



ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

LOSS ASSESSMENT OF CONSTRUCTION EQUIPMENT PRODUCTIVITY AND ITS IMPACT ON EQUIPMENT FINANCIAL PERFORMANCE IN FEDERAL ROAD PROJECTS: A CASE STUDY ON THREE FEDERAL ASPHALT ROAD PROJECTS IN SNNPR.

By

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A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirement for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)



Advisor: Wubishet Jekale (Dr. Ing.)

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LIST OF ABBREVIATION

AR	Availability Rate
PR	Performance Rate
QR	Quality Rate
AACE	Association of Advancement of Cost Engineering
FRCP	Federal Road Construction Projects
RAM	Reliability, Availability and Maintainability
OEE	Overall Equipment Efficiency
TPM	Total Productivity Maintenance
ERA	Ethiopian Road Authorities
RII	Relative Importance Index
AAU	Addis Ababa University
MnF	Management Factor
MF	Machine Factor
HF	Human Factor
AAIT	Addis Ababa Institute of Technology
%	Percent
Sec	Second
m	Meter
m ³	Meter Cube
mm	Millimeter
Kg	Kilogram
Sym	Symbol
Hr	Hour
CF	Contributing Factor
Km	Kilo Meter
SNNPR	South Nation and Nationality People Region
SAE	Society of Automotive Engineers

ABSTRACT

Modern construction, characterized by effective and efficient utilization of construction equipment to accomplish numerous construction activities. Equipment may range from simple hand tools or apparatus to heavy-duty construction equipment. As a high level of productivity is important to any company's success and survival, this paper help to fill the gap created by the absence of proper equipment management on the construction sites and helps to examine the overall performance of heavy-duty construction equipment. This study also examines the major contributing factors for productivity loss on the case study federal road construction projects to find important interventions for changes; this is because machinery management have high influence on productivity, cost and quality. Three federal roads where involved in this study, Namely, Matoria-Durame-Hadero, Hadero-Durgi and Alaba-Alemgebeya-Hulbarek road projects in the southern regional state of Ethiopia. The assessment involved in this study was field observation and measurement to quantify downtime and the actual productivity and desk study to identify main factors contributing for productivity loss. In the entire study site, the OEE index show low percentage of productivity in between 55% to 68%. Out of the three primary component rates of OEE index only quality rate have a higher performance, which is about 90% and above. However, the performance rate in the entire study site shows lower performance(less than 76%). Due to this weak performance of the construction equipment productivity, the contractors forced to incur an additional cost from 1 – 2 % of the total monthly running cost allocated for the equipment. Out of the four main contributing factors for equipment productivity loss (machine factor, human factor, management factor and work factor) the management problem ranked first. Although there was low construction equipment productivity in the entire study site, the Resident Engineers (RE) do not have any compliant on the contractor regarding to their poor Performance.

Keywords: Overall Equipment Effectiveness, Performance Measure, Productivity, Construction Equipment, Equipment Management

CHAPTER I INTRODUCTION

1.1 Background

Construction Equipment of what ever type, may be heavy or Simple, cheap or expensive, is liable to breakdown/failure when they are used continuously to perform construction activities or when they are used with out repair or preventive maintenace for a long time. Beside, construction equipment may not available for work as scheduled due to various factors. As a result there is a reduction in its intended productivity rate or performance. Thus, 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 (Jose, 2001).

Beside to the above facts, stakeholders of the construction industry have to know the extent of their construction equipment productivity, associated losses during the production, factors contributing to the equipment productivity loss and its impact on the project performance. And knowing the extent of loss of construction equipment productivity is very crucial for profesional's engagement in the field and will enable the stackeholders to minimize the possible losses and maximize the outcomes obtained though the use of individual construction equipment. Otherwise, the stakeholder will suffer with time and cost overrun, which in turn affects the project performance of the construction industry.

According to Getaneh (2012) the determination of construction equipment productivity and loss assessment is not an easy task or it is tiresome. But, through aproximation and simplification one can reach to an optimal result. For this use of Total Productivity Maintenance(TPM) measure using Overall Equipment Effectiviness(OEE) index is helpful. Beides, the determination of the three most important performance indicators Such as

availability rate, performance rate and quality rate is very crucial. Moreover, increasing these rates will help to increase the output and quality of the work with less downtime.

Loss related to equipment direct cost and running cost are easily determined. However, loss associated with productivity is difficult to track it easily or cannot “be discerned separately and contemporaneously”. At the same time, it is very difficult to establish precise measurement of equipment productivity. Compounding this situation, there is no uniform agreement within the construction industry as to a preferred methodology of calculating loss of equipment productivity. Moreover, loss assessment of construction equipment productivity on the road projects involves a greater depth of detail. In fact, there are numerous ways to calculate loss of equipment productivity. One of such a method is the concept of Overall Equipment Effectiveness (OEE) index. This index indicates area of improvement and enable better assessment of productivity losses (AACE, 2004).

Many other studies show that productivity growth is strongly correlated to economic growth and increases in welfare (Khyomesh et al., 2011). This fact may holds true in our construction industries in 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.

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. Moreover, there has been a lack of research in our country in respect of assessment of loss of equipment productivity and factors contributing for low productivity. Nevertheless, it requires in depth understanding to improve productivity.

In this study, investigation of loss of construction equipment productivity and its impact on equipment running cost carried out using an appropriate metrics such as equipment Reliability, Availability and Maintainability (RAM). Moreover, one of the objective of this study was to get an update information on current loss of construction equipment

productivity and its impact on the equipment financial performance in terms of project completion time and the associated cost.

1.2 Statement of the Problem

Improving the productivity of heavy-duty construction equipment is the main concern of construction industries in Ethiopia. However, it is difficult to tackle it easily. Moreover, in our country no more such study carried-out in an area, which formulate a method to compute loss of equipment productivity and its impact on the equipment financial performance as compared with the base line productivity. On the other hand, minimizing loss of construction equipment productivity have a significant impact on the project successful accomplishment. These all facts needs a detail investigation along with an improving intervention. As a result, a clear procedure for estimating loss of equipment productivity is required to minimize its impact on project output. Finally, the need for higher output per input of individual equipment is crucial for project success. Therefore, to address the problem understanding and quantifying the impact and loss of equipment productivity using work-study method helps to control equipment performance loss.

1.3 The Research Questions/Expected Findings

This study addressed the following research questions:

- ✓ What is the extent of loss of construction equipment productivity on the three federal road projects in SNNPR?
- ✓ What factors contribute for the loss of construction equipment productivity?
- ✓ How does equipment productivity loss, affects monthly equipment running cost?

1.4 Objectives

1.4.1 General Objective

Assessment of the current situation of loss of construction equipment productivity and its impact on equipment monthly cost in SNNPR road construction projects in general and to formulate and give recommendations based on the outcome of the research.

1.4.2 Specific Objective

1. To assess the current production rate of heavy-duty construction equipment
2. To identify the main factors contributing to the loss of construction equipment productivity
3. To evaluate the extent of equipment productivity losses per day and its impact on the equipment financial performance

1.5 The Scope of the Study

1. This study mainly focuses on productivity loss assessment of heavy-duty construction equipment namely, loader, motor- grader, dozer and excavator on the selected Projects.
2. All charts, graphs, tables or standard values incorporated in the determination of the design/ideal production rates referred from manufacturer's technical specification corresponding to each particular mark and models of the construction equipment.
3. 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.
4. The productivity rate of other construction equipment like, shovel family, haul units, hand compactors (plate compactor) etc. that are not used intensively in the construction industries were not covered in this study.
5. Limitation of this study was unavailability of adequate documented information about the construction equipment productivity in the construction industry and lack of proper machinery work schedule in the project work plan.

1.6 Application of the Study

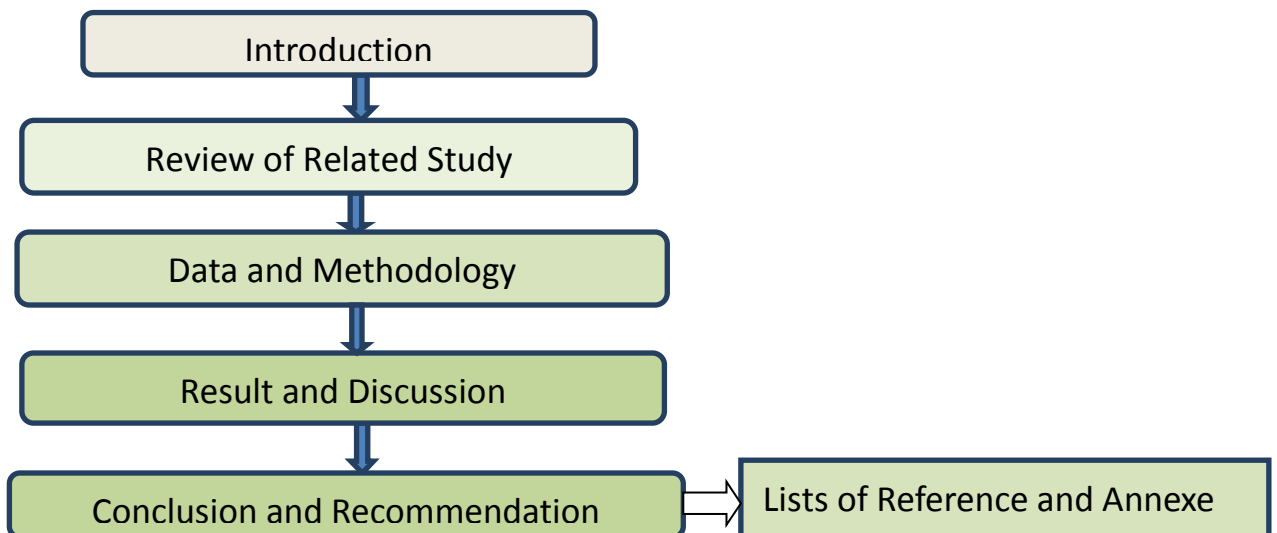
As construction is a risky business and requires substantial amount of money for its work accomplishment, increasing the productivity of heavy-duty construction equipment will play a role to minimize problem in money transaction. Moreover, School of Graduate studies- AAU

increasing machine productivity is very crucial for successful project management. Therefore, knowing the impact and the extent of loss of construction equipment productivity will safeguard the contractors and the client of the projects from time and cost overrun resulted from poor overall performance of the construction equipment. With this perspective, the primary benefit of this study is to provide additional scientific knowledge and tools that enables the stakeholders to quantify loss of construction equipment productivity and to detect area of improvement. Hence, it promotes the success of the client by producing good quality of work through proper utilization of the existing machines with appropriate time and cost.

1.7 Thesis out line

This thesis organized in to five chapters. The first chapter is the introduction. The second chapter presents the review of related study. The data and methods used in the study, concisely described in chapter three. This chapter describes method to determine productivity rate, OEE Index and impact factors. Chapter-4 explains results of OEE index and primary component rates used for the determination of the OEE index. The last chapter describes analysis of equipment productivity rate, factor contributing for productivity loss and extent of current productivity of the construction equipment on the three case study projects in SNNPR.

The following chart summarize the thesis out line.



CHAPTER II LECTRATURE REVIEW

2.1 Introduction

Loss of construction equipment productivity is the productivity, affected adversely by unexpected factors or impact factors. A number of factors affects construction equipment productivity. This productivity loss has a delay impact on the project schedule and work accomplishment of the construction projects. To safeguard the construction industry from financial losses, the project managers have to play a great role to minimize losses and optimize productivity by improving the management problems, equipment utilization techniques, the effectiveness of the operators and the working conditions on the site. Besides, quantification of the extent of equipment productivity and the main contributing factors is very crucial in solving problem related to equipment productivity. This study focused not only on the productivity measurement but also on the computation of the associated equipment productivity loss using the OEE Index.

2.2 Heavy-Duty Construction Equipment as a Resource

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).

Study shows that at the start of 21st century, construction accounted for approximately 10% of the U.S GNP and employed approximately 4.5 million people. For this development, heavy-duty construction equipment is one of the primary resources. (Douglas et al., 2006). Besides, the construction of civil engineering structures such as:

- connection of building to the earth by using foundation to create stability
- To bury utilities underground in a way not visible on other system

-
- To provide suitable surface drain using bridges spanning over the river and valleys or tunnel through mountains and to harness water for our existence by constructing dams and to link our towns or villages using highway, construction industries requires heavy construction equipment as a main resource.

The development of automated heavy-duty construction equipment for earth moving, excavating, pushing, compacting and lifting occurred in the last two centuries and 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 construction equipment (like Dozer, loader, grader, and excavator) for different activities. In fact, heavy construction work typically requires high-volume or high capacity equipment (Douglas et al., 2006). Once a day many types of construction activities undertaken by local or international contractor requires different combination of these heavy-duty construction equipment to be used for different activities, like earth moving, excavating, compacting and lifting.

2.3 Heavy-Duty Construction Equipment Productivity and its Measurement

2.3.1 Equipment Productivity in General

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

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 (f_s) 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. $Q_a = Q_p * f_w * f_j$) (Getaneh, 2012).

On the other hand, manufacturer specification provide 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 (Getaneh, 2012).

As Peurifoy et al. (2006) argued there are high degree of interdependency between the size and complexity of the construction projects with equipment utilized. Therefore, this interdependency needs different combination of heavy-duty construction equipment (like 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.

The following sections explain this equipment in detail.

2.3.2 Dozer/Bulldozer Production Rate

Dozer is one of the most commonly used earth moving equipment that has a blade attached to the machine front for earth moving and which provide a tract power for the drawbar work. Besides, to dozing, dozer can do land clearing, ripping, assisting scraper in loading, rough excavation of a soil and pushing of soils, debris, or other materials. Its production rate is highly affected by dozing distance. “Economical haulage distance is up to 50 meters” (Gashaw, 2009).

It is difficult to measure the production rate of a dozer by volumetric bases since it does not have hopper to load the material. However, the material left in front of the dozer is used for estimating dozer production rate. 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 (Peurifoy, 2006).

$$\text{Production rate (Lm}^3\text{/h)} = \frac{\text{Job efficiency} * \text{Blade Load}}{\text{Pushtime(min)} + \text{Reverse time(min)} + \text{maneuver time(min)}}$$

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.

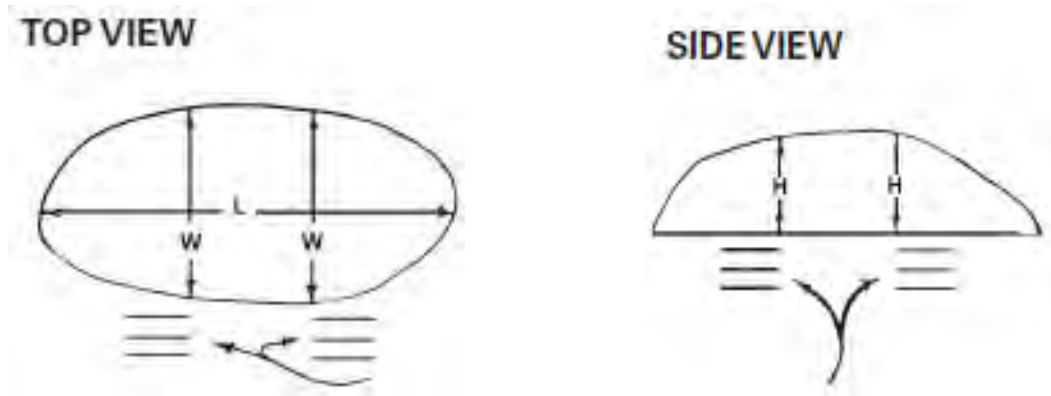


Figure 2.1: Measurement of Required Dozer Blade Load
Source: Caterpillar Performance hand book (2012)

From these figures it is easy to determine the average height (H) as measured like in Figure 2.1(right), the average width as measured like in Figure 2.1 (left) and the greatest length of the pile (L) as shown in Figure 2.1 (left) and then blade load is calculated by the expression

$$0.0138 * H * W * L.$$

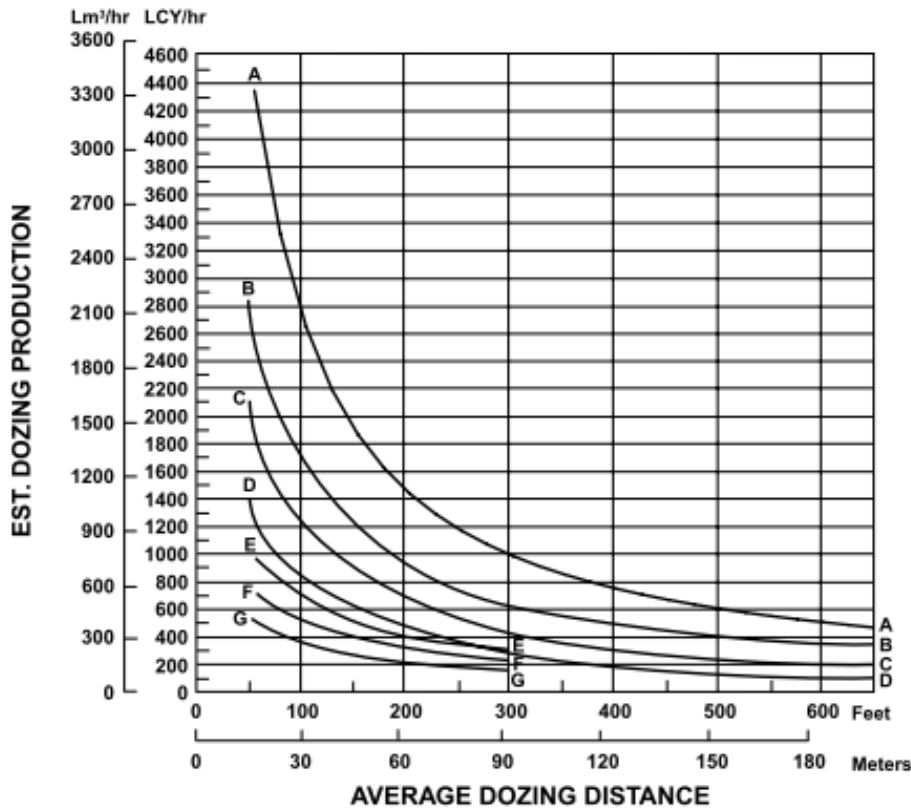
Table 2.1: Typical Dozer Fixed Cycle Time

Operating Condition	Time (Min)
Power- shift transmission	0.05
Direct- drive transmission	0.10
Hard – digging	0.15

Source: Gashaw (2009), Fundamentals of earth moving equipment

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

ESTIMATED DOZING PRODUCTION • Semi-Universal Blades • D6M through D11R



KEY

- A — D11R-11SU
- B — D10R-10SU
- C — D9R-9SU
- D — D8R-8SU
- E — D7R-7SU
- F — D6R-6SU
- G — D6M-6SU

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 2.2: Caterpillar Job Condition Correction Factor for Estimating Dozer Production

	Track type tractor	Wheel type tractor
Operator		
Excellent	1.00	1.00
Average	0.75	0.60
Poor	0.60	0.50
Material		
Loose stockpiles	1.20	1.20
Hard to cut; frozen		
- With tilt cylinder	0.80	0.75
- Without tilt cylinder	0.70	-
- Cable- controlled blade	0.60	-
- Hard to drift; "dead"(dry, no cohesive	0.60	-
Material) or very sticky material	0.80	0.80
- Rock, ripped or blasted	0.60- 0.80	-
Slot dozing	1.20	1.20
Side- by- side dozing	1.15- 1.25	1.15- 1.25
Visibility		

- Dust, rain, snow, fog or darkness	0.80	0.70
Job efficiency		
- 50min/hr	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 Society of Automotive Engineers(SAE) capacity relative to the base blade used in the estimated dozing production graph

For grades verses dozing correction factors see the following graph.

Source: caterpilla performance hand book (2012)

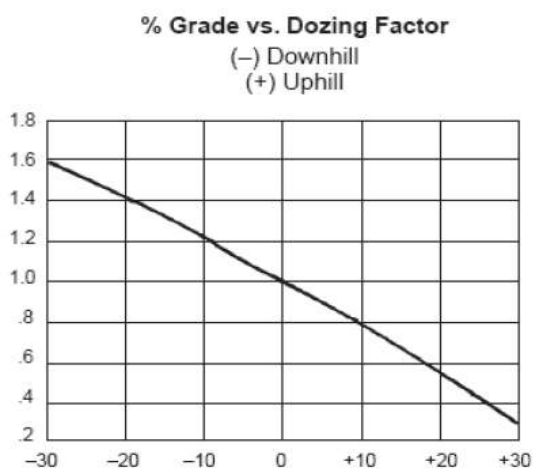


Figure 2.3: Grades vs. Dozing Factors

Source: Caterpillars performance hand book (2012)

*Note: Angling blade and crushing blades are not considered as production dozing tools. Depending on job conditions, 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. 2).

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.

2.3.3 Motor Grader Production Rate

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

$$Q_a \text{ (m}^2\text{/h)} = S \times (L_e - L_o) \times 1000 \times E \text{ (caterpillar performance handbook, 2012)}$$

Where: Q_a : Hourly operating area (m²/h)

S: Operating speed (km/h)

L_o : Width of overlap (m)

L_e : Effective blade length (m)

E: Job efficiency

Alternatively, it is possible to use this relation:

$$Q_a = B * L * f_N * f_z * 60/T \text{ [m}^2\text{/ h]} \text{ (Gashaw, 2009)}$$

$$B = l * \text{Cos } A$$

For this Computation the following data are required:

the width per trip (B) with due consideration of overlapping, length of the blade(l), Angle of the blade(A) with respect to the axis, lift thickness after compaction(L), factor to taker of site conditions, operator effectiveness (f_N) , the time factor (f_z) and cycle time(T) =

$0.06\Sigma P/V$ [min/meter]. If the blade is parallel to the axis, A = zero and cosine of A = one and P = number of pass and V= forward and backward average speed in Km/h.

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

The following tables and figure helps to have all parameters required for the calculation.

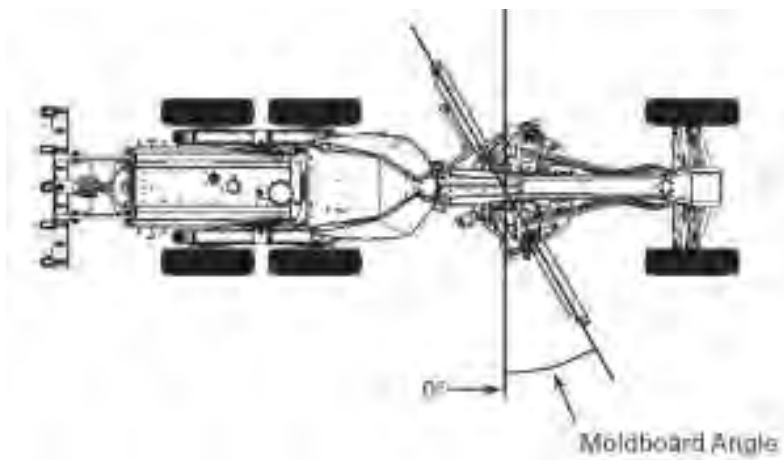


Figure 2.4: Orientation of Blade Angle

Source: Caterpillar performance handbook (2012)

Table 2.3: Angle of Response

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

Source: Caterpillar performance hand book (2012)

Table 2.4: Factor for Site Condition and Operator Effectiveness

	Very good	good	average	poor
Site condition	0.95	0.9	0.8	0.6
Operator effectiveness	1.0	0.85	0.75	0.6

Source: Gashaw (2009), Fundamentals of earth moving equipment

Table 2.5: Time Factor

Length of application	Hour	Day	Week	Month	Year
Factor	0.95	0.85	0.80	0.75	0.7

Table 2.6: Speed for Different Type of Operation

Type of operations	Speed in Km/hr
Road maintenance	4-9
Mix	8
Spread	4-9
Sub base work	4-8
Fine leveling	9-22
Cutting slopes	7-9
Ditching	4-8
Backward and idle non-operational speed	10- v_{max} as per manufacturer specification

Source: Gashaw (2009), Fundamentals of earth moving equipment

Table 2.7: Proper Gear Ranges for Grader Operations

Operation	Gear
Road maintenance	Second to third
Spreading	Third to fourth
Mixing	fourth to sixth
Bank sloping	First
Ditching	first to second
Finishing	Second to fourth

Source: Peurifoy (1995), Construction planning equipment and methods

2.3.4 Loader Production Rate

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

$$\text{Production rate} = \frac{3600\text{sec}}{\text{hr}} * \text{Bucketcapacity} * \text{Bucketfillfactor} * \frac{\text{Fixedcyletime} \left(\frac{\text{sec}}{\text{hr}}\right)}{\text{hr}} * \text{Efficiency factor} *$$

Load factors (Peurifoy, 2006)

To perform this calculation, the following data are required.

Table 2.8 Bucket Fill Factor for a Wheel and Truck Loader

Material	Wheel Loader	Track loader
	Fill factor (%)	Fill factor (%)
Loose Material		
Mixed moist aggregate	95-100	95-100
Uniform aggregates, up to 1/8in.	95-100	95-110
1/8 – 3/8 in.	90-95	90-110
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 2.9: Fixed Cycle Time for Loaders

Loader size, heaped bucket capacity(cy)	Wheel loader cycle time*(sec)	Truck loader cycle time(sec)
1.00-3.75	27-30	15-21
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.

Table 2.10: Representative Specification for Wheel Loader

Size heaped bucket capacity(cy)	Bucket dump clearance(ft.)	Static tipping load(lb.)	Maximum forward speed(mph)				Maximum reverse speed(mph)				Raise/dump/Lower cycle(sec)
			1 st	2 nd	3 rd	4 th	1 st	2 nd	3 rd	4 th	
1.25	8.4	9,600	4.1	7.7	13.9	21	4.1	7.7	13.9	-	9.8
2.00	8.7	12,700	4.2	8.1	15.4	-	4.2	8.3	15.5	-	10.7
2.25	9.0	13,000	4.1	7.5	13.3	21	4.4	8.1	14.3	23	11.3
3.00	9.3	17,000	5.0	9.0	15.7	26	5.6	10.0	17.4	29	11.6
3.75	9.3	21,000	4.6	8.3	14.4	24	5.0	9.0	15.8	26	11.8
4.00	9.6	25,000	4.3	7.7	13.3	21	4.9	8.6	14.9	24	11.6
4.75	9.7	27,000	4.4	7.8	13.6	23	5.0	8.9	15.4	26	11.5
5.50	10.70	37,000	4.0	7.1	12.4	21	4.6	8.1	14.2	24	12.7
7.00	10.4	50,000	4.0	7.1	12.7	22	4.6	8.2	14.5	25	16.9
14.00	13.6	98,000	4.3	7.6	13.0	-	4.7	8.3	14.2	-	18.5
23.00	19.1	222,000	4.3	7.9	13.8	-	4.8	8.7	15.2	-	20.1

Source: Peurifoy (2006), Construction planning, equipment and methods

Table 2.11 Representative Specification for Truck Loader

Size	heaped bucket capacity(cy)	Bucket dump clearance(ft)	Static tipping load(lb)	Maximum forward speed(mph)	Maximum reverse speed(mph)	Raise/dump/ Lower cycle(sec)
1.00		8.5	10,500	6.6	6.9	11.8
1.30		8.5	12,700	6.5	6.9	11.8
1.50		8.6	17,000	5.9*	5.9*	11.0
2.00		9.5	19,000	6.4*	6.4*	11.9
2.60		10.2	26,000	6.0*	6.0*	9.8
3.75		10.9	36,000	6.4*	6.4*	11.4

*Hydrostatic drive.

Source: Peurifoy (2006), Construction planning, equipment and methods

Note: Use tables 2.10 and 2.11 for checking static tipping of load in load factor calculation.

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.

2.3.5 Excavator Production Rate

Hydraulic excavator is a power driven digging machine. It is used primarily in road construction work for trenches or mass excavation below 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(Nunnally, 2007)

Digging depth is the other factor considered in estimating excavator production. The optimum depth of cut is mainly depend 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:

$$\text{Production rate} = \frac{3,600\text{sec} * \text{Heaped bucket capacity(Lm3)} * \text{fill factor}}{\text{cycle time (Sec)}} * \frac{\text{Efficiency}\left(\frac{\text{min}}{\text{hr}}\right)}{\frac{60\text{min}}{\text{hr}}} * \frac{1}{\text{Volume corection}}$$

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

$$\text{For loose volumes of tons} = \frac{\text{Loos unit weight,lb}}{2000\text{lb/ton}}$$

To perform this calculation, the following data are required and it is necessary to refer standard bucket fill factor (based on the type of machine and class of material being excavated) from standard tables and total cycle time (loading, swing, dump and swing empty) was noted out in the site. Refer Tables 2.12 to 2.14.

Table 2.12: Representative Properties of Earth and Rock

Material	Bank weight		lose weight		Percent swell	Swell Factor*
	lb/cy	kg/m3	lb/cy	kg/m3		
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 gravel	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
Rock, well blasted	4200	2490	2640	1565	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)

Table2.13: Bucket Fill Factor for Excavators

Material	Bucket 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 Management

Table 2.14 Excavation Cycle Time for Hydraulic Crawler 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
0 - 1 $\frac{1}{2}$	6	4	2	3	15
0 - 2 $\frac{1}{2}$	6	4	3	4	17
3	7	5	4	4	20
3 $\frac{1}{2}$	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 30° to 60°, loading hauls units on the same level as the excavator

Source: Peurifoy (2006)

Table 2.14 Indicates excavator cycle time which is based on swinging angle of 30- 60°. See Figure 2.5 below.

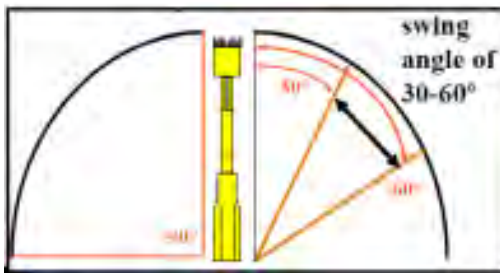


Figure 2.5: Swinging Angle for Hydraulic Excavator

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 60 min job efficiency factor.

2.4 Loss of Construction Equipment Productivity and Impact on Financial Performance

2.4.1 Loss Associated with Construction Equipment Productivity

Loss of equipment productivity is the decline in the output/ productivity of the construction equipment due to various circumstances or events.

According to Carlos (2009), the idea of Total Production Maintenance (TPM) consider the main equipment related-losses with the production time and later Carlos supports the idea of Nakajima (1988) equipment related losses with equipment related wastage. To minimize equipment productivity loss, TPM is an essential tool in the construction industry. Accordingly, the main equipment related losses are:

- Availability losses/ Inactivity Losses
- Performance loss/ Speed Losses
- Quality loss /Defective losses

2.4.1.1 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.

a. 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 loss

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).

b. 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 hammer in case of excavator, old blade change for dozers and so forth. “It is simply a change in operation conditions.”

2.4.1.2 Performance Loss/ Speed Losses

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

a. 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)

b. Production Capacity Losses

These losses are generally associated with the difference between the theoretical and the actual production rate as stated in section 2.3 (Carlos, 2009)

2.4.1.3 Quality Loss /Defective Losses

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

a. 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).

b. 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).

2.4.2 Impact of Equipment Productivity Losses on Equipment Financial Performance

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).

Over the past two decades, academic researchers received substantial attention for performance measure, but still a construction industry needs preference for measuring performance in terms of time and cost (Saad and Andrew, 2013).

If there is low productivity, obviously the project will not be performing well. Low productivity will lead to poor performance or low performance of the project in terms of time, cost and quality and these low performances in public road projects are strongly associated with time and cost over runs. Moreover, “time, cost, quality and program objectives were assessed for performance determination” (Wubishet, 2004).

As pointed out by Wubishet (2004) time performance has two approaches. The first approach is in terms of project completion time and progress time. This approach relates planned versus actual project accomplishments time. The second approach is in terms of “Management or Administrative process”. Cost performance also has two directions; budgetary commitment together with their utilization rate which is the first approach and project cost vibration both in unit cost and in total project cost, the second approach.

This study anticipates assessing equipment cost overrun due to productivity loss. Time performance was assessed based on comparison between the planned time (total loading time) assigned to a certain activity done by particular equipment versus time taken actually to accomplish the same activity by the same equipment. Cost performance was assessed based the comparison made between actual running cost with the planned cost.

2.5 Factor Contributing to the Loss of Construction Equipment Productivity

Relative importance is defined as the proportionate contribution each predictor makes to R^2 , taking in to account both the independent relationship with the criterion and its relationship when combined with other predictors (Johnson & LeBreton, 2004). Indices of relative importance do not determine the causal importance of particular variables but are used to establish variable importance in terms of associated variation.

According to Makulsawatudom and Emsley (2001) following are main contributing factor for low equipment productivity in the construction industry. In addition, these factors

listed out based on their impact on productivity using Relative Importance Index (RII) and their potential for improvement.

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 factor 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 occur 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 need 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).

Following table summarizes main contributing factors for productivity loss (Makulsawatudom and Emsley, 2001).

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 supervisor	113	0.554	4	94	0.553	2
Instruction time	111	0.544	5	95	0.559	1
Lack of tools & equipment	110	0.539	6	93	0.547	4
Poor communication	107	0.525	7	92	0.541	7
Poor site condition	105	0.515	8	66	0.388	22
Change order	104	0.510	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	93	0.456	15	86	0.506	18
Overcrowding	90	0.441	16	71	0.418	21
Worker turnover & changing crewmember	88	0.431	17	87	0.512	17
Specification and Standardization	86	0.422	18	92	0.541	7
Schedule working over time	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(incident)	76	0.373	22	91	0.535	11
Shift work	69	0.338	23	73	0.429	20

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2.6 Availability, Performance and Quality Rate as a Function to Determine OEE

2.6.1 Overall Equipment Effectiveness (OEE)

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

In order to calculate the OEE index, it is necessary to correlate the major losses described in section 2.4.1 with time (production time).

2.6.2 Relation between Major Production Losses with the Production Time

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

Active time/ Loading time = Available time – planned downtime

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

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

Operating time = Active time – Downtime losses

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

Net operating time = operating time – Idling and minor stoppage loss

Again, equipment may not operate at its full capacity within the net operating time. Therefore, the net operating time further reduced due to production capacity losses, which led to performing time.

Performing Time = Net operating time – Production capacity losses/speed losses down time

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

Valuable operating time = Performing time – Start up yield losses.

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

For simplicity, the discussion in section 2.6.2 shortly summarized in the following table.

Table 2.16: Summary of the Relation between Time and Major Production Losses

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

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

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

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

$$OEE = AR * PR * QR$$

Where: AR - Availability Rate

PR - Performance Rate and

QR - Quality Rate

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

2.6.3 Availability Rate as a Function to Determine OEE

Activity rate

$$\text{Activity rate} = \frac{\text{available time} - \text{planned down time}}{\text{loading time}} * 100$$

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

Availability/Operativity rate

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

It is a primary component of OEE

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

2.6.4 Performance Rate as a Function to Determine OEE

Net operating rate

$$\text{Net operating rate} = \frac{\text{Out put} * \text{actual cycle time} - \text{planned down time}}{\text{operating time}} * 100$$

It is also not direct Components of the OEE

Operating speed coefficient = $\frac{\text{Design cycle time}}{\text{Actual cycle time}}$, not expressed as percentage and it is not direct component of OEE but it is used to calculate the third component of OEE index.

Performing rate

$$\text{Performing rate} = \text{Net operating rate} * \text{Operating speed coefficient} * 100$$

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

2.6.5 Quality Rate as a Function to Determine OEE

Quality Rate

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

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

Finally,

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

CHAPTER III METHODOLOGY

3.1 Introduction

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 (Abiy et al., 2001). The methodology in this study consists of three parts. The first part focuses on the methods to know the extent of construction equipment productivity. The second part focuses on the associated loss of construction equipment productivity due to downtime or idleness and the last part is determination of impact of productivity loss on the financial performance and main contributing factors to productivity loss. These includes; site description, study design, method of data collection, data collection tools/research instrument and method of data analysis and evaluation.

3.2 Description of the Study Area

The study areas are located around Welayita Sodo, in the southern region of Ethiopia. These study sites are located in SNNPR about 280 km south of Addis Ababa and all projects are measurement type of contract.

The three case study projects are double surface treatment asphalt road project with, 34.5 Km, 37.5 Km and 75 Km length and all having 20 m width and these projects are executed by thee private general contractors (Nasew Construction P.L.C, Aster Mengstu Construction P.L.C and Sunshine Construction P.L.C). Ethiopian Road Authority owns these projects as a client.

3.3 Study Design

The research methodology was a case study on three projects. This is because actual measurement and observation is very tiresome to assess all projects throughout the region (SNNPR). Once again, as personal observation and actual field measurement was set out as a study design for this thesis, the case study mainly divided into two main parts.

1. Observation

Field or site observation was mainly to know:

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- **Actual equipment down time:** this is due to accessory break down or change in operation condition.
 - **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 - turning and dumping in case of loader, loading the bucket- swinging with load - dump load - return swing in case of excavator. Push the load - back track - maneuver into position to push again in case of dozer and motor grader.
 - **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).
 - **Actual work condition:** its visibility the work (dust, rainy, sunny or darkness) and techniques of operation.
 - **Management systems:** to note out the key factors for productivity.

2. Actual Measurement

This includes actual measurement of all parameters (average width, average depth, average height of soil piles and material actually carried by the bucket) which were incorporated in the actual productivity rate calculation.

Beside to these relevant observed and measured data, Soil type of the study area, equipment work schedule for a particular job and the percentage of budget allocated for the machineries on the contract document were collected from the organizations as of the agreement to execute the work. These office data helps to know all job correction factors and help to analyze the impact of loss of equipment productivity on the equipment financial performance.

3.4 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

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measured and recorded when the machineries were assigned to do certain activities or when the machine do the same activity repeatedly. The recorded 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.

3.5 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 observed and measured data.

Calculation of OEE is based on three parameters. They are availability, Performance and quality. These based on 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:

$$\text{Availability Rate (AR)} = \frac{\text{Loading time} - \text{break down losses}}{\text{Loading Time}} * 100$$

$$\text{Performing Rate (PR)} = \text{Net operating rate} * \text{Operating speed coefficient} * 100$$

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

then the final productivity loss indicator OEE is given by:

$$\text{OEE} = \text{AR} * \text{PR} * \text{QR} = \frac{\text{Valuable Operatingtime}}{\text{Activetime}} * 100$$

Other than these three, the six big losses also take in to account. Those losses included are:

- Breakdown and
- Setup-adjustment losses
- Speed or production capacity loss
- Downtime losses
- Small steps losses and quality losses.

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. This result provide solution for the first research question.

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

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

CHAPTER IV RESULT AND DISCUSSION

4.1 Introduction

This chapter describes the findings of the computation carried out on the evaluation of the construction equipment overall performance. The assessment result divided in to three main sections, i.e. Performance analysis of heavy-duty construction equipment productivity on projects to depict the extent of the current productivity, analysis of the contributing factors for equipment Productivity loss and impact of productivity loss on the financial performance of the equipment. The result obtained from these three sessions comprises the finding of this study.

4.1.1 Basic Information about the Three Projects

Throughout this session, the three federal road construction projects owned by ERA, considered as case study, named a Mazoria-Durame-Hadero, (Hadero-Durgi) and (Alaba-Alemgebeya-Hulbarek).

Concerning to the soil properties and classification on the three projects, Annex - C of this paper provide the detail discription on each station where the machinaries data were collected. Moreover, this soil data were fully considerd in the determination of the actual prodaction of each equipment as it was incorporated in the calculation to find the job correction factors.

Though the contructors of the three projects have some other machinary type and model, they all are mostly equiped with catterpillar machinaries, as a result the study only evaluates the productivity of equipment with Catterpilars model. Every data concerning to the manufacturer spesification used in the computation of ideal production of the machines can be seen in catterpilars performance hand books or any other standards related to the catterpillar model.

4.2 Performance Analysis of Heavy - Duty Construction Equipment

The performance of heavy-duty construction equipment such as dozer, motor grader, 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.

4.2.1 Performance Analysis of Heavy-Duty Construction Equipment on Matoria-Durame – Hadero Road Project

The result in this session provide the rank of factors affecting the performance of the construction equipment on this project and the extent of equipment productivity. Table 4.1 shows the computation of dozer productivity rate and the percentage of individual component rates with the summary of corespondig factors to each indipendant rate.

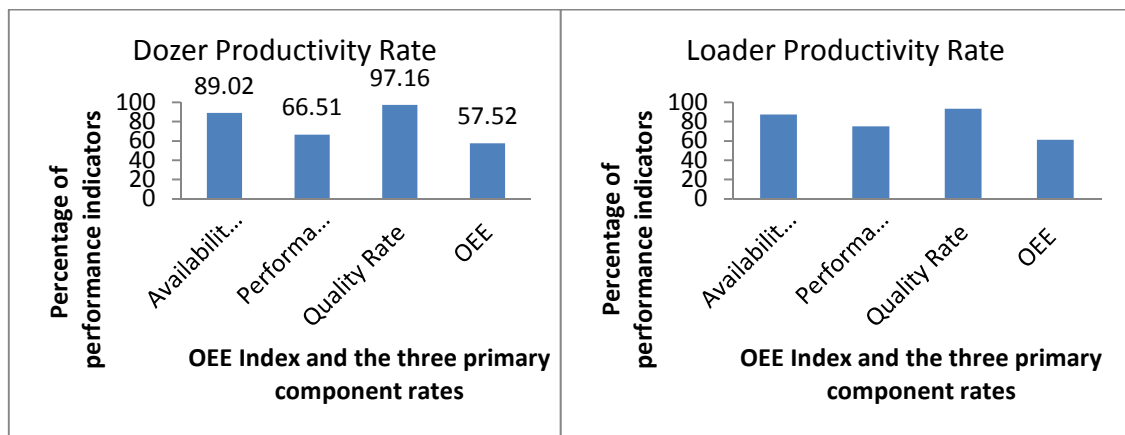
Table 4.1: Performance of Dozer Production and Summary Factors Affecting Dozer Productivity on Mazoria-Durame-Hadero Road Project

Data Collection Template					
Machinery Type - <u>Dozer</u> Mark - <u>Caterpillar</u> Model - <u>D8R</u>					
Average of Five Days Result with One Day = 12 working hours					
(Construction Equipment with Cyclic Operating Machines)					
Dozer Productivity Rate on Mazoria – Durame – Hadero road Project					
Type of Activity – Cutting and Pushing of Common Earth Material					Contributing Factors
Productivity Rate	Sym	Independent variables	Values	Unit	
Dependent Variables	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	110	min	Lunch break(MnF)
	C	loading time (=A-B)	610	min	Morning inspection (MnF)
AR(%)= 100*E/C	D1	Recorded break downtime	45	min	Old blade failure(MF)
89.01639344	D2	Time spent for change in Operation condition	22	min	
	D	Major Stoppage losses (= D1 + D2)	67	min	
	E	Operating Time (= C- D)	543	min	
	G	Ideal production (from manufacturer specification)	225	m ³ /h	
	H	Actual Production	155.66	m ³ /h	Long dosing distance(MnF)
		Dozing distance	135	m	
		Applicable correction factor			Lack side by-side dozing (MnF)
		Job efficiency - 48min/hr	0.797		
		Type of doze - slot dozing	1.2		
		Grade correction – Downhill (for 15%)	1.4		
		- uphill			
		Average operator	0.75		
		Weight correction	0.83		
PR(%) = P*R		Material type - Clay soil(A-7-5) with gravel	0.83		

66.5052185	O	Actual cycle time	3.25	min	
	I	Production Capacity losses downtime = $[1-H/G] \times L$	161.18	min	
	K1	Number of minor stoppage	2	No.	Tea break (MnF)
	K2	Average Duration of minor stoppage	10	min	Lubricant shortage(MnF)
	K3	Idle time		min	
	K	Minor stoppages / Idle losses (= $K1 \times [K2] + K3$)	20	min	
	L	Net Operating Time (= $E - K$)	523	min	
	M	Performing Time ($L - I$)	361.82	min	
	N	Valuable Operating Time($M - J$)	351.82	min	
	P	Net Operating Rate = $(100 * (H * O))/E$	93.165	%	
	Q	Ideal/ theoretical/ design cycle time	2.32	min	
	R	Operating Speed coefficient(= Q/O)	0.7138		
	J	Time spent for rework and start up yield losses	10	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	912.71	m ³	
97.15759819	T	reworked amount(unit)	25.943	m ³	Inspection delay(MnF)
OPR/OEE =AR*PR*QR			57.51782955	%	

Table 4.2: Summary of Average Productivity Rates on Mazoria-Durame-Hadero Road Project

Dozer productivity rate		Motor - grader productivity rate	
Indexes	Percentage	Indexes	Percentage
Availability Rate	89.02	Availability Rate	84.1
Performance Rate	66.51	Performance Rate	71.7
Quality Rate	97.16	Quality Rate	98.7
OEE	57.52	OEE	59.53
Loader productivity rate		Excavator productivity rate	
Indexes	Percentage	Indexes	Percentage
Availability Rate	87.25	Availability Rate	85.25
Performance Rate	75.11	Performance Rate	75.82
Quality Rate	93.31	Quality Rate	94.13
OEE	61.16	OEE	60.83



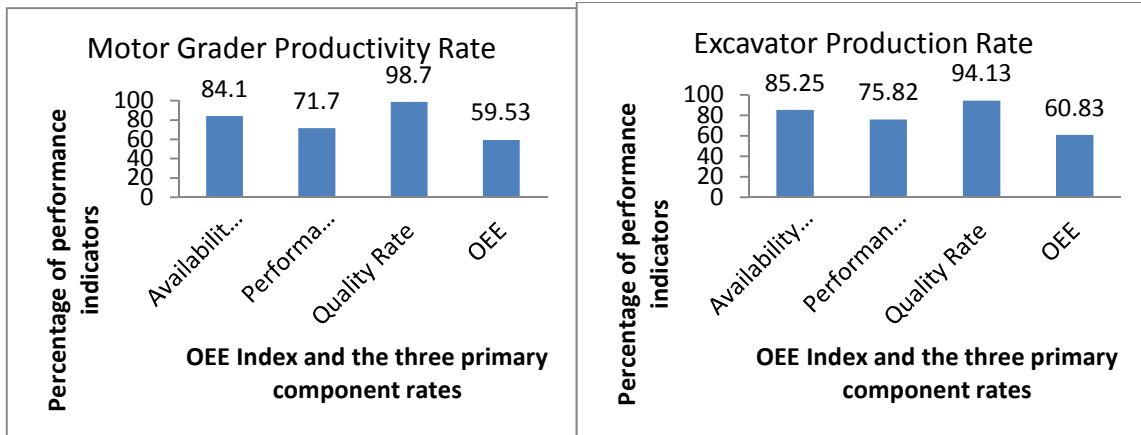


Figure 4.1: Distribution of Primary Component Rate of Individual Equipment and Percentage of OEE on Matoria-Durame-Hadero Road Project

A summary of all the primary component rates and OEE indexes are contained in Table 4.2, and Figure 4.1. Detail computation was made in Tables 4.1 as shown above for dozer production rate (for loader, excavator and grader, refer independent calculation in Appendix D -1). Table 4.2 and Figures 4.1 shows that the rank of the three primary component rates in order of their effect on the overall performance of the corresponding machines on Matoria-Durame-Hadero road project. From this table and figure, the performance rate ranked first, availability next and quality rate with a lesser effect on the productivity. Besides, the computation in Table 4.1 shows the extent of the overall productivity of dozer is very poor (i.e 59.53%). 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, larger grade, more cycle time and lack of side-by-side dozing were the main contributing factor for the productivity loss. Moreover, this analysis shows, the performance rate for all the machines 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 all the machines.

4.2.2 Performance Analysis of Heavy-Duty Construction Equipment on Hadero-Durgi Road Project

The result on this project also provide an indication of the rank of factors affecting the performance of the construction equipments on Hadero-Durgi road project.

Table 4.3 shows the computation of Motor-grader productivity rate and summary of factors affecting productivity corresponding to each component rate. The extent of the productivity of individual equipment also shown in this table.

Table 4.3: Performance of Motor-Grader Production Rate and summary Factors Affecting Productivity on Hadero-Durgi Road Project

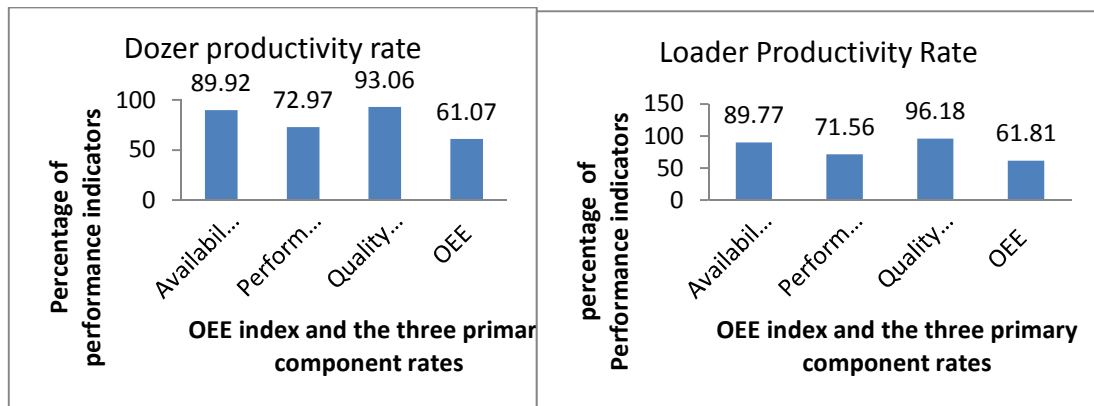
Data Collection Template					
Machinery Type – <u>Motor- Grader</u> Mark - <u>Caterpillar</u> Model - <u>140H</u>					
Average of Five Days Result with One Day = 12 working hours					
(Construction Equipment with Cyclic Operating Machines)					
Motor- Grader Productivity Rate on Hadero-Durgi Road Project					
Type of Activity - Sub - Base Mixing and Placing					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent	A	Available time (12 hrs. x 60')	720	min	
Variables	B	Scheduled maintenance + scheduled production break	60	min	Oil checkup, absentees(HF)
	C	loading time (=A-B)	660	min	lunch break(MnF)
AR(%)=					
100*E/C	D1	Recorded break downtime	20	min	Radiator problem(MF)
89.39393939	D2	Time spent for change in Operation condition	50	min	Operator change(MnF)
	D	Major Stoppage losses (= D1 + D2)	70	min	
	E	Operating Time (= C- D)	590	min	
	G	Ideal production (from manufacturer specification)	227	m ² /h	Long working
	H	Actual Production	172.1	m ² /h	length(MnF)
		Blade length(I) including overlap	3.64	m	
		Width per trip(B) = I * Cos A	3.375	min/h	
		Tilting angle of the blade(A)	22°		High number of
		Lift thickness after compaction(L)	0.2	m	pass(MnF)
		Number of pass(P)	11	m	
		Average speed correspond to the work type (V)	5.5	m	

		Cycle time(T) =0.06ΣP/V	0.12	No.	
		Product of correction factors for [site condition*	0.51		
PR(%) = P*R		operator effectiveness * time factor (day]]		m	
71.48018029	O	Actual cycle time – as stated above	3	min	
	I	Production Capacity losses downtime = [1-H/G] x L	134.1	min	
	K1	Number of minor stoppage	2	No.	Third person,
	K2	Average Duration of minor stoppage	10	min	Communication(HF)
	K3	Idle time	15	min	and tea Break,(MnF)
	K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	35	min	
	L	Net Operating Time (= E- K)	555	min	
	M	Performing Time (L – I)	420.9	min	
	N	Valuable Operating Time(M – J)	405.9	min	
	P	Net Operating Rate = (100 * (H * O)/E) = H/G	87.53	%	
	Q	Ideal/ theoretical/ design cycle time	2.45	min	
	R	Operating Speed coefficient(= Q/O)	0.817		
	J	Time spent for rework and start up yield losses	15	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	1164	m ²	Improper
96.30415348	T	reworked amount(unit)	43.03	m ²	work order(MnF)
OPR/OEE					
=AR*PR*QR			61.53734196	%	

Table 4.4 Summary of Average Productivity Rates of Equipmente on Hadero-Durgi Project

Dozer productivity Rate		Motor grader productivity Rate	
OEE Indexes	Percentage	Indexes	Percentage
Availability Rate	89.92	Availability Rate	89.39
Performance Rate	72.97	Performance Rate	71.48
Quality Rate	93.06	Quality Rate	96.03
OEE	61.07	OEE	61.54

Loader Productivity Rate		Excavator Productivity Rate	
Indexes	Percentage	Indexes	Percentage
Availability Rate	89.77	Availability Rate	89.39
Performance Rate	71.56	Performance Rate	70.60
Quality Rate	96.18	Quality Rate	94.96
OEE	61.81	OEE	59.93



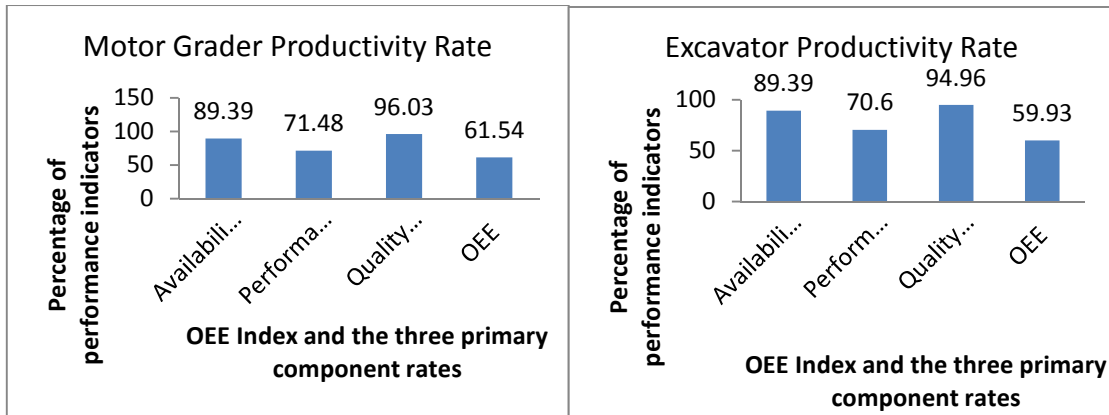


Figure 4.2: Distribution of Primary Component Rate of Individual Equipment and Percentage of OEE on Hadero-Durgi Road Project

The summary described in Table 4.4, and Figure 4.2 shows the result found on Hadero-Durgi project for all machines with their primary component rates and OEE index. The detail computation for this project was made in Tables 4.3 as shown above for grader production rate (for loader, excavator and dozer, refer independent calculation in Appendix D -2). Table 4.4 and Figures 4.2 shows that the rank of the three primary component rates in order of their effect on the overall performance of the corresponding machines on Hadero-Durgi road project. Once again the performance rate ranked first, availability next and quality rate with a lesser effect on the productivity. Besides, the computation in Table 4.3 shows the extent of the overall productivity for motor-grader is very poor (i.e 61.54%). This is due to the problem of work management in the utilization of the machine. As shown in the table, they used larger blade angle, longer damp distance, more cycle time and more number of pass.

This analysis also shows the performance rate for all the machines on this project is also low. The same happened like that of Mazoria-Durame-Hadero road project. This rate is the most important rate that needs a special attention from the management. In addition, it is the one mainly affecting the overall performance of all the machines in this project.

4.2.3 Performance Analysis of Heavy - Duty Construction Equipment on Alaba- Alemgebeya- Hulbarek Road Project

The results of this session also provide an indication of the rank of the factors affecting the performance of the construction equipments on Alaba-Alemgebeya-Hulbarek road project. Table 4.5 and Table 4.6 shows the computation of loader and excavator productivity rate and summary of factors corresponding to each component rate respectively.

Table 4.5: Performance of Loader Productivity Rate and Summary Factors Affecting Productivity on Alaba – Alemgebeya - Hulbarek

Data Collection Template Machinery Name - <u>Loader</u> Mark - <u>Caterpillar</u> Model - <u>950H</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with cyclic operating Machines) Loader Productivity Rate on Alaba-Alemgebeya-Hulbarek Road Project					
Type of Activity - Pushing of Common Earth material					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent Variables	A	Available time (12 hrs. x 60 ')	720	min	
	B	Scheduled maintenance + scheduled production break	100	min	Oil checkup,
	C	loading time(Active time) (=A-B)	620	min	Lunch break,(MnF)
	D1	Recorded break downtime	0	min	
	D2	Time spent for change in Operation condition	65	min	Operator
AR(%)= 100*E/C	D	Major Stoppage losses (= D1 + D2)	65	min	change(MnF)
	E	Operating Time (= C- D)	555	min	
	G	Ideal production (from manufacturer specification)	231.2	m ³ /h	
	H	Actual Production	152.4	m ³ /h	
		Job efficiency	50		
		Bucket load	3.15	m3	

		Material type- soil earth wet		m	Higher cycle time,
		Bucket fill factor corresponding to the material	0.9	m	Longer dump
		Static tipping load -from table		m	Distance(MnF)
PR(%) = P*R		Swell factor - from table	0.8	No.	
77.58282476	O	Actual cycle time	31	sec	
	I	Production Capacity losses downtime = $[1-H/G] \times L$	155.1	min	
	K1	Number of minor stoppage	4	No.	Engine oil check
	K2	Average Duration of minor stoppage	15	min	Up, tea break
	K3	Idle time	40	min	(MnF)
	K	Minor stoppages / Idle losses (= $K1 * [(K2 + K3)]$)	100	min	
	L	Net Operating Time (= $E - K$)	455	min	Poor preparation
	M	Performing Time ($L - I$)	425	min	from morning(HF)
	N	Valuable Operating Time($M - J$)	395	min	
	P	Net Operating Rate = $(100 * (H * O)/E) = H/G$	85.14	%	
	Q	Ideal/ theoretical/ design cycle time	28.25	sec	
	R	Operating Speed coefficient(= Q/O)	0.911		
	J	Time spent for rework and start up yield losses	30	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	1003	m ³	Failure to meet the
92.40506329	T	reworked amount(unit)	76.21	m ³	specification (MnF)
OPR/OEE =AR*PR*QR			64.17452318	%	

Table 4.6: Performance of Excavator Productivity Rate and summary Factors Affecting Productivity on Alaba-Alemgebeya-Hulbarek Road Project

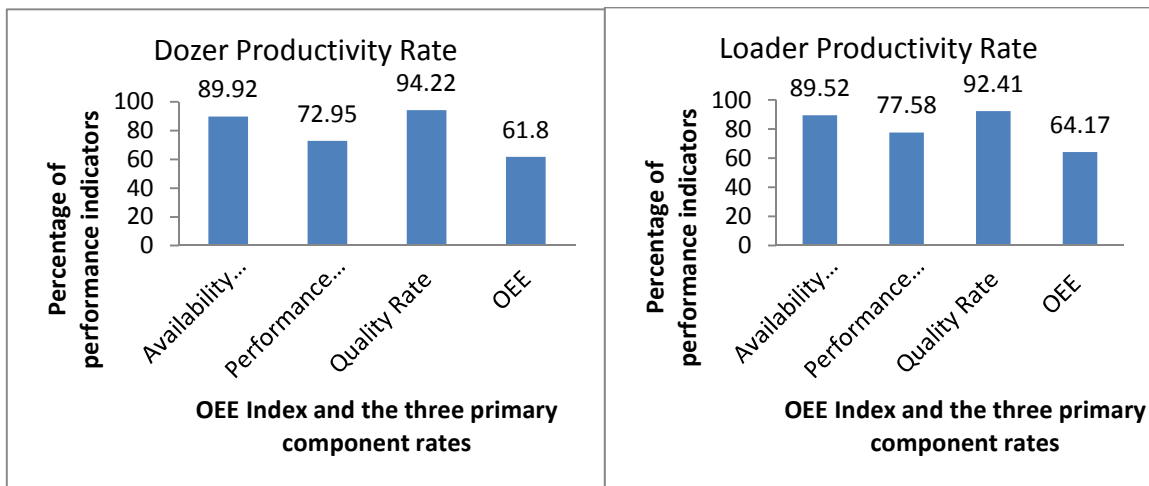
Data collection Template Machinery Type - <u>Excavator</u> Mark - <u>Caterpillar</u> Model - <u>325B</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Excavator Productivity on Alaba-Alemgebeya-Hulbarek					
Type of Activity - Common Earth Excavation				Contributing Factors	
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent variables	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch break(MnF)
	C	loading time (=A-B)	660	min	
	D1	Recorded break downtime	20	min	Mechanical problem
	D2	Time spent for change in Operation condition	50	min	(MF)
AR(%)= 100*E/C 89.39393939	D	Major Stoppage losses (= D1 + D2)	70	min	
	E	Operating Time (= C- D)	590	min	
	G	Ideal production (from manufacturer specification)	164.9	m ² /h	
	H	Actual Production	149.5	m ² /h	
		Job efficiency	48	min/h	
PR(%) = P*R 70.6010929		Heaped bucket capacity	2.2	m ³	Higher cycle time,
		Material type- soil mixed moist aggregate		m	Long dump
		Bucket fill factor corresponding to the material	0.95	m	Distance(MnF)
		Swell factor - from table	0.83	m	
	O	Actual cycle time	22	sec	
	I	Production Capacity losses downtime = [1-H/G] x L	42.93	min	
	K1	Number of minor stoppage	4	No.	Absentees(HF),
	K2	Average Duration of minor stoppage	20	min	third person
K3	Idle time	50	min	Communication(HF) Tea break(MnF)	

	K	Minor stoppages / Idle losses (= $K1 * [(K2 + K3)]$)	130	min	
	L	Net Operating Time (= $E - K$)	460	min	
	M	Performing Time ($L - I$)	417.1	min	
	N	Valuable Operating Time($M - J$)	397.1	min	
	P	Net Operating Rate = $(100 * (H * O)/E)$	91.37	%	
	Q	Ideal/ theoretical/ design cycle time	17	sec	
	R	Operating Speed coefficient(= Q/O)	0.773		
	J	Time spent for rework and start up yield losses	20	min	
QR (%) =					
(S-T)/S	S	Total executed amount(unit)	989.4	m ²	
94.96306246	T	reworked amount(unit)	49.84	m ²	Inspection delay(MnF)
OPR/OEE =AR*PR*QR			59.93413086	%	

Table 4.7: Summary of Average Productivity Rates of Equipments on Alaba-Alemgebeya-Hulbarek Road Project

Dozer Productivity Rate		Motor grader productivity Rate	
Indexes	Percentage	Indexes	Percentage
Availability Rate	89.92	Availability Rate	89.39
Performance Rate	72.95	Performance Rate	68.67
Quality Rate	94.22	Quality Rate	94.81
OEE	61.80	OEE	58.20

Loader Production Rate		Excavator Productivity Rate	
Indexes	Percentage	Indexes	Percentage
Availability Rate	89.52	Availability Rate	89.39
Performance Rate	77.58	Performance Rate	70.60
Quality Rate	92.41	Quality Rate	94.94
OEE	64.17	OEE	59.93



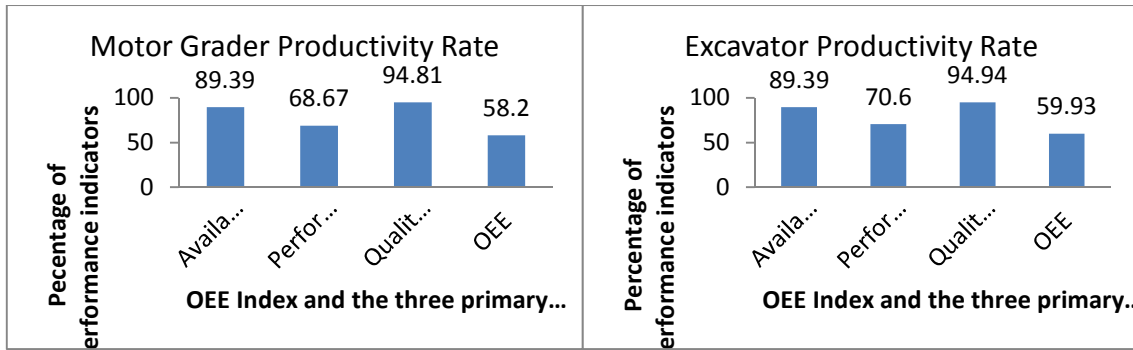


Figure 4.3: Distribution of Primary Component Rate of Individual Equipment and Percentage of OEE on Alaba-Alemgebeya-Hulbarek Road Project

Average result for the primary component rates and OEE indexes for the machines are contained in Table 4.7, and Figure 4.3. The detail computation were made in Tables 4.5 and Table 4.6 as shown above for loader and excavator productivity rate respectively (for dozer, and grader, refer independent calculation in Apindex D - 3). 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 coresponding machines on Alaba-Alemgebeya-Hulbarke road project. From these data, the performance rate ranked first, availability rate next and quality rate with a lesser effect on the productivity like that of the previous projects. Besides, the computation in Table 4.5 and Table 4.6 shows the the extent of the overall productivity of loader and excavator are very poor(i.e. 64.17% and 59.93%) . This is due to the problem of management mainly in the utilization of the machine. As we can see they used higher digging depth, longer dump distance, minimum maneuver space and more cycle time.

The above analysis also shows the performance rate for all the machines on Alaba-Alemgebeya-Hulbarek is the most important rate that needs more attention. In addition, it is the one mainly affecting the overall performance of all the machines in this project.

Finally, from the three analysis result, the OEE indexes on three projects is found in between 55 - 68% for all the machines under consideration. Theses low percentege of the OEE index on the three projects indicate that the extent of the current construction equipment productivity in SNNPR road projects was not good.

As repeatedly 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 those projects. Minimalizing 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 Analysis of Main Contributing Factors for the Loss in Productivity

Results in Table 4.8 revealed that, the leadership skill of project managers/ Engineers, forman or superintendent of the projects have been ranked first as main causes for poor performance of the construction equipment. This is because the performance rates are highly affected by work management problem and the result in all the case study projects were found in between 70 – 80 % . Besides, the key factors affecting equipment productivity are found within this rate.

The performance rate is low in all the three cases for the four machines. In all the cases it was found that impact of higher cycle time, longer dozing distance, longer dump distance and poor work coordination or lack of proper sequence of work dependancy and higher digging depth were the main factors for low performance rate and low OEE index. The result was not surprising because it was as expected; any one can generalize that as larger blade angel decreases grader production rate but no correlation is made to what extent it affects productivity. However, the this study proved that, it is not the availability of the machines on the or quality failure to meet the specification affects the projecte performance the higher extent. But it is the performance rate which highly affects the machine productivity. This can be solved by a good technical knoweledge on work management in using the construction equipment. Therefore, when the project managers are well acquainted or equipped with technical skill in the utilization of the machines, the project performance can be well controlled and managed with high quality which lead to high OEE index. Besides, the availability of personnel's with high experience and qualification solve the problem and leads to better performance interms of quality, time, cost and productivity. This result is in line with Makulsawatudom et al. (2001) as

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inspection delay and incompetent supervisor...etc. affects strongly and directly the performance of the construction machine and indirectly the performance of the construction projects.

Rework due to lack of achieving the required specification which was discussed under quality rate in the literature part ranked second in affecting the productivity of the machines which is found to be between 85 – 90 % for all machines on the three projects, but lower than availability rate(90 -96%). This result agrees with Makulsawatudom et al. (2001) study results in which rework and absentees during the morning ranks 11th and 12th based on their relative importance index as factor affecting equipment productivity.

The impact of major losses (equipment breakdown and setup adjustment losses) assessed under availability rate was relatively small in all the three cases for all machines. Nevertheless, it have been kept in mind that, if major accessory breakdown occur which cannot be maintained or repaired within the valuable time, it will be a severe disaster for the project.

Productivity loss analysis using OEE index is not applicable for long lasting or severe type of equipment accessory failure. This was the main reason why this study did not consider this type of failure. Once such type of problems occurred, it have the possibility to continue for a month, half a year or even a year.

The following table summarizes the findings of key factors contributing for equipment productivity losses on the three case study projects (i.e. Mazonia-Durame-Hadero, Hadero-Durgi and Alaba-Alemgebeya-Hulbarek).

Table 4.8 Summary of Factors for the Productivity Loss on the Study Projects

Contributing Factors	Class of Contributing Factors
Activity dependency	MnF
Incompetent Forman	HF
Longer working length	MnF
Radiator problem	MF
Pin breakdown and exchange	MF
Lunch and tea break	MnF
Surveyor inefficiency	HF
Absentees	HF
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
Old teeth breakdown	MF
Transmission filter check up	MnF
Lack of communication	MnF
waiting for surveyor	MnF
Weather condition(heavy rain)	WF
Lack of side by side dozing	MnF
Lubricant shortage	MnF
Improper work order	MnF
Oil checkup	MnF
Poor preparation in the morning	HF
Failure to meet specification	HF
Tire inflation and replace	MF
Inspection delay	MnF
Longer dump distance	MnF
Inefficient operator	HF
Operator exchange	MnF
Mobilization time	MnF
Inspection time	MnF
Forman exchange	MnF
Electrical problem	MF
Change order	MnF
Minimum working space	WF
Fuel shortage	MnF
Chain breakdown problem	MnF
Old blade break down	MF

Fuel filter problem	MF
Higher cycle time	MnF
Accessory repair	MnF
Waiting for spare part	MnF
Lack of coordination	MnF
Bearing problem	MF
Mechanical problem	MF

Notice: **MnF** = Management Factor

Hu = Human Factor

MF = Machine Factor

WF = Work Factor

From the result summarized in Table 4.8, it is possible to conclude that the management problems were the key factors in affecting equipment productivity in all projects and it was ranked first (i.e. 59.57%) 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 three projects was the machine factor with the percentage of 19.15. The human factor and work factor with a percentage of 17.02 and 4.26 respectively ranked third and last in contributing for equipment productivity loss.

4.4 Impact Analysis of Equipment Productivity Loss on the Financial Performance

The following table provide the summary of total project cost and machinery cost breakdown for the three projects. these data were used on the decision of impact of productivity loss on the financial performance of the equipments on the three case study projects.

Table 4.9: Total Monthly Cost Allocated to the Machineries out of the Total Project Cost

Project name	Total project cost (Birr)	Total monthly cost allocated to the machineries (Birr)
Mazoria-Durame- Hadero	285,915,621.40	Dozer- 967517.8 Grader-1128771 Loader-725638.3 Excavator-1209397
Hadero- Durgi	368,311,075.52	Dozer-982022.2 Grader-1145693 Loader-736516.6 Excavator-1227528
Alaba-Alemgebeya- Hulbarek	447,573,991.70	Dozer - 989,083.23 Grader- 734,545.85 Loader- 1,256,515.99 Excavator-1,172,049.20

From the overall performance analysis result summerised in Table 4.2 for dozer, motor-grader, loader and excavator of Mazoria-Durame-Hadero road project and using Table 4.9, the following simple calculation was made to indicate the impact of construction equipment productivity loss on monthly equipment running cost.

Dozer productivity loss = $[(100-89.02) + (100-66.1) + (100-97.16)] \times 967517.8 / (30 \times 2 \times 100)$
=7695 Birr/day/machine.

Grader productivity loss = $[(100 - 84.1) + (100-71.7) + (100-98.7)] \times 1128771 / (30 \times 2 \times 100)$
=8560 Birr/day/machine

Loader productivity loss = $[(100 - 87.25) + (100-75.11) + (100-93.1)] \times 725638.3 / (30 \times 2 \times 100)$ =5387 Birr/day/machine

Excavator productivity loss = $[(100 - 85.25) + (100-75.82) + (100 - 94.13)] \times 1209397 / (30 \times 2 \times 100)$ =9030 Birr/day/single machine

From these computation this project incurs an additional cost overrun of $7695 \times 2 + 8560 \times 2 + 5387 \times 2 + 9030 \times 2 = 61,344$ Birr/month due the associated losses of the construction equipment productivity, which is about 1.55 % of the total cost allocated monthly for the machineries as a running cost.

Similarly, from the overall performance analysis result summerised in Table 4.4 for dozer, motor-grader, loader and excavator of Hadero-Durgi road project and using Table 4.9, the following simple calculation was made to indicate the impact of construction equipment productivity loss on monthly equipment running cost.

Dozer productivity loss = $[(100 - 89.92) + (100-72.97) + (100- 93.06)] \times 982022.2 / (30 \times 2 \times 100)$ =7210 Birr/day/machine

Grader productivity loss = $[(100 - 89.37) + (100-71.48) + (100-96.03)] \times 1145693 / (30 \times 2 \times 100)$ =8234 Birr/day/machine

Loader productivity loss = $[(100 - 89.77) + (100-71.56) + (100-96.18)] \times 736516.6 / (30 \times 4 \times 100)$ =2608 Birr/day/ machine

Excavator productivity loss = $[(100 - 89.39) + (100-70.6) + (100-94.96)] \times 1227528 / (30 \times 2 \times 100)$ = 9217 Birr/day/ machine.

From these computation the second project also incurs an additional cost overrun of $7210 \times 2 + 8234 \times 2 + 2608 \times 4 + 9217 \times 2 = 59,754$ Birr/month due the associated loss of the construction equipment productivity, which is about 1.46 % of the total cost allocated monthly for the machineries as a running cost.

Finally, from the overall performance analysis result summarised in Table 4.7 for dozer, motor-grader, loader and excavator of Alaba-Alemgebeya-Hulbarek road project and using Table 4.9, the following simple calculation was made to indicate the impact of construction equipment productivity.

Dozer productivity loss = $[(100 - 89.92) + (100-72.95) + (100-94.22)] \times 989,083.23 / (30 \times 2 \times 100) = 5544$ Birr/day/single machine

Grader productivity loss = $[(100 - 89.39) + (100-70.60) + (100-94.94)] \times 734,545.85 / (30 \times 2 \times 100) = 5518$ Birr/day/machine

Loader productivity loss = $[(100 - 89.52) + (100-77.58) + (100-92.41)] \times 1,256,515.99 / (30 \times 4 \times 100) = 4240$ Birr/day/machine

Excavator productivity loss = $[(100- 89.39) + (100- 70.60) + (100-94.94)] \times 1,172,049.20 / (30 \times 2 \times 100) = 8804$ Birr/day/single machine.

From these computation, the third project once again incurs an additional cost overrun of $5544 \times 2 + 5518 \times 2 + 4240 \times 4 + 8804 \times 2 = 56,692$ Birr/month due the associated loss of the construction equipment productivity, which is about 1.37% of the total monthly cost allocated for the machineries.

Chapter V Conclusion and Recommendation

5.1 Conclusion

This section describes the current productivity rates of heavy-duty construction equipment, main contributing factor for productivity loss and impact of equipment productivity loss in all the study road projects using different variables affecting the valuable production time in Mazoria-Durame-Hadero, Hadero-Durgi and Alaba-Alemgebeya-Hulbarek road projects. To minimize the impact of equipment productivity loss on time, cost and quality, deep understanding of how equipment productivity loss is computed using OEE index is very crucial. To design, forecast and implement an effective equipment productivity mentoring programs, investigation of equipment characteristics and identification of main contributing factor for productivity loss are important issues to be assessed first; because different construction equipment needs different work management measure. In this study, the common and dominant productivity loss factors were identified and the impact of equipment productivity loss on equipment running cost were assessed in all case study projects. This helps planner to implement the right productivity loss mitigating measures in road construction projects by knowing the dominant factor for productivity loss.

In general the following conclusion are drawn from this study

- The OEE index revealed that, all the machines under consideration have productivity problem in their performance that was laying between 55 – 68%.
- Out of the three primary component rates of OEE, the availability rates are relatively week (84%-90%) but the Performance rates for all the machines were poor (68-75%). Only the quality rates for all the machines in all the study projects have an acceptable result which is $\geq 90\%$.
- The loss in productivity of the construction equipment forces the organization to incur an additional cost from 1 - 2% of the total monthly running cost allocated for the equipment.

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- The Management Factors (MnF) were the most critical factors affecting equipment productivity.

5.2 Recommendation

This session describes three main issues to be considered in maximizing heavy-duty construction equipment productivity, i.e. waste productivity in relation to contractor's perception, productivity loss and associated cost and the technical conditions in machine management. In fact, there are many other factors which initiate or need to be considered in future study.

I. Lost productivity in relation to contractors perception

- The contractor's perception in minimizing hidden productivity losses (those related to Availability and Quality rate) is very poor. However, contractors need to have a periodic maintenance schedule (especially predictive and preventive maintenance) to minimize hidden time losses to maximize productivity.

II. Productivity loss and associated cost

- Hidden costs such as waiting time in search of spare parts, to get operator, for input construction material, for fuel need to be considered in the planning stage of the project. In this regard, Knowing Activity Rate (AR) can help the project managers in making a decision to reduce planed production break and OEE Index analysis is also very useful in determining productivity loss for cyclic operating machines.

III. Technical conditions in machine management

As noted out on the analysis part, the selection of appropriate type and size of construction equipment often affects the required amount of job-site productivity, time and cost incurred for the equipment. It is therefore important for site managers and construction leaders to be familiar with the characteristics and technical usage of the major types of equipment most commonly used in

construction projects. For this, Contractors work more on work factors that affects the performance rate.

- May comprises, side - by- side dosing, dawn slope dozing, use of shorter dozing distance, using minimum blade angle, optimum number of passes, using shorter dump distance, providing sufficient maneuver space and using optimum digging depth.
- In fact, project leaders did not exercise these technical conditions in all the study projects. However, project leader need to exercise these technical condition for proper equipment management.

5.3 Future study

As mentioned in the review and methodology part of this paper the main contributing factors identified using the three primary component rates of OEE index. This method only tells as the significant contributing rate for the loss and those significant contributing factors found within the lowest primary rate. In addition, OEE index method does not show the relative importance of those factors. RII method will be the methodology for such identification and I will propose it as alternative method for future study to identify factors in order of their impact on productivity and their relative importance.

Reference

- AACE Estimating lost labor Productivity in Construction claims. *International recommended practice No. 25R- 03*.
- Abiy Z, et al. (2009). *Methodology of a research. Introduction to research methods(pp. 50-60)*Addis Ababa university, Addis Ababa
- An Online International Journal Available at <http://www.cibtech.org/jet.htm> 2012 vol. (2) April-June, PP. 39-48/Kumar et al.
- *Caterpillar's performance handbook*. (2012), 42th Ed., Caterpillars Inc., East Peoria, Ill.
- Douglas D. Grasberg, Calin M. proscu, Puchard C. Ryan. (2006). Equipment life and Replacement Procedures. In *Construction equipment management for Engineers, Estimators and owners* (PP. 39-46).U.S.A: Tayilor and Francis group, CRS.
- Douglas D. Grasberg, Calin M. proscu, Puchard C. Ryan. (2006). Evolution of heavy Construction Equipment. In *Construction equipment management for Engineers, Estimators and owners* (PP. 1-16).U.S.A: Tayilor and Francis group, CRS.
- E-book: World-Class TPM - How to calculate Overall Equipment Effectiveness (OEE)
January 2009. From <http://www.scodanibbio.com>(accessed on July, 2013)
- Gashaw, Y. (2009). Dozer Production. In *Fundamentals of Earthmoving Equipment* (PP.101-106). Addis Ababa, Ethiopia: Mega Publishing and Distribution P.L.C.
- Gashaw, Y. (2009). Motor Grader Production. In *Fundamentals of Earthmoving Equipment* (PP.128-140). Addis Ababa, Ethiopia: Mega Publishing and Distribution P.L.C.
- Getaneh, G. (2012, July 25). *Construction Equipment and Plant Management*. Unpublished lecture note, University of Addis Ababa, Addis Ababa, Ethiopia.
- Johnson, J. W., & LeBreton, J. M. (2004). History and use of relative importance indices in organizational research. *Organizational Research Methods*, 7, 238 – 257.
- Jose, L. P. (2001). *Detailed Haul Units Performance Model*. Unpublished Master's thesis, Virginia Polytechnic Institute State University, Blacksburg, Virginia.

-
- Khyomesh, V. (2013). Construction material management on project sites. Found in E-Mail: Khyomesh_Civil@yahoo.com (accessed on Jun,2014)
 - MAkulsawatudom, A and Emsley, M (2001) Factors affecting the productivity of the construction industry in Thailand: The project manager's perception. In: Akintoye, A (ED.), 17th Annual ARCOM conference, 5-7 September 2001, University of Salford. Association of research in construction Management, Vo.1, 281- 290.
 - Peurifoy, R.L., W.B. Ledbetter and C. J. Schexnayder, (2006). Dozer Production. *Construction Planning, Equipment and methods* (7th ed., PP. 171 -195). New York: McGraw- Hill.
 - Peurifoy, R.L., W.B. Ledbetter and C. J. Schexnayder, (2006). Excavators Production. *Construction Planning, Equipment and methods* (7th ed., PP. 253 -273). New York: McGraw- Hill.
 - Peurifoy, R.L., W.B. Ledbetter and C. J. Schexnayder, (2006). Loader production. *Construction Planning, Equipment and methods* (7th ed., PP. 274 -283). New York: McGraw- Hill.
 - Pintelon, Lilian, Muchiry and peter. *Performance measurement using over all equipment effectiveness (OEE): literature review and practical application discussion*. International journal of production research. 2006. Found in <http://mc.manuscriptcentral.com/tpr> (accessed on August,2015)
 - SEMI Standard for Definition and Measurement of Equipment Productivity. Semiconductor Equipment and Materials International .E79-0200) its role in supporting the application of lean construction concepts. *Australasian Journal of Construction Economics and Building*. 13(1) 23-35.
 - Wubshet, J. (2004). *Performance for Public Construction Projects in (least) Developing countries: Federal Road and Educational Building Projects in Ethiopia*. Unpublished Doctoral Dissertation, University of NTNU, Trondheim.

Annex A: Related Productivity Terms in Assessment of Loss of Construction Equipment Productivity

Following are words or phrases used repeatedly throughout this paper (Adapted from SEMI E79-0200, 2000).

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

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

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

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).

None scheduled time: the time when the construction equipment not scheduled to perform a certain activities.

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

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

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

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

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

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

Performance measure is the process of quantifying effectiveness and efficiency of an action

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

Valuable operating time is “time during which equipment actually operates, under stable Conditions, at optimal speed, and producing acceptable out puts.” (Carlos, 2009)

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

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

Job efficiency: the actual number on minutes worked by the machines during an hour (Caterpillar performance handbook, 2012)

Bucket fill factor: is the ratio of the volume of soil required per cycle to the standard bucket size (Caterpillar performance handbook, 2012)

Annex: B Sample Format for Data Collection

Table 3.1: Sample Format for Data Collection

Data Collection Template					
Machinery Type -----		Mark -----	Model-----		
One day= 12hrs					
(Construction Equipment with cyclic operating Machines)					
Name of Contractor- W Construction P.L.C					
Type of Activity -----					CF
Productivity Rate	Sym	Indepandant variables	Values	Unit	
Dependant variables	A	Available time (12 Hrs*60')		min	
	B	Scheduled maintenance + scheduled production break		min	
	C	loading time (=A-B)		min	
AR(%)= 100*E/C	D1	Recorded break downtime		min	
	D2	Time spent for change in Operation condition		min	
	D	Major Stoppage losses (= D1 + D2)		min	
	E	Operating Time (= C- D)		min	
	G	Ideal production (from manufacturer specification)		m3/hr	
	H	Actual Production		m3/hr	
		Dozing distance		m	
		Applicable corection factor			
		Job efficiency - 45min/hr			
		Type of doze - slot dozing			
		Grade corection - Downhill(for 10%)			
		- uphill			
		Avarage operator			
		Weight corection			
PR(%) = P*R		Material type - Clay soil(A-7-6) with gravel			
	O	Actual cycle time		min	
	I	Production Capacity losses downtime = [1- H/G]*L		min	
	K1	Number of minor stoppage		No.	
	K2	Average Duration of minor stoppage		min	
	K3	Idle time		min	
	K	Minor stoppages / Idle losses (= K1*[K2] +K3)		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)			
	J	Time spent for rework and start up yield losses		min	
QR(%) = (S-T)/S	S	Total executed amount(unit)		Unit	
	T	reworked amount(unit)		Unit	
OPR/OEE =AR*PR*QR				%	

N.B This table was designed to simplify the data collection. However, it have some modification for different type of machine

Annex C: Soil Properties of the Three Projects

C - 1. Soil Properties of Mazoria-Durame-Hadero and Hadero-Durgi road projects

Summary For Test Results of Material from Road Way Excavation

No.	Represent Station	Sample Date	MDD (g/cc)	OMC (%)	LL (%)	PI (%)	CBR (%)	Swell (%)	Sieve Analysis (mm)			Soil Classification	Material Type
									2	0.425	0.075		
1	37+660 - 37+900	07-Mar-12	1.55	22.4	51	25	5.6	2.64	-	-	-	-	Reddish Brown Clay Soil
2	42+120 LHS	20-Nov-12	1.54	20.3	48	18	36	0.9	73.83	66.62	57.24	Clayey Soil(A-7-5)	Yellowish Silty Soil With
3	42+900 - 43+100	30-Mar-12	1.52	27.4	48	16	21	0.93	97.9	90.2	80.25	Clayey Soil(A-7-5)	Yellowish to Brown Silty
4	43+240 - 43+380 LHS	12-Mar-12	1.42	31.6	-	-	18	1.13	-	-	-	-	Brown Silty Clay Soil
5	43+380 - 43+440	12-Mar-12	1.52	20	46	18	10	1.08	-	-	-	-	Greyish Silty Soli
6	43+380 - 43+480	29-Feb-12	1.53	19.8	45	16	15.6	1.72	-	-	-	-	Light Brown Silty Clay
7	43+520 - 43+600	15-Mar-12	1.75	17.8	39	11	23	0.56	-	-	-	-	White Silty Soil
8	43+520 - 43+600	15-Mar-12	1.59	19.2	41	14	12.4	1	-	-	-	-	Yellowish Silty Soil
9	43+520 - 43+640	24-Oct-12	1.56	19.8	39	10	20.2	0.86	67.36	53.22	43.49	Silty Soil (A-4)	Yellowish Silty Soil
10	43+520 - 43+740	10-Mar-12	1.63	18.9	39	30	30.3	0.52	-	-	-	-	White Silty Soil
11	43+600 - 43+640	23-Oct-12	1.46	28.5	47	15	11	1.41	86.51	70.45	60.37	Clayey Soil(A-7-5)	Yellowish Silty Clay
12	43+600 - 43+700	08-Jun-12	1.44	31.1	48	15	13.5	0.92	97	80	50	Clayey Soil(A-7-5)	Clayish Gravel
13	43+600 - 43+760	29-Dec-12	1.56	19.8	47	17	18.5	1.05	86.46	74.37	63.96	Clayey Soil(A-7-5)	Greyish Silty Soli
14	43+640 - 43+700	12-Nov-12	1.54	25.9	43	16	13	1	89.41	79.03	66.81	Clayey Soil(A-7-6)	Light Brown Silty Clay
15	43+640 - 43+740	20-Dec-12	1.47	24.7	41	11	17.8	1.01	92.45	77.21	64.9	Clayey Soil(A-7-5)	Greyish Silty Soli
16	43+680 - 43+700	24-Oct-12	1.51	26.3	53	22	9.5	1.56	97.16	82.27	63.66	Clayey Soil(A-7-5)	Brown Clay
17	43+700 - 43+740	23-Oct-12	1.52	27.4	47	18	10.6	1.33	84.81	75.48	60.77	Clayey Soil(A-7-6)	Clayish Silty Clay
18	43+700 - 43+760	03-Jun-12	1.6	24	47	18	35.2	0.85	91	71	30	Silty or Clayey Gravel & Sand (A-2-	Brown Silty to Tuff Soil
19	43+700 - 43+760	06-Dec-12	1.54	22.5	59	25	8.1	1.9	97.92	91.37	78.43	Clayey Soil(A-7-5)	Brown Clay Soil
20	43+900 - 44+040	03-Dec-12	1.52	26.5	64	30	7.5	2.9	98.3	91.76	74.37	Clayey Soil(A-7-5)	Red Clay
21	43+980 - 44+020	11-Oct-12	1.67	20.9	55	23	11	1	98	79	40	Clayey Soil(A-7-5)	Brown Clay With Gravel
22	44+120 - 45+540	12-Feb-13	1.48	22.8	58	27	9.1	1.87	92.64	76.31	53.47	Clayey Soil(A-7-5)	Brown Clay Soil
23	45+540 - 45+640	02-Mar-13	1.45	24.2	59	25	7.8	1.84	98.33	91.76	74.37	Clayey Soil(A-7-5)	Red Clay
24	48+500 - 49+000	24-Mar-12	1.8	17.8	-	-	-	-	-	-	-	-	Clayish Gravel
25	48+560 - 48+620 RHS	04-May-12	1.75	15.4	45	16	31	0.92	97	59	37.6	Clayey Soil(A-7-6)	Light Brown Silty Soil

26	49+600 - 49+740	18-Feb-13	1.66	21.5	47	17	17.6	1.34	70.6	61.33	45.27	<i>Clayey Soil(A-7-5)</i>	<i>Clayish Gravel</i>
27	50+020 - 50+300	16-Jun-13	1.5	26.4	57	28	8.4	1.74	91.12	63.32	44.44	<i>Clayey Soil(A-7-6)</i>	<i>Red Silty Clay Soil</i>
28	50+540+50-800	05-Oct-13	1.71	18.1	46	17	28	1.1	62.08	48.64	39.56	<i>Clayey Soil(A-7-6)</i>	<i>Light Silty Soil</i>
29	50+800-51+140	24-Sep-13	1.59	26.3	49	16	12.3	1.59	86.06	74.51	60.48	<i>Clayey Soil(A-7-6)</i>	<i>Light Silty Soil</i>
30	51+160 - 51+360	21-May-13	1.55	21.3	56	23	8.5	1.77	92.68	63.05	43.92	<i>Clayey Soil(A-7-5)</i>	<i>Red Silty Clay Soil</i>
31	51+580 - 51+700	24-May-13	1.69	19.8	40	16	19.1	1.33	58.66	47.82	35.65	<i>Clayey Soil(A-6)</i>	<i>Light Silty Clay Soil</i>
32	51+860 - 51+960	20-Apr-13	1.64	17.3	43	14	28.5	0.86	86.6	64.58	46.45	<i>Clayey Soil(A-7-6)</i>	<i>Light Silty Clay</i>
33	52+000-52+380	22-Jun-13	1.66	17.4	40	12	21.9	0.75	80.61	50.6	34.34	<i>Silty or Clayey Gravel & Sand (A-2-2)</i>	<i>White Silty Soil</i>
34	52+380 - 52+500	25-Apr-13	1.56	23.9	43	14	24.3	0.6	59.29	49.09	37.99	<i>Clayey Soil(A-7-6)</i>	<i>Light Silty Clay</i>
35	53+160-53+360	31-Aug-13	1.47	30.3	54	25	14	0.84	89.93	70.75	58.06	<i>Clayey Soil(A-7-6)</i>	<i>Red Silty Clay Soil</i>
36	53+360-53+460	23-Sep-13	1.68	19.3	45	15	34	0.83	47.81	38.51	31.4	<i>Silty or Clayey Gravel & Sand (A-2-2)</i>	<i>Light Silty Clay & Gravel</i>

37	53+600-53+720	27-Aug-13	1.72	18	42	14	29	0.88	72.1	50.81	33.31	<i>Silty or Clayey Gravel & Sand (A-2-2)</i>	<i>Light Silty Clay Soil</i>
38	53+700-54+000	23-Sep-13	1.53	25.3	56	24	14.1	1.04	82.05	60.17	45.48	<i>Clayey Soil(A-7-5)</i>	<i>Red Silty Clay Soil</i>
39	54+400-55+000	23-Sep-13	1.48	28.8	52	22	8.1	1.58	67.53	43.71	35.65	<i>Clayey Soil(A-7-5)</i>	<i>Red Silty Clay Soil</i>
40	56+050-56+150	19-Oct-13	1.57	19.9	44	12	37	0.8	78.59	62.75	54.91	<i>Clayey Soil(A-7-5)</i>	<i>Light Reddish Clay</i>
41	56+060-56+300	20-Nov-13	1.67	21.4	45	14	20	1.28	74.14	49.33	31.48	<i>Silty or Clayey Gravel & Sand (A-2-2)</i>	<i>Light Brown Silty Soil</i>
42	56+150-56+250	12-Oct-13	1.49	18	40	10	16	1.25	78.76	66.95	59.15	<i>Clayey Soil(A-7-6)</i>	<i>Light Silty Soil</i>
43	56+250-56+380	19-Oct-13	1.46	25.8	44	0.32	11	1.07	66.7	55.08	49.18	<i>Clayey Soil(A-7-5)</i>	<i>Light Reddish Clay</i>
44	56+800-57+360	16-Oct-13	1.53	29.7	55	20	21	1.1	72.14	58.27	51.91	<i>Clayey Soil(A-7-6)</i>	<i>Brown Silty Soil</i>
45	59+940-60+080	10-Nov-13	1.42	27.6	52	20	6.8	1.67	96.44	75.58	57.27	<i>Clayey Soil(A-7-5)</i>	<i>Light Brown Silty Soil</i>
46	60+360-60+640	10-Nov-13	1.47	30.3	55	25	9.7	1.64	90.83	61.94	47.02	<i>Clayey Soil(A-7-5)</i>	<i>Red Brown Soil</i>
47	61+040-61+280	03-Dec-13	1.59	25.4	52	20	12.9	1.64	80.9	51.94	57.82	<i>Clayey Soil(A-7-5)</i>	<i>Brown Clay Soil</i>
48	61+440-61+580	18-Dec-13	1.6	26.5	56	23	25	1.59	78.12	59.86	43.32	<i>Clayey Soil(A-7-5)</i>	<i>Brown Clayey Soil</i>
49	61+580-61+720	17-Dec-13	1.52	26.43	59	19	14	1.8	77.86	59.1	40.05	<i>Clayey Soil(A-7-5)</i>	<i>Red Clayey Soil</i>
50	61+900-62+200	15-Dec-13	1.54	27.9	55	18	23	1.58	82.33	61.71	43.88	<i>Clayey Soil(A-7-5)</i>	<i>Light Brown Clayey Soil</i>
51	63+840-63+940	13-Dec-13	1.41	32	55	24	11	1.76	95.78	65.63	43.54	<i>Clayey Soil(A-7-5)</i>	<i>Red Clayey Soil</i>
52	64+960-64+980	10-Dec-13	1.41	29.6	55	24	10.1	1.58	95.71	62.52	40.06	<i>Clayey Soil(A-7-5)</i>	<i>Red Clayey Soil</i>
53	66+720-66+860	10-Dec-13	1.47	29.8	56	25	11.3	1.69	95.3	74.21	39.02	<i>Clayey Soil(A-7-5)</i>	<i>Brown Clayey Soil</i>

Summary of laboratory test results for borrow material for fill and capping/improved sub grade material sources

No.	Location	Material Description	Specification ▲	Laboratory Test Results							Degree of compaction (%)	Remarks
				LL (%)	PI (%)	MDD (gm/cc)	OMC (%)	CBR at 95 % of MDD	Swell (%)	Field moisture content (%)		
				≤40 %	≤15 %	-	-	≥15%	≤2%	±2% of the lab. OMC		
01	2+100,			-	6	-	-	26	-	-	-	Recommended to be used for fill/embankment construction
02	10+980			-	10	-	-	26	-	-	-	Recommended to be used for fill/embankment construction
03	28+040, 100m RHS	Light Brown/Yellowish/Whitish Highly Weathered Tuffaceous Rock (Clay Material With Gravel)		38.7	10.4	1.45	21.4	29	1.34	-	-	Recommended to be used in construction for selected sub grade/capping layer
04	Km 28+040 - km 28+880	Reddish brown silty clay soil with gravel (Existing road sub grade material)		43.47	12	1.61	24.8	27	0.26	-	-	Recommended to be used in construction for selected sub grade/capping layer with due care/proper mixing

05	31+840, 50m RHS	Light Brown/Yellowish/ Whitish Highly Weathered Tufficious Rock (Clay Material With Gravel)	48.3	9.5	1.48	27.8	35	0.75	-	-	Recommended to be used in construction for selected sub grade/capping layer
06	31+950,		-	16	-	-	18	-	-	-	Recommended to be used for fill/embankment construction
07	Km 33+000 - km 34+000	Light Brown/Yellowish/ Whitish Highly Weathered Tufficious Rock (Existing road selected sub grade material)	36.4	11	1.75	18.6	39	0.34	-	-	Recommended to be used in construction for selected sub grade/capping layer with due care/proper mixing

Summary of laboratory test results for natural gravels sub-base material Sources

No	Location	Specification ▲	Sieve analysis (% of passing)					PP (%)	LL (%)	PL (%)	PI (%)	LAA (%)	MDD (gm/cc)	OMC (%)	CBR at 97 % of MDD	Swell (%)	Remarks
			Sieve size (mm)														
			63	50	25	4.75	0.075										
			100	90-100	51-80	35-70	5-15	≤75%	≤4-5%	-	≤12%	≤51	-	-	≥30%	≤2%	The source is approved as
1	49+700 10m LHS		100	96	60	38	7	70	41	31	10	38.54	1.68	13.6	66	0.6	Natural Gravel
2	49+700 5m RHS		100	95	54	39	8	80	41	31	10	39.26	1.74	9.5	50	0.79	Natural Gravel
3	51+100 300m RHS		100	95	51	19	4	48	49	37	12	36.06	1.82	14.9	68	0.8	Natural Gravel
4	52+800 50m RHS		100	95	72	45	11	121	39	28	11	Not Conducted	1.93	11.4	59	0.56	Natural Gravel
5	73+200 4Km RHS		100	93	64	36	7	70	40	30	10	Not Conducted	1.86	14.4	65	0.62	Natural Gravel
Applicable standard			AASHTO T-27					AAHTO T-89 and 90			AASHTO T-89	AASHTO T-96	-	-	AASHTO T-193	-	

Summary for Test Results of Sub grade Soil (Design Review)

No	Station	MDD (g/cc)	OMC (%)	LL (%)	PI (%)	CBR (%)	Swell (%)	Sieve Analysis			Soil Classification, AASHTO	Group Index
								2mm	0.425m m	0.075 mm		
1	37+500 - 38+810	1.45	31.5	61	22	4.1	1	98.3	95.9	89.1	Clayey Soil(A-7-5)	25
2	38+810 - 43+400	1.57	27.4	54	21	6.4	1.01	98.6	95.5	85.9	Clayey Soil(A-7-5)	22
3	43+350 - 43+520	1.56	25.4	51	24	6	1.56	95.1	95.6	85.5	Clayey Soil (A-7-6)	23
4	43+520 - 45+740	1.72	18.6	39	16	14	1.33	89	83.2	65	Clayey Soil (A-6)	10
5	45+740 - 47+740	1.41	33.3	53	24	5.3	0.85	97.9	90.3	80.3	Clayey Soil (A-7-6)	21
6	47+740 - 48+960	1.62	22.4	55	26	5.1	1.9	84	60	40	Clayey Soil (A-7-6)	5
7	48+500 - 49+000	1.8	17.8	43	29	14.6	2.9	91	70.6	30.4	Salty or Clayey Gravel (A-2-7)	2
8	49+000 - 54+100	1.54	24.4	50	18	15	1	93	73	43	Clayey Soil(A-7-5)	4
9	54+100 - 55+600	1.5	25.6	50	21	20	1.87	93.9	81.1	54.8	Clayey Soil(A-7-5)	9
10	55+600 - 56+900	1.5	26.5	51	21	16.9	1.84	96.9	91.3	78.3	Clayey Soil(A-7-5)	18
11	56+900 - 57+750	1.5	29.2	55	23	20	—	94.5	83	54.8	Clayey Soil(A-7-5)	8
12	57+750 - 61+100	1.51	27.3	57	28	4.6	0.92	94.3	89.9	89.1	Clayey Soil (A-7-6)	29
13	61+100 - 61+850	1.65	16.7	39	18	15	1.34	84	76	61	Clayey Soil (A-6)	9
14	61+850 - 62+000	1.51	23.4	49	23	4.72	1.74	95	92.4	91	Clayey Soil (A-7-6)	24
15	62+000 - 62+300	1.72	12.4	37	14	24	1.77	75.2	56.4	27.6	Silty or Clayey Gravel (A-2-6)	0
16	62+300 - 67+500	1.4	22.5	54	25	3.6	1.33	99	97.4	93.5	Clayey Soil (A-7-6)	27

17	67+500 – 71+200	1.41	33.3	53	24	4.3	0.86	99.7	93	86.3	Clayey Soil (A-7-6)	24
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Summary for test results of sub grade soil samples (design review)

No.	Represent Station	MDD (g/cc)	OMC (%)	LL (%)	PI (%)	CBR (%)	Swell (%)	Sieve Analysis (mm)			Soil Classification, AASHTO	Group Index
								2	0.425	0.075		
1	0+000 - 2+500	1.47	19	37.4	18	5.4	2.64	95.3	89.9	68.1	Clayey Soil(A-7-6)	16
2	2+500 - 5+500	1.47	24	46	20	7.7	0.9	93	92.3	89	Clayey Soil(A-7-6)	20
3	5+500 - 8+500	1.4	17.7	42	18	5.7	0.93	94.6	92.3	85	Clayey Soil(A-7-6)	14
4	8+500 - 11+350	1.45	23	48	22	5.8	1.13	98.3	95.4	88.5	Clayey Soil(A-7-6)	22
5	11+350 - 13+500	1.64	19.5	61	25	3.3	1.72	99.1	97.2	90.4	Clayey Soil(A-7-5)	28
6	13+500 - 15+500	1.62	21.2	43	15	4.9	1.08	93	90	86	Clayey Soil(A-7-6)	15
7	15+500 – 16+700	1.54	22.3	49	23	3.3	0.56	94.2	91.1	87.3	Clayey Soil(A-7-6)	22
8	15+500 - 19+100	1.61	19.5	40	16	10.3	1	92	87.1	78.6	Clayey Soil (A-6)	13
9	19+100 - 21+500	1.42	20.2	41	13	15.5	0.86	72	54	33	Silty or Clayey Gravel (A-2-6)	0
10	21+500 - 24+000	1.44	22.4	46	23	4	0.52	99.2	97.6	91.2	Clayey Soil (A-7-6)	22
11	24+000 - 31+700	1.45	21.8	44	20	4	1.41	98.7	93.4	88.1	Clayey Soil (A-7-6)	19
12	31+700 - 32+500	1.61	20.3	41	16	18	0.92	73	57	34	Silty or Clayey Gravel (A-2-7)	1
13	32+500 - 37+500	1.43	22.1	51	21	5.7	1.05	97.1	89.9	89.7	Clayey Soil(A-7-5)	22

Summary of Laboratory Test Results for Natural Gravel Sub base Material Sources

No.	Location	Specification ▲	Sieve analysis (% of passing)					PP (%)	LL (%)	PL (%)	PI (%)	LAA (%)	MDD (gm/cc)	OMC (%)	CBR at 97 % of MDD	Swell (%)	Placed		Remarks									
			Sieve size (mm)														≤75%	≤45%		-	≤12%	≤51	-	-	≥30%	≤2%	From	to
			63	50	25	4.75	0.075																				100	90-100
1	10+840 200m RHS		100	98	72	44	28.8	271	38.7	29.3	9.4	-	1.87	8.9	64	0.28	0+000	7+460	Blending with cinder material which is found at km 0+000 LHS Mazoria, towards Sodo (2:1 ratio) by volume									
2	11+460 1.5km LHS		100	96.7	63.8	34.9	23.6	273	42	30.4	11.6	42.9	1.76	20.0	52.1	0.22	7+460	12+714	Approved for use as Natural Gravel Sub base Material									
3	14+600 500m RHS		97	88.7	62.7	33.5	5.8		NP			-	2.08	10.7	36	0.046	Not utilized		Does not comply with the quality requirements for Natural Gravel Sub base Material									
4	14+600 2.0km RHS		74	69.0	51.0	31.0	12.0	124	34.2	23.9	10.3	-	2.11	12	90	0.47	12+714	21+980										
5	26+960 1.5km LHS		100	96.9	80.7	50.6	14.7	119	34.9	26.8	8.1	75.96	1.73	20.4	89	0.25	21+980	23+900	Blending with existing pavement material (2:1 ratio) by volume									
Applicable standard			AASHTO T-27					AAHTO T-89 and 90			AASHTO T-89	AASHTO T-96	-	-	AASHTO T-193	-												

C-2-Soil classification of Alaba-Alemgebeya-Hulbarek road project

**Double Surface Treatment Asphalt Road Project
Soil Laboratory Test Results for Sub grade Material Sources**

No	station	Distance	Type of soil	No	Station	Distance	Soil type
1	0	900m- LHS	yellowish silty soil	14	39+000	1.7km- LHS	yellowish silt in granular soil
2	2+700	200m- LHS	yellowish silt in granular soil	15	39+000	1.7km- LHS	yellowish silt in soil
3	4+260	50m- RHS	Light brown silt soil	16	42+200	600m- RHS	white silt soil
4	9+400	1.2km- LHS	yellowish silt soil	17	44+050	50m- LHS	white silt soil
5	10+820	2.1km- RHS	yellowish silt in granular soil	18	48+800	300m- RHS	yellowish silt in soil
6	10+820	2.1km- RHS	yellowish silt soil	19	52+820	50m-RHS	yellowish silt in soil
7	18+000	600m- LHS	white granular silt sandy soil	20	52+820	50m-RHS	white granular silt sandy soil
8	19+700	1.5km-	white in yellowish silt soil	21	53+660	400m-RHS	yellowish silt clay soil
9	22+300	2Km- RHS	yellowish silt soil	22	54+600	100m-RHS	yellowish silt soil
10	27+375	3km- RHS	yellowish silt soil	23	54+600	100m-RHS	Red clay soil
11	33+630	3.7km- RHS	yellowish in white silt soil	24	55+200	50m- RHS	Red clay soil
12	33+630	3.7km- RHS	white silt sandy soil	25	55+200	50m-RHS	white silt sandy soil
13	36+000	4 km- RHS	yellowish silty in granular soil	26	55+200	50m-RHS	white silt sandy soil

Annex D: Average OEE Index of selected Construction Equipment

D-1: OEE Index for Motor Grader on Mazoria-Durame-Hadero Road Project

Data Collection Template Machinery Type - <u>Motor Grader</u> Mark - <u>Caterpillar</u> Model - <u>140H</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Motor-grader Productivity on Mazoria-Durame-Hadero Road Project					
Type of Activity - Sub -base Mixing and Placing					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent	A	Available time (12 hrs. x 60')	720	min	
Variables	B	Scheduled maintenance + scheduled production break	60	min	Lunch break(MnF)
	C	loading time (=A-B)	660	min	
AR(%)= 100*E/C	D1	Recorded break downtime	75	min	Bearing problem(MF)
84.09090909	D2	Time spent for change in Operation condition	30	min	Bearing change(MnF)
	D	Major Stoppage losses (= D1 + D2)	105	min	
	E	Operating Time (= C- D)	555	min	
	G	Ideal production (from manufacturer specification)	300	m ² /h	
	H	Actual Production	185.09	m ² /h	
		Blade length(I) including overlap	3.64	m	
		Width per trip(B) = I*Cos A	3.2993	m	Luck of coordination,
		Tilting angle of the blade(A)	25	m	Higher number of pass,
		Lift thickness after compaction(L)	0.2	deg.	Long working
		Number of pass(P)	10	m	length(MnF)
		Average speed correspond to the work type (V)	5.5	km/h	
		Cycle time(T) =0.06ΣP/V	0.1091	min/m	
PR(%) = P*R		Product of correction factors for [site condition* operator effectiveness * time factor (day)]	0.51		
71.70182618	O	Actual cycle time	2.31	min	

	I	Production Capacity losses downtime = $[1-H/G] \times L$	52.8	min	
	K1	Number of minor stoppage	2	No.	Third person
	K2	Average Duration of minor stoppage	15	min	Communication(HF)
	K3	Idle time	30	min	Waiting for parts(MnF)
	K	Minor stoppages / Idle losses (= $K1 \times [(K2 + K3)]$)	60	min	
	L	Net Operating Time (= $E - K$)	495	min	
	M	Performing Time ($L - I$)	442.2	min	
	N	Valuable Operating Time($M - J$)	392.2	min	
	P	Net Operating Rate = $(100 * (H * O)/E)$	77.038	%	
	Q	Ideal/ theoretical/ design cycle time	2.15	min	
	R	Operating Speed coefficient(= Q/O)	0.9307		
	J	Time spent for rework and start up yield losses	50	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	1209.9	m ²	
98.72514023	T	reworked amount(unit)	15.424	m ²	Operator problem(HF)
OPR/OEE					
=AR*PR*QR			59.52604438	%	

D-2: OEE Index for Loader on Mazoria-Durame-Hadero Road Project

Data Collection Template Machinery Type - <u>Loader</u> Mark - <u>Caterpillar</u> Model - 930H Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Loader Productivity on Mazoria-Durame-Hadero Road Project					
Type of Activity - Pushing of Common Earth material					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent	A	Available time (12 hrs. x 60')	720	min	
Variables	B	Scheduled maintenance + scheduled production break	108	min	Under repair, lunch
	C	loading time (=A-B)	612	min	(MnF)
AR(%)= 100*E/C	D1	Recorded break downtime	0	min	Operator
87.25490196	D2	Time spent for change in Operation condition	78	min	Exchange(MnF)
	D	Major Stoppage losses (= D1 + D2)	78	min	
	E	Operating Time (= C- D)	534	min	
	G	Ideal production (from manufacturer specification)	151.42	m ³ /h	
	H	Actual Production	140.74	M ³ /h	
		Job efficiency	52	min/h	
		Bucket load	2.54	m ³	
		Material type- soil mixed moist aggregate			
		Bucket fill factor corresponding to the material	0.975	%	Higher cycle time,
		Static tipping load -from table		No.	Long dump
		Swell factor - from table	0.83	%	Distance(MnF)
PR(%) = P*R	O	Actual cycle time	30	sec	
75.1145699	I	Production Capacity losses downtime = [1-H/G] x L	30.265	min	
	K1	Number of minor stoppage	4	No.	Absentees
	K2	Average Duration of minor stoppage	15	min	Third person
	K3	Idle time	45	min	communication(HF)
	K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	105	min	

	L	Net Operating Time (= E- K)	429	min	
	M	Performing Time (L – I)	398.73	min	
	N	Valuable Operating Time(M – J)	373.73	min	
	P	Net Operating Rate = (100 * (H * O)/E)	79.068	%	
	Q	Ideal/ theoretical/ design cycle time	28.5	sec	
	R	Operating Speed coefficient(= Q/O)	0.95		
	J	Time spent for rework and start up yield losses	25	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	876.66	m ³	change order(MnF)
93.31076554	T	reworked amount(unit)	58.642	m ³	
OPR/OEE					
=AR*PR*QR			61.15694352	%	

D-3: OEE Index for Excavator on Mazonia-Durame-Hadero Road Project

Data Collection Template					
Machinery Type - <u>Excavator</u> Mark - <u>Caterpillar</u> Model - <u>325B</u>					
Average of Five Days Result with One Day = 12 working hours					
(Construction Equipment with Cyclic Operating Machines)					
Excavator Productivity on Mazonia-Durame-Hadero Road Project					
Type of Activities- Common Earth Excavation					Contributing Factors
Productivity Rate	Sym	Independent variables	Values	Unit	
Dependent Variables	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	110	min	Fuel filter, lunch(MnF)
AR(%)= 100*E/C 85.24590164	C	loading time (=A-B)	610	min	
	D1	Recorded break downtime	50	min	Chain problem(MF)
	D2	Time spent for change in Operation condition	40	min	Old blade
	D	Major Stoppage losses (= D1 + D2)	90	min	change(MnF)
	E	Operating Time (= C- D)	520	min	
	G	Ideal production (from manufacturer specification)	164.9	m ³ /h	

PR(%) = P*R 75.81594635	H	Actual Production	139.14	m ³ /h		
		Job efficiency	52	Min/h		
		Heaped bucket capacity	1.89	m ³		
		Material type- soil mixed moist aggregate		m		
		Bucket fill factor corresponding to the material	0.95	m		
		Swell factor - from table	0.83			
		O	Actual cycle time	22	Sec	
		I	Production Capacity losses downtime = [1-H/G] x L	73.405	min	
		K1	Number of minor stoppage	2	No.	Fuel
		K2	Average Duration of minor stoppage	15	min	Shortage(MnF)
		K3	Idle time	20	min	Activity
		K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	50	min	Dependence(MnF)
		L	Net Operating Time (= E- K)	470	min	
		M	Performing Time (L – I)	396.59	min	
	N	Valuable Operating Time(M – J)	374.59	min		
	P	Net Operating Rate = (100 * (H * O)/E)	98.115	%		
	Q	Ideal/ theoretical/ design cycle time	17	sec	Minimum working,	
	R	Operating Speed coefficient(= Q/O)	0.7727		Space, poor site,	
	J	Time spent for rework and start up yield losses	22	min	condition (MnF)	
	S	Total executed amount(unit)	868.71	m ³	Change	
	T	reworked amount(unit)	51.02	m ³	Order(MnF)	
QR(%) = (S-T)/S 94.12698336 OPR/OEE =AR*PR*QR			60.83425716	%		

D-4: OEE Index for Dozer on Hadero-Durgi Road Project

Data Collection Template Machinery Type - <u>Dozer</u> Mark - <u>Caterpillar</u> Model - <u>D8R</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Dozer Productivity on Hadero-Durgi Road Project					
Type of Activity - Pushing of Common Earth material					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent Variables AR(%)= 100*E/C 89.92248062	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	75	min	Mobilization, lunch
	C	loading time (=A-B)	645	min	(MnF)
	D1	Recorded break downtime	45	min	Electrical problem
	D2	Time spent for change in Operation condition	20	min	(MF)
	D	Major Stoppage losses (= D1 + D2)	65	min	
	E	Operating Time (= C- D)	580	min	
PR(%) = P*R 72.97678047	G	Ideal production (from manufacturer specification)	235	m ³ /h	
	H	Actual Production	169.3	m ³ /h	
		Dozing distance	120	m	
		Applicable correction factor			
		Job efficiency - 50min/h	0.83		Longer dozing
		Type of doze - slot dozing	1.2		Distance, higher
		Grade correction - Downhill (for 14.5%) - uphill	1.4		grade(MnF)
		Average operator	0.75		
		Weight correction	0.83		
		Material type - dry non cohesive material	0.83		
	O	Actual cycle time	2.5	min	
	I	Production Capacity losses downtime = [1-H/G] x L	149.6	min	
	K1	Number of minor stoppage	2	No.	Tea break,

	K2	Average Duration of minor stoppage	10	min	Communication gap(MnF)
	K3	Idle time	25	min	
	K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	45	min	Forman change (MnF)
	L	Net Operating Time (= E- K)	535	min	
	M	Performing Time (L – I)	385.4	min	
	N	Valuable Operating Time(M – J)	360.4	min	
	P	Net Operating Rate = (100 * (H * O)/E) =	72.98	%	
	Q	Ideal/ theoretical/ design cycle time	1	min	
	R	Operating Speed coefficient(= Q/O)	0.4		
	J	Time spent for rework and start up yield losses	25	min	Inspection time(MnF)
QR(%) = (S-T)/S	S	Total executed amount(unit)	1017	m ³	
93.06406396	T	reworked amount(unit)	70.54	m ³	
OPR/OEE =AR*PR*QR			61.07099448 %		

D-5: OEE Index for Loader on Hadero-Durgi Road Project

Data Collection Template Machinery Type - <u>Loader</u> Mark - <u>Caterpillar</u> Model - <u>953H</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Loader Productivity on Hadero-Durgi Road Project					
Type of Activity - Pushing of Common Earth material					Contributing Factors
Productivity Rate	Sym	Independent Variables	Value	Unit	
Dependent Variables AR(%)= 100*E/C 89.7689769	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	114	min	Mobilization, lunch
	C	loading time (=A-B)	606	min	(MnF)
	D1	Recorded break downtime	0	min	
	D2	Time spent for change in Operation condition	62	min	Operator change
	D	Major Stoppage losses (= D1 + D2)	62	min	(MnF)
PR(%) = P*R 71.59568617	E	Operating Time (= C- D)	544	min	
	G	Ideal production (from manufacturer specification)	188.4	m ³ /h	
	H	Actual Production	136.7	M ³ /h	inefficacy
		Job efficiency	52	min/h	Operator(HF)
		Bucket load	2.7	m ³	Long dump
		Material type- soil mixed moist aggregate		m	Distance(MnF)
		Bucket fill factor corresponding to the material	0.95	m	
		Static tipping load -from table	6766	kg	
		Swell factor - from table	0.83	No.	
	O	Actual cycle time	32	Sec	
	I	Production Capacity losses downtime = [1-H/G] x L	144	min	
	K1	Number of minor stoppage	2	No.	Third person
	K2	Average Duration of minor stoppage	10	min	Communication(HF)
	K3	Idle time	0	min	
K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	20	min		
L	Net Operating Time (= E- K)	524	min		

	M	Performing Time (L – I)	380	min	
	N	Valuable Operating Time(M – J)	366	min	
	P	Net Operating Rate = (100 * (H * O)/E)	80.39	%	
	Q	Ideal/ theoretical/ design cycle time	28.5	sec	
	R	Operating Speed coefficient(= Q/O)	0.891		
	J	Time spent for rework and start up yield losses	14	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	833.7	m ³	Inspection delay(MnF)
96.17504068	T	reworked amount(unit)	31.89	m ³	
OPR/OEE =AR*PR*QR			61.81238628	%	

D-6: OEE Index for Excavator on Hadero-Durgi Road Project

Data Collection Template Machinery Type - <u>Excavator</u> Mark - <u>Caterpillar</u> Model - <u>322C</u> Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines) Excavator Productivity on Hadero-Durgi Road Project					
Type of Activity - Common Earth Excavation					Contributing Factors
Productivity Rate	Sym	Independent Variables	Value	Unit	Machine Factor:-
Dependent Variables AR(%)= 100*E/C 89.39393939	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch(MnF)
	C	loading time (=A-B)	660	min	
	D1	Recorded break downtime	20	min	Tire inflation(MF)
	D2	Time spent for change in Operation condition	50	min	Replacing new
	D	Major Stoppage losses (= D1 + D2)	70	min	tire(MF)
	E	Operating Time (= C- D)	590	min	
	G	Ideal production (from manufacturer specification)	164.9	m ³ /h	
	H	Actual Production	149.5	M ³ /h	
		Job efficiency	48	min/h	
		Heaped bucket capacity	2.2	m ³	

PR(%) = P*R 70.6010929		Material type- soil mixed moist aggregate		m	
		Bucket fill factor corresponding to the material	0.95	m	
		Swell factor - from table	0.83	m	
	O	Actual cycle time	22	sec	
	I	Production Capacity losses downtime = $[1-H/G] \times L$	42.93	min	
	K1	Number of minor stoppage	4	No.	Weather(WF)
	K2	Average Duration of minor stoppage	20	min	
	K3	Idle time	50	min	Waiting for
	K	Minor stoppages / Idle losses (= $K1 * [(K2 + K3)]$)	130	min	surveyor(MnF)
	L	Net Operating Time (= $E - K$)	460	min	
	M	Performing Time (L – I)	417.1	min	
	N	Valuable Operating Time(M – J)	397.1	min	
	P	Net Operating Rate = $(100 * (H * O)/E) = H/G$	91.37	%	
	Q	Ideal/ theoretical/ design cycle time	17	sec	
	R	Operating Speed coefficient(= Q/O)	0.773		
	J	Time spent for rework and start up yield losses	20	min	
	QR(%) = (S-T)/S 94.96306246	S	Total executed amount(unit)	989.4	m ³
T		reworked amount(unit)	49.84	m ³	Communication(MnF)
OPR/OEE =AR*PR*QR			59.93413086	%	

D-7: OEE Index for Dozer on Alaba-Alemgebeya-Hulbarek Road Project

Data Collection Template					
Machinery Name - <u>Dozer</u> Mark - <u>Caterpillar</u> Model - <u>D8R</u>					
Average of Five Days Result with One Day = 12 working hours					
(Construction Equipment with Cyclic Operating Machines)					
Dozer Productivity on Alaba-Alemgebeya-Hulbarek Road Project					
Type of Activity - Pushing of Common Earth material					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent variables AR(%)= 100*E/C 89.91596639	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	125	min	Transmission filter check
	C	loading time (=A-B)	595	min	Up, lunch(MnF)
	D1	Recorded break downtime	30	min	Old teeth breakdown(MF)
	D2	Time spent for change in Operation condition	30	min	
	D	Major Stoppage losses (= D1 + D2)	60	min	
	E	Operating Time (= C- D)	535	min	
PR(%) = P*R 72.94769159	G	Ideal production (from manufacturer specification)	300	m ³ /h	
	H	Actual Production	173.5	m ³ /h	Longer dozing distance,
		Dozing distance	110	m	Higher grade,
		Applicable correction factor			Poor site condition
		Job efficiency - 50min/hr	0.83		(MnF)
		Type of doze - slot dozing	1.2		
		Grade correction – Downhill (for 14.5%)	1.29		
		- uphill			
		Average operator	0.75		
		Weight correction	0.75		
		Material type - dray non cohesive material	0.8		
O	Actual cycle time	3	min		
I	Production Capacity losses downtime = [1-H/G] x L	200.4	min	Hydraulic oil check	
K1	Number of minor stoppage	3	No.	up, Tea break (MnF)	
K2	Average Duration of minor stoppage	10	min		

	K3	Idle time	30	min	Operator delay(HF)
	K	Minor stoppages / Idle losses (= K1*[(K2 +K3)])	60	min	Absentees, third
	L	Net Operating Time (= E- K)	475	min	Person
	M	Performing Time (L – I)	274.6	min	communication (HF)
	N	Valuable Operating Time(M – J)	259.6	min	
	P	Net Operating Rate = (100 * (H * O)/E)	97.26	%	
	Q	Ideal/ theoretical/ design cycle time	2.25	min	
	R	Operating Speed coefficient(= Q/O)	0.75		
	J	Time spent for rework and start up yield losses	15	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	750.6	m ³	Surveyor
94.22264872	T	Reworked amount(unit)	43.36	m ³	problem(HF)
OPR/OEE =AR*PR*QR			61.80216344	%	

D-8: OEE Index for Motor Grader on Alaba-Alemgebeya-Hulbarek Road Project

Data collection Template					
Machinery Type - <u>Motor Grader</u> Mark - <u>Caterpillar</u> Model - <u>140H</u>					
Average of Five Days Result with One Day = 12 working hours (Construction Equipment with Cyclic Operating Machines)					
Motor Grader Productivity on Alaba-Alemgebeya-Hulbarek Road Project					
Type of Activity - sub-base mixing and placing					Contributing Factors
Productivity Rate	Sym	Independent variables	Value	Unit	
Dependent variables AR(%)= 100*E/C 89.39393939	A	Available time (12 hrs. x 60')	720	min	
	B	Scheduled maintenance + scheduled production break	60	min	Lunch(MnF)
	C	loading time (=A-B)	660	min	Radiator, pin break
	D1	Recorded break downtime	40	min	problem(MF)
	D2	Time spent for change in Operation condition	30	min	Pin exchange(MnF)
	D	Major Stoppage losses (= D1 + D2)	70	min	
	E	Operating Time (= C- D)	590	min	
PR(%) = P*R 68.66791693	G	Ideal production (from manufacturer specification)	310	m ² /h	
	H	Actual Production	158.9	m ² /h	
		Blade length(l) including overlap	3.64		
		Width per trip(B) = l*cos A=	3.398	Min/h	
		Tilting angle of the blade(A)	21	m ³	Longer working
		Lift thickness after compaction(L)	0.2	m	Length,
		Number of pass(P)	12	m	Higher number of
		Average speed correspond to the work type (V)	5.5	m	Pass (MnF)
		Cycle time(T) =0.06ΣP/V	0.131	No.	
		Product of correction factors for [site condition* operator effectiveness * time factor (day)]	0.51		
	O	Actual cycle time – as stated above	2.31	min	
	I	Production Capacity losses downtime = [1-H/G]*L	197.4	min	
	K1	Number of minor stoppage	3.5	No.	

	K2	Average Duration of minor stoppage	30	min	
	K3	Idle time	80	min	Activity
	K	Minor stoppages / Idle losses (= $K1 * [(K2 + K3)]$)	185	min	dependency(MnF)
	L	Net Operating Time (= E- K)	405	min	
	M	Performing Time (L – I)	207.6	min	
	N	Valuable Operating Time(M – J)	385	min	
	P	Net Operating Rate = $(100 * (H * O)/E) = H/G$	62.21	%	
	Q	Ideal/ theoretical/ design cycle time	2.55	min	
	R	Operating Speed coefficient(= Q/O)	1.104		
	J	Time spent for rework and start up yield losses	20	min	
QR(%) = (S-T)/S	S	Total executed amount(unit)	1019	m ²	Incompetent
94.80519481	T	reworked amount(unit)	52.96	m ²	Forman(HF)
OPR/OEE =AR*PR*QR					58.19612715 %

Annex E: Machinery Maintenance Schedule

Machine Type	First round(250hrs)	Second round(500hrs)	Third round(750hrs)	Fourth round(1000hrs)	Eighth round(250hrs)
Dozer	Engine oil Oil Filter Equalizer bar oil	Engine oil Oil Filter Fuel filter fuel water separator Clean breezier Equalizer bar oil	Engine oil Oil Filter Equalizer bar oil	Engine oil Oil Filter Fuel filter Transmission filter Equalizer bar oil Final drive oil	Engine oil Oil Filter Fuel filter Transmission filter Equalizer bar oil Final drive oil Hydraulic oil hydraulic filter
Excavator	First round(250hrs) Engine oil Oil Filter	Second round(250hrs) Engine oil Oil Filter Fuel filter fuel water separator Clean breezier Equalizer bar oil	Third round (250hrs) Engine oil Oil Filter	Fourth round(250hrs) Engine oil Oil Filter Fuel filter Transmission filter Equalizer bar oil Final drive oil Circle drive oil	These cycles repeat itself in the same way
Grader	First round(250hrs) Engine oil Oil Filter	Second round(500hrs) Engine oil Oil Filter Fuel filter fuel water separator	Third (750hrs) Engine oil Oil Filter	Fourth round(1000hrs) Engine oil Oil Filter Fuel filter Transmission filter	These cycles repeat itself in the same way

		Clean breezier Equalizer bar oil		Equalizer bar oil Final drive oil Circle drive oil	
	First round(250hrs)	Second round(500hrs)	Third (750hrs)	Fourth round(1000hrs)	
loader	Engine oil Oil Filter	Engine oil Oil Filter Fuel filter fuel water separator Clean breazer	Engine oil Oil Filter	Engine oil Oil Filter Fuel filter Transmission filter Final drive oil	These cycles repeat itself in the same way

Annex F: Pictures on Site



Excavator with its four cycle time: Excavating, swinging with load, dumping and swinging empty





Excavating and pushing earth material using dozer



Spreading and leveling of sub-base material using motor grader



Portion of finished road surface with double surface treatment and memory of the topography of the area



Stages in loading Stock material using loader

Declaration

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

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