Jimma University

School of Graduate Studies

Jimma Institute of Technology

School of Civil and Environmental Engineering

(Construction Engineering and Management Stream)

COMPARATIVE STUDY OF ACTUAL PRODUCTIVITY AND THEORETICAL PRODUCTIVITY OF CONSTRUCTION EQUIPMENTS AND ITS REMEDIAL MEASURES

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Construction Engineering and Management

By: Tsegaye Damtew

June, 2017

Jimma, Ethiopia

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Main Advisor: Dr.Eng. Esayas Alemayehu, Asso.Prof.,

Co-Advisor: Eng. Elmer C. Ago

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DECLARATION

I, the undersigned, declare that this thesis entitled "**Comparative Study of Actual and Theoretical Productivity of Construction Equipments and its Remedial Measures**" is my original work, and has not been presented for any other person for an award of a degree in this university or any other universities, and all sources of material used for the thesis have been duly acknowledged. Therefore, whatever the result of my thesis final defense based on the criteria as evaluated by the examiners, will be ACCEPTED in good faith.

Tsegaye Damtew ____________________ ____________________

Student Signature Date

As Master research Advisors, we hereby certify that we have reviewed carefully the document and prepared under our guidance by **Mis. Tsegaye Damtew,** her thesis entitled: "**Comparative Study of Actual and Theoretical productivity of construction Equipments and its Remedial Measures''**

Therefore, we recommend that this document would be submitted to fulfilling the MSc Thesis requirements in this University.

Dr,Ing. Esayas Alemahehu ____________________ ____________________

(Advisor) Signature Date

Eng. Elmer C. Agon ____________________ ____________________

(Co-Advisor) Signature Date

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ABSTRACT

Modern construction is characterized by effective and efficient utilization of equipment to accomplish numerous construction activities. Construction industry in Ethiopia suffers with low productivity performance; improving heavy-duty construction equipment productivity in the sector has a significant effect on the industries economy as construction projects are equipment intensive. This paper help to minimize losses of equipment productivity by identifying factors contributing to equipment productivity loss and examine the overall performance of heavy duty construction equipment on the case study federal road construction project, namely Beddelle –Mattu upgrading road project. This study also lists some remedial measures to improve productivity of construction equipments.

The assessment involved in this study was field observation and measurements to quantify equipment actual production per hour and downtime. Desk study to identify main factors contributing for productivity loss and their remedial measures.

From the computation the OEE index shows that low percentage of productivity in between (48-65%). Out of the three primary component performance rate lower (less than 75%) while quality rate (greater than 90%) which is acceptable and availability rate between (84-88%) which indicate weak performance at the selected site. Management factor ranked first (64.24%) for the performance losses and human factor (17.85%),machine factor (10.71%) and work factor (7.14) respectively ranked second, third and the least factor that contributing to equipment productivity losses. Dozer and excavator have lowest efficiency with an actual to theoretical hourly production ratio of 0.615, 0.682 respectively while wheel loader has the highest efficiency with a ratio of 0.749. Actual production of construction equipments were more suitable for project planning and scheduling.

It was concluded Minimizing the difference between actual productivity and theoretical productivity by identifying factors contributing to this difference and taking proper remedial measures to increase actual productivity was the responsibility of project managers and all stakeholders in construction industry

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Key words: Actual productivity, construction equipments, overall equipment effectiveness, performance ratio, theoretical productivity

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ACRONYMS

AR	Availability Rate
ERA	Ethiopian Road Authorities
HF	Human Factor
Hp	Horse Power
JiT	Jimma Institute of Technology
MF	Machine Factor
MnF	Management Factor
OEE	Overall Equipment Efficiency
PR	Performance Rate
PPR	Production Performance Ratio
QR	Quality Rate
RII	Relative Importance Index
TPM	Total Productivity Maintenance
WF	Work Factor

CHAPTER -1

INTRODUCTION

1.1 Background of the study

The construction industry is one of the most important sectors to be given due consideration in Ethiopia because it directly or indirectly affects all other sectors of the economy. Roads in Ethiopia are significant and potential means of transporting human and materials. The provision of adequate road transport services (in quality, coverage and organization) is essential for the economic and social development of Ethiopia.

Many other studies show that productivity growth is strongly correlated to economic growth and increases in welfare (Khyomesh et al., 2011). This fact may hold true in construction industries of Ethiopia. This is because; improving heavy-duty construction equipment productivity in the sector has a significant effect on the industries economy as construction projects are equipment intensive.

Construction productivity is one of the main drivers for completing projects within time and cost limitations and as such its appropriate estimation is quite important for preparing construction schedules and budgets. To determine construction productivity one needs to estimate an average production rate and then adjust it to the specific operational conditions of the job, material type, overall site organization, operator skill, on the job (AbouRizk, S.M, 2008).

Construction productivity, which is measured by output per unit of resource input, plays a key role in the success of a construction project. Analyzing construction productivity, however, is a challenging task because of the nature of construction field conditions which contain complex resource flows that lack the organized production lines of a manufacturing facility in a controlled and weather protected environment. Measuring construction productivity requires observing a work task for an extended period of time (Yun-Yisu, 2010).
To get a maximum productivity or to make a profit in any earthmoving, excavating and lifting operations, it is vital to plan the operation and selection of appropriate equipment. Maximum

productivity is one of the primary objectives of project management personnel's in the construction project but it is one of the greatest challenge in the construction industries

Construction equipment plays an important role in the execution of high cost and time bound construction projects. This equipment produces output at the accelerated speed and enables the completion of task in a limited time. Equipment saves manpower, a source, which is becoming insufficient as per the demand, costly and becoming more demanding day-by-day. Equipment improves productivity, quality and safety. Planning in the construction industries, as is well known plays an important part in the successful outcome of a project (www.ijetae.com).

It has been universally accepted that the equipment hourly production is one of the key factors in construction projects. It is also well known that the actual hourly production of the equipment differs from the nominal hourly production provided by the manufacturers. Increasing the actual hourly production has always been an ideal aim in achieving success throughout large scale earthmoving construction projects. It should be taken into account that the actual production at the site is different from the nominal production given by the manufacturer and depends mainly on the condition of the site (H. Nabizadeh Rafsanjani, 2009).

Stakeholders of the construction industry have to propose some methods used for the accurate estimation of machinery hourly production in earth –moving operation and significantly concentrate on type, number and schedule of presence of equipment at the project site in construction plan. Equipment productivity is a key factor that enables contractors to make decisions regarding project scheduling and project costs.

Optimum planning for heavy construction machinery is a vital task in succeeding the construction projects. Manufacturers provide an ideal hourly production of their own machinery to users, according to the machinery's specifications. Determining the actual production can make considerable help in gaining a more suitable planning for the fleet of construction machinery which would, in turn, lead to a more accurate planning throughout the project (H.Oglesby, W.Parker, 1989).

Equipment performance must ultimately be measured in unit cost of material moved, a measure that includes both production and costs. Factors bearing directly on productivity include such things as weight to horsepower, capacity, type of transmission, speeds and operating cost.

In this study, investigation of factors affecting construction equipment productivity by comparing actual and theoretical /ideal productivity of equipments and its remedial measures carried out using manufacturer's production rate and calculating current actual productivity of those selected equipments. One of the objectives of this study was to compare actual and theoretical productivity of construction equipment and to identify factors that make the difference and suggest remedial measures for the construction equipment productivity loss.

Using the performance handbooks, manufacturer catalogues and construction charts estimates the data of the nominal hourly production. The data of the actual production analysis was collected from Beddelle –Mattu upgrading road construction around Oromia region Illu Abba Bor Zone.

1.2 Statement of the problem

Projects are desirable to be completed within the time frame and budgeted cost. But unfortunately, many projects take longer to complete and cost more than necessary because of lack of using proper machine and man power wisely skills and other various factors directly and/or indirectly related with it. In most developing countries this problem is more aggravated than those developed ones; as a result many project-sponsoring organizations are discouraged to sponsor projects in these poor countries.

According to Peurifoy (2006), weak performance of construction equipment productivity is contributed by many factors. Besides, identification and evaluation of factors affecting construction equipment productivity in many construction projects is also very weak.

Poor equipment productivity is a problem faced by the construction industry in developed as well as developing country. Thus, it is essential to improve equipment productivity. The objective of this study is to identify the factors that affect the equipment productivity in the construction projects.

Construction industry in Ethiopia suffers with low productivity performance; improving heavy-duty construction equipment productivity in the sector has a significant effect on the industries economy as construction projects are equipment intensive. This improvement in productivity can be achieved by understanding the factors that adversely affect productivity.

Determining the actual production can make considerable help in gaining a more suitable planning for construction machinery which would, in turn, lead to a more accurate planning throughout the project

This research will address problems with loss of productivity identifying factors that contributing to productivity losses and suggest remedial measures.

1.3 The Research Questions/Expected Finding

- ✓ What are current actual and theoretical production rate of construction equipments?
- ✓ How does construction equipment productivity loss can be measured?
- ✓ What factors contributes to construction equipment productivity loss?

1.4 Objective of the study.

1.4.1 General objective

- ➢ The general objective of this study is to compare Actual and Theoretical productivity of construction equipment and identify factors affecting equipment productivity.

1.4.2 Specific objective

- ➢ To determine current actual and theoretical productivity of construction equipments
- ➢ To evaluate overall equipment effectiveness
- ➢ To identify factors contributing to construction equipment productivity loss

1.5. Significance of the Study

This study, generally, contributes the following major values

This research identify, which one is more accurate and more suitable for scheduling equipment and enable contractors to make decisions regarding project scheduling and project cost.

Identify factors that affect actual productivity of construction equipment and its remedial measures for construction productivity loss.

This can add a value on construction industry of Ethiopia by maximizing construction equipment productivity and reduce delay on road construction projects.

This adds a value on environmental and socio-economic activities of Ethiopian to ensure sustainable development.

1.6. Scope of the Research

- ✓ This study was limited to compare actual and theoretical productivity of construction equipment namely, loader, dozer and excavator on the selected Projects. And identify factors affecting productivity and its remedial measures of selected equipments.

- ✓ All charts, graphs, tables or standard values incorporated in the determination of the theoretical /ideal production rates referred from manufacturer's technical specification corresponding to each particular mark and models of the construction equipment.

- ✓ The influence of mechanical problems, history of past record and engine internal working system that have the contribution to the loss of equipment productivity rate were not evaluated in this study.

CHAPTER 2

LETERATURE REVIEW

The construction industry is one of the major development constraints in developing countries. This is mainly because; developing countries are considerably dependent on the growth & development of their physical infrastructures. Without the development of these physical infrastructures, developing countries will remain deficit in.

Researchers mention that the physical infrastructures that countries possess are indicators for economic growth. This fact is true because researchers had found out that the correlation between infrastructures development and the growth of the nations are considerably interlinked (Khyomesh et al., 2011). In general, one thing is obvious is that physical infrastructure has influences in facilitating and enhancing economic activities.

The construction industry is one of the most important sectors to be given due consideration in Ethiopia because it directly or indirectly affects all other sectors of the economy. Investment in nearly every field: Agriculture, Health, and Education etc. must eventually have a construction component. Besides, the employment opportunity that this sector provides is of great importance for the country (Emad.E, 2012).

2.1 Construction Equipments

Each piece of construction equipment is specifically designed by the manufacturer to perform certain mechanical operations. The task of the project planner/estimator or the engineer on the job is to match the right machine or combination of machines to the job at hand. Considering individual tasks, the quality of performance is measured by matching the equipment spread's production against its cost. Production is work done; it can be the volume or weight of material moved the number of pieces of material cut, the distance traveled, or any similar measurement of progress (Peurifoy, 2006).

Heavy-duty construction equipment is of extremely important in earth moving, excavating and finishing operations. This equipment facilitates cutting of earth, finishing and transportation of soil from the point of cutting to the point where it is required or disposed.

The main function of heavy-duty construction equipment is moving material, cutting and leveling the ground to meet the primary objectives of the owners (Jose, 2001).

The selection of the appropriate type and size of construction equipment often affects the required amount of time and effort and thus the job-site productivity of a project. It is therefore important for site managers and construction planners to be familiar with the characteristics of the major types of equipment most commonly used in construction.

2.2 Construction Equipment Productivity and its Measurement

2.2.1 Construction Equipment Productivity in General

The rate of production or the number of productive units that can be generated per hour, per day, or other period of time must be considered. Construction productivity is ratio of useful work out put to the time spent to complete that work.

As Abebawu. W (2014) 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 dozer, loader, grader, and excavator) for different activities. In fact, construction work typically requires high-volume or high capacity equipment used intensively in road construction projects.

This thesis was limited primarily to heavy construction units such as Excavator, loaders and dozers. The concepts developed, however, are applicable to all types of construction equipment performing basically repetitive or cyclic operations.

Peak Productivity (Q p) : The ideal/theoretical productivity governed by design limitation only. It is the product of Volume carried/ bucket capacity (V), bank volume/ loss volume (fs) and bucket fill factor (f f) (i.e. Q p =V * f s * f f). Whereas **actual productivity(Q a)** is the productivity of an equipment after taking care of effective working hours(f w) and job management factors (f j) on peak productivity(i.e. Q a =**Q p** *f w * f j).

The computation of the actual production of construction equipment is complex. But through idealization, approximation and in general simplification, one can arrive at an optimum result.

Equipments can be broadly classified into two based on equipment productivity concepts:

- ✓ *Cyclic Operating* or *Continuously Operating*.

Cyclic operating equipments: These are machines which are intentionally or unintentionally influenced by their operators. The actual productivity can be computed from:

$$Qa = Vn \times no \times \eta$$

$$no = 60/\ T\ o$$

Manufacturer specification provides the theoretical productivity of the construction equipment whereas actual productivity of the equipment obtained using the data from the field measurement or by applying job correction factors on the ideal productivity.

Thus this paper compare the theoretical and actual productivity of dozer, excavator and loader and identifies factors that affect their productivity and discuss it remedial measures.

The following sections explain the above equipments (dozer, excavator and loader) in detail which are studied in this paper.

2.2.2 Dozer productivity

Dozers (track laying crawlers or wheel tractors equipped with a blade) are perhaps the most basic and versatile items of equipment in the construction industry. Dozers are designed to provide high drawbar pull and traction effort. They are the standard equipment for land clearing, dozing, pushing of soils and assisting in scraper loading. A crawler dozer consists of a power plant (typically a diesel engine) mounted on an undercarriage, which rides on tracks. Production rate is highly affected by dozing distance (Peurifoy, 2006).

A dozer has no set volumetric capacity. There is no hopper or bowl to load; instead, the amount of material the dozer moves is dependent on the quantity that will remain in front of the blade during the push. The major factors that control dozer production rate are: Condition of the material, Blade type, Cycle time. Manufacturer's blade rating, previous experience or field measurement can do this. Hence, the measurement procedures for determining dozer production rate from the field data by computing blade load uses the following production formula:

$$\Pr oduction = \frac{60 \min x blade\ load}{push\ time + return\ time + maneuver\ time (\min)}$$

To obtain this actual production rate, Figure 2.1 provides the way to measure required dozer blade load in the field along with appropriate measurement technique and Table 2.1, provides required typical fixed cycle time.

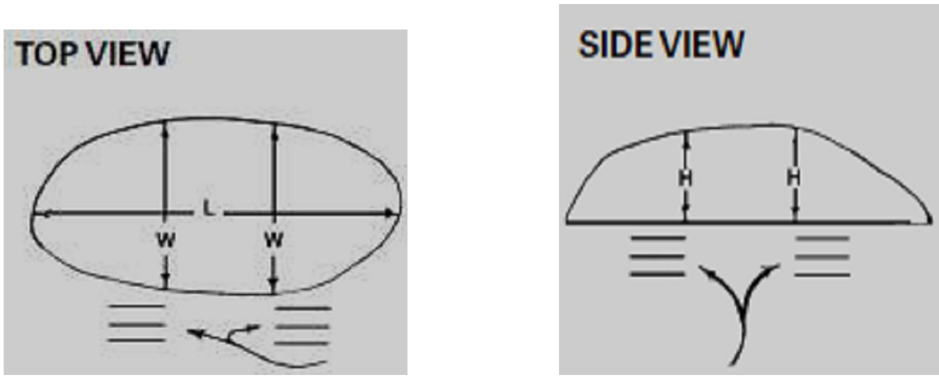


Figure 2.1: Measurement of Required Dozer Blade Load
Source: Caterpillar Performance hand book (2012)

From the figure 2.1, field measurement can be: Measure the height *(*H*)* of the pile at the inside edge of each track. Measure the width *(*W*)* of the pile at the inside edge of each track. Measure the greatest length (L) of the pile.

Then the Computation: Average both the two height and the two width measurements. If the measurements are in feet, the blade load in lcy is calculated by the formula

Blade load (Icy) = O.0139HWL

Manufacture Production Estimation Guidance

Equipment manufacturers provide dozer production guidance through formulas and factor information. Equation below is a *rule-of thumb* formula proposed by International Harvester (IH). This formula equates the net horsepower of a power-shift crawler dozer to an Icy production value.

$$\text{Production (Icy per 60-min hr)} = \frac{\text{net hp X 330}}{D + 50}$$

Where

Net hp = net horsepower at the flywheel for a power-shift crawler dozer

D = one-way push distance, in feet

It is also possible to determine dozer production rate using caterpillar production estimating curve using the following graph and following job correction factors

Dozer Production Estimates

Step 1: Find the Ideal maximum dozer production rate.

- ✓ Using production charts based on the particular dozer model and type of blade.

Step 2: Find the different correction factors for less than ideal conditions.

- ✓ Material – weight Correction Factor , CF = 2,300lb/LCY(ideal)/actual lb/LCY
- ✓ Operator correction factor - use table provided
- ✓ Material – Type Correction Factor - use table provided
- ✓ Operating technique Correction Factor - use table provided
- ✓ Visibility Correction Factor - use table provided
- ✓ Efficiency Factor - use table provided or assume number operating per hour
- ✓ Machine transmission factor - use table provided
- ✓ Blade adjustment factor - use table provided
- ✓ Grade Correction Factor - use chart/graph provided

Step 3: Determine total Correction Factor - multiple all correction factors

Step 4: Determine Production - Multiple Step 3 by Step 1

Step 5: Make sure it is in the right units of production

- ✓ BCM, CCM, LCM per hour. - use the shrinkage or swell factor given to calculate or use tables.

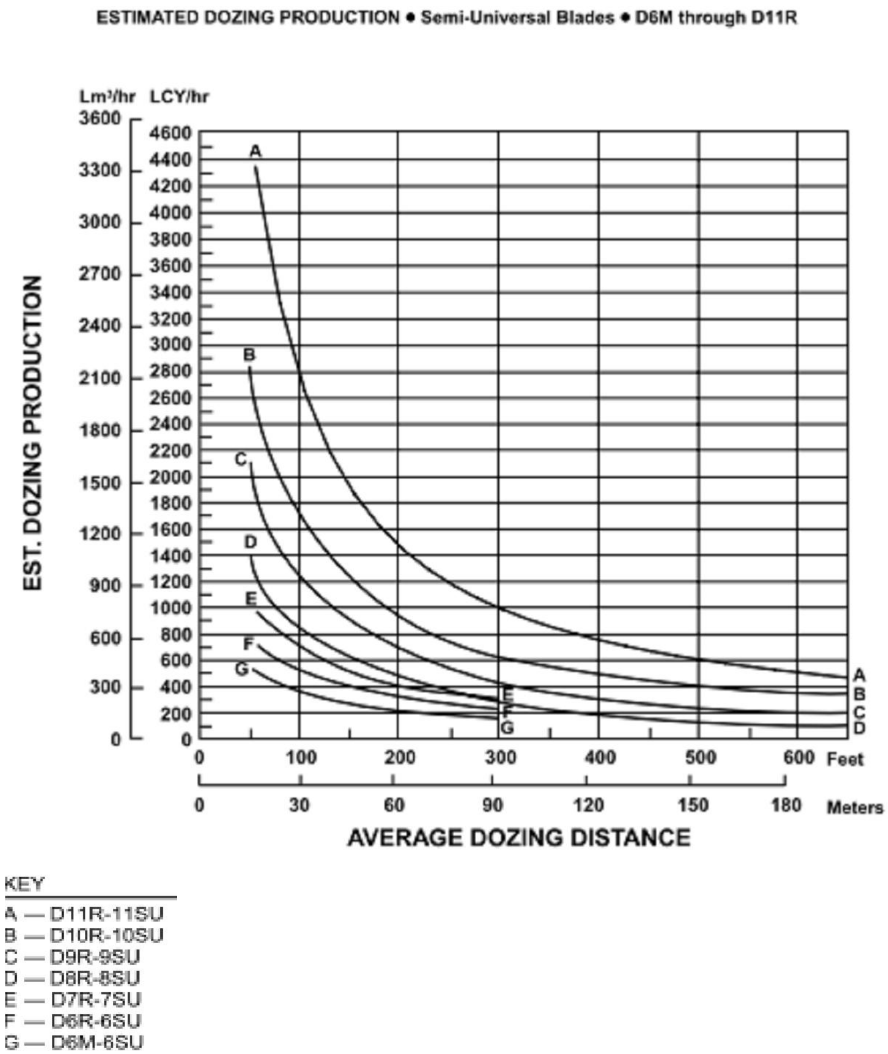


Figure 2.2: Dozing production estimating curve for caterpillar for D11R-11SU through D6M-6SU dozers equipped with universal blades.

Source: Caterpillar Performance hand book (2012)

Note: Refer the job correction factors on the following table. Moreover, this production curve is not the only one for estimation of dozer ideal production rate. Caterpillar performance handbook provides different production curve for different dozer type (model) with different blade type.

Table 2.1: Caterpillar Job Condition Correction Factor for Estimating Dozer Production

	Track type tractor	Wheel type tractor
Operator		
Excellent	1.00	1.00
Average	0.75	0.75
Poor	0.6	0.5
Material		
Loose stockpile	1.20	1.20
Hard to cut; frozen		
with tilt cylinder	0.8	0.75
without tilt cylinder	0.7	-
cable-controlled blade	0.6	
Hard to drift; "dead" (dry, non cohesive material) or very sticky material	0.8	0.8
Rock, ripped or blasted	0.6	-
Slot dozing	1.20	1.20
Side-by-side dozing	1.15	1.15
Visibility		
Dust, rain, snow, fog, or darkness	0.8	0.7
Job efficiency		
50 minlhr	0.83	0.83
40 min/hr	0.67	0.67
Direct-drive transmission	0.8	-
(0.1-min fixed time)		
Bulldozer" Adjust based on SAE capacity relative		
to the base blade used in the estimateddozing production graphs		
Grades-see the graph		

For grades verses dozing correction factors see the following graph.
Source: caterpilla performance hand book (2012)

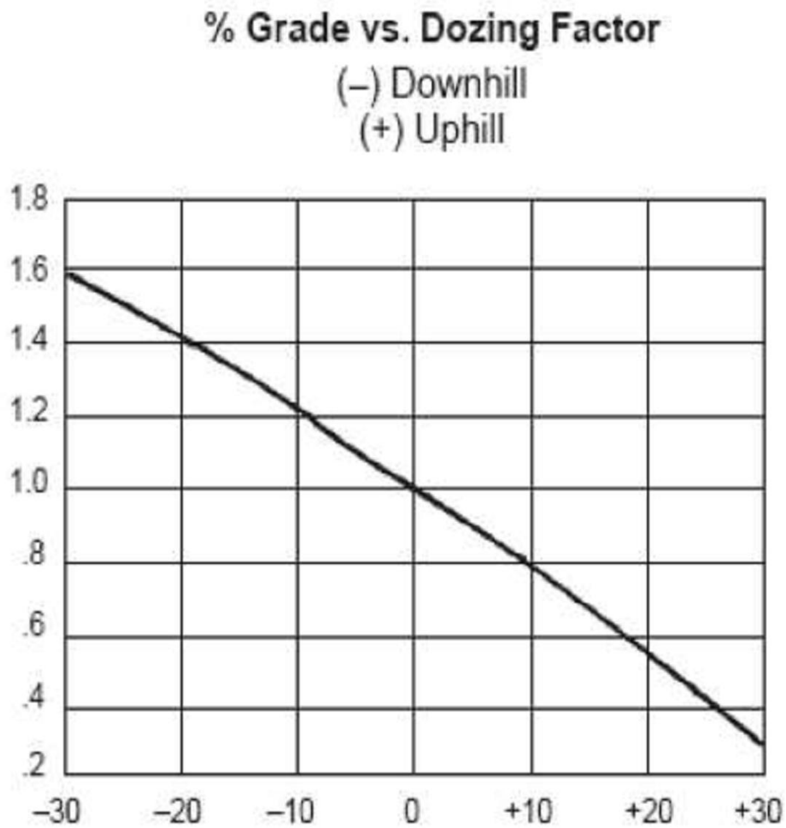


Figure 2.3: Grades vs. Dozing Factors

Source: Caterpillars performance hand book (2012)

Note: Angling blades and cushion blades are not considered production-dozing tools. Depending on job condition, the A blade and C blade Will average 50-75% of straight-blade production.

Production (Lm3/h) = Ideal Production (from Figure 2.2) x Product of all production correction factors (See Table 2. 1).

For this study, as caterpillars model was selected the chart method is appropriate which fit model D8R with semi-universal blade that are commonly found on the three case study projects

2.2.3 Excavator production rate

Hydraulic excavator is a power driven digging machine. It is used primarily in road construction work for trenches or mass excavation bellow the natural ground surface, lifting of objects or soil, loading trucks with excavated materials, pipe placing, and sometimes for digging out buried objects. The production rate of excavator is a function of the digging cycle; time required to load the bucket, time required to swing with a loaded bucket, time required to dump the bucket and time required to swing with an empty bucket (Mr. Mundane, 2015).

Excavators are probably the most common piece of construction equipment found on commercial construction projects. They come in many sizes and are ideal for light excavation, trenching, material moving, and loading. Excavators can be used as a hoe or a loader and can accommodate many different accessories and attachments for different operations. One of the backhoe's greatest strengths is that many attachments can be used to increase its versatility on a job site. Simple efficient systems are designed for easy connection of most attachments. If the contractor does not need the attachment all of the time, it can be rented as needed. The operator drives and operates the loader bucket from the front seat and operates the hoe from the rear seat. Backhoes are designed to operate using outriggers for stability. Outriggers are spread on the digging end (excavator). The scooping bucket supports the front end. All four wheels are off the ground when digging. The backhoe is ideal for light underground utility construction. The hoe can be used for trenching and lifting like the excavator. The bucket can be used for hauling material and backfill. In the selection of a hoe for use on a project: Maximum excavation depth required, Maximum working radius required for digging and dumping, Maximum dumping height required, and Hoisting capability required i.e., handling pipe Digging depth are factor considered in estimating excavator production. The optimum depth of cut is mainly depends 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:

$$\text{Production rate} = \frac{3600\ \text{sec} * Q * F}{t} * \frac{E}{60\text{min/hr}} * \frac{1}{\text{volume correction}}$$

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.

Table 2.2: Representative Properties of Earth and Rock

Material	**Bank weight Ib/cy kg/m3**	**lose weight Ib/cy kg/m3**	**Percent Swell**	**swell factor**
Clay, dry	2700 1600	2000 1185	35	0.74
Clay, wet	3000 1780	2200 1305	35	0.74
Earth, dry	2800 1660	2240 1325	25	0.80
Earth, wet	3200 1895	2580 1525	25	0.80
Earth and grave	3200 1895	2600 1575	20	0.83
Gravel , dry	2800 1660	2490 1475	12	0.89
Gravel, wet	3400 2020	2980 1765	14	0.88
Lime stone	4400 2610	2750 1630	60	0.63
Sand , dry	4600 1572	2260 1340	15	0.87
Sand, wet	2700 1600	2360 1400	15	0.87
Shale	3500 2075	2480 1470	40	0.71

*The swell factor is equal to the loose weight divided by the bank weight per unit volume.

Source: caterpillar performance handbook (2012)

Table2.3: Bucket Fill Factor for Excavators

Material type	**Fill factor**
Common earth, loam	0.80 -1.10
Sand and gravel	0.90 -1.00
Rock- poorly blasted	0.40 - 0.70
Rock- well blasted	0.70 - 0.90
Hard clay	0.65 – 0.95
Wet clay	0.50 – 0.90

Source: Nunnally (2007), Construction method and Managemen

Table 2.4: Excavation Cycle Time for Hydraulic Hoes under Average Conditions*

Bucket Size (cy)	Load Bucket (sec)	Swing Loaded (Sec)	Dump Bucket (Sec)	Swing empty (sec)	Total cycle (sec)
<1	5	4	2	3	14
1-1 ½	6	4	2	3	15
2-2 ½	6	4	3	4	17
3	7	5	4	4	20
3 ½	7	6	4	5	22
4	7	6	4	5	22
5	7	7	4	6	24

*Depth of cut 40 to 60% of maximum digging depth; swing angle 30o to 60o, loading hauls units on the same level as the excavator

Indicates excavator cycle time which is based on swinging angle of 30- 60o. See figure below.

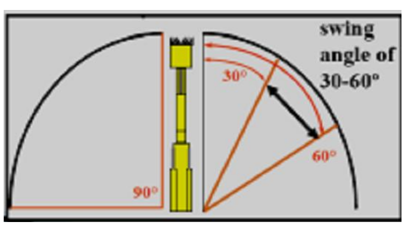


Figure 2.4 Swinging Angle for Hydraulic Excavator
Source: Caterpillar performance hand book (2012)

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 50 min job efficiency factor as the observation from the site.

Performance measure is the process of quantifying effectiveness and efficiency of an action. Effectiveness is the extent to which the objective of the client achieved whereas efficiency is the evaluation of how the owner utilized the resource economically to meet the client objective (Saad and Andrew, 2013).

The same elements that affect shovel excavation production are applicable to backhoe excavation operations. Excavator cycle times are approximately 20% longer in duration than those of a similar-size shovel because the hoisting distance is greater as the boom and stick must be fully extended to dump the bucket.

Factors that affect excavator production are the ; - Width of the excavation , Depth of the cut, Material type, Working radius for digging and dumping, Required bucket dumping height [Douglass D.Gransberg].

Excavator production rate can be estimated using the following steps:

Step 1. Obtain the heaped bucket load volume from the manufacturers' data sheet. This would be a loose volume (lcy) value.

Step 2. Apply a bucket fill factor based on the type of machine and the class of material being excavated. Table 2.1. Fill factor for hydraulic excavator (caterpillar)

Step3. Estimate a peak cycle time. This is a function of machine type and job conditions to include angle of swing, depth ·or height of cut, and in the case of loaders, travel distance.

Step 4. Apply an efficiency factor.

Step 5. Conform the production units to the desired volume or weight units (lcy to bcy)

Step 6. Calculate the production rate. for loose volume to tons, 2,000Ib/ton

NOTE: Fill factor A numerical value used to adjust rated heaped excavator bucket capacity based on the type of material being handled and the type of excavator.

Factors Affecting Performance of Excavators

Based on the literature and related work, following are some factors found that affecting on performance of excavator (Dushyant A., 2016).

Proper Equipment Selection: Equipment is a critical factor in construction project. Rational selection of suitable equipment leads to profit for contractors. At the same time, miscalculation proper size and number of required equipment for the project may result in suffering from overhead costs and wastage of time. Therefore, contractor considers proper selection of earthmoving equipment a vital factor for any construction

Site Condition: The performance of excavator depends on site conditions also which includes the physical conditions of site such as topography and geology of the site, geotechnical characteristics of ground or rocks etc. Excavation might be tough for site containing hard soil.

Cycle Time: Cycle time is defined as the amount of time taken by machine to perform a repetitive segment of an operation, typically measured as the time it takes the machine to return to the same position. It is the time taken to complete one entire excavating process of an excavator which includes excavation time, time to swing to dumping position, dumping time and time to return to the digging position.

Bucket Size: A bucket is a bulk material handling equipment provided at the end of the arm of an excavating machine. Selection of bucket size depends on the material to be excavated. The size of this bucket determines its capacity to excavate the material in one particular cycle. Thus, maximum capacity of bucket can save number of cycle and time required for excavation.

Angle of Swing: Angle of swing is a horizontal angle in between the position of excavator while excavating and the hauling unit where it dumps the material. Is one of the elements of cycle time. If the angle of swing is more, the cycle time required will be more and vice-versa. Thus, keeping the angle of swing minimum can save the cycle time of excavator.

Operator's Skill: A skilled or trained operator can handle the equipment in an effective manner providing maximum output from machine. Improper use equipment can cause damages to it and injuries to the operator as well. Thus, operator's skill is an important parameter to be considered.

2.2.4 Loader production Rate

Loaders are used extensively in construction work to handle and transport bulk material, such as earth and rock; to load trucks; to excavate earth; and to charge aggregate bins at asphalt and concrete plants. The loader is a versatile piece of equipment designed to excavate at or above wheel/track level. The hydraulic-activated lifting system exerts maximum breakout force with an upward motion of the bucket. 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). Accordingly, the following formula helps to compute loader production rate.

$$\text{Production rate} = \frac{3600\text{sec./hr} * \text{bucket capacity} * \text{Fill factor}}{\text{Fixed cycle time (sec./hr)}} * \text{Efficiency factor} * \text{Load Factor}$$

To perform this calculation the following tables are required

Table 2.5 Bucket Fill Factor for a Wheel and Truck Loader

Material	Wheel loader Fill factor (%)	Truck loader Fill factor (%)
Loose material		
Mixed moist aggregates	95-100	95-100
Uniform aggregates, up to 1/8in	95-100	95-110
1/8 – 3/8 in.	90-95	95-110
1/2 -3/4 in.	85-90	90-110
1 in. and over	85-90	90-110
Blasted rock, Well blasted	80-95	80-95
	75-90	75-90
	60-75	60-75
Other, Rock dirt mixtures	100-120	100-120
Moist loam	100-110	100-120
Soil	80-100	80-100
Cemented material	85-95	85-100

Source: Caterpillar performance handbook (2012)

Table 2.6 Fixed Cycle Time for Loaders

Loader size, bucket capacity	Wheel loader cycle time /sec.	Track loader Cycle time /sec.
1.00-3.75	27-30	15-22
4.00-5.50	30-33	-
6.00-7.00	33-36	-
14.00-23.00	36-42	-

*includes load, maneuver with four reversal of direction (minimum travel)

Source: caterpillar performance handbook, 2012.

In calculating the ideal production rate of loader it is required to consider the manufacturer specification for bucket capacity and a 60 min job efficiency factor.

2.3 Construction Equipment Actual and theoretical /ideal productivity

Nominal/theoretical production: the production given by the manufacturer, which recognizes an ideal production while the equipment is operated on a continuous basis.

Actual production: the production of the equipment at the site and is, obviously, less than the nominal production. Thus, the more efficient it is estimated, the better result would be obtained from managing the project.

Apparently, each manufacturer provides the users with an ideal hourly production plan, according to the equipment's specifications. It should be taken into account that the actual production at the site is different from the nominal production given by the manufacturer and depends mainly on the condition of the site. Thus, determining the actual production will make considerable help in gaining a more suitable planning for the construction equipment which would, in turn, lead to a more accurate planning throughout the project.

Edmonds *et al*. (1994) took actual production of machinery into account and proposed the actual production as a percentage of full capacity by using several methods such as running time and running speed analyses. The actual production of construction machinery, on the basis of their results, has been estimated as 52.5% of the nominal production.

The production performance ratio compares the actual productivity against the estimated productivity to demonstrate the amount of loss of productivity and, thus, judge the level of productivity.

The production performance ratio compares the volume of work done by each equipment is compared with its planned production (Volume of work to be done) and Actual production (Volume of work done) and, thus, the level of productivity can be justified.

The actual construction conditions at various project sites differ according to the climate, the soil type, equipment age and the driver's workmanship (H. Nabizadeh Rafsanjani, 2009).

A measure of productivity which has been long used in the estimating process is the performance ratio (PR), whose mathematical expression is given as follows.

$$PR = \text{Actual Productivity} / \text{Theoretical Productivity}$$

The Production Performance Ratio was found to be less than 1 which indicated that, the equipment failed to perform as it was expected to be.

2.4. Loss Associated with Construction Equipment Productivity and its remedial measures

It is essential to understand and quantify the disturbance of manufacturing process that leads to stoppage of the machines. The OEE tool is designed to identify losses that reduce equipment effectiveness. Those losses execute by the events that consume resources but generate no value (S. Nakajim, 1989) and the following six big losses can be depicted and shown in integration with equipment and perspective of performance.

- Down time losses- facilitates to calculate the availability of machine
- Speed losses- facilitates to determine performance efficiency of a machine
- Quality losses- facilitates to evaluate the quality level of a machine

Thus, OEE depends on equipment's availability (how much productive time the equipment is actually available), its performance (how much time the machine is operating, but not been able to any product), the quality (how much time machine is taking in producing the quality product only).

OEE = Availability rate (%)* performance rate (%)*quality rate (%)

2.4.1 Availability Losses/ Inactivity Losses

These losses occurs when the construction equipment are not "active" to work. Equipment breakdown and setup adjustment losses are listed out under this category.

i. Break Down Losses

It is clearly visible type of losses and it occurs due to part failure when they do not work more and needs either repair or replace. When some part or accessories of the equipment fails, obviously there is work interruption or it took some considerable time duration until get fixed or repaired. As a result, the equipment will not produce the intended output as scheduled to execute a particular activity. Accessory or part failure is one of the main causes for equipment productivity losses especially in road construction projects. Equipment breakdown losses are measured by recording the time it takes from failure until fixing and equipment failure or breakdown is both a time and quantity losses (Pintelon et al., 2006).

ii. **Setup Adjustment Losses**

Other visible type of loss is set-up adjustment losses and it occurs when a production changed from requirement of one item to another item (Pintelon et al., 2006) or change in operation. For instance, in the construction industry these type of losses occurs during replacing bucket to jack hummer in case of excavator, old blade change for dozers and so forth. "It is simply a change in operation conditions."

2.4.2 Performance Loss/ Speed Losses

Under this category Idling - minor stoppage and Capacity production losses found out.

i. Idling - Minor Stoppage

In construction work this types of losses occurs when production process is interrupted temporary by malfunctioning of the equipment. However, the machine is in normal working condition. A classic example for this type of loss in construction industry is equipment may be idle due to input material shortage/absence or waiting for fuel etc. and it is possible to say that equipment is ready for work but no input material gets ready.

Minor - stoppage may also occur due to some subsequent activity preparation (e.g. on cross drainage work, pipe installation and back fill to give immediate access) or when the operators are engaged in some other business for a moment. These losses are highly dependent on the operators. However, they are minor or small; their cumulative effects have an impact on the productivity loss. In addition, this type of loss is difficult to eliminate because it is difficult to observe and measure and operators or maintenance personnel are not aware of them (Pintelon et al., 2006).

ii. Production Capacity Losses

These losses are generally associated with the difference between the theoretical and the actual production rate.

2.4. Quality Loss /Defective Losses

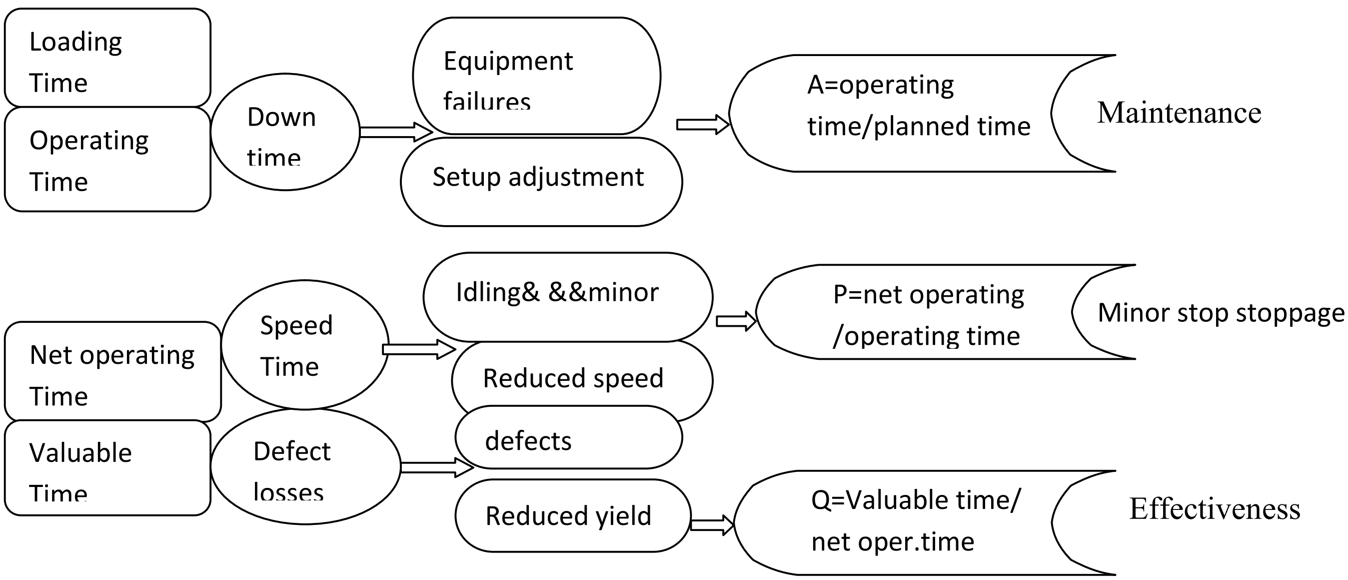
Under this category quality defect, rework and start up yield losses found out.

i. Quality Defect and Rework

Equipment may produce a defective quality of work which is not performed as per the specification; due to equipment malfunctioning, defective construction material , carelessness of the operator, inadequate preventive maintenance, inappropriate work order or some other reason leading to reworking of the same activity one and again. In addition, it reduces the expected output of the concerned equipment. In fact, if there is a rework, there is wastage of time and construction material, which have an adverse effect on the financial performance of the construction industry (Carlos, 2009).

ii. Start Up yield Losses

These losses occur at the early stage of the production time. This is because some machines need to go through "warm-up" process to produce the yielding production. The initial time is time spent at the morning to start up the machine (Pintelon et al., 2006).



2.5 Factor affecting construction Equipment Productivity

Concerning site condition, the actual production differs from the theoretical production given by manufacturers. The major factors causing this difference are climate conditions, earthmoving operations, driver's workmanship, machinery age, and construction time according to various seasons (H. Nabizadeh Rafsanjani, 2009)

Belay Assefa, 2016 identified the top ten identified factors affecting on site construction productivity : poor planning and scheduling (RII of 0.9), failure to follow a project schedule (0.875), wrong construction method (0.825), failure to maintain equipment on time (0.810), incomplete drawing (0.805), unfavorable weather condition (0.8), lack of technology adaptation (0.795), wrong estimation (0.790), lack of equipment (0.780), and lack of qualified workers (0.775) have significant negative impact on productivity

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

Their study qualitatively identified critical factors leading to the loss of productivity. In this regard, extensive literature review was done and the 27 factors affecting productivity were identified. Also they found out that Management issues have a significant impact on road construction productivity, and worker issue has less impact on productivity, which verifies that large road construction is not a labor driven sector

Table 2.7. Summary of factors affecting on-site construction productivity

No	Group Factors	Factors Affecting On-site Productivity
1	Material	Lack of Materials
		Delays of material delivery to site
		Availability of material
		Inflation / fluctuations in material prices
2	Drawing	Incomplete drawing
		Needed information not on drawings
		Availability of drawings
		Design change
		Design complexity
		Project complexity: scale and design
		Poor drawings or specifications
3	Equipment	Lack of tools and equipment
		Tools/equipment breakdown
		Suitability or adequacy of the plant and equipment employed
		There are frequent tools/equipment breakdowns due to aging or poor

		maintenance
		Inappropriate uses of tools/equipment
		Equipment breakdown
4	Experience	Level of skill and experience of the workforce
		Operatives do not pose skills and experience to perform the task
		Lack of local experienced labor
5	Inspection Delay	Inspection delay
		Work delay caused by Inspection delays by the Local Authority
		Stoppage because of inspection delays
		Inspection regime
6	Shift Work	Shift work
		Poor use of multiple shifts or overtime
7	Motivation	Lack of labor motivation
		Level of motivation
		Motivation
8	Skill	Lack of trades' skill
		Level of skill and experience of the workforce
		Skilled workers are not adequate on jobs
		Operatives do not pose skills and experience to perform the task
		Shortage of skilled labor
		Skills and experience of workforce
9	Specification	Specification and standardization
		Poor drawings or specifications
10	Rework	Rework
		Change orders and rework
		The works need to be redone because it fails quality control inspection or testing

		The works need to be redone frequently due to poor quality of documents, The jobsite layout is poor
		The work needs to be redone due to changes in design, drawings or specifications
11	Error in Fabrication	There were errors in fabrication that needs to be corrected in rework
12	Absenteeism	Absenteeism
		Absenteeism and turnover
13	Construction Method	Utilizing the traditional construction methods instead of modern technology
		Inappropriate construction methods
		Construction method
		Poor Construction methods
		Adequacy of method of construction
14	Turnover	Absenteeism and turnover
		Level of staff turnover/churn rate
		Worker turnover
		Changing of foremen
15	Weather	Weather enclosures
		Hot weather
		Cold weather
		Weather conditions
16	Safety	Safety
		Accident/Safety
		Management does not support safety plan
17	Training	Site manager does not have the ability in training workers to perform their jobs properly
		Level of empowerment (training and resourcing)
		Lack of Workforce training

		Lack of training and education to implement and operate new technologies
18	Project Feature Issue- Site condition	Poor site conditions
		A poor site layout
		Congestion and overcrowding on the site/interference among people
		Poor access to work area (e.g. Poor scaffolds)
		Height of worksite above ground
		Working on the jobsite
		Site irritants - pollution, noise
		Adequacy of site layout
		The site is slippery or steep imposing terrible conditions
		Site conditions: access, subsoil, topography.
		Site location and environment
		The jobsite is too noisy/dusty
		Poor site conditions
		A poor site layout
		Congestion and overcrowding on the site/interference among people
19	Planning and Scheduling	Poor planning and scheduling
		There is no construction planning/project schedule in place
		Schedule Pressure caused by the Government
		Job planning
		Lack of Pre-task planning
		Adequacy of planning and risk management process
20	Cost	High cost of needed resources: material, money & Machinery
		Dispute and litigation costs
		Cost of the wasted materials on site

		High cost of foreign labor
		Lack of cost accounting control
		Insurance costs
		Fluctuations in exchange rate
		Interest rate/cost of capital
		Energy crises/costs
21	Technology	Resistance to accept new technologies
		Adequacy of technology employed
		Rapid technological advances
22	Change Order	Change Order
		Change orders and rework
		Frequency of design changes/ change orders
23	Project Management	Resistance to change at Management Level
		Better management
		Relationship management/degree of harmony, trust and cooperation
		Project management style
		Project organizational culture
24	Estimation	Undervalued work
		Poor Estimation
25	Communication	Poor communication
		Lack of communication between Government Authority and Contractor
		Poor communication between office and field
26	Overtime	Working overtime
		Occasional working overtime
27	Other External Factor	Disruption of power services

2.5.1 Human Factor

Lack of construction material: As Makulsawatudom and Emsley (2001) stated lack of construction material is the most critical factor affecting productivity. This is because if construction material is not available, machinery will not work at all. It occurs mainly due to "contractor liquidated problem" and when contractors have insufficient finance to procure the necessary materials. On the other hand, when suppliers have previous experience, as there is lack of payment, they hold material delivery. Lack of construction material may also occur due to "incompetent project manager", who give inadequate priority of material delivery and lack of knowledge about the material.

Incompetent supervisor: The supervisor may be responsible for defective works and for using in appropriate equipment. One cause of this factor is "poor human resource management" where by inappropriate person care the supervision role.

Rework: More rework needs more time and cost for construction. This problem mainly caused by incompetent artisan and incompetent supervisor. Lack of working skill and knowledge of drawings are character of incompetent artisans, while lack of experience and leading to deficient supervision is a characteristic of incompetent supervisor. Other causes for rework were change order and incomplete drawings.

Operator's efficiency: Operators work experience, motivation from the management to the operators and operator own capacity is one of the main human factors affecting equipment productivity in the construction work (Gashaw, 2009).

2.5.2 Management Factor

Poor coordination between the site and the office is one of the main contributing factors for this problem.

Inspection time frequency: The main cause of this factor is inadequate management. For example, insufficient numbers of supervisors employed to minimize cost of employees. As a result, repeated instructions occur to rectify defective works not stopped timely. This may cause construction equipment used repeatedly for the same work once and again.

Inspection delays: This factor has a considerable effect on productivity. It may cause equipment idleness. This in turn affects the equipment valuable production time.

Inspection delay mainly occurs due to "incompetent project manager" who does not prioritize job inspection and who does not realize job interdependency.

Poor Communication: It is the main factor for defective work and come from "incompetent communication skill". To minimize this problem, formal documentation, such as work procedure, manual, chart and guidelines are better than informal or verbal communication.

Lack of Equipment: To obtain the intended quality or output from the machines, the machines are needs to be available at the required time. For example, ignorance of preventive or predictive maintenance program, shortage of spare parts and the use of old and obsolete equipment causes this problem. Beside to this overestimate of the capacity of the machine may result insufficient number of machine for utilization.

2.5.3 Work Factor

Incomplete drawings: When there are incomplete, unclear and impractical drawings, it takes time for revision or clarification of drawings to meet specification. This leads to construction delay waiting for clarification and it is one of the main factors affecting productivity.

Poor site coordination: Poor site preparation is the cause of this factor, which may lead to difficulty and unsafe working condition. Work condition varies from site to site, type of job, material handled or soil to be compacted. Any hindrance or obstacles are work factors for loss of equipment productivity.

2.5.4 Machine Factor

Size of the machines: size of the machine is a machine related factors that affects equipment productivity in the construction work. The larger the bucket size more material can be handled with the bucket and the higher the engine capacity the more power to push material or more power to excavate stiff work condition (Nunnally, 2007).

Table 2.15 Factor Affecting Productivity and Their Potential for Improvement

Factor	Effect on productivity			Potential for productivity Improvement		
	Total Score	RII	Rank	Total score	RII	Rank
Lack of material	131	0.642	1	91	0.535	11
Incomplete drawing	121	0.593	2	93	0.547	4
Inspection delay	114	0.559	3	88	0.518	15
Incompetent supervisors	113	0.554	4	94	0.553	2
Instruction time	111	0.544	5	95	0.559	1
Lack of tools and equipment	110	0.539	6	63	0.547	4
Poor communication	107	0.525	7	62	0.541	7
Poor site conditions	105	0.515	8	66	0.388	22
Change orders	104	0.542	9	82	0.482	19
Poor site layout	103	0.505	10	93	0.547	4
Rework	100	0.490	11	94	0.553	2
Absenteeism	97	0.475	12	91	0.535	11
Occasional working overtime	95	0.466	13	92	0.541	7
Tools/equipment breakdown	94	0.461	14	92	0.541	7
Interference from other trades or other crew members	93	0.456	15	86	0.506	18
overcrowding	90	0.441	16	71	0.418	21
Workers turn over	88	0.431	17	87	0.512	17
Specification and standardization	86	0.422	18	92	0.541	7
Scheduled working overtime	81	0.397	19	89	0.524	14
Weather	80	0.392	20	47	0.276	23
Changing of foremen	78	0.382	21	88	0.518	15
Safety (accidents)	76	0.373	22	91	0.535	11
Shift work	69	0.338	23	73	0.429	20

2.6 Performance Evaluation by using Overall Equipment Effectiveness (OEE)

OEE assessment tool is derived from the concept of total productive maintenance (TPM) and depicted as a performance evaluation tool that measures different types of production losses (six big losses) and reveals areas of process improvement.

The demand for increasing productivity in the current competitive construction industry led to a need for performance measurement system for the production process. One of such a performance measurement tool which measures different production losses and which indicate area of process improvement is an Overall Equipment Effectiveness (OEE) index. It is a tool designed to distinguish factors contributing for productivity losses. Knowing the three fundamental performance rate (Availability Rate (AR), the Performance Rate (PR) and the Quality Rate (QR) will help to compute overall equipment effectiveness index. These rates indicate the degree to which the required output is achieved (Pintelon et al., 2006). Those equipment production losses stated in section 2.4, measured quantitatively by OEE, which is a function of the three fundamental performance rates.

Loading Time

Available time* - Planned Downtime =loading time/Active time

Operating Time

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

Net Operating Time

Operating time- Idle minor stoppage= Net operating time

Performing Time

Net operating time - Production capacity loss =Performing time

Valuable Operating Time**

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

* Time during a given period, a day, a week or a month

** Time during which effective output are produced

$OEE = \frac{Valuable\ operating\ time}{loading/active\ time}$*100 (Pintelon et al.,2006)

2.7 Research Gaps

As discussed above the issue of machine productivity is very critical in road construction in both globally and locally. The construction industry in Ethiopia suffers with low productivity performance. The available research materials in this understudied area are small in number and productivity in road projects was not assessed as compared to the attention given to this construction sector in Ethiopia. This shows that there is a wide gap of literatures in studying the problem.

CHAPTER 3

RESEARCH METHODOLOGY

In conducting research, the methodology part is very crucial. Because it indicates how a research inquiries should processed, while a research method is a particular tools or technique used to obtain and analyze data. The methodology in this study consists of site description, study design, method of data collection, data collection tools/research instrument and method of data analyzing.

3.1 Study area

The research study area was located entirely within in Illubabor Zone of the Oromia National Regional State, some 500 km west of Addis. The estimated road length is 112 km and Asphalt Concrete surfacing with a 7m carriageway and 1.5m shoulders width in each side. The Bedele – Metu road commences at Bedele town at the junction with the Nekemte – Bedele Road, and ends at the edge of Metu town at the Sor River Crossing. The project road serves 11 villages in five woredas (Chora, Yayu, Hurumu, Metu and Bedele). Currently this upgrading project is under construction.

3.2 Research Design

The research design was based on comparative approach and the comparison has been done between actual productivity and theoretical productivity of selected equipments. Quantitative approach is mostly applied and some qualitative approach is applied for the current study. The research methodology was a case study on Beddelle –Mattu asphalt road construction project. Once again, as personal observation, actual field measurement and some interview was set out as study design for this thesis, the case study mainly divided into three parts.

Observation

Field or site observation was mainly to know:

- Actual idle time: the time when the machine is ready but work is not available.
- Actual time for minor - stoppages: Time loss due to frequent interruption or short duration of machine malfunction
- Actual operation cycle time: time noted while loading the bucket- swinging with load – dump load - return swing in case of excavator.

- Actual work condition: its visibility the work (dust, rainy, sunny or darkness) and techniques of operation.
- Actual Operation condition: this is mainly to note out techniques of operation (slot dozing, side – by side dozing, down a hill or up a hill) includes operator's skill (excellent, average or poor).
- Management systems: to note out the key factors for productivity

Actual measurement

This includes actual measurement of all parameters (average width, average depth, average height of soil piles, material actually carried by the bucket, average equipment output per hour using field measurement methods).

Beside to these relevant observed and measured data, Soil type of the study area, equipment work schedule for a particular job on the contract document were collected from the contractor contract documents and agreement to execute the work.

Interview

Some interviews were found to analyze factors that affect construction equipment like age of machine, operator experience, Bucket capacity and condition of current construction project.

3.3 Study Population

The populations of the study are three construction equipments (dozer, loader and excavator) and the data for the theoretical hourly production was estimated using the performance handbooks, different tables, formulas and construction charts. The data for the actual production analysis was collected from Beddele –Mattu upgrading road project.

The equipments (dozer, loader and excavator) are selected since they are currently used at the site, soil type of the area, interviewed operators and project managers, are contractors and consultants from the selected project.

3.5 Sample size and Sampling technique

3.5.1 Sample Size

The type of sampling adapted for this research is purposive sampling. Three equipments namely dozer, loader and excavator are selected for current study, and their actual productivity and theoretical productivity per hour calculated. The result has been by calculating theoretical productivity using standard formula and different standard tables and actual productivity

Measuring on site output. The method was non-probability sampling which are used for computation purpose.

3.6 Data Collection Tools/Research Instrument

Data were collected mainly based on field measurement and actual observation of all independent variable that were incorporated in the calculation of overall performance rate of the machines. On the field the actual production rate of the machines was measured and recorded when the machineries were assigned to do certain activities or when the machine do the same activity repeatedly. The recorded production rate were used to compare with theoretical production rate of the machine and the time are meant to know downtime and the availability of the machines as it is scheduled for particular job and to measure the time spent due to machine malfunctioning or idleness.

3.7 Method of Data Analysis and Evaluation

Following are method employed in the analysis and evaluation part of this thesis to achieve the objectives of the research using the observation, measured manufacturers data.
Calculation of performance ratio based on actual productivity and theoretical productivity of equipments. The calculation of OEE based on availability, performance and quality these are time pried calculation and production unit calculation. On the other hand, manufacturer’s specifications provides the ideal/theoretical production rates
These rates are computed by formulae given in the literature reviewing section of this thesis such as:

$$\mathrm{Pr}\,oduction = \frac{60\,\mathrm{min}\,xblade\ load}{push\ time + return\ time + maneuver\ time(\mathrm{min})}$$

Production (Lm3/h) = Ideal Production x Product of all production correction factors
Blade load (Icy) = O.0139HWL
Average bucket pay load = (heaped bucket capacity)*(bucket fill factor)
Actual hourly production = 60min h production *job efficiency factor

$$\text{Production} = \frac{3600\text{sec./hr} * \text{Heaped bucket capacity} * \text{Fill factor}}{\text{Cycle time /sec.}} * \frac{\text{Efficiency}}{60\text{min}} \ \ldots\text{production in lcm}$$

$$\text{Production} = \frac{3600\text{sec./hr} * \text{Heaped bucket capacity} * \text{Fill factor}}{\text{Cycle time /sec.}} * \frac{\text{Efficiency}}{60\text{min}} * \frac{1}{\text{volume correction}}$$

Bank cubic meter production.

$$\text{Production rate} = \frac{3600\text{sec./hr} * \text{bucket capacity} * \text{Fill factor}}{\text{Fixed cycle time (sec./hr)}} * \text{Efficiency factor} * \text{Load Factor}$$

$$\text{Availibility rate}(\%) = \frac{\text{Operating time}}{\text{planned production time}} * 100$$

Performing Rate (PR) = Net operating rate * Operating speed coefficient * 100

$$\text{Performance rate}\ (\%) = \frac{\text{Actual production rate}}{\text{Theoretical production rate}} * 100$$

$$\text{Quality rate}\ (\%) = \frac{\text{total actual production} - \text{total rejected work}}{\text{total actual production}} * 100$$

and then the final

Productivity loss indicator OEE is given by:

$$\text{OEE} = \text{AR*PR*QR} = \frac{\text{Valuable Operating time}}{\text{Active time}} * 100$$

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

The extent of the current productivity of the construction equipment during the valuable operating time noted from the ratio of actual production rate to the theoretical production rate.

CHAPTER 4

RESULT AND DISCUTION

This chapter describes the findings on Performance analysis of heavy-duty construction equipment productivity on project to depict the extent of the current productivity, analysis of the contributing factors for equipment Productivity loss and remedial measures should be taken. The assessment result divided in to three main sections, the first part focuses on calculating the theoretical and actual productivity per hour of construction equipments concentrates on three road construction equipments [Dozer, Excavator and Loader] in selected area Mattu –Beddele road project. The second part focuses on factor that affects construction equipment productivity and the last part provided remedies/suggestion for improving productivity of equipment.

4.1. Basic information about Bedele –Matu upgrading Road Project

Throughout this study, Bedelle –Matu upgrading Project owned by Ethiopia road authority (ERA), considered as a case study, which is ongoing project by Hawk International Finance Construction co. Ltd contractors. And Roughton international in JV with Beza consulting engineering plc as consultant.

Every data concerning to the manufacturer specification used in the computation of ideal production of the machines can be seen in caterpillars performance hand books or any other standards related to the caterpillar model. Concerning to the soil properties and classification is used as secondary data take from the office document.

Though the contractors of Rot1 have dozer, loader and excavator which are mostly equipped with caterpillar machineries; as a result the study only evaluates the actual productivity and theoretical productivity of those equipments and identify production rate losses.

This study was conducted at this job sites consisting different equipments loader, excavator and dozer. The actual job operating condition which might affect productivity were identified and recorded which includes causes of material, operator's skill, condition of equipment. The time-motion study was conducted and productivity, total cycle time and cycle time of element were estimated for each equipment with respect to bucket size, blade type. The estimations were made following the guidelines given in the manufacturer's performance handbook. The actual productivity was then calculated based on the data obtained from site. The term Production Performance Ratio (PPR) was used to compare the actual productivity against estimated productivity to demonstrate the amount of loss of productivity.

4.1 Performance Analysis of Heavy - Duty Construction Equipment

The performance of heavy-duty construction equipment such as dozer, loader and excavator, 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. The most significant loss factors are associated with the lowest component rate of OEE as stated by different authors in the literature part.

4.2 Performance Analysis of Heavy Duty Construction Equipment On Beddelle-Mattu Upgrading road project

4.2.1 Performance Analysis of Dozer On Mattu - Beddelle Upgrading Road Project

The computation of the actual pro0duction of dozer was done from using measured data and site observations. And theoretical /ideal production was from manufactures data, performance ratio was ratio of actual productivity to theoretical productivity.

Spreading Sub-base material using dozer

Table 4.1 Indicates the computation of dozer productivity rate and the percentage of individual component rates with the summary of corresponding factors to each independent rate

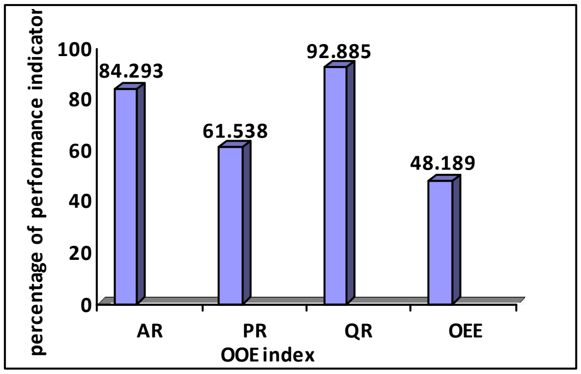
Table 4.1: Performance of Dozer Production and Summary Factors Affecting Dozer Productivity on Bedelle –Matu Upgrading Road Project

Machinery Type - Dozer Mark - Caterpillar Model - D8R Average of Five Days Result with One Day = 8 working hours (Construction Equipment with Cyclic Operating Machines) Dozer Productivity Rate on Beddelle – Mattu Updrading road Project				
Type of Activity – sub base spreading				**Factors contributing**
Productivity rate	**Independent variables**	**Value**	**Unit**	
Dependent variable	A Available time (8 hrs. x 60')	480	min	
	B Scheduled production break	98	min	lunch break & (HF)
	C Loading time	382	min	morning inspection
AR(%)=				Poor communication
100*E/C	D Major Stoppage losses	60	min	(HF)
= 84.293%	E Operating Time (C- D)	322	min	
	F Ideal production (from manufacturer specification)	130	m^3/h	
	G Actual Production	80	m^3/h	
PR(%)=G/F*100	Dozing distance	120	m	large dozing
= 61.538%	Job efficiency -	48	min/hr	distance (MnF)
	Type of doze - slot dozing	1.2		
	Grade correction	1.4		

	Average operator	0.75		
	Weight correction	0.83		
	Material type – sub base material	0.8		
	H Actual cycle time	2.25	min	
	I Production Capacity losses	141.153	m^3/hr	
	Down time = [1-H/G] x L			
	J Minor stoppage	15	min	inspection delay
QR (%) =	K Net Operating Time (= E- K)	367	min	(MnF)
(O-P)/O	L Performing Time (L – I)	225.847	min	
92.885%	M time spent for rework	15	min	Overcrowding (WF)
V	N Valuable Operating Time	210.847	min	
	O Total executed amount (unit)	281.129	m^3/hr	
	P reworked amount (unit)	20	m^3/hr	
OEE =AR*PR*QR		**48.189%**		

Table 4.2: Summary of Average Productivity Rates Of Dozer on Beddelle –Mattu Upgrading Road Project

Dozer productivity rate **Indexes**	**Percentage**
Availability rate	84.293
Performance rate	61.538
Quality rate	92.885
OEE	48.18



Graph 4.1 Dozer Productivity Rate

A summary of all the primary component rates and OEE indexes are contained in Table 4.2, and Figure 4.1 and shows that the rank of three primary component rates in order of their effect on the overall performance of corresponding machine on Bedelle –Metu upgrading road project. From this table and figure, the performance rate ranked first, availability next and quality rate with a lesser effect on the productivity. The production performance ratio (0.615) observed was relatively low which indicates poor production per hour .This considerable difference is one of the controversial issues in managing of construction projects.

Besides, the computation in Table 4.1 Shows the extent of the overall productivity of dozer is very poor (i.e 48.189%). This is due to improper work management in the utilization of the machine. As noted out on column of the contributing factor, larger dozing distance, poor communication, more cycle time, inspection delay and overcrowding along the road were the main contributing factor for the productivity loss. Moreover, this analysis shows the performance rate for the machine on this road project is the most important rate that needs more attention from the management side. In addition, it is the one mainly affecting the overall performance of the machines.

4.2.2 Performance Analysis of excavator on Bedele - Matu Upgrading Road Project

In this research work the data collected for Excavator was from current construction project of Beddelle –matu upgrading road project, which was available at site. The data collected was for 55 Minutes to compare the Actual productivity with its Theoretical productivity.

Table 4.3 Actual and theoretical production rate of crawler excavator

Factors	Site
Class of Material	Weathered rock
Angle of Swing	90degree
operator skill	Average
Bucket capacity(cum)	1.22
Cycle time Recorded (sec.)	22
Cycle time Theoretical(sec.)	15
Operator experience (yrs)	7
Age of the machine (yrs)	6
Job efficiency (min)	48
Working Conditions	Weathered rock production 0.8 fill factor
Theoretical work hour Production (m^3/hr)	189
Actual work hour Production (m^3/hr)	129
Production Performance Ratio (%)	68

Sub base material production by excavator

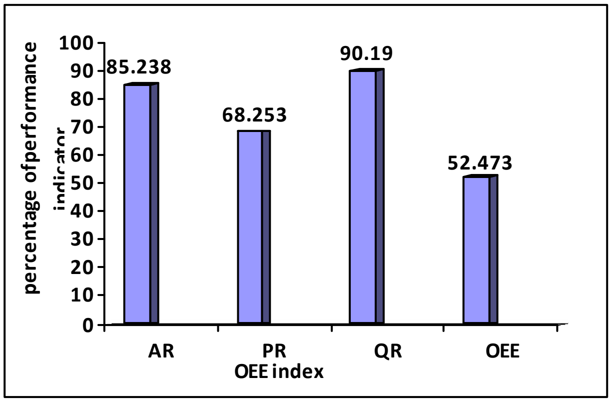
Table 4.4: Performance of excavator Production and Summary Factors Affecting excavator Productivity on Bedele –Matu Upgrading Road Project

Machinery Type - Excavator Mark - Caterpillar Model - 325B Average of Five Days Result with One Day = 8 working hours (Construction Equipment with Cyclic Operating Machines) Excavator Productivity on Beddelle –Mattu upgrading road project				
Type of Activity – sub base production				**factors Contributing**
Productivity rate	**Independent variables**	**value**	**unit**	
Dependent variable	A Available time (8 hrs. x 60')	480	min	
	B Scheduled production break	60	min	lunch and morning
	C Loading time	420	min	inspection (HF)
AR(%)=				
100*E/C	D Major Stoppage losses	62	min	Fuel shortage
(MnF)				
= 85.238%	E Operating Time (= C- D)	358	min	
	F Ideal production (from manufacturer specification)	189	m^3/h	
	G Actual Production	129	m^3/h	
PR(%)=G/F*100	Job efficiency	48	min	
= 68.253% (MF)	Heaped bucket capacity	1.22	m^3	machine size
	Bucket fill factor	0.8		
	H Actual cycle time	22	sec.	Higher cycle time (MnF)

	I Theoretical /ideal cycle time	15	sec.	
	J Ideal losses	79	min	Tea break(HF)
	K Net Operating Time (= E- J)	279	min	
	L Performing Time	244	min	
QR (%) =	M time spent for rework	20	min	Separating big stone
(O-P)/O	N Valuable Operating Time	204	min	from sub base (WF)
90.196%	O Total executed amount (unit)	438.6	m^3/hr	
	P reworked amount (unit)	43	m^3/hr	improper work
OEE =AR*PR*QR		**52.473%**		order (MnF)

Table 4.5: Summary of Average Productivity Rates Of Excavator on Beddelle –Mattu Upgrading Road Project

Excavator productivity rate **Indexes**	**Percentage**
Availability rate	85.238
Performance rate	68.253
Quality rate	90.196
OEE	52.253



Graph 4.2 Excavator productivity rate

From table 4.5 and figure 4.2 the production performance ratio (68.253%) relatively low which indicates poor production per hour though, rank first, availability rate (85.238%) next and quality rate(90.196%) with lesser effect on the productivity of excavator. The product of those three components results in low overall productivity (52.473%) of excavator. This figure shows that the extent of OEE of excavator is poor.

As shown on table 4.4 factors contributing to productivity losses, productivity losses of crawler excavator mainly related to its cycle time, and other factors are shortage of fuel at the site, machine size, for sub base production the size of material is not equal so that the excavator need a time to separate big rocks from the material, tea and launch place are far from the site which need long time to back to the site.

To sum up, the above analysis shows that the performance rate for the machine on Bedele – Metu upgrading road project is the most important rate that needs more attention. In addition, it is the one mainly affecting the overall performance of machine in this project so, extent of the current construction equipment productivity in Bedele –Matu upgrading road project was not good.

4.2.3 Performance Analysis of Loader on Bedele –Metu Upgrading Road Project

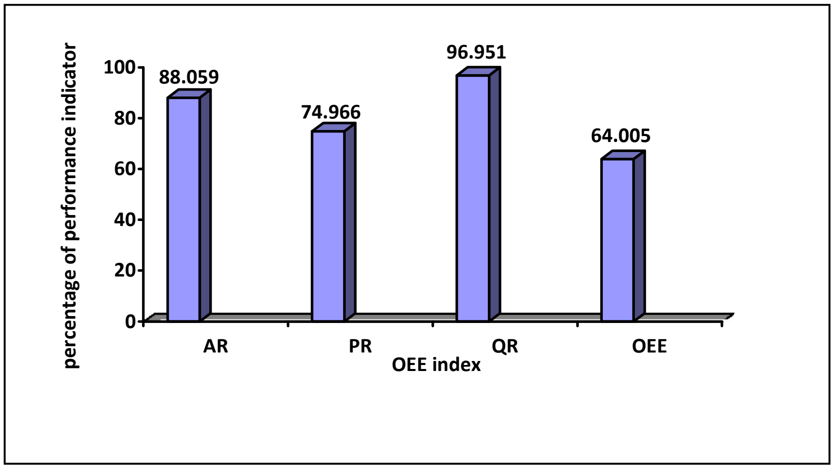
Table 4.6: Performance of Loader Production and Summary Factors Affecting Loader Productivity on Beddelle –Mattu Upgrading Road Project

Machinery Type - Dozer Mark - Caterpillar Model – 950H Average of Five Days Result with One Day = 8 working hours (Construction Equipment with Cyclic Operating Machines) Loader Productivity Rate on Beddelle – Mattu Updrading road Project				
Type of Activity – Loading				**factors Contributing**
Productivity rate	**independent variables**	**value**	**unit**	
Dependent variable	A Available time (8 hrs. x 60')	480	min	
	B Scheduled production break	78	min	lunch break & morning inspection (HF)
	C Loading time	402	min	
AR(%)= 100*E/C = 88.059%	D Major Stoppage losses	48	min	
	E Operating Time (C- D)	354	min	
	F Ideal production (from manufacturer specification)	186.75	m^3/h	
	G Actual Production	140	m^3/h	
PR(%)=G/F*100 = 74.966%	Job efficiency	50	min/hr	
	Bucket fill factor	0.9		
	Swell factor	0.8		
	Actual cycle time	23	min	higher cycle time
	H Production Capacity losses downtime	91.87	m^3/hr	(HF)
	[1-H/G] x L			
	J Net Operating Time (= E- K)	260	min	

	K Actual cycle time	2.25	min	
	Minor stoppage	15	min	lack of dump truck
	K Net Operating Time (E- k)	367	min	(MF)
	L Performing Time (L – I)	225.8	min	
	Theoretical cycle time	28	sec.	
QR (%) =	M time spent for rework	10	min	Poor access to work
(O-P)/O	N Valuable Operating Time	210.847	min	(WF)
96.951%	O Total executed amount (unit)	491.976	m^3/hr	
	P reworked amount (unit)	15	m^3/hr	Inspection delay
OEE =AR*PR*QR		**64.005%**		(MnF)

Table 4.7: Summary of Average Productivity Rates of Loader on Beddelle –Mattu Upgrading Road Project

Loader productivity rate	
Indexes	**Percentage**
Availability rate	88.059
Performance rate	78.966
Quality rate	96.957
OEE	64.005



Graph 4.3 Loader Productivity rate

Average result for the primary component rates and OEE indexes for loader is contained in Table 4.7, and Figure 4.3. The detail computation was made in Tables 4.6.

Table 4.7 and Figures 4.3 shows the rank of the three primary component rates in order of their effect on the overall performance of the machines on Beddelle –Mattu upgrading road project. From these data, the performance rate (74.966%) ranked first, availability rate (88.059%) next and quality rate (96.951%) with a lesser effect on the productivity like that of the previous equipments.

Besides, the computation in Table 4.6 shows the extent of the overall productivity of loader is poor (i.e. 64.005%). This is due to the problem of management mainly in the utilization of the machine. As we can see they used, longer dump distance, small number of dump truck, poor access to work and more cycle time.

As we noted out on the above analysis, the most important issues that need more attention from the management side are the work conditions that highly affect the overall performance of machines in this project. Minimizing those technical problems discussed on the above session will help to promote higher equipment productivity. This also helps in increasing effectiveness in terms of time, cost and quality.

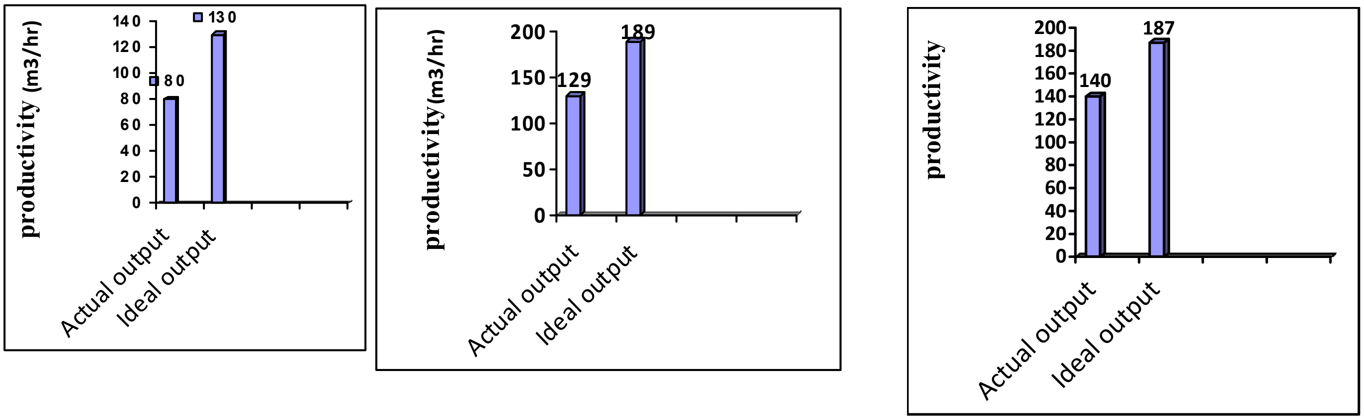
4.3 Comparison of Actual and Theoretical productivity of Equipments on Bedele –Matu upgrading road project

The above analysis indicates that the actual production of the equipments differs from their theoretical production given by manufacturers; the actual output was less than the theoretical output which results in lower performance rate.

According to Nabizadeh et al. proposed actual hourly production of seven different pieces of earthmoving equipment used in earth-fill dam project, separately. Their results show that sheepsfoot rollers have the lowest efficiency with an actual to nominal hourly production ratio of 0.32 whilst the wheel loader has the highest efficiency with a ratio of 0.6. A loader shows the lowest shortfall, with a constant actual to nominal hourly production ratio of 0.6 for various engine horse powers, whereas the highest range of variation of 0.5 is observed for a dozer.

Table 4.8 Summary of actual and theoretical productivity of selected equipments on Beddelle –Mattu upgrading Road project

	Equipments		
	Dozer	**Excavator**	**Loader**
Actual productivity (m^3/hr)	80	129	140
Theoretical productivity ($m^{3/}$hr)	130	189	186.75
Performance ratio (%) = actual production/ theoretical production	61.538	68.253	74.966



Dozer production Excavator production Loader production

Figure 4.4 Actual production Vs Theoretical production of equipments at Bedele –Matu upgrading project

From table 4.8 and figure 4.4 The actual production of a loader and dozer showed had the least difference with its ideal production; while the excavator had the most difference in actual and ideal production.

This result shows that dozer and excavator have lowest efficiency with an actual to theoretical hourly production ratio of 0.615, 0.682 respectively while wheel loader has the highest efficiency with a ratio of 0.749. Wheel loader shows the lowest productivity losses than dozer and excavator at the site.

The result shows that the actual hourly production has an impressive difference with ideal production given by manufacturers. Ignoring the difference leads to difficult challenges in the management of projects.

Since, the actual production were estimated by considering the site condition on the basis of real construction project, this study explored separate factors of actual hourly production for dozer, loader and excavator on Bedele –Matu road upgrading project. The obtained results are realistic. These results can contribute greatly to project management teams in order to schedule the construction machinery more effectively as well as decreasing project risk.

4.4 Analysis of Main Contributing Factors for Equipment Productivity losses

This study identified critical factors leading to the loss of productivity and found out that Management issues have a significant impact on road construction productivity.

Performance rates are highly affected by work management problem and the result in this case study project was found in between 60 – 80 % for those selected equipments. Besides, the key factors affecting equipment productivity are found within this rate.

This analysis obtains the actual hourly production of three selected equipments at Beddelle-Mattu upgrading project sites and considers the effective factors causing the productivity losses. For example, managerial problems, work factor, human factor and machine factor and accordingly, improperly use of time for the machinery causes a significant difference between nominal and actual productions. Several elements prevent full capacity of machinery. These non-productive time elements include setup time, scheduled maintenance, and operation disengagement (e.g. breaks and meals.)

The performance rate is low in this case study for the three machines (dozer, excavator and loader).

Table 4.9 Summary of Factors for the Productivity Loss on the Study Projects

Contributing Factors	**Class of Contributing Factors**
Activity dependency	MnF
Lack of equipment	MnF
Incompetent Forman	HF
Longer working length	MnF
Lunch and tea break	MnF
Third person communication	HF
Operator delay	HF
Hydraulic oil check up	MnF
Poor site condition	MnF
Longer dozing distance	MnF
Higher number of pass	MnF

Lack of communication	MnF
waiting for surveyor	MnF
Weather condition (heavy rain)	WF
Lack of side by side dozing	MnF
Improper work order	MnF
Oil checkup	MF
Poor preparation in the morning	HF
Inspection delay	MnF
Machine age	MF
Longer dump distance	MnF
Inefficient operator	HF
Inspection time	MnF
Material type	WF
Change order	MnF
Higher cycle time	MnF
Minimum working space	WF
Fuel shortage	MnF
Size of machine	MF

Notice: MnF = Management Factor

Hu = Human Factor

MF = Machine Factor

WF = Work Factor

From the result summarized in Table 4.9, it is possible to conclude that the management problems were the key factors in affecting equipment productivity in this projects and it was ranked first (i.e. 64.28%) among the main contributing factors for equipment productivity loss such as human factor, machine factor and work factor. The second critical factor that affects equipment productivity on the project was the human factor with the percentage of 17.85. The machine factor and work factor with a percentage of 10.71 and 7.14 respectively ranked third and lest in contributing for equipment productivity loss.

4.5 Remedial measures for factors contributing equipment productivity losses

This research found out that Management issues have a significant impact on road construction productivity. So, this study provided a list of remedial measures for significant factors on how to mitigate losses of equipment productivity.

The selection of the appropriate type and size of construction equipment often affects the required amount of time and effort and thus the job-site productivity of a project. It is therefore important for site managers and construction planners to be familiar with the characteristics of the major types of equipment most commonly used in construction.

- ❖ Project managers should prepare a very detailed project schedule that integrates time and resources on the schedule.
- ❖ They should identify best construction practices by establishing performance goals, and evaluating their performance accordingly.
- ❖ The construction managers should be committed to their equipment life. They should develop a routine maintenance schedule for their machineries. Providing training for equipment operators regarding equipment, safety and easy maintenance. Introducing new machineries and management system which helps for efficient performance, and measuring impacts on construction output.
- ❖ Further, they should standardize their construction method so that variation in construction productivity among projects can be minimal.
- ❖ To avoid breakdown, proper and timely maintenance of equipments should be done.
- ❖ Minor Stoppages can be saved by keeping sufficient materials on site and making the site condition favorable for work.
- ❖ To reduce the cycle time and time required for excavation, Maximum Capacity of Bucket should be used.
- ❖ Dumping Site should be near to the Excavating Site can save time and the vehicles used for carrying excavated materials.
- ❖ Reducing the angle of swing can reduce the cycle time and work can be done more efficiently.

- Operator should be skilled as a skilled operator can handle the equipment more effectively providing maximum output from machine
- It is recommended that high production rates can be obtained by giving proper training to the operator.
- Putting the truck in the right position also saves time for operator
- Side-by-side dozing will increase production 15 to 25 percent when moving material When the distance is less than 50 feet, the extra time needed to maneuver and position the dozers will offset the increased production.

Table 4.10 summary of factors affecting equipment productivity and its remedial measures

Group of factors	**Factors contributing to Equipment productivity losses**	**Remedial measures**
MnF	Activity dependency	Properly planning and scheduling activities separately
MnF	Lack of equipment	Properly Equipment utilization and early maintenance
MnF	Longer working length	Minimize working distance
MnF	Lunch and tea break	Providing food, tea and coffee at site area or proving transport service for operators, Forman , surveyors and other supporting crews
MnF	Hydraulic oil check up	Early preparation is required before starting work on site
MnF	Poor site condition	Avoiding congestion and overcrowding on site
MnF	Lack of communication	The crew should communicate about the work and all members should be ready for work Daily communication between office and field With stakeholders and supporting staff
MnF	waiting for surveyor	Surveyors should ready before the machine start the work
MnF	Lack of side by side dozing	Verifying and assigning Side-by-side dozing, since this method increase production
MnF	Improper work order	Works should be according to the plan and schedule
MnF	Inspection delay	Consultants should inspect day to day activities on site
MnF	Longer dump distance	Dumping Site should be near to the site
MnF	Change order	Early ordering the change before the work

		executed
MnF	Higher cycle time	To reduce the cycle time, use maximum bucket capacity of machine and motivate operator
MnF	Fuel shortage	Fuel should be available at the site
HF	Inefficient operator	Operators should be skilled by providing proper training to them.
HF	Poor preparation in the morning	Early preparation for all crew required
HF	Incompetent Forman	The Forman should be Skilled person who know technical and scientific method instead of only by experience &traditional
HF	Third person communication	No need of interference among people when they are on work
HF	Operator delay	Giving clear orientation about next day work schedule and plan. Appreciating and awarding punctual operators
MF	Size of the machine	selection of the appropriate type and size of construction equipment depending project size
MF	Machine age	New equipments should used for high production
WF	Weather condition (heavy rain)	
WF	Material type	
WF	Minimum working space	

Table 4.10 shows that factors contributing to productivity losses that observed at the site and their remedial measures most of them are managerial problems that should solved in order to increase productivity at site.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Low equipment performance in road sector has been a great concern in Ethiopia and construction industry cannot have good performance without improving machine productivity.

Estimating the actual production of machinery plays an important role in succeeding of construction projects

Current productivity rates of heavy-duty construction equipment, main contributing factor for productivity loss and its remedial measures of selected equipments in Bedele- Matu road upgrading project were described in this section.

In this study productivity loss is computed using OEE index which are components of availability rate, performance rate and quality rate and from those three primary components the performance rate highly affects machine productivity, this indicates that the actual productivity of the equipments and theoretical productivity which is given by manufactures are not the same means the actual productivity is less because of various factors that affect on site equipment productivity.

The OEE index calculated for the machines under this study have all productivity problems in their performance laying between (48-65%).

Out of the three primary component rates of OEE performance rate of those machines were poor (60-75%) and the availability rate were relatively week (84-90%) but the availability rate have an acceptable range (>=90%).

Comparing the actual productivity with their corresponding theoretical productivity was also analyzed in this thesis. Thus, wheel loader has the highest efficiency with an actual to theoretical hourly production ratio of 0.749 and dozer and excavator relatively have lowest efficiency with an actual to theoretical hourly production ratio of 0.615 and 0.682

respectively. Considering this high range of shortfall is certainly useful in planning of machinery in project sites.

Factor causing productivity losses in this finding are grouped as management factor (MnF), human factor (HF), machine factor (MF) and work factor (WF). Among this, Management factor were ranked first (64.28%) and the second were human factor with percentage 17.85. Machine and work factor with the percentage of 10.71 and 7.14 respectively ranked third and least in contributing for the equipments productivity losses.

It was concluded that minimizing the difference between actual productivity and theoretical productivity by identifying factors contributing to this difference and taking proper remedial measures to increase actual productivity was the responsibility of project managers and all stakeholders in construction industry.

This study provided some remedial measures for significant factors on how to mitigate losses of equipment productivity.

- Project managers should identify best construction practices by establishing performance goals, and evaluating their performance accordingly
- Project managers should prepare a very detailed project schedule that integrates time and resources on the schedule
- Good communication with office and field and between stakeholders and supporting staff.
- Providing training for equipment operators regarding equipment, safety and easy maintenance.
- Properly Equipment utilization and early maintenance.
- selection of the appropriate type and size of construction equipment depending project size
- Side-by-side dozing will increase production
- Reducing angle of swing and using maximum bucket capacity to reduce cycle time

5.2 Recommendations

- ✓ Planning and project schedules should have to made based on equipment actual productivity
- ✓ Contractors need to have a periodic maintenance schedule (especially predictive and preventive maintenance) to minimize hidden time loses to maximize productivity
- ✓ Contractors should measure their performance rate and work more on factors that affects performance rate
- ✓ They should introduce new machineries and management system which help for efficient performance and they should always measure their impact on construction output.
- ✓ Project managers should select appropriate type and size of construction equipment which often affects the required amount of job-site productivity. And to be familiar with the characteristics and technical usage of the major types of equipment most commonly used in construction projects.
- ✓ Training machine operators how to maximize machine productivity and motivating them on their work
- ✓ Consultants and clients should proceed the payment, change order and consulting on time
- ✓ Government should solve admistrative problems around the road projects.

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APPENDIX

A- Definition of basic terms

Related Productivity Terms formulas in **Comparative Study of Actual Productivity and Theoretical Productivity of Construction Equipment**

Understanding of these terms will help readers to go easily through the remaining pages.

- **Actual production**: the production of the equipment at the site and is, obviously, less than the nominal production. Thus, the more efficient it is estimated, the better result would be obtained from managing the project (H. Nabizadeh Rafsanjani, 2009).
- **Active Time/Loading Time** is the time when the construction equipment is actually available for work. That is available time minus planned downtime
- **Available time:** The total scheduled time for the production. It also referred as production time. Alternatively, It is the portion of the time when equipment is in actual production or is available for production, is the opposite of downtime. For example, if the equipment's downtime is 10%, then its availability is 90% (Douglas et al., 2006a).
- **Bucket fill factor:** is the ratio of the volume of soil required per cycle to the standard bucket size (Caterpillar performance handbook, 2012)
- **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".
- **Job efficiency:** the actual number on minutes worked by the machines during an hour (Caterpillar performance handbook, 2012)
- **Net operating time:** "the time during which the equipment operates under stable condition"
- **None scheduled time**: the time when the construction equipment not scheduled to perform a certain activities.
- **Non-Productivity time:** the time in which a given construction equipment is not capableof doing any activities. This is may be the case of accessory breakdown, doing unnecessary or non-value adding activities

- **Operation time:** the total available time minus non- scheduled time
- **Overall Equipment Effectiveness** is a measure of value added to the production by a certain machine in a production time
- **Performance measure** is the process of quantifying effectiveness and efficiency of an action
- **Performance time is** the time during which construction equipment operates under stable conditions at its design speed or capacity.
- **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"
- **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.
- **Theoretical production**: the production given by the manufacturer, which recognizes an ideal production while the equipment is operated on a continuous basis.
- **Valuable operating time is** "time during which equipment actually operates, under stable Conditions, at optimal speed, and producing acceptable out puts." (Carlos, 2009)

$$\Pr oduction = \frac{60\min xblade\ load}{push\ time + return\ time + maneuver\ time(\min)}$$

Blade load (Icy) = O.0139HWL

$$\text{Production (Icy per 60-min hr)} = \frac{\text{net hp X 330}}{D + 50}$$

Production (Lm3/h) = Ideal Production (figure) x Product of all production correction factors

$$\textit{Production rate} = \frac{3600\ sec*Q*F}{t} * \frac{E}{60min/hr} * \frac{1}{volume\ correction}$$

$$\text{Production rate} = \frac{\text{3600sec./hr * bucket capacity *Fill factor}}{\text{Fixed cycle time (sec./hr)}} \text{ *Efficiency factor *Load Factor}$$

Performance Rate (PR) = Actual Productivity / Theoretical Productivity

OEE = Availability rate (%)* performance rate (%)*quality rate (%)

$$OEE = \frac{Valuable\ operating\ time}{loading\ /active\ time}$$

Available time - Planned Downtime = **loading time/Active time**

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

Operating time- Idle minor stoppage = **Net operating time**

Net operating time - Production capacity loss =**Performing time**

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

Calculation for actual and theoretical productivity of Excavator

Bucket Capacity = 1.22 m3.

Fill factor for weathered rock = 80%

Thus, Net capacity = (Bucket Capacity * 80%)

= 1.22*80%

= **0.97m3**.

Time per swing (swing, fill, swing, unload)

= 22 seconds……………………………………………….recorded actual time

∴ Time per swing /60 = 22/60

= **0.36 minutes**.

Consider 12 minutes of rest time taken by the operator every one hour

∴Number of swing cycles per hour = (60 min – Rest Time) / Time per swing in min.

= (60 – 12) / 0.36

= **133 cycles**

Per hour Capacity of Excavator = Number of swing cycles per hour * Net capacity

= 133 * 0.97

= **129 m3/hour**

To calculate theoretical production rate using standard tables and equipment specification manuals. The machine under study bucket capacity =1.12m^3

t=15sec/hr…………………………………….theoretical cycle time from manufacturers

$$p = \frac{3600sec/hr.*1.22*0.8}{15sec./hr} * \frac{48min}{60min}$$

= **189 m^3/hr**

APPENDIX –B Sample Format for Data Collection

<table>
<tr><td colspan="6">Data Collection Template</td></tr>
<tr><td colspan="6">Machine type ______________Mark ___________________Model _______________</td></tr>
<tr><td colspan="6">One day = 8hrs</td></tr>
<tr><td colspan="6">(Construction Equipment with cyclic operating Machines)</td></tr>
<tr><td colspan="6">Name of Contractor- Hawk International finance and construction co. Ltd</td></tr>
<tr><td colspan="5">Type of Activity ------------------------------</td><td>CF</td></tr>
<tr><td>Productivity Rate</td><td>Sym</td><td>Independent variable</td><td>Value</td><td>Unit</td><td></td></tr>
<tr><td rowspan="7">Independent variables

AR(%)= 100*E/C</td><td>A</td><td>Available time (12 Hrs*60')</td><td></td><td>min</td><td></td></tr>
<tr><td>B</td><td>Scheduled maintenance + scheduled production break</td><td></td><td>min</td><td></td></tr>
<tr><td>C</td><td>loading time (=A-B)</td><td></td><td>min</td><td></td></tr>
<tr><td>D1</td><td>Recorded break downtime</td><td></td><td>min</td><td></td></tr>
<tr><td>D2</td><td>Time spent for change in Operation condition</td><td></td><td>min</td><td></td></tr>
<tr><td>D</td><td>Major Stoppage losses (= D1 + D2)</td><td></td><td>Min</td><td></td></tr>
<tr><td>E</td><td>Operating Time (= C- D)</td><td></td><td>Min</td><td></td></tr>
<tr><td rowspan="5">PR(%) = P*R</td><td>G</td><td>Ideal production (from manufacturer specification)</td><td></td><td>M^3/hr</td><td></td></tr>
<tr><td>H</td><td>Actual Production</td><td></td><td>M^3/hr</td><td></td></tr>
<tr><td></td><td>Dozing distance</td><td></td><td>M</td><td></td></tr>
<tr><td rowspan="2"></td><td>Applicable correction factor
Job efficiency - 45min/hr
Type of doze - slot dozing
Grade correction – Downhill (for 10%)
- uphill
Average operator
Weight correction</td><td></td><td></td><td></td></tr>
<tr><td>Material type - Clay soil(A-7-6) with gravel</td><td></td><td></td><td></td></tr>
</table>

	O	Actual cycle time			
	I	Production Capacity losses downtime = [1-H/G]*L		min	
	K	Minor stoppages / Idle losses		min	
	L	Net Operating Time (= E- K)		min	
	M	Performing Time (L – I)		min	
	N	Valuable Operating Time(M – J)		min	
	P	Net Operating Rate = (100 * (H * O)/E)		%	
	Q	Ideal/ theoretical/ design cycle time		min	
	R	Operating Speed coefficient(= Q/O)		Min	
	J	Time spent for rework and start up yield losses		min	
	S	Time spent for rework and start up yield losses		Unit	
QR(%) = QR(%) = (S-T)/S	T	reworked amount(unit)		Unit	
OPR/OEE =AR*PR*QR					

APPENDIX –C Name of Construction Company Involved in the study

- **Projec**t: Bedele – Metu Road Upgrading Project
- **Client** : ERA
- **Contractor** : Hawk International finance and construction co. Ltd
- **Consultant** : Roughton international in JV with Beza consulting engineering plc

APPENDIX –D Pictures on site : Onsite productivity

Spreading sub base material using dozer

Sub base material production by excavator

Loading waste material by loader