	HF
	Shortage of material	MF
	Change order	MF
Excavator	Operator delay	HF
	Radiator check up	EF
	Traffic jam	WF
	Mobilization within the site	MF
	Activity dependency	WF
	Interference of other trades	WF
	Work place change	MF
	Obstruction for swinging	MF
	Buried water line breakage	MF

Loader	Rework	HF
	Fuel filling on working time	MF
	Absenteeism	HF
	Traffic jam	WF
	Mobilization within the site	MF
	Tyre problem	EF
	Minimum working space	WF
	Activity dependency	WF
Dump Truck	Excavator break down	EF
	Traffic jam	WF
	Work order not given	MF
	Interference of other trades	WF
Asphalt Paver	Pneumatic roller breakdown	EF
	Delay of dumping trucks	MF
	Delay of Asphalt Plant	EF

4.5 Analysis of Main contributing factors for the loss of productivity

4.5.1 Results of Questionnaire for the contributing factors for the loss of productivity

The contributing factor for the loss of productivity from questionnaire survey was identified based on the respondents' response.

4.5.1.1 Population characteristics

This part mainly designed to provide general information about the respondents in terms of position and experience of the contact person. The projects contractors are grade one company type.

4.5.1.1.1 Types of Responses

Table 4.5 shows that in this study, 32.84% project managers, 34.32% Site Engineers and 32.84 %Operators participated in the questionnaire. The general response rate for the project managers, Site Engineers and operators was 100% and the total number of responses for the three parties was 67 out of 67 questionnaires. The response rate of the project managers was 100 %(22 out of 22 questionnaire), for sire Engineers 100 %(23 out of 23 questionnaire) and 100 %(22 out of 22 questionnaire) for the operators.

Table 4.5 Type of respondents' designation

No.of respondents	Questionnaire distributed	Questionnaire returned	Response rate
Project Manager	22	22	100%
Site Engineer	23	23	100%
Operators	22	22	100%

4.5.1.1.2 Experience of the Respondents

Table 4.6 Experience of the Respondents

Experience years	Project Manager	Site Engineer	Operator	Total
1-4		2		2
4-8		3		3
8-12	3		10	13
>12	2		12	14

Table 4.6 shows that 6.25%(2) of the respondents have experience between 1 to 4 years at construction works, 9.37%(3) of the respondents have experience between 4 to 8, 40.63%(13) of the respondents have experience between 8 to 12 and 43.75%(14) who have experience of more than 12 years.

4.5.1.2 Contributing factors for the loss of productivity of Selected Equipments

This part consists of the result and discussion of factors contributing for the productivity loss for the following equipments, i.e. Motor Grader, Excavator, Loader, Asphalt Paver and Dump Trucks, from all active ongoing asphalt road projects as the project managers' view, as the Site Engineers' view and as the Operators' view and the general view based on the selected factors.

4.5.1.2.1. Contributing factors for Grader

1. The Project Managers' view

Table 4.7 shows that the project Managers ranked "efficiency of the grader, equipment maintenance facility and skill of the grader Operator" in the first position with a mean score of 4.60.This indicates how the equipment factors affect the productivity of the equipment.

The second important factor ranked by the project managers was "no. of Dump Trucks assigned to the site" with a mean score of 4.40. This leads to the Grader not to perform well within its available time due to idle time incurred because of shortage of dumped materials.

The project managers respond and ranked "the delay on supply of dumping material and fuel and maneuverability of the equipment" on the third with a mean score of 4.20. This indicates that the grader is available but not productive.

Table 4.7: Contributing factors for the loss of productivity of Motor Grader from point view of Project Managers, Site Engineers and Operators

For Grader	PM		SE		OP		W.A	
Factors	Msi	Rank	Msi	Rank	Msi	Rank	Msi	Rank
Efficiency of the Grader	4.60	1	4.40	2	3.80	2	4.27	1
Right of way problem	3.60	6	4.80	1	4.40	1	4.27	1

Traffic conditions	3.80	5	4.00	4	4.40	1	4.07	2
Delay on supply of dumping materials	4.20	3	3.80	5	3.80	2	3.93	3
Skill of the Grader operator	4.60	1	4.20	3	2.80	7	3.87	4
Equipment maintenance facility	4.60	1	3.60	6	3.20	5	3.80	5
Maneuverability of equipment	4.20	3	4.00	4	3.00	6	3.73	6
No of dumping trucks	4.40	2	3.80	5	2.80	7	3.67	7
Poor grading crew coordination	4.00	4	3.80	5	3.20	5	3.67	7
Absenteeism of the operator	3.80	5	3.80	5	2.40	9	3.67	7
Effective blade width	3.80	5	3.60	6	3.20	5	3.53	8
Delay on fuel supply	4.20	3	3.80	5	2.60	8	3.53	8
Activity dependency	3.60	6	3.40	7	3.60	3	3.53	8
Level of crew motivation	3.80	5	3.40	7	3.40	4	3.53	8
Gradation of the material	3.40	7	3.60	6	3.40	4	3.47	9
Delay on leveling work	4.00	4	3.20	8	3.20	5	3.47	9
Restricted work hours	3.40	9	3.40	7	3.40	4	3.40	10
Efficiency of the roller	3.60	6	3.20	8	3.20	5	3.33	11
Operation type	3.80	5	3.40	7	2.80	7	3.33	11
Discontinuity of grading work	3.80	5	3.20	8	3.00	6	3.33	11
Skill of the roller operator	3.80	5	3.60	6	2.60	8	3.33	11
Availability of working space	3.60	6	3.40	7	2.80	7	3.27	12
Weather conditions	3.80	5	3.00	9	3.00	6	3.27	12
Condition of haul roads	3.40	7	3.60	6	2.80	7	3.27	12
Shortage of shower truck	3.80	5	3.20	8	2.80	7	3.27	12
Turning radius of the grader	3.20	8	3.20	8	3.20	5	3.20	13
Maximum digging depth of the ripper	3.60	6	3.20	8	2.80	7	3.20	13
Specification requirement	3.40	7	3.40	7	2.80	7	3.20	13

The blade type(length ,height, thickness)	3.40	7	3.20	8	2.80	7	3.13	14
Moisture content of the material	3.00	9	3.20	8	3.20	5	3.13	14
Long job span	3.40	7	3.40	7	2.60	8	3.13	14
Placing width	3.20	8	3.40	7	2.80	7	3.13	14
Speed and timing of roller	3.20	8	3.40	7	2.60	8	3.07	15
Placing related equipments break down	3.20	8	2.80	10	3.00	6	3.00	16
Nature of the material	3.40	7	2.60	11	3.00	6	3.00	16
Expedited project schedule(over time, extra shifts, more crew)	3.20	8	3.20	8	2.60	8	3.00	16
No of passes of the roller	3.20	8	3.40	7	2.20	10	2.93	17
Roughness of the surface	3.20	8	3.40	7	2.20	10	2.93	17
Mobilization within the site	2.80	10	3.60	6	2.40	9	2.93	17
Grade change of the section	2.80	10	3.00	9	3.00	6	2.93	17
Work place preparation problem	3.60	6	2.80	10	2.40	9	2.93	17
Changing of the foremen	3.80	5	2.60	11	2.20	10	2.87	18
Skill of the shower truck operator	3.60	6	2.80	10	2.20	10	2.87	18
Interference from other trades	3.20	8	2.80	10	2.60	8	2.87	18
Life of grading related equipments	3.00	9	2.80	10	2.60	8	2.80	19
Direction of travel	3.00	9	3.20	9	2.20	10	2.80	19
No of rollers	2.80	10	2.80	10	2.40	9	2.67	20
Type of roller	2.60	11	2.60	11	2.20	10	2.47	21
Night time work	3.20	8	2.00	13	2.20	10	2.47	21
Unforeseen conditions	3.00	10	2.20	12	2.20	10	2.47	21

2. The Site Engineers' view

Table 4.7 shows that the Site Engineers ranked "Right of way problem" in the first position with a mean score of 4.80.This indicates how right of way problem affects the productivity of the equipment. If there is a right of way problem in the construction site, it will lead to a significant loss of productive time.

The second factor ranked by the site Engineers was "the efficiency of the grader" with a mean score of 4.40.This is an indication that the efficiency of the grader will cause loss of productivity.

The third factor ranked by the Site Engineers was skill of the grader operator. If the operator is not well skilled on the operation, the productivity of the grader will reduce.

3. The Operators' view

Table 4.7 shows that the Operators ranked "the right of way problem and the traffic conditions" in the first position with a mean score of 4.40. This indicates that how the traffic conditions also affect the productivity of the grader by increasing the idle time.

The second factor ranked by the operators was "efficiency of the grader and delay on supply of dumping materials "with a mean score of 3.80.

The third factor ranked by the Operators was "activity dependency" with a mean score of 3.60. Other activities affect the operation of the grader not to be more productive.

4. Overall View

Table 4.7 shows that overall view of the respondents ranked "Right of way problem and efficiency of the grader" in the first position with a weighted average mean score of 4.27.Both the right of way problem and efficiency of the grader cause a loss of productive time which will be a reason for the loss of productivity.

The second important factor ranked by the respondents was "the traffic conditions of the working Site" with a weighted average mean score of 4.07.

Because the projects are on upgrading, the existing traffics use the corridor and the execution is being executed parallel. So, it will create a loss of productivity for the grader.

The third factor which contributes for the loss of productivity by the view of all the respondents was “delay on supply of dumping materials” with a mean score of 3.93.This is a strong indication that the shortage of no. of Dump Trucks and the traffic condition for the delay of the dump trucks will cause the loss of productivity of the grader.

4.5.1.2.2. Contributing factors for Excavator

1. The Project Managers’ view

Table 4.8 shows the project managers ranked “the efficiency of the excavator” in the first position with a mean score of 4.60. This is an indication that the efficiency of the excavator will cause loss of productivity.

The second factor which contributes for the loss of productivity by the view of the project managers was skill of the excavator operator with a mean score of 4.40.Because of lack of skill, the excavator can’t produce well.

The third factor ranked by the project managers was “no. of dump trucks assigned in the site with a mean score of 4.20.Unless the excavator-dump truck link is maintained by assigning enough dump trucks, the excavator is going to be idle for loss.

2. The Site Engineers’ view

Table 4.8 shows that the site Engineers ranked “right of way problem” in the first position with a mean score of 4.80. This indicates how right of way problem affect the productivity of the excavator.

The second factor which contributes for the loss of productivity by the view of the Site Engineers was “the no. of dump trucks assigned” with a mean score 4.60. Unless enough dump trucks are assigned for the excavator, the idle time incurs loss for its productivity.

The site Engineers ranked "the efficiency of the excavator and the skill of the operator" as a third important factor that can affect the productivity of the machine with a mean score of 4.40.

Table 4.8: Contributing factors for the loss of productivity of Excavator from point view of Project Managers, Site Engineers and Operators

For Excavator	PM		SE		OP		W.A	
Factors	Msi	Rank	Msi	Rank	Msi	Rank	Msi	Rank
Right of way problem	4.00	4	4.80	1	4.40	1	4.400	1
Efficiency of the Excavator	4.60	1	4.40	3	3.60	3	4.200	2
Skill of the Excavator operator	4.40	2	4.40	3	3.20	5	4.000	3
No of dumping trucks	4.20	3	4.60	2	2.80	7	3.867	4
Maneuverability of equipment	4.40	2	3.80	5	3.20	5	3.800	5
Operation type (excavating, digging, loading, sloping)	3.40	7	3.60	6	4.00	2	3.667	6
Nature of the material(rock, soil, intermediate)	4.20	3	3.20	8	3.40	4	3.600	7
Traffic conditions	3.40	7	4.40	3	3.00	6	3.600	7
Equipment maintenance facility	4.20	3	3.80	5	2.60	8	3.533	8
Poor crew coordination	3.80	5	3.80	5	3.00	6	3.533	8
Digging depth	3.40	7	3.80	5	3.20	5	3.467	9
Absenteeism of the operator	4.40	2	3.20	8	2.80	7	3.467	9
Specification requirement for slope work	3.60	6	3.40	7	3.20	5	3.400	10
Activity dependency	3.60	6	3.80	5	2.80	7	3.400	10
Angle of swing	2.80	10	4.00	4	3.20	5	3.333	11
Amount of movement	3.80	5	3.40	7	2.60	8	3.267	12
Expedited project schedule(over time, extra	3.60	6	3.60	6	2.40	9	3.200	13

shifts, more crew)								
Haul unit positioning	3.20	8	3.60	6	2.60	8	3.133	14
Level of motivation of the crew	3.80	5	3.00	9	2.60	8	3.133	14
Moisture content of the material	2.80	10	3.40	7	3.00	6	3.067	15
Unforeseen conditions	2.80	10	3.20	8	3.00	6	3.000	16
Size distribution	3.00	9	3.60	6	2.20	10	2.933	17
Delay on fuel supply	4.20	3	3.00	9	1.60	13	2.933	17
Weather conditions	3.40	7	2.80	10	2.60	8	2.933	17
Mobilization within the site	3.60	6	3.00	9	2.00	11	2.867	18
Dump height on trucks	3.00	9	3.20	8	2.40	9	2.867	18
Place for cycle route	3.00	9	2.80	10	2.80	7	2.867	18
Work place preparation problem	3.80	5	2.60	11	2.00	11	2.800	19
Slope of the operating area	3.00	9	3.00	9	2.20	10	2.733	20
Restricted work hours(start and stop time limited by contract)	3.60	6	2.80	10	1.40	14	2.600	21
Interference from other trades	3.40	7	2.40	11	2.00	11	2.600	21
Night time work	3.00	9	2.00	12	2.40	9	2.467	22
Effects of the looseness	3.00	9	2.40	11	1.80	12	2.400	23
Project length	2.40	11	2.60	11	1.00	15	2.000	24

3. The Operators' view

Table 4.8 shows that the operators ranked "right of way problem" in the first position with a mean score of 4.40, operation type in second place with a mean score 4.0 and the efficiency of the excavator in the third rank with a mean score of 3.60.

4. Overall View

Table 4.8 shows that overall view of the respondents ranked “right of way problem” in the first position with a mean score of 4.40, the efficiency of the excavator in the second place with a mean score of 4.20 and skill of the excavator operator in the third place with a mean score of 4.0. These all contributing factors have influence on the productivity of the machine. Mainly, the external factor, the equipment factor and the human factor mentioned above will cause the excavator to be idle and the loss will occur.

4.5.1.2.3. Contributing factors for Loader

1. The Project Managers’ view

Table 4.9 shows that the project managers ranked “ the efficiency of the loader and skill of the operator” in the first position with a mean score of 4.60.This is an indication that the efficiency of the loader will cause loss of productivity.

The second factor which contributes for the loss of productivity by the view of the project managers were “the no. of dump trucks and maneuverability of the equipment” with a mean score of 4.40. Unless the loader – dump truck link is maintained by assigning enough dump trucks, the loader is going to be idle for loss.

The third factors ranked by the project managers were “equipment maintenance facility, delay on fuel supply and level of motivation of the operator” with a mean score of 4.20.when there is a better level of motivation, the operator can minimize the cycle time as much as possible and so the productivity will increase and if there is delay on supply of fuel, the idle time will incur and via cause loss of productivity.

2. The Site Engineers’ view

Table 4.9 shows that the site Engineers ranked “the efficiency of the loader and the traffic conditions” in the first position with a mean score of 4.20, “skill of the loader operator and the equipment maintenance facility” in the second place with a mean score of 4.0 and “maneuverability of the equipment, delay on fuel supply and dump height on trucks” in the third place with a mean score of 3.80.

3. The Operators' view

Table 4.9 shows that the operators ranked "the efficiency of the loader and the traffic conditions" in the first position with a mean score of 4.00, "maneuverability of the equipment" in the second place with a mean score of 3.80 and "skill of the loader operator, no. of dump trucks, mobilization within the site and weather conditions" in the third place with a mean score of 3.40.

Table 4.9: Contributing factors for the loss of productivity of Loader from point view of Project Managers, Site Engineers and Operators

For Loader	PM		SE		OP		W.A	
Factors	Msi	Rank	Msi	Rank	Msi	Rank	Msi	Rank
Efficiency of the loader	4.60	1	4.20	1	4.00	1	4.27	1
Traffic conditions	4.00	4	4.20	1	4.00	1	4.07	2
Maneuverability of equipment	4.40	2	3.80	3	3.80	2	4.00	3
Skill of the Loader operator	4.60	1	4.00	2	3.40	3	4.00	3
Equipment maintenance facility	4.20	3	4.00	2	3.20	4	3.80	4
No of dumping trucks	4.40	2	3.60	4	3.40	3	3.80	4
Right of way problem	3.40	7	3.20	6	3.00	5	3.60	5
Delay on fuel supply	4.20	3	3.80	3	2.80	6	3.60	5
Mobilization within the site	3.40	7	3.20	6	3.40	3	3.33	6
Activity dependency	3.40	7	3.60	4	3.00	5	3.33	6
Absenteeism of the operator	3.80	5	3.20	6	3.00	5	3.33	6
Dump height on trucks	3.40	7	3.80	3	2.60	7	3.27	7
Level of motivation of the crew	4.20	3	2.60	9	3.00	5	3.27	7
Weather conditions	3.80	5	2.60	9	3.40	3	3.27	7
Size distribution	3.40	7	3.40	5	2.60	7	3.13	8
Moisture content of the material	3.80	5	3.40	5	2.20	9	3.13	8
Nature of the material(rock,	3.40	7	3.40	5	2.60	7	3.13	8

soil, intermediate)								
Operation type (cutting, loading, sloping)	3.80	5	3.00	7	2.60	7	3.13	8
Digging depth	3.60	6	2.80	7	3.00	5	3.13	8
Place for cycle route	3.60	6	3.20	6	2.60	7	3.13	8
Slope of the operating area	3.80	5	3.00	7	2.60	7	3.13	8
Haul unit positioning	3.60	6	3.00	7	2.80	6	3.13	8
Poor crew coordination	4.00	4	3.00	7	2.40	8	3.13	8
Expedited project schedule(over time, extra shifts, more crew)	3.60	6	3.00	7	2.60	7	3.07	9
Work place preparation problem	4.20	3	3.00	7	1.80	10	3.00	10
Restricted work hours(start and stop time limited by contract)	3.40	7	3.00	7	2.60	7	3.00	10
Amount of movement	3.80	5	2.80	8	2.20	9	2.93	11
Unforeseen conditions	3.00	9	2.80	8	3.00	5	2.93	11
Interference from other trades	3.20	8	2.00	11	2.40	8	2.53	12
Effects of the looseness	3.00	9	2.80	8	1.60	11	2.47	13
Project length	3.00	9	2.80	8	1.40	12	2.40	14
Night time work	3.40	7	2.40	10	1.40	12	2.40	14

4. Overall View

Table 4.9 shows that the overall view of the respondents ranked “efficiency of the loader” in the first position with a weighted average mean score of 4.27.

The second factor which contributes for the loss of productivity by the view of all the respondents was “the traffic conditions” with a mean score of 4.06.

Because the operation is being carried out on the existing upgrading roads; the traffic jam will affect the productivity of the loader by reducing its effective performing time.

The third factors ranked by the respondents were "maneuverability of the equipment and skill of the operator" with a mean score of 4.0. Unless the operator has a better skill and the machine is easily maneuverable, the loader can't perform well with limited working space.

4.5.1.2.4. Contributing factors for Dump Trucks

1. The Project Managers' view

Table 4.10 shows that the project managers ranked "the efficiency of the dump truck" in the first position with a mean score of 4.80, "the equipment maintenance facility, delay on fuel supply and maneuverability of the truck" in the second place with a mean score of 4.40 and "skill of loading equipment operator and dump trucks, poor crew coordination and loading related equipments break down" in the third place with a mean score of 4.20.

Table 4.10: Contributing factors for the loss of productivity of Dump Truck from point view of Project Managers, Site Engineers and Operators

For Dump Truck	PM		SE		OP		W.A	
Efficiency of the Dump Truck	4.80	1	3.60	4	3.60	2	4.000	1
Traffic conditions	4.00	4	3.80	3	4.00	1	3.933	2
Skill of the Loading equipment operator	4.20	3	4.20	1	3.20	4	3.867	3
Skill of the Dump Truck operator	4.20	3	4.20	1	3.00	5	3.800	4
Efficiency of the loading equipment	4.00	4	4.00	2	3.20	4	3.733	5
Equipment maintenance facility	4.40	2	3.60	4	3.20	4	3.733	5
Poor crew coordination	4.20	3	3.40	5	3.40	3	3.667	6

Maneuverability of trucks	4.40	2	3.40	5	3.00	5	3.600	7
Right of way problem	3.60	6	3.20	6	2.80	6	3.533	8
Loading related equipments break down	4.20	3	3.60	4	2.60	7	3.467	9
Delay on fuel supply	4.40	2	3.20	6	2.60	7	3.400	10
Length of the hauling distance	3.80	5	3.40	5	2.80	6	3.333	11
Level of motivation of the crew	4.00	4	3.00	7	3.00	5	3.333	11
Weather conditions	3.80	5	3.00	7	3.00	5	3.267	12
Grade of the travel route	4.00	4	3.20	6	2.40	8	3.200	13
Absenteeism of the operator	3.80	5	2.80	8	2.00	10	3.200	13
Dumping place preparation problem	4.00	4	3.00	7	2.00	10	3.000	14
Mobilization within the site	4.00	4	2.80	8	2.20	9	3.000	14
Restricted work hours	3.80	5	2.80	8	2.00	10	2.867	15
Unforeseen conditions	3.20	8	3	7	2.20	9	2.800	16
Night time work	4.00	4	2.60	9	1.40	13	2.733	17
Expedited project schedule	3.80	5	2.40	10	1.80	11	2.667	18
Project length	3.00	9	2.80	8	1.80	11	2.533	19
Interference from other trades	3.60	6	2.20	11	1.60	12	2.467	20
Nature of the material	3.40	7	2.40	10	1.40	13	2.400	21
Size distribution	2.40	10	2.80	8	1.60	12	2.267	22
Effects of the looseness	3.00	9	2.40	10	1.40	13	2.267	22
Moisture content of the material	3.40	7	2.00	12	1.20	13	2.200	23

2. The Site Engineers' view

Table 4.10 Shows that the site Engineers ranked "skill of loading equipment operator and dump trucks" in the first position with a mean score of 4.20, "efficiency of the loading equipment " in the second place with a mean score of 4.00 and "traffic conditions" in the third place with a mean score of 3.80.

3. The Operators' view

Table 4.10 shows that the Operators ranked "traffic conditions" in the first position with a mean score of 4.00, " efficiency of the dump truck " in the second place with a mean score of 3.60 and "poor crew coordination" in the third place with a mean score of 3.40.

4. Overall View

Table 4.10 shows that the overall view of all the respondents ranked "the efficiency of the dump truck" in the first position with a weighted average mean score of 4.0.

The second factor which contributes for the loss of productivity by the respondents was "the traffic conditions" with a weighted average mean score of 3.933. When the traffic condition on the hauling and return route is crowded, the total cycle time will increase and then the hourly productivity of the truck will be highly affected.

The third factor ranked by the respondents was "skill of the loading equipment operator" with a weighted average mean score of 3.867. If the loading equipment operator is not well skilled, the loading time and the loading amount of the truck will be affected. Being so, the productivity of the truck will reduce.

4.5.1.2.5. Contributing factors for Asphalt Paver

1. The Project Managers' view

Table 4.11 shows that the project managers ranked "the no. of dump trucks" in the first position with a mean score of 4.67, "Asphalt plant efficiency and the efficiency of the paver" in the second place with a mean score of 4.33 and "Project constraints like intersection, driveway, roundabouts, presence of utilities, Limited work area,

Weather conditions ,Paving related equipments break down ,Traffic conditions, Right of way problem, Delay on supply of the asphalt concrete, Efficiency of the roller ,Staged construction and Instruction time" in the third place with a mean score of 4.00.

2. The Site Engineers' view

Table 4.11 Shows that the site Engineers ranked "Asphalt plant efficiency and Paving related equipments break down" in the first position with a mean score of 4.33, "efficiency of the paver, No of dumping trucks, Right of way problem and Traffic conditions " in the second place with a mean score of 4.00 and "Project constraints like intersection, driveway, roundabouts, presence of utilities , Delay on leveling work, Instruction time, Restricted work hours, Poor paving crew coordination, Discontinuity of paving work and Mobilization within the site" in the third place with a mean score of 3.67.

Table 4.11: Contributing factors for the loss of productivity of Asphalt Paver from point view of Project Managers, Site Engineers and Operators

Asphalt plant efficiency	4.33	2	4.33	1	4.00	1	4.25	1
Efficiency of the paver	4.33	2	4.00	2	4.00	1	4.125	2
No of dumping trucks	4.67	1	4.00	2	3.00	2	4	3
Project constraints	4.00	3	3.67	3	4.00	1	3.875	4
Limited work area	4.00	3	3.33	4	4.00	1	3.75	5
Weather conditions	4.00	3	3.33	4	4.00	1	3.75	5
Paving related equipments break down	4.00	3	4.33	1	2.00	3	3.625	6
Traffic conditions	4.00	3	4.00	2	2.00	3	3.5	7
Right of way problem	4.00	3	4.00	2	1.00	4	3.5	7
Skill of the paver operator	3.67	4	3.33	4	3.00	2	3.375	8
Absenteeism of the operator	3.67	4	3.33	4	1.00	4	3.375	8
Delay on supply of the asphalt concrete	4.00	3	3.00	5	3.00	2	3.375	8
Activity dependency	3.67	4	3.33	4	3.00	2	3.375	8
Efficiency of the roller	4.00	3	3.33	4	2.00	3	3.25	9
Hauling distance	3.00	5	3.00	5	4.00	1	3.25	9
Delay on leveling work	4.33	2	3.67	3	1.00	4	3.25	9

Skill of the roller operator	3.67	4	3.00	5	3.00	2	3.25	9
Type of operation(may be overlay)	3.33	5	2.67	6	4.00	1	3.25	9
Type of roller	3.33	5	3.00	5	3.00	2	3.125	10
No of rollers	3.33	5	3.00	5	3.00	2	3.125	10
Staged construction	4.00	3	3.00	5	2.00	3	3.125	10
Instruction time	4.00	3	3.67	3	1.00	4	3.125	10
Level of motivation of the crew	3.33	5	3.00	5	2.00	3	3.125	10
Expedited project schedule(over time, extra shifts, more crew)	3.33	5	3.33	4	2.00	3	3	11
Restricted work hours(start and stop time limited by contract)	3.67	4	3.67	3	1.00	4	3	11
Poor paving crew coordination	3.67	4	3.67	3	1.00	4	3	11
Discontinuity of paving work	3.67	4	3.67	3	1.00	4	3	11
Mobilization within the site	3.00	6	3.67	3	2.00	3	3	11
Speed and timing of roller	3.67	4	3.00	5	2.00	3	3	11
Delay on fuel supply	3.67	4	3.33	4	1.00	4	2.875	12
Auger diameter of the paver	3.67	4	3.00	5	1.00	4	2.75	13
No of passes of the roller	3.33	5	3.33	4	1.00	4	2.75	13
Paving width	3.33	5	3.33	4	1.00	4	2.75	13
Joint preparation for extension	2.00		3.33	4	3.00	2	2.75	13
Grade change of the section	3.00	6	2.33	7	3.00	2	2.75	13
Shortage of shower truck	3.33	5	2.33	7	2.00	3	2.625	14

Size and proximity of production yard and staging areas	3.00	6	2.67	6	2.00	3	2.625	14
Type of terrain(level ,rolling, or hilly)	3.33	5	2.33	7	2.00	3	2.625	14
Asphalt hauling time to job site	3.00	6	2.67	6	2.00	3	2.625	14
Dumping the asphalt to the paver	2.67	7	3.00	5	2.00	3	2.625	14
Changing of the foremen	3.67	4	2.67	6	1.00	4	2.625	14
Hopper capacity of the paver	3.67	4	2.33	7	1.00	4	2.5	15
Shortage of small supportive tools	3.33	5	2.67	6	1.00	4	2.5	15
Project length	3.33	5	2.67	6	1.00	4	2.5	15
Turning radius of the paver	3.00	6	2.67	6	1.00	4	2.375	16
Mix property(gradation, size, shape ,volume)	3.00	6	2.67	6	1.00	4	2.375	16
Need for scratch or leveling layer	3.33	5	2.33	7	1.00	4	2.375	16
Asphalt Lift thickness	3.00	6	2.67	6	1.00	4	2.375	16
Hot mix asphalt production temperature	2.33	8	3.00	5	1.00	4	2.25	17
Night time paving	3.00	6	2.33	7	1.00	4	2.25	17
Interference from other trades	2.67	7	2.67	6	1.00	4	2.25	17
Asphalt binder grade or viscosity	2.33	8	2.67	6	1.00	4	2.125	18
Foundation support for the paver	2.33	8	2.67	6	1.00	4	2.125	18
Unforeseen conditions	2.67	7	2.00	8	1.00	4	2	19

3. The Operators' view

Table 4.11 shows that the operators ranked "Asphalt plant efficiency, Efficiency of the paver ,Project constraints like intersection, driveway, roundabouts, presence of utilities, Limited work area, Weather conditions, Hauling distance and Type of operation" in the first position with a mean score of 4.00, "efficiency of the paver, No of dumping trucks, Skill of the paver operator, Delay on supply of the asphalt concrete, Activity dependency, Skill of the roller operator, Type of roller, No of rollers, Joint preparation for extension, Grade change of the section " in the second place with a mean score of 3.00 and "Paving related equipments break down, Traffic conditions, Efficiency of the roller, Staged construction, Level of motivation of the crew, Expedited project schedule, Mobilization within the site, Speed and timing of roller, Shortage of shower truck, Size and proximity of production yard and staging areas, Type of terrain ,Asphalt hauling time to job site, Dumping the asphalt to the paver" in the third place with a mean score of 2.0.

4. Overall View

Table 4.11 shows that the overall view of the respondents ranked "Asphalt plant efficiency" in the first position with a mean score of 4.25. Unless the asphalt plant is more efficient, the asphalt paver will incur loss due to idle time.

The second factor which contributes for the loss of productivity was "efficiency of the paver" with a mean score of 4.125.

Unless the paver is more efficient to lay the mix, the asphalt plant may stop production instead of continue the production to keep the temperature of the mix.

The third factor ranked by the respondents was "the no. of dump trucks" with a mean score of 4.0. Unless the asphalt plant-paver-dump truck link is maintained by assigning enough dump truck, the paver is going to be idle for loss.

4.5.1.2.6. Overall view of the respondents on the common Contributing factors for all the targeted equipments

Table 4.12 shows that all the respondents ranked “the efficiency of the equipment” in the first position for all the equipments with an average weighted average means score of 4.17. This is an indication that the efficiency of the equipment will cause loss of productivity. The efficiency of the equipment describes the degree to which the equipment is done well without wasted capacity. If the equipment efficiency is maintained, the loss of productivity will be highly less.

The second factor which contributes for the loss of productivity by the view of all the respondents was “the right of way problem” with an average weighted average means score of 3.86. This indicates how right of way problem affects the productivity of the equipment. If there is a right of way problem in the construction site, it will lead to a significant loss of productive time. Right of way problems are problems that are not settled ahead of delivery of site to the contractor. Because different stakeholders are involved on the road corridor that the upgrading work is being executed, there are challenges both the client and the contractor are going to face so as to make free from any obstructions for the operation. The challenges that come later will affect the productivity of the equipment under operation.

The respondents ranked “the traffic conditions of the existing road and the no. of Dump Trucks assigned on the site” as a third important factors that can affect the productivity of the equipment with an average weighted average means score of 3.83. Because the projects are on upgrading, the existing traffics use the corridor and the execution is being executed parallel.

So, placing, paving and delivering material to the working site will be highly affected by the traffic jam. This will create a loss of productivity for the equipments. Unless the equipments – dump truck link is maintained by assigning enough dump trucks, the equipments are going to be idle for loss.

The fourth factor ranked by the respondents for all the targeted equipments was skill of the equipments' operators with an average weighted average means score of 3.81. If the operators are not well skilled on the operation, the productivity of the equipments will reduce.

The respondents ranked "maneuverability of the equipment" as a fifth important factor that can affect the productivity of the equipment with an average weighted average means score of 3.78.Unless the equipment is easily maneuverable, it can't perform well with limited working space.

Table 4.12: The common Contributing factors for the loss of productivity of all the targeted equipments from point of view of all the respondents

Common Contributing Factors	For Grader	For Excavator	For Loader	For Dump Truck	For Paver		
	W.A. Msi					Averag	Rank
Efficiency of the Equipment	4.27	4.2	4.27	4.00	4.13	**4.17**	1
Right of way problem	4.27	4.4	3.60	3.53	3.5	**3.86**	2
Traffic conditions	4.07	3.6	4.07	3.93	3.5	**3.83**	3
No of dumping trucks	3.67	3.87	3.80		4	**3.83**	3
Skill of the operator	3.87	4	4.00	3.80	3.38	**3.81**	4
Maneuverability of equipment	3.73	3.8	4.00	3.60		**3.78**	5
Equipment maintenance facility	3.80	3.53	3.80	3.73		**3.72**	6
Absenteeism of the operator	3.67	3.47	3.33	3.20	3.38	**3.41**	7
Activity dependency	3.53	3.4	3.33		3.38	**3.41**	7

Poor crew coordination	3.67	3.53	3.13	3.67	3	**3.40**	8
Operation type	3.33	3.67	3.13		3.25	**3.35**	9
Weather conditions	3.27	2.93	3.27	3.27	3.75	**3.30**	10
Level of motivation	3.53	3.13	3.27	3.33	3.13	**3.28**	11
Delay on fuel supply	3.53	2.93	3.60	3.40	2.88	**3.27**	12
Mobilization in the site	2.93	2.87	3.33	3.00	3	**3.03**	13
Expedited project schedule	3.00	3.2	3.07	2.67	3	**2.99**	14
Restricted work hours	3.40	2.6	3	2.87	3	**2.97**	15
Gradation of the material	3.47	2.93	3.13	2.27		**2.95**	16
Work place preparation problem	2.93	2.8	3	3.00		**2.93**	17
Unforeseen conditions	2.47	3	2.93	2.80	2	**2.64**	18
Interference from other trades	2.87	2.6	2.53	2.47	2.25	**2.54**	19
project length	3.13	2	2.4	2.53	2.5	**2.51**	20
Night time work	2.47	2.47	2.4	2.73	2.25	**2.46**	21

4.5.2 Tests for Agreements on the contributing factors for the loss of productivity Among Respondents in the projects.

One of the purposes of this research paper is to investigate whether there is agreement or not on the attitudes of respondents towards the factors contributing for the loss of productivity for equipments involved in upgraded Asphalt road projects in Addis Ababa. Hence in this section respondents' response will be tested for correlation using Spearman rank correlation coefficients, to see if there is difference in ranking between two groups of respondents; these are Project Managers (PM) versus Site Engineers (SE); Site Engineers (SE) versus Operators (OP); and Project Managers (PM) versus Operators (OP), on the variables of contributing factors and their rate of occurrence.

The purpose of a hypothesis test is to avoid being deceived by chance occurrences. The tests also helped to evaluate whether consensus of opinions exist among respondents.

The Null Hypothesis (HO) is: -There is no agreement in the ranking of factors affecting productivity between two groups of respondents

The Alternative Hypothesis (HA) is: -There is agreement in the ranking of factors affecting productivity between two groups of respondents

The spearman correlation coefficient (ρ) is calculated using

$$\text{Rho } (\rho cal) = 1 - \frac{6 \times (\Sigma di2)}{N \times (N2 - 1)}$$

In order to decide whether to accept or reject the null hypothesis, the level of significance 95% ($P = 0.05$) is used. This allows to state whether or not there is "agreement" between respondents response.

If the calculated value of ρ is greater than the critical value, H0 is rejected, i.e. there is evidence of a statistically significant agreement between the groups. If the calculated value of ρ is less than the critical value, H0 is accepted, i.e. there is no evidence of a statistically significant agreement between the two groups.

Table 4.13 shows that the calculated value of ρ for all groups of respondents is greater than the critical value of ρ with a significance level of 95%($p<0.05$), so the hypothesis that there is no significant agreement between the respondents is rejected i.e. the null hypothesis is rejected.

It can be concluded that there is a strong correlation between the attitudes of the respondents in all the three groups and hence the null hypothesis should be rejected and the alternative hypothesis will be accepted. This means that most of the respondents have the same perception about the contributing factors for the loss of productivity.

Table 4.13: Summary of correlation test on the ranking of factors affecting productivity for Motor Grader, Excavator, Loader, Asphalt Paver and Dump Trucks

Equipment	Respondents	Rho (ρcal) = $1 - \frac{6 \times (\Sigma di2)}{Nx\ (N2-1)}$	Critical value of ρ for sample size 5	Significance for P < 0.05
Grader	PM Vs SE	0.9994	0.9000	Significant reject
	PM Vs OP	0.9982	0.9000	Significant reject
	SE Vs OP	0.9990	0.9000	Significant reject
Excavator	PM Vs SE	0.9977	0.9000	Significant reject
	PM Vs OP	0.9933	0.9000	Significant reject
	SE Vs OP	0.9958	0.9000	Significant reject
Loader	PM Vs SE	0.9972	0.9000	Significant reject
	PM Vs OP	0.9927	0.9000	Significant reject
	SE Vs OP	0.9972	0.9000	Significant reject
Asphalt paver	PM Vs SE	0.9993	0.9000	Significant reject
	PM Vs OP	0.9933	0.9000	Significant reject
	SE Vs OP	0.9947	0.9000	Significant reject
Dump Truck	PM Vs SE	0.9937	0.9000	Significant reject
	PM Vs OP	0.9824	0.9000	Significant reject
	SE Vs OP	0.9950	0.9000	Significant reject

4.6 Comparing the performance Analysis results with the contributing factors analysis result on the selected active projects.

4.6.1 Comparison for the Motor Grader

The overall view of the respondents ranked "right of way problem and efficiency of the grader, traffic conditions of the working site, and delay on supply of dumping materials" as the first four factors with a weighted average mean scores of 4.27, 4.07 and 3.93 respectively.

On the performance analysis, the performance rate ranked first as a reason for the loss of productivity. From all other factors, right of way problem and efficiency of the grader, traffic conditions of the existing road and delay on supply of dumping materials can highly affect the performing time of the grader even if it is available on the site and can do quality work.

From the Actual observation on the three selected case study projects, the management factors are the most critical reason for the loss of the Grader productivity. It is in line with the questionnaire result that shows most of the ranked factors grouped in management factor. Therefore, it is concluded that both the analysis results are in line for the indication of the loss of productivity.

4.6.2 Comparison for the Excavator

The overall view of the respondents ranked "right of way problem, efficiency of the excavator and the skill of the operator" as the first three factors with a weighted average mean scores of 4.40, 4.20 and 4.0 respectively.

On the performance analysis, the performance rate ranked first as a reason to have less OEE index on the three selected road projects. Unless the working place is free from right of way problem, the operation will not be easily executed even if the machine is available. In the mean time, if the excavator is not efficient by and the operator doesn't have a better skill, the performing cycle time will increase from the expected.

From the Actual observation on the three selected case study projects, the management factors are the most critical reason for the loss of the Excavator productivity. It is in line with the questionnaire result that ranked “right of way problem i.e. obstruction for swinging” in the first place which is grouped in management factor. These factors will lead to have less productivity which is in line with the result obtained by its OEE index.

4.6.3 Comparison for the Loader

The overall view of the respondents ranked “right of way problem, traffic conditions of the working site and maneuverability of the machine and skill of the operator” as the first four factors with a weighted average mean scores of 4.27, 4.06 and 4.0 respectively.

On the performance analysis, the quality rate ranked in the first place in Jhosansen Mola maru and Mexico Round About- Amstegna Polis Tabiya projects and performance rate in Huletegna Polis Tabiya-Kidiste Mariyam- Minilik Hospital project for the reason to have less OEE index. The contributing factors ranked in the first place are causes for the reduction of the performance rate. The quality rate becomes lower than the others due to the fact that the assignment of the loader is here and there in other engagements which are not productive.

From the Actual observation on the three selected case study projects, the Work factors are the most critical reason for the loss of the Loader productivity. It is nearly in line with the questionnaire result that ranked “traffic conditions of the working site” in the second place which is grouped in Work factor. Therefore, it is concluded that both the analysis results are nearly in line for the indication of the loss of productivity.

4.6.4 Comparison for the Asphalt paver

The overall view of the respondents ranked “Asphalt plant efficiency, efficiency of the paver and the no. of dump trucks assigned to the site” as the first three factors with a weighted average mean scores of 4.25, 4.125 and 4.0 respectively. On the performance analysis, the performance rate ranked first as a reason to have less OEE index on the three selected road projects.

From all other factors, Asphalt plant efficiency, efficiency of the paver and the no. of dump trucks assigned to the site can highly affect the performing time of the paver even if it is available on the site and can do quality work.

From the Actual observation on the two selected case study projects, the Equipment factors are the most critical reason for the loss of the Asphalt Paver productivity. It is in line with the questionnaire result that shows most of the ranked factors grouped in Equipment factor. Therefore, it is concluded that both the analysis results are in line for the indication of the loss of productivity.

4.6.5 Comparison for the Dump Truck

The overall view of the respondents ranked “efficiency of the dump truck, traffic conditions of the working site and skill of the loading equipment operator” as the first three factors with a weighted average mean scores of 4.0, 3.933 and 3.867 respectively. On the performance analysis, the performance rate ranked first as a reason to have less OEE index on the three selected road projects. If the truck is not more efficient, it is difficult to minimize the total cycle time to increase its productivity.

Unless the traffic condition on the hauling and return route is free to drive and the loading equipment operator is well skilled, the total cycle time for the truck will become longer than the expected. This will affect the performing time of the truck which results a reduction on productivity.

From the Actual observation on the three selected case study projects, the Work factors are the most critical reason for the loss of the Dump Truck productivity. It is nearly in line with the questionnaire result that ranked “traffic conditions of the working site” in the second place which is grouped in Work factor. Therefore, it is concluded that both the analysis results are nearly in line for the indication of the loss of productivity.

CHAPTER FIVE

5. Conclusions and Recommendations

This chapter includes the conclusions and recommendations that would help in solving the key problems that causes the deviation of the actual productivity with the standard performance of the construction equipment. The first objective of this study was to measure the current actual productivity of heavy-duty construction equipment. The second objective was to compare the actual with the standard performance of the construction equipment productivity based on performance charts. Identifying the key problems that causes the deviation was the third objective and the last one was to recommend corrective actions for improving the performance of the equipment.

Case study was done to evaluate and compare the actual productivity with the standard performance of the construction equipment productivity based on performance charts.

Questionnaire survey was also used to identify the contributing factors affecting the productivity of the equipments. The data gathered from the survey are analyzed using the mean score (MS).

5.1 Conclusions

Based on the results of the analysis of Case study and respondents' responses the following conclusions are drawn.

1. The OEE index revealed that, all the equipments under consideration have productivity problem in their performance that ranged from 27 – 89%.
2. Out of the three primary component rates of OEE, the availability rates ranges from (71%-98%) , the Performance rates for all the machines poorly ranges from (44-91%) and the quality rates for all the machines in all the study projects have a tolerable result ranges from (78-100%) except for the loader which has a quality range from (46-57%).

3. The third specific objective was to identify key problems influencing the productivity of the equipments. The most common contributing factors to the loss of productivity for all the equipments under consideration are Right of way problem, traffic conditions of the working site, the efficiency of the equipments and skill of the operators. These show that all the factor groups: Management factors, Work factors, Equipment factors and Human factors are the main factors affecting the equipment productivity.
4. Except for Asphalt paving operation, the External Factors, right of way problem and the traffic condition of the site were the most critical factors affecting equipment productivity which indicates that the Management factor and Work factors are the most critical factor groups.
5. The efficiency of the equipments and skill of the operators were ranked in the second place to be factors to affect the productivity.

5.2 Recommendations

The following points are recommended to all parties in order to maximize heavy-duty construction equipment productivity especially assigned on upgrading Concrete Asphalt Road projects.

1. The client should give attention on the right of way problem. Before the construction starts the client has to fulfill all the necessary requirements for delivering the site. Failure to deliver the site properly will affect the productivity of the equipments on operation.
2. In order to minimize the influence of the existing traffic condition, all possible existing diversion routes should be assessed for detour. Otherwise it is better to execute the work by making half of the lane open for traffic. Sometimes the management team of the Contractor also should consider night time work especially for materials transportation and spreading of materials.

3. Unless efficient equipments are assigned for the operation, all other factors which are related to the performance of the equipment such as searching of spare parts, maintenance period, and related equipment idleness are going to be factors for less productivity.
4. Because the projects are upgrading projects and the existing traffics are serving the road, there is a limitation of working space than other projects. Unless the operator is skilled enough to maneuver the equipment easily within that limited working area, the elapsed cycle time will highly affect the productivity. This is therefore; the project management should employ skilled operators to have a better productivity from the equipment.
5. From all other equipments, the Loader on all studied projects was engaged on other unproductive operations which can be served by other equipment types like Dumper. So, the Management can assign the loader to be more productive by assigning other equipments for transporting materials within the site.

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APPENDIX A

A-1: OEE Index for the Motor Grader on Jhosansen- Mola Maru Upgrading Road Project

Format for Data collection				
Machinery Type:- Motor Grader Mark Caterpillar Model 140H				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :Base course placing				
Productivity Rate	Sym	Independent variables	value	unit
Dependent variables	A	Available time(11 Hrs*60’)	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	201	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	459	Min
	D1	Recorded break down time(From Site)	107	Min
76.23	D2	Time spent for change in operation condition(From site)	9	Min
	D	Major stoppage losses(D= D1+D2)	116	Min
	E	Operating time(E= C-D)	343	Min
PR(%) = P*R	G	Ideal production(from manufacturer spec.)	201.51	M2/hr
50.22	H	Actual Production	168.66	M2/hr
		Width per trip(B)	3.85m	
		Length of blade(l)	4.25m	
		Angle of moldboard(A)	25.06	
		Lift thickness(L)	0.2m	

		site condition, Oper. effectiveness(f N)	0.68	
		Length of operation(f Z)	0.85	
		Number of pass(P)	19	
		Forward and backward av. speed(V)	7.2	
	O	Actual Cycle time	2	Min
	I	Production capacity losses down time I =(1-H/G)*L	33.9	Min
	K1	Number of minor stoppage	10	No.
	K2	Average duration of minor stoppage	3	Min
	K3	Idle time	105	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	135	Min
	L	Net operating time(L = E-K)	208	Min
	M	Performing time(M=L-I)	174.1	Min
	N	Valuable operating time(N= M-J)	159.1	Min
	P	Net operating rate (P = 100*H/G)	83.70	%
	Q	Ideal/theoretical/design cycle time	1.2	Min
	R	Operating speed coefficient (R =Q/O)	0.600	
	J	Time spent for rework and start up yield losses(Recorded from site)	15	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	447.20	Unit
90.57	T	Reworked amount(unit)	42.16	Unit
OEE=AR* PR*QR	34.67			%

A-2: OEE Index for the Excavator on Jhosansen- Mola Maru Upgrading Road Project

Format for Data collection				
Machinery Type:- Excavator Mark CATERPILLAR Model 318				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :- loading selected sub base				
Productivity Rate	Sym	Independent variables	value	unit
Dependent variables	A	Available time(11 Hrs*60')	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	156	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	504	Min
	D1	Recorded break down time(From Site)	5	Min
92.86	D2	Time spent for change in operation condition(From site)	31	Min
PR(%) =	D	Major stoppage losses(D= D1+D2)	36	Min
P*R	E	Operating time(E= C-D)	468	Min
44.53	G	Ideal production (from manu. spec.)	144.262	M3/hr
	H	Actual Production	85.66	M3/hr
		For Shovel Excavator		
		Job efficiency	50	min/hr
		Heaped bucket capacity	1.1	M3
		Material type	sub base	
		Bucket fill factor	0.95	

		Cycle time	20	sec
		Swell factor	0.83	
	O	Actual Cycle time	0.333	Min
	I	Production capacity losses down time I =(1-H/G)*L	136.1	Min
	K1	Number of minor stoppage	12	No.
	K2	Average duration of minor stoppage	4	Min
	K3	Idle time	85	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	133	Min
	L	Net operating time(L = E-K)	335	Min
	M	Performing time(M=L-I)	198.9	Min
	N	Valuable operating time(N= M-J)	163.9	Min
	P	Net operating rate (P = 100*H/G)	59.38	%
	Q	Ideal/theoretical/design cycle time	0.25	Min
	R	Operating speed coefficient (R =Q/O)	0.75	
	J	Time spent for rework and start up yield losses(Recorded from site)	35	Min
QR(%)= (S-T)/S	S	Total executed amount(unit)	233.99	Unit
	T	Reworked amount(unit)	49.97	
78.65				Unit
OEE=AR* PR*QR	32.52			%

A-3: OEE Index for the Loader on Jhosansen- Mola Maru Upgrading Road Project

Format for Data collection				
Machinery Type:- Loader Mark ZL50G				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :waste loading and leveling				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(11Hrs*60')	660	Min
AR(%)= 100*E/C	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	98	Min
91.46	C	Loading time(C= A-B)	562	Min
	D1	Recorded break down time(From Site)		Min
	D2	Time spent for change in operation condition(From site)	48	Min
	D	Major stoppage losses(D= D1+D2	48	Min
	E	Operating time(E= C-D)	514	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	338.700	M3/hr
66.56	H	Actual Production	240.47	M3/hr
		Job efficiency	50	min/hr
		Bucket load	3	M3
		Loaded material type	excavation	
		Cycle time	30	

		Load factor	0.9	
		Bucket fill factor	0.95	
	O	Actual Cycle time	0.533	Min
	I	Production capacity losses down time I =(1-H/G)*L	99.2	Min
	K1	Number of minor stoppage	15	No.
	K2	Average duration of minor stoppage	2	Min
	K3	Idle time	142	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	172	Min
	L	Net operating time(L = E-K)	342	Min
	M	Performing time(M=L-I)	242.8	Min
	N	Valuable operating time(N= M-J)	157.8	Min
	P	Net operating rate (P = 100*H/G)	71.00	%
	Q	Ideal/theoretical/design cycle time	0.50	Min
	R	Operating speed coefficient (R =Q/O)	0.94	
	J	Time spent for rework and start up yield losses(Recorded from site)	85	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	632.48	Unit
	T	Reworked amount(unit)	340.66	
46.14				Unit
OEE=AR* PR*QR	28.09			%

A-4: OEE Index for the Dump Truck on Jhosansen- Mola Maru Upgrading Road Project

Format for Data collection				
Machinery Type:- Dump Truck Mark :- Sino Truck				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :Hauling of Selected Sub base				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(11Hrs*60')	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	60	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	600	Min
	D1	Recorded break down time(From Site)		Min
96.67	D2	Time spent for change in operation condition(From site)	20	Min
	D	Major stoppage losses(D= D1+D2)	20	Min
	E	Operating time(E= C-D)	580	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	10.066	M3/hr
88.17	H	Actual Production	9.45	M3/hr
		For Dump Truck		
		unit weight of the material	2.09	g/cm3
		load factor	0.9	
		bucket fill factor	0.95	

		Rolling Resistance	0.02	
		loader capacity	3	m3
		pay load	231.24	KN
		empty weight of vehicle	145.04	KN
		Average speed factor	0.60	
		efficiency of drive	0.75	
		power or output of the motor	250.62	KW
		cycle time of loader	30.00	sec
		dump time	60.00	sec
		maneuver time	15.00	sec
	O	Actual Cycle time	53.750	Min
	I	Production capacity losses down time I =(1-H/G)*L	33.2	Min
	K1	Number of minor stoppage	0	No.
	K2	Average duration of minor stoppage	0	Min
	K3	Idle time	35	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	35	Min
	L	Net operating time(L = E-K)	545	Min
	M	Performing time(M=L-I)	511.8	Min
	N	Valuable operating time(N= M-J)	511.8	Min

	P	Net operating rate (P = 100*H/G)	93.90	%
	Q	Ideal/theoretical/design cycle time	50.47	Min
	R	Operating speed coefficient (R =Q/O)	0.94	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)= (S-T)/S	S	Total executed amount(unit)	80.62	Unit
	T	Reworked amount(unit)	0.00	
100.00				Unit
OEE=AR*PR*QR	85.23			%

A-5: OEE Index for the Asphalt Paver on Jhosansen- Mola Maru Upgrading Road Project

Format for Data collection				
Machinery Type:- Asphalt Paver Mark:- Dynapac				
One day = 10 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :-Asphalt Paving				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(10Hrs*60')	600	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	40	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	560	Min
	D1	Recorded break down time(From Site)		Min

90.27	D2	Time spent for change in operation condition(From site)	54.5	Min
	D	Major stoppage losses(D= D1+D2)	54.5	Min
	E	Operating time(E= C-D)	505.5	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	120.000	ton/hr
80.00	H	Actual Production	96.00	ton/hr
		Truck loading time	12	min
		Truck haul time	15	min
		Truck dump time	9	min
		Truck return time	15	min
		Truck total cycle time	51	min
		Paving thickness	6	cm
		Width of paving per pass	7	m
		Unit weight of the AC	2.423	ton/m3
		Average plant production	96	ton/hr
		No of dump trucks Assigned	9	
		truck capacity	24	ton
	O	Actual Cycle time	51.00	Min
	I	Production capacity losses down time I =(1-H/G)*L	101.1	Min
	K1	Number of minor stoppage	0	No.
	K2	Average duration of minor stoppage	0	Min
	K3	Idle time	0	Min

	K	Minor stoppages/Idle losses(K= K1*K2+K3)	0	Min
	L	Net operating time(L = E-K)	505.5	Min
	M	Performing time(M=L-I)	404.4	Min
	N	Valuable operating time(N= M-J)	404.4	Min
	P	Net operating rate (P = 100*H/G)	80.00	%
	Q	Ideal/theoretical/design cycle time	51.00	Min
	R	Operating speed coefficient (R =Q/O)	1.00	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	647.04	Unit
	T	Reworked amount(unit)	0.00	
100.00				Unit
OEE=AR*PR*QR	72.21			%

A-6: OEE Index for the Motor Grader on Huletegna Polis Tabiya- Kidiste Mariyam-Minilik Hospital Upgrading Road Project

Format for Data collection				
Machinery Type:- Motor Grader Mark Caterpillar Model 140H				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :- Selected sub base placing				
Prod.Rate	Sym	Independent variables		unit

D.variables	A	Available time(11 Hrs*60’)	660	Min
AR(%)= 100*E/C	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	122	Min
78.93	C	Loading time(C= A-B)	538	Min
	D1	Recorded break down time(From Site)	100	Min
	D2	Time spent for change in operation condition(From site)	14	Min
	D	Major stoppage losses(D= D1+D2)	114	Min
PR(%) =	E	Operating time(E= C-D)	424	Min
P*R	G	Ideal production (from manu. spec.)	201.51	M2/hr
49.33	H	Actual Production	165.67	M2/hr
		Width per trip(B)	3.85m	
		Length of blade(l)	4.27m	
		Angle of moldboard(A)	25.63	
		Lift thickness(L)	0.15m	
		Operator effectiveness(f N)	0.765	
		Length of operation(f Z)	0.85	
		Number of pass(P)	15	
		Forward and backward av. speed(V)	6.6	
	O	Actual Cycle time	2	Min
	I	Production capacity losses down time I =(1-H/G)*L	43.57	Min

	K1	Number of minor stoppage	4	No.
	K2	Average duration of minor stoppage	2	Min
	K3	Idle time	171	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	179	Min
	L	Net operating time(L = E-K)	245	Min
	M	Performing time(M=L-I)	201.43	Min
	N	Valuable operating time(N= M-J)	168.43	Min
	P	Net operating rate (P = 100*H/G)	82.21	%
	Q	Ideal/theoretical/design cycle time	1.2	Min
	R	Oper. speed coefficient (R =Q/O)	0.600	
QR(%)=(S-T)/S 80.41	J	Time spent for rework and start up yield losses(Recorded from site)	33	Min
	S	Total executed amount(unit)	465.05	Unit
	T	Reworked amount(unit)	91.12	Unit
OEE=AR* PR*QR	31.31			%

A-7: OEE Index for the Excavator on Huletegna Polis Tabiya- Kidiste Mariyam- Minilik Hospital Upgrading Road Project

Format for Data collection				
Machinery Type:- Excavator Mark CATERPILLAR Model 320				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :- loading capping				
Prod.Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(11 Hrs*60')	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	118	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	542	Min
	D1	Recorded break down time(From Site)		Min
85.79	D2	Time spent for change in operation condition(From site)	77	Min
	D	Major stoppage losses(D= D1+D2)	77	Min
PR(%) =	E	Operating time(E= C-D)	465	Min
P*R	G	Ideal production (from manu. spec.)	144.26	M3/hr
69.58	H	Actual Production	107.07	M3/hr
		Job efficiency	50	min/hr
		Heaped bucket capacity	1.1	M3
		Material type	capping	
		Bucket fill factor	0.95	

		Cycle time	16	sec
		Swell factor	0.83	
	O	Actual Cycle time	0.267	Min
	I	Production capacity losses down time I =(1-H/G)*L	112.4	Min
	K1	Number of minor stoppage	8	No.
	K2	Average duration of minor stoppage	2	Min
	K3	Idle time	13	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	29	Min
	L	Net operating time(L = E-K)	436	Min
	M	Performing time(M=L-I)	323.6	Min
	N	Valuable operating time(N= M-J)	323.6	Min
	P	Net operating rate (P = 100*H/G)	74.22	%
	Q	Ideal/theoretical/design cycle time	0.25	Min
	R	Operating speed coefficient (R =Q/O)	0.9375	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)= (S-T)/S	S	Total executed amount(unit)	577.45	Unit
	T	Reworked amount(unit)	0.00	
100.00				Unit
OEE=AR* PR*QR	59.70			%

A-8: OEE Index for the Loader on Huletegna Polis Tabiya- Kidiste Mariyam- Minilik Hospital Upgrading Road Project

Format for Data collection				
Machinery Type:- Loader Mark ZL50G				
One day = 11 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :waste loading and leveling				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(11Hrs*60')	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site	98	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	562	Min
	D1	Recorded break down time(From Site)		Min
91.46	D2	Time spent for change in operation condition(From site)	48	Min
	D	Major stoppage losses(D= D1+D2	48	Min
	E	Operating time(E= C-D)	514	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	338.700	M3/hr
66.56	H	Actual Production	240.47	M3/hr
		Job efficiency	50	min/hr
		Bucket load	3	M3
		Loaded material type	excavation	

		Cycle time	30	
		Load factor	0.9	
		Bucket fill factor	0.95	
	O	Actual Cycle time	0.533	Min
	I	Production capacity losses down time I =(1-H/G)*L	99.2	Min
	K1	Number of minor stoppage	15	No.
	K2	Av.duration of minor stoppage	2	Min
	K3	Idle time	142	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	172	Min
	L	Net operating time(L = E-K)	342	Min
	M	Performing time(M=L-I)	242.8	Min
	N	Valuable operating time(N= M-J)	157.8	Min
	P	Net operating rate (P = 100*H/G)	71.00	%
	Q	Ideal/theoretical/design cycle time	0.50	Min
	R	Oper. speed coefficient (R =Q/O)	0.94	
	J	Time spent for rework and start up yield losses(Recorded from site)	85	Min
QR(%)=(S-T)/S=46.14	S	Total executed amount(unit)	632.48	Unit
	T	Reworked amount(unit)	340.66	
OEE=AR* PR*QR	28.09			%

A-9: OEE Index for the Dump Truck on Huletegna Polis Tabiya- Kidiste Mariyam- Minilik Hospital Upgrading Road Project

Format for Data collection				
Machinery Type:- Dump Truck Mark :- Sino Truck				
One day = 11 hrs 9Construction Equipment with cyclic operating Machines)				
Type of Activity :Hauling of Selected Sub base				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(11Hrs*60')	660	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	60	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	600	Min
	D1	Recorded break down time	0	Min
97.33	D2	Time spent for change in operation condition(From site)	16	Min
	D	Major stoppage losses(D= D1+D2	16	Min
	E	Operating time(E= C-D)	584	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	8.352	M3/hr
91.04	H	Actual Production	7.97	M3/hr
		unit weight of the material	2.18	g/cm3
		load factor	0.9	
		bucket fill factor	0.95	

		Rolling Resistance	0.02	
		loader capacity	3	m3
		pay load	241.19	KN
		empty weight of vehicle	145.04	KN
		Average speed factor	0.60	
		efficiency of drive	0.75	
		power or out put of the motor	250.62	KW
		cycle time of loader	30.00	sec
		dump time	60.00	sec
		manuever time	15.00	sec
	O	Actual Cycle time	63.75	Min
	I	Production capacity losses down time I =(1-H/G)*L	25.5	Min
	K1	Number of minor stoppage	0	No.
	K2	Average duration of minor stoppage	0	Min
	K3	Idle time	27	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	27	Min
	L	Net operating time(L = E-K)	557	Min
	M	Performing time(M=L-I)	531.5	Min
	N	Valuable operating time(N= M-J)	531.5	Min
	P	Net operating rate (P = 100*H/G)	95.41	%
	Q	Ideal/theoretical/design cycle time	60.83	Min

	R	Operating speed coefficient (R =Q/O)	0.95	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	70.59	Unit
100.00	T	Reworked amount(unit)	0.00	unit
OEE=AR* PR*QR	88.61			%

A-10: OEE Index for the Asphalt Paver on Huletegna Polis Tabiya- Kidiste Mariyam-Minilik Hospital Upgrading Road Project

Format for Data collection				
Machinery Type:- Asphalt Paver Mark:- Dynapac				
One day = 10 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :-Asphalt Paving				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(10Hrs*60’)	600	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	80	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	520	Min
	D1	Recorded break down time		Min
97.12	D2	Time spent for change in operation condition(From site)	15	Min

	D	Major stoppage losses(D= D1+D2)	15	Min
	E	Operating time(E= C-D)	505	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	120.000	ton/hr
75.56	H	Actual Production	96.00	ton/hr
		Truck loading time	15	min
		Truck haul time	30	min
		Truck dump time	15	min
		Truck return time	30	min
		Truck total cycle time	90	min
		Paving thickness	6	cm
		Width of paving per pass	7	m
		Unit weight of the AC	2.423	ton/m3
		Average plant production	96	ton/hr
		No of dump trucks Assigned	9	
		truck capacity	24	ton
	O	Actual Cycle time	90.000	Min
	I	Production capacity losses down time I =(1-H/G)*L	95.4	Min
	K1	Number of minor stoppage	0	No.
	K2	Average duration of minor stoppage	0	Min
	K3	Idle time	28	Min

	K	Minor stoppages/Idle losses(K= K1*K2+K3)	28	Min
	L	Net operating time(L = E-K)	477	Min
	M	Performing time(M=L-I)	381.6	Min
	N	Valuable operating time(N= M-J)	381.6	Min
	P	Net operating rate (P = 100*H/G)	80.00	%
	Q	Ideal/theoretical/design cycle time	85.00	Min
	R	Operating speed coefficient (R =Q/O)	0.94	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	610.56	Unit
	T	Reworked amount(unit)	0.00	
100.00				Unit
OEE=AR*PR*QR	73.38			%

A-11: OEE Index for the Motor Grader on Mexico Round About-Amstegna Polis Tabiya Upgrading Road Project

Format for Data collection				
Machinery Type:- Motor Grader Mark Caterpillar Model 140H				
One day = 9 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :-Base course placing				
Pty Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(9 Hrs*60')	540	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	99	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	441	Min
	D1	Recorded break down time		Min
94.78	D2	Time spent for change in operation condition(From site)	23	Min
	D	Major stoppage losses(D= D1+D2	23	Min
PR(%) =P*R	E	Operating time(E= C-D)	418	Min
62.69	G	Ideal production(from manu spec.)	291.31	M2/hr
	H	Actual Production	228.28	M2/hr
		Width per trip(B)	2.75	
		Length of blade(l)	3.65	
		Angle of moldboard(A)	41.11	

		Lift thickness(L)	0.2	
		Operator effectiveness(f N)	0.765	
		Length of operation(f Z)	0.85	
		Number of pass(P)	10	
		Forward & backward av. speed(V)	6.4	
	O	Actual Cycle time	1.5	Min
	I	Production capacity losses down time I =(1-H/G)*L	67.73	Min
	K1	Number of minor stoppage	5	No.
	K2	Av. duration of minor stoppage	9	Min
	K3	Idle time	60	Min
	K	Minor stoppages/Idle losses	105	Min
	L	Net operating time(L = E-K)	313	Min
	M	Performing time(M=L-I)	245.27	Min
	N	Valuable operating time(N= M-J)	195.27	Min
	P	Net operating rate (P = 100*H/G)	78.36	%
	Q	Ideal/theoretical/design cycle time	1.20	Min
	R	Operating speed coefficient (Q/O)	0.800	
QR(%)=(S-T)/S 74.40	J	Time spent for rework and start up yield losses(Recorded from site)	50	Min
	S	Total executed amount(unit)	742.95	Unit
	T	Reworked amount(unit)	190.23	Unit
OEE=AR*PR*QR	44.21			%

A-12: OEE Index for the Excavator on Mexico Round About-Amstegna Polis Tabiya Upgrading Road Project

Format for Data collection				
Machinery Type:- Excavator Mark CATERPILLAR Model 320				
One day = 9hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :- ditch excavation				
Pty Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(9Hrs*60’)	540	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	78	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	462	Min
	D1	Recorded break down time		Min
94.59	D2	Time spent for change in operation condition(From site)	25	Min
	D	Major stoppage losses(D= D1+D2)	25	Min
	E	Operating time(E= C-D)	437	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	245.000	M3/hr
55.19	H	Actual Production	175.00	M3/hr
		Job efficiency	50	min/hr
		Heaped bucket capacity	2.1	M3
		Bucket fill factor	1.0	

		Cycle time	22	sec
		Swell factor	0.8	
		Material type	excavation	
	O	Actual Cycle time	0.367	Min
	I	Production capacity losses down time I =(1-H/G)*L	94.6	Min
	K1	Number of minor stoppage	3	No.
	K2	Av. duration of minor stoppage	5	Min
	K3	Idle time	91	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	106	Min
	L	Net operating time(L = E-K)	331	Min
	M	Performing time(M=L-I)	236.4	Min
	N	Valuable operating time(N= M-J)	207.4	Min
	P	Net operating rate(P = 100*H/G)	71.43	%
	Q	Ideal/theoretical/design cycle tim	0.28	Min
	R	Operating speed coefficientQ/O)	0.77	
	J	Time spent for rework	29	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	605.00	Unit
86.02	T	Reworked amount(unit)	84.58	
OEE=AR* PR*QR	44.91			%

A-13: OEE Index for the Loader on Mexico Round About-Amstegna Polis Tabiya Upgrading Road Project

Format for Data collection				
Machinery Type:- Loader Mark ZL50G				
One day =9 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :waste loading and leveling				
Pty Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(9Hrs*60')	540	Min
AR(%)= 100*E/C	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	79	Min
	C	Loading time(C= A-B)	461	Min
	D1	Recorded break down time	3	Min
94.36	D2	Time spent for change in operation condition(From site)	23	Min
	D	Major stoppage losses(D= D1+D2)	26	Min
	E	Operating time(E= C-D)	435	Min
PR(%)= P*R	G	Ideal production (from manufacturer	360.0	M3/hr
67.50	H	Actual Production	243.00	M3/hr
		Job efficiency	50	min/hr
		Bucket load	3	M3
		Loaded material type	excavation	

		Cycle time	30	sec
		Load factor	0.9	
		Bucket fill factor	0.95	
	O	Actual Cycle time	0.5	Min
	I	Production capacity losses down time I =(1-H/G)*L	115.1	Min
	K1	Number of minor stoppage	10	No.
	K2	Average duration of minor stoppage	5	Min
	K3	Idle time	31	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	81	Min
	L	Net operating time(L = E-K)	354	Min
	M	Performing time(M=L-I)	239.0	Min
	N	Valuable operating time(N= M-J)	167.0	Min
	P	Net operating rate (P = 100*H/G)	67.50	%
	Q	Ideal/theoretical/design cycle time	0.50	Min
	R	Operating speed coefficient (R =Q/O)	1.00	
	J	Time spent for rework and start up yield losses(Recorded from site)	72	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	676.15	Unit
	T	Reworked amount(unit)	291.60	
56.87				Unit
OEE=AR*PR*QR	36.22			%

A-14: OEE Index for the Dump Truck on Mexico Round About-Amstegna Polis Tabiya Upgrading Road Project

Format for Data collection				
Machinery Type:- Dump Truck Mark :- Sino Truck				
One day =9 hrs(Construction Equipment with cyclic operating Machines)				
Type of Activity :Hauling of waste materials				
Productivity Rate	Sym	Independent variables		unit
Dependent variables	A	Available time(9Hrs*60')	540	Min
	B	Scheduled maintenance + scheduled production break (To be recorded from the site)	40	Min
AR(%)= 100*E/C	C	Loading time(C= A-B)	500	Min
	D1	Recorded break down time(From Site)	0	Min
96.00	D2	Time spent for change in operation condition(From site)	20	Min
	D	Major stoppage losses(D= D1+D2)	20	Min
	E	Operating time(E= C-D)	480	Min
PR(%) = P*R	G	Ideal production (from manufacturer spec.)	16.850	M3/hr
77.92	H	Actual Production	14.88	M3/hr
		unit weight of the material	2.3	g/cm3
		load factor	0.9	
		bucket fill factor	0.95	
		Rolling Resistance	0.02	
		loader capacity	3	m3
		pay load	254.47	KN
		empty weight of vehicle	145.04	KN
		Average speed factor	0.60	

		efficiency of drive	0.75	
		power or out put of the motor	250.62	KW
		cycle time of loader	35.00	sec
		dump time	60.00	sec
		maneuver time	15.00	sec
	O	Actual Cycle time	34.160	Min
	I	Production capacity losses down time I =(1-H/G)*L	49.6	Min
	K1	Number of minor stoppage	5	No.
	K2	Average duration of minor stoppage	8	Min
	K3	Idle time	16.5	Min
	K	Minor stoppages/Idle losses(K= K1*K2+K3)	56.5	Min
	L	Net operating time(L = E-K)	423.5	Min
	M	Performing time(M=L-I)	373.9	Min
	N	Valuable operating time(N= M-J)	373.9	Min
	P	Net operating rate (P = 100*H/G)	88.30	%
	Q	Ideal/theoretical/design cycle time	30.15	Min
	R	Operating speed coefficient (R =Q/O)	0.88	
	J	Time spent for rework and start up yield losses(Recorded from site)	0	Min
QR(%)=(S-T)/S	S	Total executed amount(unit)	92.72	Unit
	T	Reworked amount(unit)	0.00	
100.00				Unit
OEE=AR*PR *QR	74.80			%

APPENDIX B

Questionnaire for Research Thesis

Introduction

Dear respondents this questionnaire is prepared to obtain information from key informants with semi –structured questions. The information is required for the academic research entitled "Assessment of Construction Equipments Productivity on Upgraded Concrete Asphalt Road Projects: A Case Study in Addis Ababa.", which is being conducted as partial fulfillment of MSc in construction technology and management. One of the objectives of this research is to identify the main factors that cause the difference of actual productivity from the standard performance.

The questionnaire consists of two sections. Section A general organization information and Section B contains main factors that cause the difference of actual productivity from the standard performance on upgraded concrete asphalt road projects in Addis Ababa. At the end there is a space that left for general comments regarding the research topic.

Your response, in this regard, is highly valuable and contributory to the outcome of the research.

All feedback will be kept strictly confidential, and utilized for this academic research only.

Thank you,

Tewodros Demissie

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Adama

SECTION A: GENERAL INFORMATION

1. Name of the Contractor: ---

2. Grade of the Contractor:---

3. Respondents designation:

Project manager ☐ Site Engineer ☐ Operator ☐ Other ☐

4. Relevant working experience (Years):

1-4Yrs ☐ 4-8Yrs ☐ 8-12Yrs ☐ >12Yrs ☐ others ☐

Section B: Main factors that cause the difference of actual productivity from the standard performance on upgraded concrete asphalt road projects in Addis Ababa.

According to the scope of the study, this questionnaire is prepared to obtain information about the following Equipments.

1. Asphalt Paver
2. Motor Grader
3. Excavator
4. Loader
5. Dump Trucks

Please indicate the significance of each factor by ticking the appropriate boxes. Add any remarks relating to each factor on the last column e.g. as to the reasons, the critical factors or the solutions.

Level of the factors	Weight
extremely significant	5
very significant	4
moderately significant	3
slightly significant	2
not significant	1

B1: For Asphalt Paver

No.	How Significant do you think these factors affect the productivity?	E. S. (5)	V. S. (4)	M.S. (3)	S.S (2)	N. S (1)	
	Equipment factor						
1	Efficiency of the paver						
2	Turning radius of the paver						
3	Hopper capacity of the paver						
4	Auger diameter of the paver						
5	Paving related equipments break down						
6	Efficiency of the roller						
7	Asphalt plant efficiency						
8	Shortage of small supportive tools						
9	Type of roller						
10	No of rollers						
11	Speed and timing of roller						
12	No of passes of the roller						
13	No of dumping trucks						

14	Shortage of shower truck						
	Materials property factor						
1	Hot mix asphalt production temperature						
2	Mix property(gradation, size, shape ,volume)						
3	Asphalt binder grade or viscosity						
	Construction factor						
1	Project length						
2	Paving width						
3	Mobilization within the site						
4	Joint preparation for extension						
5	Delay on supply of the asphalt concrete						
7	Delay on fuel supply						
8	Grade change of the section						
9	Night time paving						
10	Limited work area						
11	Size and proximity of production yard and staging areas						
12	Type of terrain(level ,rolling, or hilly)						
13	Need for scratch or leveling layer						
14	Asphalt Lift thickness						
15	Hauling distance						
16	Asphalt hauling time to job site						
17	Foundation support for the paver						
18	Dumping the asphalt to the paver						
19	Type of operation(may be overlay)						
20	Activity dependency						

21	Project constraints like intersection, driveway, roundabouts, presence of utilities						
22	Staged construction(portions of road way done in different stages and multiple mobilization)						
	Management factor						
1	Poor paving crew coordination						
2	Discontinuity of paving work						
3	Instruction time						
4	Expedited project schedule(over time, extra shifts, more crew)						
5	Restricted work hours (start and stop time limited by contract)						
	Human factor						
1	Delay on leveling work						
2	Absenteeism of the operator						
3	Changing of the foremen						
4	Skill of the paver operator						
5	Skill of the roller operator						
6	Level of motivation of the crew						
	External factor						
1	Interference from other trades						
2	Weather conditions (Ground temperature, Air temperature, Wind speed, paving during winter, rainy...)						
3	Traffic conditions (Paving adjacent to existing traffic, Difficulty in						

	delivering materials to paving site)						
4	Right of way problem						
5	Unforeseen conditions						

B2: For Motor Grader

No.	How Significant do you think these factors affect the productivity?	E.S (5)	V. S. (4)	M.S. (3)	S. S. (2)	N. S. (1)	
	Equipment factor						
1	Efficiency of the Grader						
2	Turning radius of the grader						
3	The blade type(length ,height, thickness)						
4	Maximum digging depth of the ripper						
5	Effective blade width (Width graded per pass)						
6	Maneuverability of equipment						
7	Placing related equipments break down						
8	Efficiency of the roller						
9	Type of roller						
10	No of rollers						
11	Speed and timing of roller						
12	No of passes of the roller						
13	No of dumping trucks						
14	Life of grading related equipments						
15	Shortage of shower truck						
	Materials property factor						

1	Gradation of the material						
2	Moisture content of the material						
3	Nature of the material						
	Construction factor						
1	Operation type (mixing, windrowing, placing, grading, shaping, cutting, edging)						
2	Direction of travel						
3	Roughness of the surface						
4	Condition of haul roads						
5	Specification requirement						
6	Long job span						
7	Availability of working space						
8	Placing width						
9	Mobilization within the site						
10	Delay on supply of dumping materials						
11	Delay on fuel supply						
12	Grade change of the section						
13	Activity dependency						
	Management factor						
1	Work place preparation problem(request for inspection, supervision, approval for continuation)						
2	Expedited project schedule(over time, extra shifts, more crew)						
3	Restricted work hours (start and stop time limited by contract)						

4	Night time work						
5	Equipment maintenance facility						
6	Poor grading crew coordination						
7	Discontinuity of grading work						
	Human factor						
1	Delay on leveling work						
2	Level of motivation of the crew						
3	Absenteeism of the operator						
4	Changing of the foremen						
5	Skill of the Grader operator						
6	Skill of the roller operator						
7	Skill of the shower truck operator						
	External factor						
1	Interference from other trades						
2	Weather conditions (Ground temperature, Air temperature, Wind speed, paving during winter, rainy...)						
3	Traffic conditions (Paving adjacent to existing traffic, Difficulty in delivering materials to placing site)						
4	Right of way problem						
5	Unforeseen conditions						

B3: For Shovel Excavator

No.	How Significant do you think these factors affect the productivity?	E.S. (5)	V.S. (4)	M.S. (3)	S.S. (2)	N.S. (1)	
	Equipment factor						
1	Efficiency of the Excavator						
2	Maneuverability of equipment						
3	Excavator working efficiency						
4	No of dumping trucks						
	Materials property factor						
1	Size distribution						
2	Moisture content of the material						
3	Nature of the material(rock, soil, intermediate)						
4	Effects of the looseness						
	Construction factor						
1	Operation type (excavating, digging, loading, sloping)						
2	Specification requirement for slope work						
3	Mobilization within the site						
4	Delay on fuel supply						
5	Digging depth						
6	Dump height on trucks						
7	Project length						
8	Angle of swing						
9	Place for cycle route						
10	Slope of the operating area						
11	Amount of movement						
12	Haul unit positioning						

13	Activity dependency						
	Management factor						
1	Expedited project schedule(over time, extra shifts, more crew)						
2	Restricted work hours (start and stop time limited by contract)						
3	Night time work						
4	Equipment maintenance facility						
5	Poor crew coordination						
6	Work place preparation problem(request for inspection, supervision, approval for continuation)						
	Human factor						
1	Absenteeism of the operator						
2	Level of motivation of the crew						
3	Skill of the Excavator operator						
	External factor						
1	Interference from other trades						
2	Weather conditions (Ground temperature, Air temperature, Wind speed, paving during winter, rainy...)						
3	Traffic conditions (Paving adjacent to existing traffic, Difficulty in delivering materials to placing site)						
4	Right of way problem						
5	Unforeseen conditions						

B4: For Loader

No.	How Significant do you think these factors affect the productivity?	E. S. (5)	V.S. (4)	M.S. (3)	S. S. (2)	N. S. (1)	
	Equipment factor						
1	Efficiency of the loader						
2	Maneuverability of equipment						
3	Loader working efficiency						
4	No of dumping trucks						
	Materials property factor						
1	Size distribution						
2	Moisture content of the material						
3	Nature of the material(rock, soil, intermediate)						
4	Effects of the looseness						
	Construction factor						
1	Operation type (cutting, loading, sloping)						
2	Mobilization within the site						
3	Delay on fuel supply						
4	Digging depth						
5	Activity dependency						
6	Dump height on trucks						
7	Project length						
9	Place for cycle route						
10	Slope of the operating area						
11	Amount of movement						
12	Haul unit positioning						
	Management factor						
1	Expedited project schedule(over time,						

	extra shifts, more crew)						
2	Restricted work hours (start and stop time limited by contract)						
3	Night time work						
4	Equipment maintenance facility						
5	Poor crew coordination						
6	Work place preparation problem(request for inspection, supervision, approval for continuation)						
	Human factor						
1	Absenteeism of the operator						
2	Level of motivation of the crew						
3	Skill of the Loader operator						
	External factor						
1	Interference from other trades						
2	Weather conditions (Ground temperature, Air temperature, Wind speed, paving during winter, rainy...)						
3	Traffic conditions (Paving adjacent to existing traffic, Difficulty in delivering materials to placing site)						
4	Right of way problem						
5	Unforeseen conditions						

B5: For Dump Trucks

No.	How Significant do you think these factors affect the productivity?	E. S. (5)	V.S. (4)	M.S. (3)	S.S. (2)	N.S. (1)	
	Equipment factor						
1	Efficiency of the Dump Truck						
2	Maneuverability of trucks						
3	Trucks working efficiency						
4	Efficiency of the loading equipment						
5	Loading related equipments break down						
	Materials property factor						
1	Size distribution						
2	Moisture content of the material						
3	Nature of the material(rock, soil, intermediate)						
4	Effects of the looseness						
	Construction factor						
1	Grade of the travel route						
2	Delay on fuel supply						
3	Length of the hauling distance						
4	Mobilization within the site						
5	Project length						
	Management factor						
1	Expedited project schedule(over time, extra shifts, more crew)						
2	Restricted work hours (start and stop time limited)						
3	Night time work						
4	Equipment maintenance facility						

5	Poor crew coordination						
6	Dumping place preparation problem(request for inspection, supervision, approval for continuation)						
	Human factor						
1	Absenteeism of the operator						
2	Level of motivation of the crew						
3	Skill of the Dump Truck operator						
4	Skill of the Loading equipment operator						
	External factor						
1	Interference from other trades						
2	Weather conditions (Ground temperature, Air temperature, Wind speed, paving during winter, rainy...)						
3	Traffic conditions (Paving adjacent to existing traffic, Difficulty in delivering materials to placing site)						
4	Right of way problem						
5	Unforeseen conditions						

If you have comments regarding actual equipments productivity kindly request to write here

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APPENDIX C

Spearman's Rank Table

Sample size(n)	p = 0.05	p = 0.025	p = 0.01
4	1.0000 - -		
5	0.9000	1.0000	1.0000
6	0.286	0.8857	0.9429
7	0.7143	0.7857	0.8929
8	0.6429	0.7381	0.8333
9	0.6000	0.7000	0.7833
10	0.5636	0.6485	0.7455
11	0.5364	0.6182	0.7091
12	0.5035	0.5874	0.6783
13	0.4825	0.5604	0.6484
14	0.4637	0.5385	0.6264
15	0.4464	0.5214	0.6036
16	0.4294	0.5029	0.5824
17	0.4142	0.4877	0.5662
18	0.4014	0.4716	0.5501
19	0.3912	0.4596	0.5351
20	0.3805	0.4466	0.5218
21	0.3701	0.4364	0.5091
22	0.3608	0.4252	0.4975
23	0.3528	0.416	0.4862
24	0.3443	0.407	0.4757
25	0.3369	0.3977	0.4662
26	0.3306	0.3901	0.4571
27	0.3242	0.3828	0.4487
28	0.318	0.3755	0.4401
29	0.3118	0.3685	0.4325
30	0.3063	0.3624	0.4251
40	0.264	0.3128	0.3681
50	0.2353	0.2791	0.3293
60	0.2144	0.2545	0.3005
70	0.1982	0.2354	0.2782
80	0.1852	0.2201	0.2602
90	0.1745	0.2074	0.2453
100	0.1654	0.1967	0.2327