

FINAL PROJECT

ANALYSIS OF HEAVY EQUIPMENT COMBINATION IN EMBANKMENT WORK IN THE YOGYAKARTA- BAWEN TOLL ROAD PROJECT

**A Thesis Presented to the Universitas Islam Indonesia Yogyakarta as Partial
Fulfillment of the Requirements to Obtain the Bachelor Degree in Civil
Engineering Department**



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ISLAMIC INDONESIA UNIVERSITY
YOGYAKARTA**

2025

FINAL PROJECT

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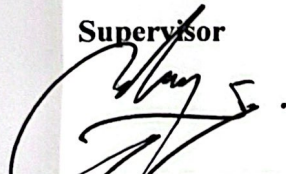
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Accepted as one of the requirements for the award of the
degree of Bachelor of Civil Engineering.

Examined on 23 September 2025

Approved by the Board of Examiners

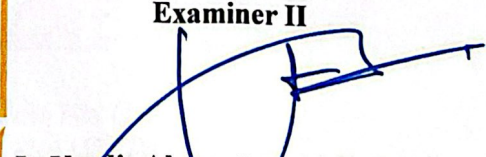
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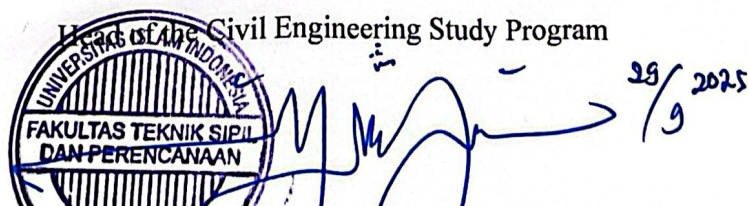
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PLAGIRISM FREE STATEMENT

I, the undersigned, hereby declare that this assignment is my own work, as a requirement for completing the Bachelor's program and obtaining a Bachelor's degree (S1) in the Civil Engineering and Planning Study Program at the Islamic University of Indonesia. There are certain parts of this Final Assignment that I have quoted from the work of others, and these have been clearly stated in the source in accordance with the norms, rules, and ethics of writing scientific papers. If it is found that part or all of this Final Assignment is not my work or contains elements of plagiarism, I am willing to accept the sanctions that will be given according to applicable laws

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author hopes that this Final Project can be beneficial to its readers and serve as additional information for interested parties.

Yogyakarta, September 2025



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PREFACE

Praise and gratitude are hereby expressed to Allah SWT for mercy and blessings, which have enabled the author to complete this Final Project entitled Analysis of Heavy Equipment Combination in Embankment Work in the Yogyakarta-Bawen Toll Road Project. This Final Project is prepared to fulfill one of the requirements for completing the undergraduate program in the Civil Engineering and Planning Study Program at Universitas Islam Indonesia, Yogyakarta.

In the completion of this Final Project, the author has received support and guidance from various parties, enabling the successful completion of this work. Therefore, the author would like to express sincere gratitude to:

1. Mrs. Ir. Yunalia Muntafi, S.T., M.T., Ph.D. (Eng)., IPM, Head of the Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia.
2. Mr. Adityawan Sigit, S.T., M.T., Ph.D., Supervisor of this Final Project, for the guidance and direction provided throughout the preparation of this project.
3. Mr. Jafar, S.T., MURP., M.T., Examiner I in the Final Project Defense, for the valuable input and assessment.
4. Mr. Ir. Vendie Abma, S.T., M.T., IPM, Examiner II in the Final Project Defense, for the constructive evaluation.
5. All institutions and parties that have provided the author with the opportunity to collect data on the project site for the preparation of this Final Project

Finally, the author realizes that this Final Project is far from perfect due to the limitations of knowledge and ability. Therefore, the author sincerely welcomes constructive criticism and suggestions for improvement in future writings. The

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LIST OF NOTATIONS AND ABBREVIATIONS

V	=	Bucket Capacity m^3
CT	=	Cycle Time
Fk	=	Correction Factor
E	=	Work Efficiency
T	=	Total Trip
Q	=	Productivity $m^3/hour$
L	=	Bed Length (m)
W	=	Bed Length (m)
H	=	Bed Height (m)
Dt	=	Distance
T1	=	Loading Time
T2	=	Loaded Travel Time
T3	=	Unloading Time
T4	=	Unloading Travel Time
J	=	Dozer Distance (m)
F	=	Forward Speed (m/minute)
R	=	Reverse Speed (m/minute)
Z	=	Fixed Time (minute)
W	=	Compaction Width
P	=	Total Passing
S	=	Rolling Speed (km/hour)
H	=	Layer Height (m)
SF	=	Shrinkage Factor
LF	=	Load Factor
Vc	=	Compacted Volume m^3

ABSTRACT

The development of toll road infrastructure in Indonesia continues to grow rapidly to support national connectivity, including the Yogyakarta–Bawen Toll Road as one of the National Strategic Projects. In this project, embankment work is a crucial stage that requires the use of heavy equipment with high productivity. The proper selection of equipment type and combination is essential to ensure efficiency in terms of time and cost. However, variations in soil conditions, cycle time, and equipment availability often affect the overall performance. Therefore, this study was conducted to analyze the productivity of heavy equipment, evaluate alternative equipment combinations, and determine the most effective option for optimizing both duration and cost of the project.

This research employed a field study approach through direct observations and data collection at the Yogyakarta–Bawen Toll Road Project, Section 1. The primary data consisted of cycle time and idle time measurements for excavators, dump trucks, bulldozers, sheepsfoot rollers, and vibratory rollers, which were recorded using a Stopwatch Time Study and Work Sampling over five working days. Secondary data, including embankment volume, project layout, and rental costs, were obtained from the contractor. Productivity was then calculated based on cycle time, efficiency factors, and equipment capacity. Three alternative equipment combinations were analyzed and compared to the existing condition to identify the most effective balance between duration and cost.

The results show that the existing combination required 107 working days at a total cost of Rp1,651,195,200. Alternative 1 reduced the duration to 82 days, Alternative 2 to 55–56 days, and Alternative 3 to 41 days. Although the alternatives required slightly higher costs (ranging from Rp1,652,327,000 to Rp1,658,685,000), the time savings were significant. Among the options, Alternative 3, which employed 4 excavators, 48 dump trucks, 3 bulldozers, 2 sheepsfoot rollers, and 2 vibratory rollers, was identified as the most suitable in terms of project duration. Conversely, Alternative 1 provided the most cost-efficient solution. These findings indicate a trade-off between time and cost, allowing decision-makers to select the appropriate alternative based on project priorities.

Keyword: Productivity, Heavy Equipment, Embankment Work, Cost Efficiency, Toll Road Construction

CHAPTER I

INTRODUCTION

1.1 Background of the Study

The development of toll road infrastructure in Indonesia has experienced significant growth in recent years to support national economic growth. One of the current National Strategic Projects is the Yogyakarta-Bawen Toll Road project, which aims to enhance connectivity within Central Java and Yogyakarta. Spanning a total length of 75.82 kilometers, this project seeks to integrate Yogyakarta into the national toll road network, including the Trans-Java Toll Road to the north and the Solo-Yogyakarta Toll Road to the south. In executing this project, one critical phase involves earthwork operations, including excavation and embankment, which require the use of heavy machinery to ensure timely and efficient implementation. Consequently, analyzing the productivity of heavy equipment is essential to optimize project outcomes.

In toll road construction projects, the productivity of heavy equipment is a key determinant of project success. The use of machinery such as excavators, bulldozers, motor graders, and sheep foot rollers plays a crucial role in expediting earthworks and material transportation processes. However, various factors can influence the productivity of heavy equipment, including unstable soil conditions, weather, and operator expertise. For instance, a study by Siddiq (2022) revealed that in a similar project in Yogyakarta, the productivity of heavy equipment in the UII Information Technology Faculty Building construction project reached 232.67 m³/hour for excavation and 281.15 m³/hour for material transfer. The combination of 3 Komatsu PC300-8 excavator units, 3 WA380 wheel loaders, and 14 dump trucks were able to complete the work in 488 hours at a cost of Rp. 589,783,400.00. This combination accelerated the work by 19.69% and saved costs by 11.31% compared to the initial conditions in the field. According on these insights, the Yogyakarta-Bawen Toll Road project presents the need to determine the most suitable combination of heavy equipment for embankment works, while also

assessing the associated costs and estimating the time required for completion to achieve both efficiency and effectiveness in execution.

The importance of this study is increasingly felt considering that large infrastructure projects, such as the Yogyakarta-Bawen Toll Road, typically require significant time and capital investment in addition to the need for land acquisition. Considering these conditions, as stated by Ramadhani (2022), the use of appropriate heavy equipment is essential to optimize the construction process. Selecting the right heavy equipment that is both efficient and cost-effective is key to ensuring optimal performance, minimizing delays, and avoiding additional costs, all of which contribute to the overall success of the project. Similarly, the study by Hasyim et al. (2020) emphasized that the selection of heavy equipment for earthworks must be aligned with the predetermined volume and time requirements, both in terms of type and quantity, to prevent losses during construction. However, most existing studies have been limited to building-scale projects or general recommendations without providing detailed productivity analysis for large-scale toll road construction. This creates a research gap, particularly in understanding the required combination of heavy equipment, the associated costs, and the estimated completion time in the context of the Yogyakarta-Bawen Toll Road project.

According to Raken et al. (2024), proper data collection is crucial to ensure a study's validity and reliability. In this research, productivity measurements will be conducted through direct field observations and analysis of data provided by the project contractor. The productivity of heavy equipment will be assessed by observing daily activities, such as the volume of material transported and the effective working hours on-site. In addition, interviews with equipment operators and project managers will be carried out to explore factors that influence performance, including soil conditions, weather, and equipment capacity. This approach is intended to provide not only accurate productivity measurements but also a deeper understanding of the practical challenges encountered during embankment work.

This Final Project examines heavy equipment productivity in the Yogyakarta-Bawen Toll Road Project, particularly in embankment operations involving excavators, dump trucks, dozers, sheep footers, and vibrator rollers. Compared to previous studies, this research takes into account variations in the types and number of equipment units, which may result in different productivity levels. The distinct location of the project, with its specific soil characteristics, also provides new insights into how local conditions affect equipment performance. Furthermore, the results will be presented with comparative graphs that illustrate the differences between several equipment alternatives and the existing field condition. The objective of this study is to determine the most suitable combination of heavy equipment for embankment work in terms of duration and costs.

1.2 Problem Statement of The Research

The following are the research problems addressed in this Final Project:

1. What is the productivity of each type of heavy equipment used in the embankment work of the Yogyakarta-Bawen Toll Road?
2. What is the most suitable combination of heavy equipment in terms of project duration?
3. What is the most suitable combination of heavy equipment in terms of project cost?

1.3 Objective of The Research

The objective of this Final Project are as follows:

1. To determine the productivity level of each type of heavy equipment used in the embankment work of the Yogyakarta-Bawen Toll Road.
2. To identify the most suitable combination of heavy equipment in terms of project duration.
3. To identify the most suitable combination of heavy equipment in terms of project cost.

1.4 Significant of The Research

This study is important because it provides insights into the productivity of heavy equipment and identifies the most suitable combination of equipment for embankment work on the Yogyakarta–Bawen Toll Road. The results are expected to help project managers and contractors optimize equipment usage to reduce project duration and cost, improve resource efficiency, and support better planning in large-scale construction projects. Additionally, the study contributes to the academic literature on construction equipment productivity and project management.

1.5 Scope and Limitation of The Research

In conducting this Final Project, the author recognizes the limitation of abilities and the constraints of time. Therefore, specific boundaries have been established to achieve the primary objectives of this final project. The limitation of this research are as follows:

1. This study is conducted at the Yogyakarta-Bawen Toll Road Project
2. The work observed focuses on embankment work
3. The object in this Final Project is heavy equipment specifically excavators, Dump Truck, Dozers, Sheep Footer, and Vibrator Roller
4. The alternatives considered are the equipment already present at the work site, though in different quantities.
5. The data utilized comprises equipment operating hours, rental costs, and transportation distances for the equipment.
6. The working hours used are based on a standard duration of 7 hours per day.
7. The total cost for each alternative will be calculated.
8. In this study, the author developed only three alternative combinations of heavy equipment.
9. Each alternative combination will be compared to identify the most effective and efficient combination of heavy equipment

CHAPTER II

LITERATURE REVIEW

2.1 Previous Research

Research on the combination of heavy equipment in excavation work has previously been conducted with variations in variables and research methods employed. The following are earlier studies that can serve as references for this research

1. The research conducted by Bajasekto (2020) examined the productivity of heavy equipment in excavation and embankment work, focusing on equipment used at the project site, including excavators, dump trucks, motor graders, wheel loaders, and tandem rollers. The methodology employed involved calculating the work cycle time for each piece of equipment, encompassing loading time, transportation, unloading, and return to the starting position. The findings revealed that the highest productivity was observed in the motor grader, with a rate of 4,564.35 m³/hour, while the dump truck exhibited the lowest productivity, recording 11.24 m³/hour for embankment work and 19.33 m³/hour for excavation work. Based on the analysis, it was concluded that the dump truck requires more time to complete tasks compared to other heavy machinery.
2. The research conducted by Harjani (2023) analyze the combination of heavy equipment for embankment work on the project. This study used excavators and bulldozers with various types. This study aims to determine the most effective and efficient combination of heavy equipment by using direct observation methods in the field, analysis of heavy equipment productivity, and calculation of rental costs. This data will then be used to make comparisons of several alternative combinations of equipment. The results of this study indicate that the second alternative using 4 Komatsu PC200-8 excavators and 2 Komatsu D85-10 bulldozers is the best combination alternative. This alternative requires 493 hours of work and costs Rp1,186,628,800.00, which is more efficient than field conditions which

require 821 hours at a cost of Rp1,208,471,400.00. This recommendation provides an optimal solution to improve the effectiveness and efficiency of the project, and can be a reference for similar work in the future. This study also emphasizes the importance of planning a combination of heavy equipment to optimize the results of construction work.

3. The research conducted by Kurniawan and Nuzola (2021) aimed to assess the productivity of the heavy equipment combinations available at the work site, as well as to identify the factors that could influence the productivity of heavy equipment, particularly for excavation and embankment work. The research analyzed two alternative calculations for heavy equipment combinations, which differed only in the capacity of the excavators and dump trucks used. In the first alternative, a combination of 2 excavators with a capacity of 2.1 m³ and 10 dump trucks with a capacity of 24 m³ was employed, compared to a second alternative that utilized 2 excavators with a capacity of 0.8 m³ and 30 dump trucks with a capacity of 30 m³. The results indicated that the calculations from the first alternative were more economical and could reduce operational time to 95 hours, with a rental cost of Rp 605,200,000. This was attributed to the larger capacity of the heavy equipment in the first combination, which reduced the number of cycles needed to transport material, thereby accelerating operational time. With a shorter working time and an appropriate transport capacity, the rental costs of the equipment were consequently lower.
4. Analysis of Productivity and Operational Costs of Heavy Equipment in the Mandalika Street-Race Circuit Development Project. The research conducted by Hasyim et al. (2020) on the Mandalika Street-Race Circuit Development project, focuses on the productivity and operational costs of heavy equipment used in embankment excavation and road preparation work. The heavy equipment analyzed includes excavators, dump trucks, motor graders, vibratory rollers, and water tankers. Based on productivity and operational cost calculations, it was found that equipment productivity varies depending

on the work type. Excavators have a productivity rate of 17,778 m³/hour for excavation tasks, while for embankment work, productivity reaches 30,521 m³/hour. The operational costs range from IDR 380,806.08 to IDR 718,048.58, contributing to a total revenue of IDR 39.49 billion and a profit of IDR 3.59 billion. The study concludes that proper planning of productivity and operational costs for heavy equipment enables the project to proceed more efficiently and profitably

2.2 Research Gap

This research presents several differences compared to previous studies. In terms of equipment, the types and quantities used are not the same, resulting in different productivity combinations being analyzed. The research location and soil conditions also differ, which directly affect the productivity outcomes. Furthermore, the cost system applied has its own characteristics, as the equipment is owned by the company, while Dump Trucks are specifically calculated based on a per-trip rental system. For the efficiency calculation method, this study remains aligned with one of the existing references, thus providing a strong basis for comparison.

2.3 Comparison of Previous and Current Research

The comparison of previous and current research will be shown in the table on the next page.

Table 2. 1 Comparison of Previous Research and Current Research

No	Aspect	Santoni Bajasekto (2020)	Harjani (2023)	Septyanto at al. (2021)	Hasyim at al. (2020)	Qolbi (2025)
1	Title	Analysis of Productivity Needs for Heavy Equipment in the Road of Inspections Opas - Indah	Analysis of Heavy Equipment Combination on Heap Work of Zone B Landfill Arrangement of TPA Regional Piyungan Project	Analysis of Excavation/Emptying Productivity Using Heavy Equipment in the Construction of the Margatiga Dam in East Lampung	Analysis of Productivity and Operational Costs of Heavy Equipment in the Mandalika Street-Race Circuit Development Project	Analysis of Heavy Equipment Combination in Embankment Work on the Yogyakarta-Bawen Toll Road Project
2	Subject	Excavator, Dum Truck, Motor Grader, Wheel Loader, and Tendem Roller	Excavator and Bulldozer	Excavator, Dump Trucks, Vibratory Rollers, and Bulldozers	Excavator, Dump Truck, Motor Grader, Vibrator Roller, Water Tanker	Excavator, Dump Truck, Dozer, Vibratory Roller and Sheep Footer

Table 2. 2 Continuation of Comparison of Previous and Current research

No	Aspect	Santoni Bajasekto (2020)	Harjani (2023)	Septyanto at al. (2021)	Hasyim at al. (2020)	Current Researchw (2024)
3	Method	The study employed observation and interview methods to gather information	This research utilized Time Study to determine the cycle time and efficiency of each type of heavy equipment	In this research, sampling techniques were employed to select the research subjects, while data analysis techniques were applied to process and interpret both primary and secondary data.	Data were collected through observation and interviews.	Stopwatch Time Study and Work Sampling.
4	Result	Motor grader had the highest productivity (4,564.35 m ³ /hour), while dump truck had the lowest (11.24–19.33 m ³ /hour) and dump trucks require more time compared to other equipment.	Conducting field observations, productivity analysis, and rental cost calculations, and resulting in Alternative 2 as the more efficient.	Analyzing the productivity of Excavators and Dump Trucks. Identifying the most efficient combination in terms of time and cost for excavation and embankment work, which is Alternative 2	heavy equipment productivity varies by type of work, with differing operational costs, and that proper planning can improve the efficiency and profitability of the Mandalika Street-Race Circuit project.	There is a trade-off between project duration and cost, where Alternative 3 is the fastest but most expensive, while Alternative 1 is the cheapest but requires the longest time.

CHAPTER III

THEORITICAL FRAMEWORK

3.1 General Overview

According to Tambunan et al. (2022) project planning that involves heavy equipment must prioritize the consideration of equipment productivity. Heavy equipment in the field of Civil Engineering is needed to make things easier for humans in projects, especially large-scale projects. This ensures that the tasks undertaken are executed according to the planned schedule. Knowledge of theoretical calculations and operational efficiency of heavy equipment facilitates accurate planning, enabling the project timeline to align with the volume of work required.

3.2 Project Construction

According to Husen (2011) a project can be defined as a combination of resources such as people, materials, equipment and capital/costs collected in a temporary organizational framework to achieve goals and objectives. A project aims to achieve specific objectives by establishing constraints, including budget size (cost), schedule, and quality standards that must be met.

Based on these definitions, a project can be summarized as a series of temporary activities designed to achieve specific objectives within the constraints of time, cost, and allocated resources. This study focuses on construction projects (development). The primary characteristics of a project include:

1. Having a specific objective, end product, or final deliverable.
2. Predetermined cost, schedule targets, and quality criteria are established to achieve the stated objectives.
3. Temporary in nature, meaning its duration is limited to the completion of the assigned task, with a clearly defined start and end point. Non-routine,

4. meaning it is not repetitive. The type and intensity of activities evolve throughout the project's progression.

3.3 Heavy Equipment

According to Rostiyanti (2008) heavy equipment is essential for assisting and facilitating human tasks in building construction projects, ensuring that work is accomplished more efficiently and swiftly. The primary purpose of utilizing heavy equipment is to enhance efficiency and productivity by completing demanding tasks more rapidly and accurately. Moreover, heavy equipment helps reduce costs, time, and the risk of worker injuries, especially in challenging terrain. By employing heavy machinery, construction and civil engineering tasks can be carried out more effectively and safely.

Under Law Number 22 of 2009 concerning Road Traffic and Transportation, heavy equipment is categorized as special motorized vehicles designed for specific purposes beyond transporting people or goods. Heavy equipment is widely used in sectors such as construction, mining, and other civil engineering projects, with its main function being to support heavy-duty operations requiring large capacity. Heavy equipment is defined as large-scale machinery used for heavy-duty tasks, such as digging soil, transporting materials, or compacting roads.

3.3.1 Heavy Equipment Classification

In general, Rostiyanti (2008) state the heavy equipment can be categorized into several classifications, one of which is the classification of heavy equipment based on functional classification and operational classification

1. Functional Classification of Heavy Equipment

Functional classification refers to the categorization of equipment based on its primary functions. Heavy equipment can be divided into seven basic functions:

a. Land Preparation Equipment

These machines are used when the project site is still in its natural state and needs to be cleared and prepared. Dozers can be utilized for clearing land,

while scrapers are suitable for removing the topsoil layer. For shaping or leveling the soil, dozers or motor graders can be employed.

b. Excavation Equipment

Commonly referred to as excavators, these machines are primarily used for digging tasks, such as basement construction or drainage systems. Equipment in this category includes front shovels, backhoes, draglines, and clamshells, which are used to excavate soil and rocks.

c. Material Transport Equipment

Material transportation can be categorized as vertical or horizontal. Cranes are used for vertical transport, while trucks and wagons are used for horizontal transport. Horizontal transport equipment is ideal for moving loose materials over relatively long distances, whereas vertical transport equipment transfers materials between different elevations over shorter ranges.

d. Material Transfer Equipment

These machines are not primarily used for transportation but to transfer materials from one piece of equipment to another. Examples include loaders and dozers.

e. Compaction Equipment

In landfilling operations, compaction is often required after filling to achieve a level and dense surface. Compaction is also necessary for road construction, whether it involves flexible or rigid pavement. Examples of compaction equipment include tamping rollers, pneumatic-tired rollers, compactors, and others.

f. Material Processing Equipment

These machines are used to convert natural rocks and minerals into desired shapes and sizes. Examples of outputs include graded aggregates, cement, concrete, and asphalt. Crushers are included in this category, as are equipment such as concrete batch plants and asphalt mixing plants, which mix materials for the production of concrete or asphalt.

g. Final Material Placement Equipment

This category includes machines that place materials at their designated locations. The materials are evenly spread and compacted according to specified requirements. Examples of such equipment include concrete spreaders, asphalt pavers, motor graders, and compactors.

2. Operational Classification of Heavy Equipment

Heavy equipment, in its operation, can either be moved from one location to another or remain stationary. Therefore, classification based on movement can be divided into:

a. Equipment with Drive Mechanism

Drive mechanisms are components of heavy equipment that translate the engine's power into movement. The drive mechanism can be a crawler (caterpillar tracks) or rubber tires. For example, trucks, scrapers, and motor graders typically use rubber tires for mobility. Rubber-tired equipment is preferred for surfaces that are in good condition. In contrast, crawler-based heavy equipment is generally used for soft, wet, or porous ground conditions, as the tracks provide better stability and traction.

b. Stationary Equipment

Stationary equipment refers to heavy machinery that does not move from its location during operation. Examples of this category include tower cranes, batching plants (for concrete or asphalt), and crusher plants. These machines are typically used for tasks that require them to stay in one place for extended periods, such as mixing materials or lifting loads at a fixed location.

3.4 Productivity

3.4.1 Definition of Productivity

According to Rostiyanti (2008) productivity is defined as the comparison between output produced and input used within a certain period and serves as a primary indicator of efficiency in construction work. In civil engineering, high productivity reflects effective use of resources and the ability of a project to be completed on schedule with optimal costs. High productivity indicates the effective

use of resources and the ability of a project to complete work on schedule with optimal costs. The basic formula for calculating equipment productivity is as follows:

$$Productivity = \frac{Capacity}{CT} \quad (3.1)$$

Where output refers to the amount of work completed (e.g., volume of material moved, length of road constructed), and input includes all resources used, such as labor, time, and equipment. Understanding and calculating productivity is essential in civil engineering projects to ensure efficient resource utilization, accurate project scheduling, and cost control.

In toll road projects, productivity is a key determinant of project success due to the large scale and complexity of work, including excavation, compaction, concreting, and road structure construction. Factors affecting productivity include site conditions, material quality, performance and capacity of heavy equipment, operator skills, work methods, as well as schedule and logistical planning. For heavy equipment, productivity is usually measured in work volume per unit of time, such as m³/hour, and is influenced by equipment capacity, cycle time, haul distance, and operational methods. Analyzing heavy equipment productivity is crucial because it determines resource efficiency, operational costs, and project completion time.

3.4.2 Cycle Time

The work cycle in material handling is a repetitive activity that includes digging, loading, transporting, unloading, and returning to the initial task. These activities are carried out by one or multiple machines. The total time required to complete all these activities is referred to as the cycle time. Below is the formula for calculating the cycle time.

$$CT = LT + HT + DT + RT + ST \quad (3.2)$$

Where:

CT = Cycle Time

HT = Hauling Time

DT = Dumping Time

RT = Return Time

ST = Spotting Time

3.4.3 Efficiency Equipment

Equipment efficiency is a factor that influences the productivity of machinery in performing tasks. This efficiency depends on several aspects, such as the operator's skill, equipment selection and maintenance, planning and positioning of the equipment, topography and work volume, weather conditions, and execution methods. According to Rostiyanti (2008), the common method to calculate equipment efficiency is by determining how many minutes the equipment operates effectively within an hour.

Table 3. 1 Efficiency Equipment

Operation Condition	Equipment Maintenance				
	Excellent	Good	Fair	Poor	Very Poor
Excellent	0.83	0.81	0.70	0.70	0.63
Good	0.78	0.75	0.61	0.65	0.60
Fair	0.72	0.69	0.65	0.60	0.54
Poor	0.63	0.61	0.57	0.52	0.45
Very Poor	0.52	0.50	0.47	0.42	0.32

(Source: Permen PUPR, Nomor 01, 2022)

Based on Table 3.1, it can be observed that the operating conditions of heavy equipment and machine maintenance significantly influence construction work productivity. In addition to using the work efficiency factors mentioned above,

estimations can also be based on practical experience with equipment usage within the Public Works Department (DPU). Since it is difficult to assign exact values to each individual factor, they are combined into a single factor representing general working conditions. This combined factor is then applied as the equipment work efficiency factor (E) (Handayani, 2017). The formula for calculating the equipment work efficiency factor is presented in the equation below.

$$\text{Efficiency Equipment Factor} = \frac{\text{Average working duration}}{60} \times 100\% \quad (3.3)$$

3.4.4 Productivity of Excavator

According to (Rostiyanti S. F., 2008) Excavators are classified into several types, including backhoe, power shovel, dragline, and clamshell. The following outlines the productivity of each type of excavator.

1. Backhoe

The determination of the backhoe cycle time is based on the selection of bucket capacity. The formula used to calculate the productivity of a backhoe according to (Rochmanhadi, 1992) is as follows:

$$\text{Prod} = \frac{q \times 3600 \times E}{Cm} \quad (3.4)$$

Where:

Prod = Productivity (m^3/hour)

q = Productivity per cycle (m^3)

Cm = Cycle Time (second)

E = Efficiency

While to calculate the productivity per cycle can be used the following equation.

$$q = q1 \times K \quad (3.5)$$

Where:

q = heaped capacity according to SAE specification

K = Bucket factor

According to (Rochmanhadi, 1992), the productivity of an excavator is influenced by two main factors, namely work conditions and management, as well as bucket filling factors. Work conditions and management are related to the operational effectiveness of the equipment and the organization of field activities. Meanwhile, the bucket filling factor refers to the degree of bucket load compared to its nominal capacity. These factors are presented in detail in the following table.

Table 3. 2 Working Condition and Operational Factor

Working Condition	Operational Condition			
	Very Nice	Nice	Fair	Bad
Very Nice	0.84	0.81	0.75	0.70
Nice	0.78	0.75	0.71	0.65
Fair	0.72	0.69	0.65	0.60
Bad	0.63	0.61	0.57	0.52

Table 3. 3 Correction Factors for Excavating Equipment

Material	Filling Bucket
Soil and Organic Soil	0.9 – 1
Sand and Gravels	0.8 – 0.9
Hard Clay	0.65 – 0.75
Wet Clay	0.50 – 0.60
Rock with poor blasting	0.6 – 0.75
Rock with good blasting	0.4 – 0.50

(Source: (Rochmanhadi, 1992))

Table 3. 4 Factor Bucket

Loading Conditions		Factor
Light	Sand, sandy soil, colloidal soil with moderate moisture content.	1.0 – 0.00
Medium	Dry sand, sandy soil, mixed clay soil, clay, unscreened gravel, compacted sand, etc., or digging and loading gravel directly from natural gravel hills.	0.8 – 0.6
Fairly Difficult	Crushed stone, hard clay, sand mixed with gravel, sandy soil, colloidal clay soil, clay with high moisture content.	0.6 – 0.5
Difficult	Rock fragments, large irregular-shaped rocks, blasted rocks, rounded rocks, sand mixed with rounded stones, sandy soil, clay-mixed soil, clay that is difficult to excavate.	0.5 – 0.4

(Source: (Rochmanhadi, 1992))

2. Power Shovel

For easily excavated materials such as sand and gravel, the optimum digging height ranges between 30% and 50% of the maximum digging height. For soil

in general, the optimum height is slightly less than 40%. The impact of digging height and swing angle is shown in the table below, representing the boom's swing angle during material loading and unloading. The cycle time of a front shovel is influenced by several factors, including the bucket loading capacity, the movement of the loaded bucket, the unloading process, and the movement of the empty bucket. As the swing angle increases, the cycle time will also increase. Ideal productivity is achieved when the swing angle is 90 degrees.

Table 3. 5 Excavator Factors for Digging Height and Swing Angle

The Optimum Depth Percentage	Swing Angle						
	45	60	75	90	120	150	180
40	0.93	0.89	0.85	0.80	0.72	0.65	0.59
60	1.10	1.03	0.96	0.91	0.81	0.73	0.66
80	1.22	1.12	1.04	0.98	0.86	0.77	0.69

Continuous Table 3. 6 Excavator Factors for Digging Height and Swing Angle

The Optimum Depth Percentage	Swing Angle						
	45	60	75	90	120	150	180
100	1.26	1.16	1.07	1.00	0.88	0.79	0.71
120	1.20	1.11	1.03	1.03	0.86	0.77	0.70

Source: (Rostiyanti S. F., 2008)

3. Dragline

The productivity of a dragline depends on factors such as material type, excavation depth, swing angle, bucket size, boom length, haulage equipment capacity, and field conditions. The productivity of the equipment is calculated under bank condition. The following table presents the optimum depths and the

ideal productivity of a dragline with a short boom, as well as the multiplying factors for excavation depth and swing effects.

4. Clamshell

The clamshell cycle time is estimated based on experience. This cycle time includes activities such as filling the bucket, lifting the full bucket, swinging, and dumping. The working process of the clamshell during bucket filling is as follows:

- The bucket is suspended from the crane head via the hoist cable
- The tag cable is then released
- The bucket descends due to its own weight, and the jaws open

3.4.5 Productivity of Dump Truck

According to Rostiyanti (2008), The productivity of an equipment depends on its cycle time. For a dump truck, the cycle time consists of loading time, return travel time, and queue time. Below are the factors that influence these times.

1. Loading Time (LT) is influenced by the size and type of loading equipment, the type and condition of the material, transport capacity, as well as the skill of the loader and transport operator.
2. Travel Time is affected by the transport distance and the condition of the road being traversed
3. Unloading Time is determined by the type and condition of the material, the method of material unloading, and the type of transport equipment
4. Return Time is influenced by the same factors as travel time.
5. Queue Time is affected by the type of loading equipment, the position of the loading equipment, and the transport equipment's turning capability.

Below is the formula for calculating the productivity of a Dump Truck:

$$Prod = Capacity \times \frac{60}{CT} \times efficiency \quad (3.6)$$

Where:

Prod = Productivity ($m^3/hour$)

Capacity = Capacity of Dump Truck (m^3)

CT = Cycle Time (minutes)

Efficiency = Factor efficiency

3.4.6 Productivity of Bulldozer

The productivity calculation for a Dozer is highly influenced by the blade size, tractor capability, and travel distance. The calculation is determined by calculating the volume of soil moved in one cycle and the number of cycles in one hour of operation (Rostiyanti I. S., 2014).

The blade capacity can be determined using data from a table or by calculating the capacity of the blade. The formula used is as follows:

$$V_1 = \frac{WHL}{2} \quad (3.7)$$

Where:

W = Material factors (1.5 to 1.67 H in meters for an angle between 30- 33 degrees)

H = Blade height (m)

L = Balde length (m)

For dozing work, productivity can be calculated using the following formula:

$$Prod = \frac{V_1 \times 60 \times FK}{\frac{J}{F} + \frac{J}{R} + z} \quad (3.8)$$

Where:

V1 = Blade Capacity

FK = Correction Factor

J = distances (meter)

F = Forward speed (meter/minutes)

R = Reverse speed (meter/minutes)

Z = Fixed Time (minute)

The productivity of a dozer is influenced by several factors, including operator efficiency and the blade factor. Operator efficiency refers to the skill, experience, and consistency of the operator in handling the equipment, which plays a crucial role in minimizing cycle time and improving work effectiveness. Meanwhile, the blade factor represents the degree of blade fill compared to its nominal capacity, meaning that the higher the blade factor, the greater the volume of material that can be moved in each cycle. These two factors play a significant role in determining the optimal performance of the dozer in the field.

Table 3. 6 Operator Efficiency Factors

Working condition	Efficiency
Good	0.9 – 1.00
Moderate	0.83
Poor	0.50 – 0.60

(Source: (Tenriajeng, 2003))

Table 3. 7 Blade Factor for Bulldozer

Operation Condition		Blade Factor
Easy to excavate	The blade pushes a full load of soil; suitable for loose soils with low moisture content	1.10 – 0.90
Moderate	The blade does not push a full load; applies to soils mixed with gravel, sand, or loose material	0.90 – 0.70
Rather difficult to excavate	Applies to clay soils with high moisture content, sand mixed with gravel, or hard clay.	0.70 – 0.60
Difficult to excavate	Applies to blasted rock or large rocks firmly embedded in the ground.	0.40 – 0.60

(Source: (Tenriajeng, 2003))

3.4.7 Productivity of Sheepsfoot Roller

To calculate the productivity of a sheep foot roller, several parameters need to be considered, such as the effective width of the equipment, working speed, time efficiency, and the number of passes required to achieve the desired compaction level. The formula to calculate productivity is as follows:

$$P = \frac{10 \times W \times S \times L \times E}{N} \quad (3.9)$$

Where:

P = productivity in m³/hour

W = effective width of the roller in (m)

S = working speed in (km/hour)

H = layer height (cm)

N = Number of passes required to achieve the desired compaction level

3.4.8 Productivity of Vibratory Roller

According to Rostiyanti (2008), To achieve effective productivity with compaction equipment like a Vibratory Roller, the thickness of the layer being compacted should not be excessively large. Specifically for vibratory rollers, it is recommended that the compaction thickness for coarse-grained soil ranges from 20 to 122 cm, while for rocks, the thickness can reach up to 2.1 m. Below is the formula for calculating the productivity of a Vibratory Roller.

$$Prod = \frac{10 \times W \times S \times L \times E}{P} \quad (3.10)$$

Where:

P = number of passes (ccm/hour)

W = compaction width per pass (m)

S = Compaction Speed (km/jam)

L = Final layer thickness (cm)

3.5 Heavy Equipment Combination

According to Wilopo (2009) equipment planning is a systematic process carried out to calculate and estimate the heavy equipment or construction tools required by a company. This process involves determining the type, capacity, and quantity of equipment needed to support project execution in accordance with the Company Work Budget Plan (RKAP) and the Long-Term Company Plan (RJPP). The goal of equipment planning is to ensure that all tasks can be carried out efficiently, on schedule, and within the allocated budget.

In preparing equipment requirements, several critical factors must be considered. First, the type of work, project volume, and execution schedule must be carefully analyzed to ensure that the available equipment matches the scale and timeline of the project. Second, quality requirements of the work must be considered, as project outcomes often depend on the suitability of the equipment used. Third, the construction method applied influences the type and number of equipment required, since each method has distinct equipment needs.

Furthermore, equipment planning must take into account equipment availability on-site as well as the project budget. Equipment availability includes both internal company inventory and the possibility of renting from third parties to prevent shortages or inefficient overstock. Cost calculations related to equipment, including operational and ownership costs, should align with the project budget to optimize resource utilization. With proper equipment planning, projects can proceed smoothly, equipment productivity is maximized, and construction costs are effectively controlled.

According to Rostiyanti (2008) in most construction projects, multiple types of equipment are commonly employed to carry out different tasks efficiently. For example, in excavation and earthmoving work, excavators are used for digging, loaders for transferring the excavated material to dump trucks, and dump trucks for transporting the material to the designated location. Each type of equipment has different productivity rates, making it essential to calculate the appropriate number of units for each to optimize workflow and minimize project duration. Proper

equipment allocation not only ensures that project schedules are met but also enhances resource utilization and cost efficiency, preventing delays caused by insufficient equipment or excessive costs from over-allocation. Productivity-based formulas are often applied to determine the required number of equipment units, considering factors such as output rates, total work volume, and project duration. By systematically planning the combination and quantity of equipment, project managers can achieve efficient operations, maintain project timelines, and control costs effectively.

$$\text{Amount of Equipment 1} = \frac{\text{Biggest Productivity}}{\text{Productivity Equipment 1}} \quad (3.11)$$

3.6 Working Duration

A work is generally performed using more than one type of equipment. According to Rostiyanti (2008) the number of equipment required should be calculated to shorten the duration of the work. Below is the method for calculating the number of equipment needed:

- a. Determine the equipment with the highest productivity
- b. Assume that the equipment with the highest productivity is one
- c. Calculate the number of other types of equipment, always referring to the equipment with the highest productivity as a reference

After calculating the number of each type of equipment using the formula above, the next step is to calculate the work duration by determining the total productivity of the equipment after multiplying by the number of units. Then, by comparing the total productivity of each type of equipment, the smallest total productivity is identified. To calculate the work duration, the following formula can be used:

$$\text{Duration} = \frac{\text{Volume per item work}}{\text{Smallest Productivity}} \quad (3.12)$$

3.7 Heavy Equipment Cost

According to Purworini (2016) The calculation of the cost of equipment requirements is the result of multiplying the volume of each job by the number of tools used and the unit price of the job. The calculation of the operational costs of this tool includes:

a. Equipment Rental Cost

In completing work on a construction project, specific heavy equipment is needed for certain jobs. The variety of work on a construction project makes contractors need to rent equipment from outside to complete the work. The rental cost of the heavy equipment is calculated per hour and for longer rentals, a minimum rental limit per heavy equipment is usually determined.

b. Fuel Costs and Operator Wages

The amounts of wages for heavy equipment operators depends on the location of the project, the company concerned, and the work contract.

c. Mobilization and Demobilization Costs

Renting heavy equipment somewhere will require transportation costs. For certain tools, it even requires a special vehicle to transport the heavy equipment from the rental place to the project location. These costs will depend on the vehicle transporting the heavy equipment and the distance of the heavy equipment transfer.

d. Total Operating Costs

Total operational costs are the total costs incurred for each type of equipment obtained from the sum of all costs incurred during the implementation of the work and the costs of mobilizing and demobilizing the equipment.

3.8 Embankment Volume

The embankment volume refers to the total amount of soil material required to fill a specific area in accordance with the planned elevations as specified in the design drawings. Calculating the embankment volume is crucial as it is directly related to project planning, cost estimation, as well as the allocation of equipment

and working time in construction projects. The accuracy of the volume calculation significantly affects the smooth execution of the work and the efficiency of resource utilization.

According to Lama, et al., (2022) in calculating the embankment volume, several methods are commonly used, such as the prismoidal method, trapezoidal rule, and the Average End Area Method. In this study, the embankment volume is calculated using the Average End Area Method because this method is relatively simple, accurate, and suitable for the available cross-section data.

The Average End Area Method calculates the volume based on the cross-sectional areas at two consecutive stations and the distance between them. To determine the cross-sectional areas, AutoCAD can be utilized by applying the Hatch and Area commands. The equation used to calculate the volume is as follows.

$$\text{Volume} = \frac{A1+A2}{2} \times d \quad (3.13)$$

Where:

A1 = Area of STA 1 (m^2)

A2 = Area of STA 2 (m^2)

d = distance between STA 1 to STA 2 (m)

In embankment work, the volume of compacted soil in the field differs from the volume of loose soil when extracted from the material source (quarry). Therefore, a conversion factor between compacted and loose soil volumes is required to ensure that the material requirements are accurately met. This conversion factor is known as the swell factor or soil expansion factor. The value of the swell factor depends on the soil type and material conditions. The following table presents the conversion factors for soil/material volumes (Tenriajeng, 2003).

Table 3. 8 Material Conversion Factor

Nature of earth	Initial condition of earth	Condition of earth to be moved		
		Bank	Loosened	Compacted
Sand	(A)	1.00	1.11	0.95
	(B)	0.90	1.00	0.86
	(C)	1.05	1.17	1.00
Sand Clay	(A)	1.00	1.25	0.9
	(B)	0.80	1.00	0.72
	(C)	1.11	1.39	1.00
Clay	(A)	1.00	1.43	0.90
	(B)	0.70	1.00	0.63
	(C)	1.11	1.59	1.00
Gravelly Soil	(A)	1.00	1.18	1.08
	(B)	0.85	1.00	0.91
	(C)	0.93	1.09	1.00
Gravels	(A)	1.00	1.13	1.03
	(B)	0.88	1.00	0.91
	(C)	0.77	1.10	1.00
Solid or Rugged Gravels	(A)	1.00	1.42	1.29
	(B)	0.70	1.00	0.91
	(C)	0.77	1.10	1.00
Broken limestone and other soft rock	(A)	1.00	1.42	1.22
	(B)	0.61	1.00	0.74
	(C)	0.82	1.10	1.00
Broken granite, basalt and other soft rock	(A)	1.00	1.65	1.31
	(B)	0.59	1.00	0.77

Continuous Table 3. 1 Material Conversion Factor

Nature of earthSS	Initial condition of earth	Condition of earth to be moved		
		Bank	Loosened	Compacted
	(C)	0.76	1.00	1.00
Broken Rock	(A)	1.00	1.35	1.40
	(B)	0.57	1.70	0.80
	(C)	0.71	1.00	1.00
Blasted Bulky Rocks	(A)	1.00	1.80	1.30
	(B)	0.56	1.00	0.72
	(C)	0.77	1.38	1.00

Note: (A): Bank Condition (B): Loosened Condition (C): Compacted Condition

Reference: Komatsu Spesification and Application Handbooks (Edition 18)

(Source: (Djoko & Wilopo, 2009)

According to (Rochmanhadi, 1992), the change in soil volume under various conditions can be calculated using the following formula:

1. Swell ins determine from

$$Swell = \frac{B - L}{L} \times 100\% \quad (3.14)$$

2. Shrinkage is determined from:

$$Sh = \frac{C - B}{C} \times 100\% \quad (3.15)$$

Where:

B: Unit weight of soil in nature/original condition

L: Unit weight of soil in loose condition

C: Unit weight of soil in compacted condition

According to (Rostiyanti, 2014), when the material is compacted, the air is expelled from the voids between soil particles. As a result, the soil occupies a smaller volume compared to its natural or loose condition. This phenomenon is referred to as shrinkage. The relationship between the natural soil condition and the compacted soil is determined by the shrinkage factor (SF) and the shrinkage percentage. The formula that relates these two conditions is

$$SF = 1 - S_h \quad (3.16)$$

$$SF = \frac{V_c}{V_b} \quad (3.17)$$

V_c represents the compacted volume. The value of S_h is obtained from:

$$S_h = \left(1 - \frac{W_b}{W_c}\right) \times 100 \quad (3.18)$$

The relationship between the original soil condition and loose soil is determined by the Load Factor (LF) and the Swell Percentage (S_w). The LF can be used to calculate the volume of material to be transported from the quarry.

$$LF = \frac{1}{1 + S_w} \quad (3.19)$$

$$LF = \frac{V_b}{V_l} \quad (3.20)$$

Table 3. 9 S_w and LF for several material type

Material Type	Swell percentage (%)	Load factor
Lempung kering	35	0.74
Lempung basah	35	0.74
Tanah kering	25	0.80
Tanah Basah	25	0.80
Tanah dan kerikil	20	0.83
Kerikil kering	12	0.89
Kerikil basah	14	0.88
Batu kapur	60	0.63
Batu hasil peledakan	60	0.63
Pasir kering	15	0.87
Pasing basah	15	0.87
Batuan sedimen	40	0.71

(Source: (Rostiyanti, 2008))

CHAPTER IV

RESEARCH METHOD

4.1 Overview

This chapter discusses the research methods used in this study. Research methods are the steps taken by the researcher to obtain data for conducting the study. This process is carried out by reviewing literature to gather information and data related to the research topic. The data can be obtained from lecture materials, internet media, printed media, and other sources.

4.2 Research Location

The research location will be at the Jogja-Bawen Toll Road Project Section 1, specifically in the Exit area from station 0+000 to station 0+600. The project map can be seen in the image below.



Figure 4. 1 Project Site Location

(Source: Google Maps)



Figure 4. 2 Site Location

4.3 Research Subjects and Objects

According to Surokim at al., (2016) the research subject refers to the component being studied, whether it is an individual, object, or institution (organization). Essentially, the research subject is where the conclusions of the research will be drawn from. Within the research subject, there are research objects and boundaries that pertain to the items, events, or individuals where the data for the research variables are collected and analyzed. In the context of a study, the research subject plays a crucial role as it is where the data on the variables being observed is gathered. The research subject is selected based on its relevance to the problem or research objectives being examined. In this study, the research subjects are heavy equipment used in earthworks, namely excavators, dump truck, dozers, sheep footers, and vibrator roller

The research object refers to the aspects or phenomena that will be studied. The research object is the core of the issue that forms the main focus of the scientific investigation. From the perspective of its sources, the research object consists of three elements: place, actors, and activities. In this research, the research object is the embankment for the Yogyakarta-Bawen Toll Road Project.

4.4 Research Method

Research methods refer to a structured and organized approach used to address problems and obtain knowledge within the framework of research. These methods consist of systematic steps designed to gather, analyze, and interpret data to achieve the specific objectives of the research. The research method serves as a guiding framework that ensures a comprehensive investigation into the research problem by providing clear procedures for each phase of the study. These steps are essential for producing valid and reliable results, as they facilitate a logical progression from data collection to analysis and interpretation.

In this particular study, the research methodology has been carefully planned and structured to begin with the selection of the research topic and the identification of the research location. Following this, both primary and secondary data will be collected to ensure a well-rounded perspective on the subject matter. Once the data is gathered, it will undergo thorough analysis to draw meaningful insights. Afterward, a detailed discussion of the findings will take place, which will lead to the formulation of conclusions and the determination of the overall results of the study. This step-by-step approach is crucial to the successful execution of the research and the attainment of its objectives.

Before processing the data, it is important to first identify the required research data and then determine the methods for collecting this data. The following is an explanation of the data and data collection methods used in this study.

4.4.1 Research Data

Data refers to information or factual material that can serve as the basis for analysis or conclusions. Data can take the form of facts, numbers, or information collected through various methods to support the research process or decision-making.

1. Primary Data

The productivity of heavy equipment was observed using a combination of Stopwatch Time Study and Work Sampling over a period of five working days.

Stopwatch Time Study was employed to measure the cycle time of each equipment in detail, from the start to the end of a work cycle, while Work Sampling was used to record the operational condition of the equipment, specifically the idle time, to determine work efficiency. In this study, each equipment was observed in three daily sessions: morning, midday, and afternoon. For the Stopwatch Time Study, 3 cycles were recorded in each session, resulting in a total of 9 cycle samples per equipment per day. This approach ensures representative cycle time measurements while reducing observer fatigue.

For Work Sampling, the idle time of each equipment was recorded during 1-hour observation periods per session. With three sessions per day, each equipment had 3 idle time data points per day. These data were then used to calculate the equipment work efficiency based on the proportion of unproductive time relative to total working time.

This observation scheme provides sufficient data distribution for each heavy equipment to analyze productivity and work efficiency accurately, while also adapting to field conditions and the observer's time constraints. The total observations over five days ensure that each equipment has an adequate number of samples for statistical analysis and reliable productivity calculation.

Based on the data collection method described earlier, each type of heavy equipment generates different data according to its characteristics and function in the project:

- Excavator

The collected data include bucket capacity, equipment work efficiency, and detailed cycle time components, namely digging time, loaded swing time, dumping time, and return swing time. These data are used to calculate the excavator's productivity and operational efficiency in earthmoving activities.

- Dump Truck

Data collected consist of dump truck bed capacity, equipment work efficiency, the distance between the quarry and the fill site, and the cycle time from loading,

hauling, dumping, to returning empty. This information is crucial for analyzing the productivity of dump trucks and overall material transport time

- Bulldozer

Observations on the dozer include forward and reverse travel time, gear-shifting time, travel speed in both directions, and equipment effective working time. Additionally, blade dimensions, layer thickness, and spreading width are recorded to calculate the soil-moving capacity per pass. These data are used to analyze the dozer's efficiency in leveling and spreading fill material.

- Sheepsfoot Roller and Vibratory Roller

For compaction equipment, collected data include roller drum dimensions, compaction layer thickness, forward and reverse travel time per pass, compaction speed, number of passes, and effective working time. These data are applied to evaluate the effectiveness and productivity of the rollers in achieving the desired soil compaction.

Below is an example of a form used to conduct observations of heavy equipment cycle time.

Table 4. 1 Excavator Observation Form

Excavator Observation Form	Project	
	Location	
	Observation	
Excavator Specification		
Type Excavator		
Bucket Size		
Equipment Condition		
Fuel		
Operator Fee		

Continuous Table 4. 1 Excavator Observation Form

Session	Hour	Cycle	Digging (second)	Swing (Second)	Loading (Second)	Swing (Second)
Average						
Cycle Time Average						
Verified by Field/Project Staff					Note:	

2. Secondary Data

Secondary data refers to data that has already been collected previously by other parties, rather than the primary researcher. This data can include reports, official documents, publications, statistics, or information from books, journals, and other media sources. Secondary data is used to complement or support primary data, helping to provide context or compare research results. In this study, the secondary data includes:

- a. Site Layout
- b. Work duration

- c. Specifications of heavy equipment
- d. Volume of earthwork

4.4.2 Data Collection Method

Data collection methods are the approaches used by researchers to obtain relevant information that supports the objectives of the study. The following are the data collection methods employed in this research.

1. Interviews

An interview is a question-and-answer process conducted with an individual to gather information or opinions about a specific matter. In the context of research, interviews serve as a valuable data collection method where the researcher interacts with respondents to obtain insights that are relevant to the research topic. This approach is particularly useful when the researcher aims to gain a deeper understanding of a subject by exploring the experiences, perspectives, or knowledge of individuals who are directly involved or knowledgeable about the area of interest.

In this study, structured interviews were employed to gather data about the working hours of each piece of heavy equipment used in the project. A structured interview format was chosen to ensure consistency in the questions asked, making it easier to compare responses across different respondents. By focusing on the working hours of the equipment, the researcher was able to obtain specific, quantifiable data that would contribute to understanding the equipment's operational efficiency. These interviews provided direct insights from key personnel on the project, which were essential for addressing the research questions related to work patterns and productivity.

2. Observations

Observation is a careful and systematic activity of watching to obtain specific information or data. In research, observation refers to the data collection method involving direct observation of the research object. For this study, observation was conducted by the researcher visiting the project site to observe the activities without participating in them. Additionally, the researcher

prepared a form to be used during the observation process. The observation steps involved include:

- a. Observing the cycle time for each piece of equipment at the site
- b. Recording the time using stopwatch and video recordings
- c. After obtaining the cycle time, the averages were calculated, and the total cycle time was determined.

3. Documentations

Documentation involves the collection, recording, or management of information in the form of documents, used as reference materials or evidence. In the context of research, documentation serves as a method of data collection where pre-existing written, visual, or audio materials are utilized to supplement the primary data. This method is essential for capturing a wide range of information that might not be immediately observable or interview-based, such as technical specifications, official reports, or visual records. Documentation helps to enhance the reliability and depth of the research by providing a comprehensive view of the research subject.

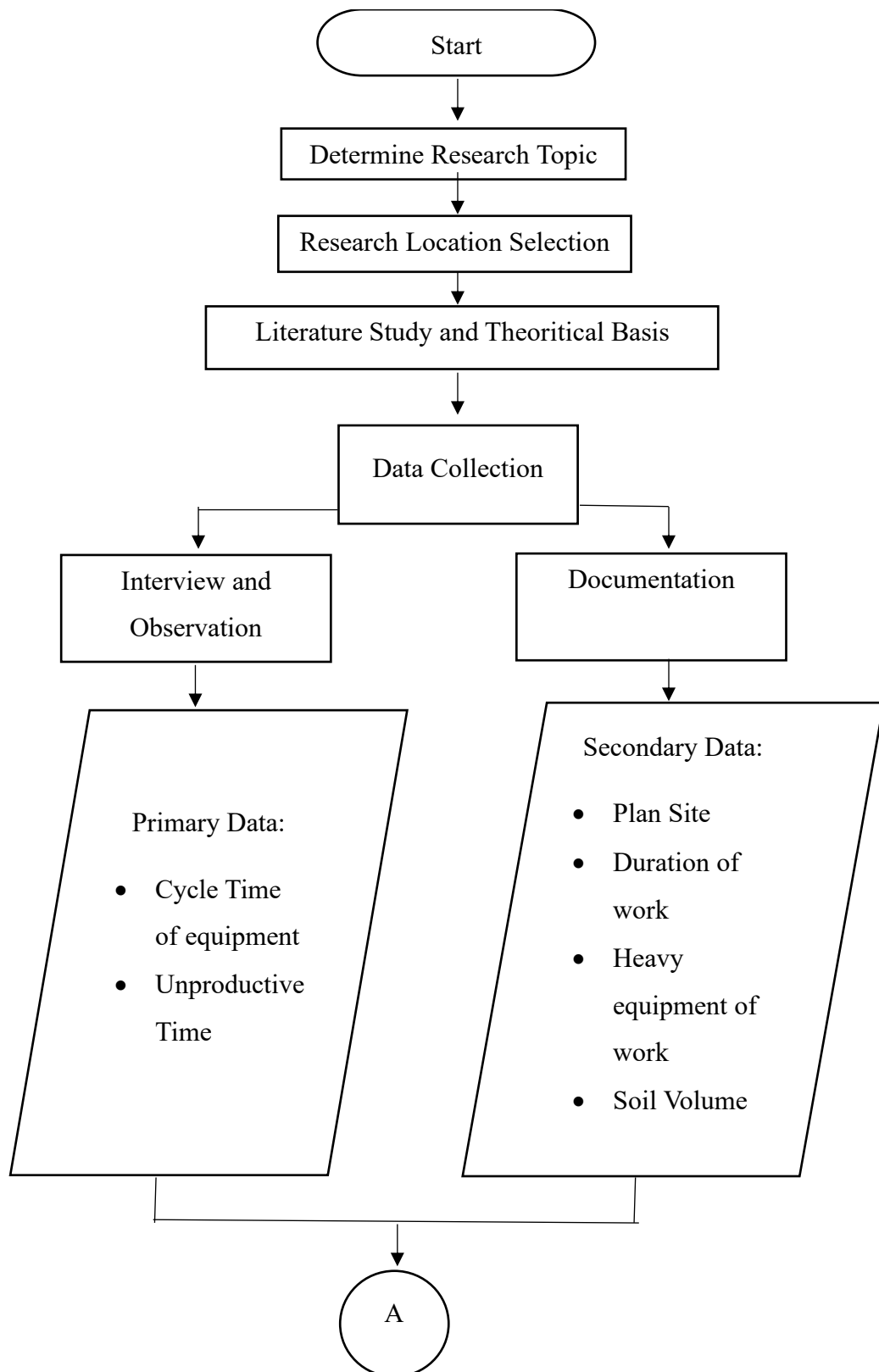
In this research, documentation played an important role in supplementing the data collected through interviews and observations. The researcher used photographs and video recordings taken at the project site to visually document the conditions and activities observed. These visual materials provided additional context for the collected data, helping to corroborate findings and offering a clear, visual representation of the work processes. Furthermore, the researcher collected relevant documents, such as project plans, specifications for the heavy equipment, and reports, which were instrumental in validating the findings and ensuring that the research was based on accurate and comprehensive data.

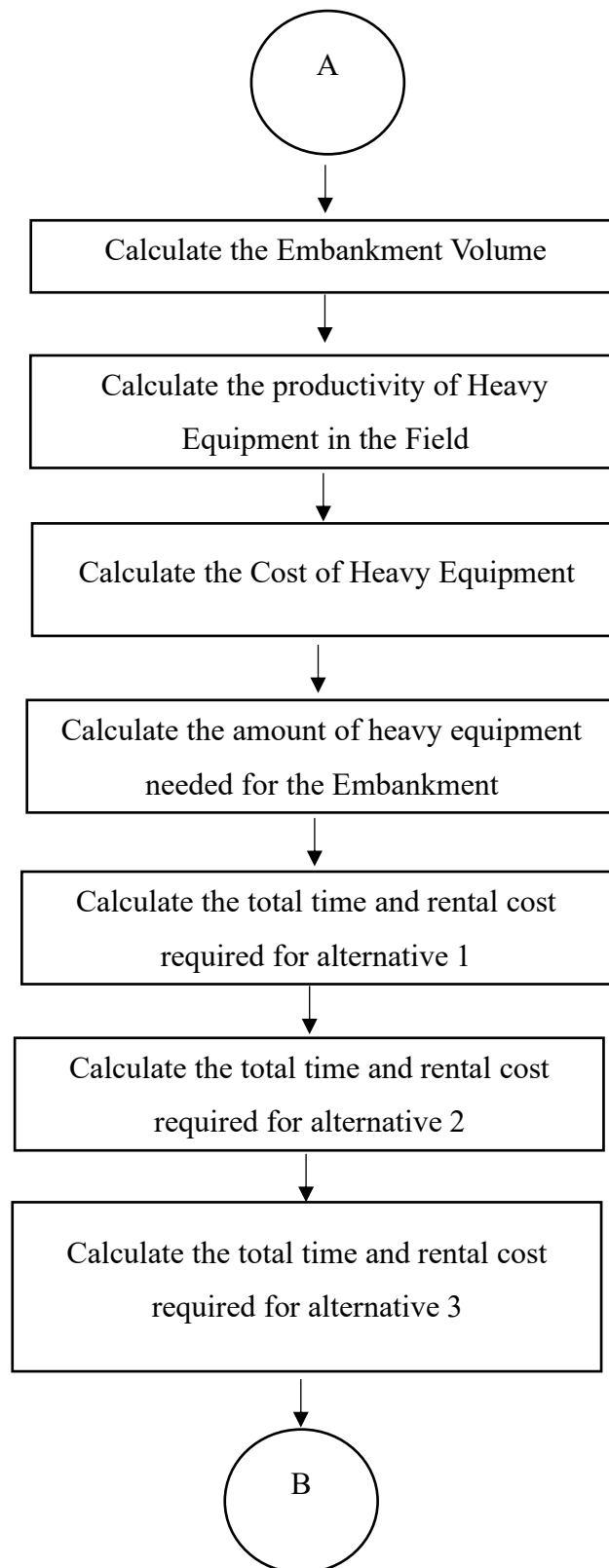
4.5 Data Analysis

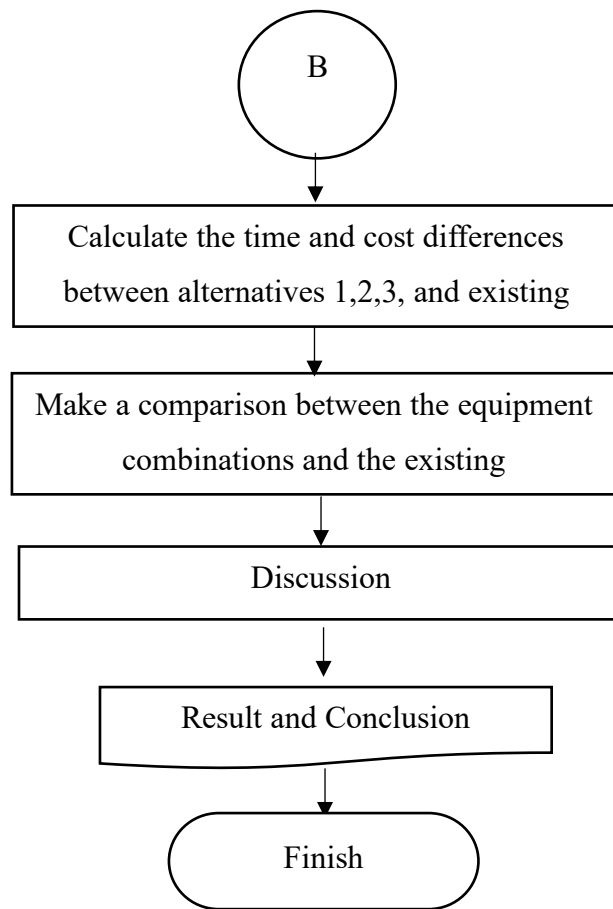
The data obtained from observations and field surveys are analyzed using productivity formulas to determine the work value of the heavy equipment under study. By applying these calculations, the researcher is able to assess the productivity of the equipment and gain insights into its operational efficiency. The

analysis of this data provides a clear understanding of how effectively each piece of equipment is performing in relation to its expected output.

From the results of these calculations, the researcher can then determine the productivity of the heavy equipment and identify the optimal combination of equipment required for the project. This information is crucial for making informed decisions about resource allocation, ensuring that the right number and type of equipment are used to meet project goals efficiently. By understanding the relationship between equipment productivity and project requirements, the researcher can propose strategies for improving overall project efficiency and cost-effectiveness.

Figure 4. 3 Research Flow Chart





CHAPTER V

ANALYSIS AND DISCUSSION

5.1 General Overview

This research was conducted on the Yogyakarta-Bawen Toll Road Project Section. The project data that has been obtained is as follows.

Project Location	: D.I Yogyakarta & Jawa Tengah STA 1+360: Gerbang Tol Bawen STA 76+300: Interkoneksi Tol Solo- Yogyakarta – YIA Kulon Progo
Toll Length	: 75.12 km
Design Speed	: 80 km/hour Main Road 40 km/hour Interchange access road and ramp
Number of Length	: 2x2 Initial Stage lanes 2x3 Final Stage Lanes
Lane Width	: 3.6 m
Construction Period	: 2023 - 2025

5.2 Data Analysis

5.2.1 Volume of Embankment

In this embankment work, the volume calculation was carried out using the with the assistance of Autodesk AutoCAD Civil 3D. This method was selected because it provides a high level of accuracy in determining volumes based on the cross-sectional areas at specific intervals. In general, the process of calculating the volume involves several stages, as outlined below.

1. Determination of Cross-Sections

The initial stage in calculating the embankment volume is the determination of cross-section locations along the project alignment. Based on the design drawings

provided by the planning team, the embankment route is divided into several cross-sections at 25-meter intervals. This systematic segmentation is essential to ensure that the calculated volume accurately represents the actual site conditions. Each cross-section displays two distinct surface profiles:

- Existing ground surface which is the natural topography of the site prior to construction.
- Design Surface which is the planned elevation and shape of the embankment according to the project specifications.

By comparing these two profiles, the fill area can be determined. The area represents the volume of soil that needs to be added in order to achieve the desired embankment elevation. This area calculation serves as the foundation for determining the total embankment volume across the entire project.

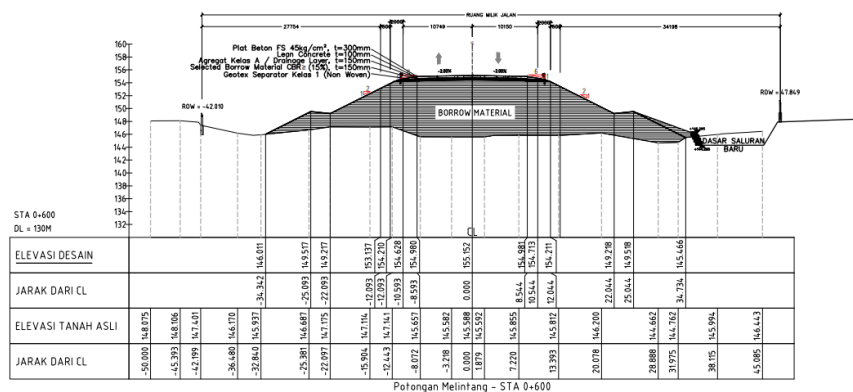


Figure 5. 1 Cross Section of STA 0+600
(Source: PT Adhi Karya (Persero) Tbk, 2023)

2. Calculating the Fill Area for Each Cross-Section

After determining the positions of the cross-sections, the next step is to calculate the fill area for each cross-section using Autodesk AutoCAD Civil 3D. This process ensures that the landfill volume can be estimated accurately based on the geometric differences between the existing ground surface and the design surface. In AutoCAD, the cross-section drawing is opened and the fill area

between the existing ground and the design surface is hatched. By accessing the hatch Properties, the area value is obtained and then recorded for each station (STA).

For example, at cross-section STA 0+025, the calculated fill area is 71.7232 m². The same procedure is repeated for all cross-sections along the project alignment, from the beginning to the end of the landfill route.

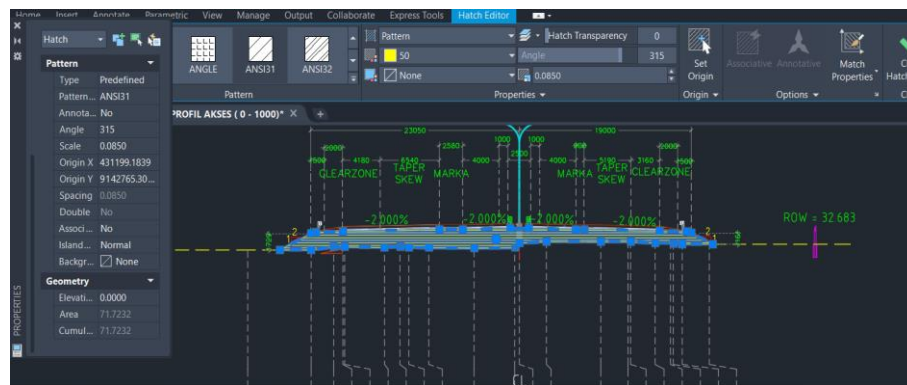


Figure 5. 2 Area at STA 0+025
(Source: PT Adhi Karya (Persero) Tbk, 2023)

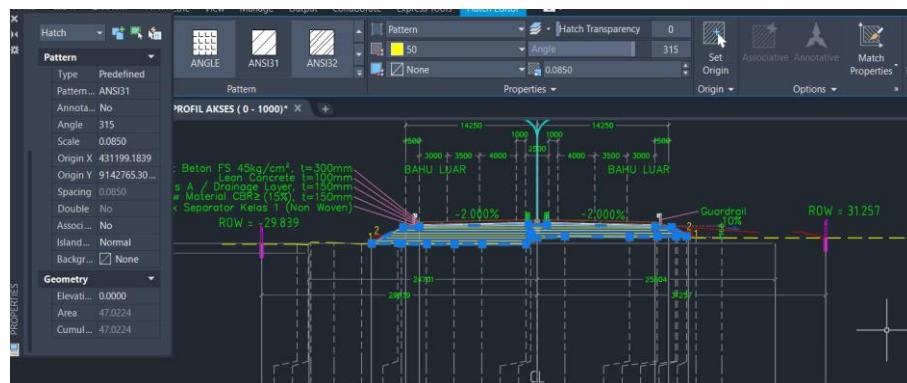


Figure 5. 3 Area at STA 0+050
(Source: PT Adhi Karya (Persero) Tbk, 2023)

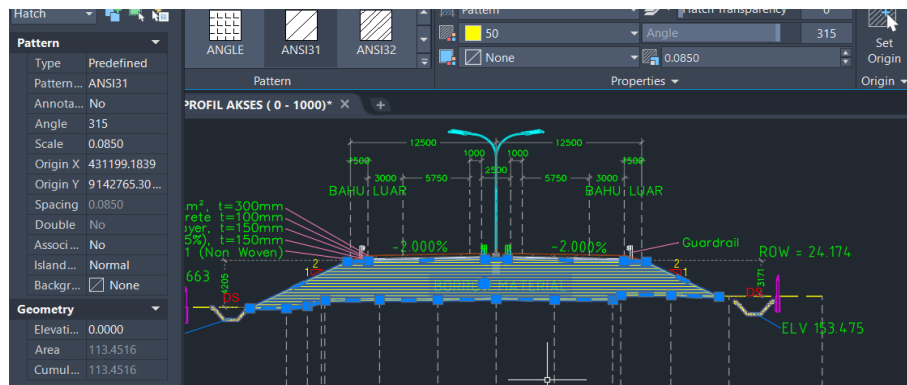


Figure 5.4 Area STA 0+075
(Source: PT Adhi Karya (Persero) Tbk, 2023)

3. Volume Calculation Using the Average End Area Method.

Once the cross-sectional areas at all stations are obtained, the landfill volume for each segment is computed using the average-end area method, where the average of the two cross-sectional areas at the segment's endpoints is multiplied by the distance between the two stations. An example of the STA 0+025 to STA 0 + 050 volume calculation is presented below.

$$\text{Area of STA 0+025} = 71.7232 \, m^2$$

$$\text{Area of STA 0+050} = 47.0244 \, m^2$$

$$\begin{aligned} \text{Average Area} &= \frac{\text{Area STA 0+025} + \text{Area STA 0+50}}{2} \\ &= \frac{71.7232 + 47.0244}{2} \\ &= 59.3728 \, m^2 \end{aligned}$$

$$\begin{aligned} \text{Volume} &= \text{Average area} \times d \text{ (Equation 3.2)} \\ &= 59.3728 \, m^2 \times 25 \, m \\ &= 1484.32 \, m^3 \end{aligned}$$

The table below presents a summary of the calculated results for landfill volumes from STA 0+025 to STA 0+600

Table 5. 1 Recapitulation of Embankment Volume

Location	Distance (m)	Area (m^2)	Volume (m^3)
0+00		71.7232	
	25		1793.08
0+025		71.7232	
	25		1484.32
0+050		47.0224	
	25		2005.925
0+075		113.4516	
	25		2452.156
0+100		82.7209	
	25		1726.871
0+125		55.4288	
	25		2488.71
0+150		143.6680	
	25		4121.639
0+175		186.0631	
	25		5423.438
0+200		247.8119	
	25		5337.694
0+225		179.2036	
	25		4842.039
0+250		208.1595	
	25		5278.574
0+275		214.1264	

Continuation Table 5.1 Recapitulation of Embankment Volume

Location	Distance (m)	Area (m^2)	Volume (m^3)
	25		5665.771
0+300		239.1353	
	25		4867.929
0+325		150.299	
	25		4152.67
0+350		181.9146	
	25		2273.933
0+375		0	
	25		0
0+400		0	
	25		0
0+425		0	
	25		3576.026
0+450		286.0821	
	25		7894.078
0+475		345.4441	
	25		8616.591
0+500		343.8832	
	25		8547.254
0+525		339.8971	
	25		8635.233
0+550		350.9215	
	25		8879.53
0+575		359.4409	
	25		8986.023
0+600		359.4409	
Total			1094048.7463

The table above shows that the total soil volume in a compacted condition for the landfill work is **109048.7463 m³**. Based on the results of the properties testing, the soil type used is classified as **GM – Silty Gravel with Sand**. The results of this test will be presented in the appendix. The conversion process from compacted soil to Bank soil for GM material can be determined using a conversion factor.

Table 5. 2 Factor Conversion of Material

Material Type	Initial Condition	Subsequent Condition Change		
		In-situ condition (A)	Loose Condition (B)	Compacted Condition (C)
Sand	A	1,00	1,11	0,99
	B	0,90	1,00	0,80
	C	1,05	1,17	1,00
Sand Clay	A	1,00	1,25	0,90
	B	0,80	1,00	0,80
	C	1,11	1,39	1,00
Clay	A	1,00	1,25	0,90
	B	0,70	1,00	0,63
	C	1,11	1,59	1,00
Gravelly Soil	A	1,00	1,18	1,08
	B	0,85	1,00	0,91
	C	0,93	1,09	1,00

(Source: (Tenriajeng, 2003))

The conversion factor for Silty Gravel with Sand soil from a compacted condition to bank condition is 0.93. Therefore, the embankment volume in a loose condition is calculated as follows.

$$\begin{aligned}
 \text{Bank Volume} &= \text{Compacted Volume} \times \text{Bank Factor} \\
 &= 109048.7463 \times 0.93 \\
 &= 101415.3 \text{ m}^3
 \end{aligned}$$

The conversion of soil volume from its natural (in-situ) state or Bank condition to the loose condition can be determined by applying the Load Factor. In general, the volume of soil material increases once it is excavated. This increase

occurs as the bonds between soil particles are broken, allowing air to fill the voids. Such a change in volume is referred to as swelling. The relationship between the in-situ condition and the loose condition of the soil is defined by the Load Factor (LF) and the swell percentage. The equation applied to this conversion is as follows.

$$\text{Load Factor} = \frac{\text{Bank Volume}}{\text{Loose Volume}}$$

Hence, the equation to convert the bank volume to loose volume is as follows.

$$\text{Loose Volume} = \frac{\text{Bank Volume}}{\text{Load Factor}}$$

The corresponding Load Factor values are presented in the following table.

Table 5. 3 Swell Factor and Load Factor

Soil Type	Swell Factor	Load factor
Dry Clay	35	0.74
Wet Clay	35	0.74
Dry Soil	25	0.8
Wet Soil	25	0.8
Soil and Gravel	20	0.83
Dry Gravel	12	0.89
Wet Gravel	14	0.88
Limestone	60	0.63
Blasted Rock	60	0.63
Dry Sand	15	0.87
Wet Sand	15	0.87
Sedimentary Rock	40	0.71

(Source: Rochmadi, 1996)

$$\begin{aligned} \text{Loose Volume} &= \frac{\text{Bank Volume}}{\text{Load Factor}} \\ &= \frac{101415.3}{0.83} \end{aligned}$$

$$\text{Loose Volume} = 122187.1 \text{ m}^3$$

Based on the field data and subsequent calculations using the Load Factor, the landfill volume in the Exit area is determined to be 101415.3 m³ for the in-situ material and 122187.1 m³ for the loose material. This result confirms the volumetric adjustment derived from the application of the Load Factor to account for soil condition changes.

5.2.2 Construction Stages

The landfill work on this project follows the construction work method prepared by the contractor and approved by the supervising consultant. This method was selected to ensure that the landfill process complies with the technical specifications and site conditions of the project.

The fill material is sourced from a designated quarry and partly reused from on-site excavation, provided that it meets the required quality standards stated in the technical specifications. Upon delivery, the material is spread using a bulldozer to level the surface and control the thickness of each layer at approximately ± 20 cm.

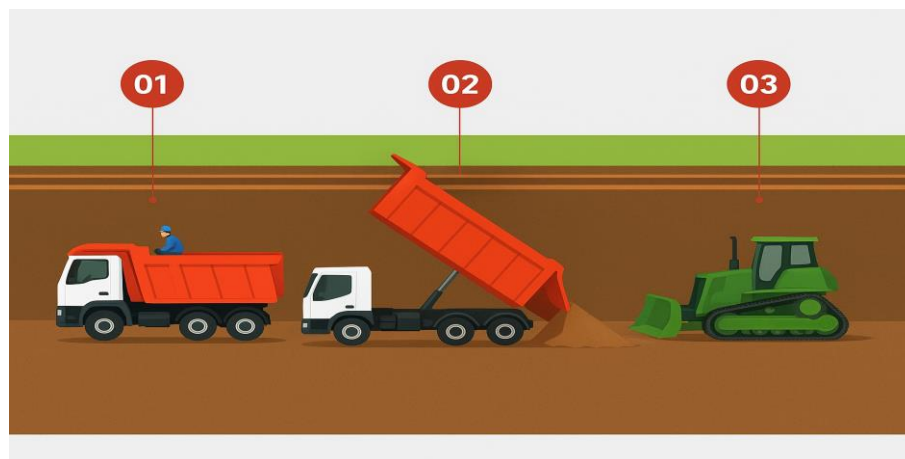


Figure 5. 5 Stockpiling Process
(Source: PT Adhi Karya (Persero) Tbk, 2023)

Compaction is performed for every layer using a combination of vibratory rollers and sheepfoot rollers. The vibratory roller generates vibrations to achieve

deep and uniform compaction, while the sheepfoot roller is more effective for compacting cohesive soils. Prior to full-scale compaction, a trial compaction is conducted to determine the most suitable combination of equipment based on site-specific soil conditions.

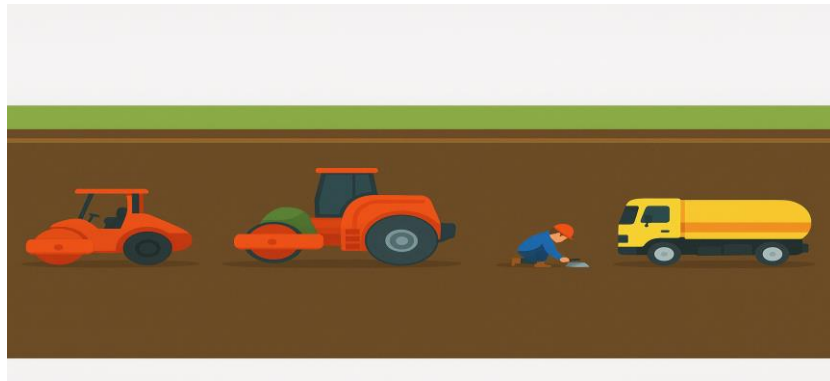


Figure 5. 6 Stockpiling Process
(Source: PT Adhi Karya (Persero) Tbk, 2023)

According to the approved work method, for the layer located approximately 30 cm below the subgrade elevation, a compaction level of 100% of the maximum dry density is required. This specification ensures the stability of the embankment, prevents excessive settlement, and provides adequate bearing capacity for the structures above.

These construction stages serve as a reference for the embankment volume calculations and productivity analysis of heavy equipment, as the specified layer thickness and compaction requirements directly affect the total material volume and project duration.

5.2.3 Types of Heavy Equipment

The existing heavy equipment utilized for the landfill work on this project is presented in the table below.

Table 5. 4 Heavy Equipment Utilized for Landfill Work

Heavy Equipment	Function of Heavy Equipment	Type	Capacity	Size	Quantity
Excavator	To excavate and load soil into the dump truck	Zoom lion ZE215E	1 m ³		2
Dump Truck	To transport embankment materials.	Isuzu HD	9.6 m ³	3.8 x 1.85 x 1.38	
		Mitsubishi Fuso	10 m ³	3.9 x 1.9 x 1.45	
		Toyota Dyna	9.8 m ³	3.85 x 1.85 x 1.38	
		Hino Dutro	9,8 m ³	3.85 x 1.85 x 1.38	10
Bulldozer	To spread and level the material.	ZDX160-3		3.3 x 0.22 x 1.1	1
Vibrator Roller	To compact the soil	QCMG XS113E		2.14 x 1.5	1
Sheep Footer		XCMG XS3EPD		2.3 x 1.5	1

(Source: PT. MAP, 2025)

The equipment employed in this earthwork project consists of five types, which are Excavator, Bulldozer, Vibratory Roller, Sheep Foot Roller, and Dump Truck. The capacity of the Bulldozer is calculated separately in the productivity analysis based on the blade dimensions provided in the previous table. All equipment, except for the Dump Trucks, is owned by the contractor, therefore, no rental costs are required, and the number of units corresponds to those listed in the

table. Meanwhile, the Mitsubishi, Toyota, and Isuzu Dump Trucks are owned by local operators, and their daily operating numbers are not fixed.

5.2.4 Equipment Efficiency Factor (E)

Each type of construction equipment possesses a distinct efficiency level. The theoretical value of equipment efficiency often differs from actual field conditions due to the influence of multiple external factors. The efficiency factor of a piece of equipment is derived from data collected on its operational time throughout the duration of the project.

The equipment efficiency factor refers to the number of minutes the equipment operates effectively within a one-hour period. It is calculated as the ratio between the effective working minutes and the total available working hours. Effective working time refers to the actual duration in which the equipment is actively used for construction activities. Therefore, it is essential to observe and record instances when the equipment is idle within each hour. Common causes for these pauses, based on field observations, include waiting for materials, awaiting instructions from the field supervisor, operator break times, and queuing for operation. The following are some documented instances of heavy machinery being temporarily non-operational.



Figure 5. 7 Excavator Waiting for Dump Truck



Figure 5. 8 Dump Truck Stops After Unloading



Figure 5. 9 Bulldozer waiting for material



Figure 5. 10 Sheepfoot waiting for Material



Figure 5. 11 Vibratory Roller on Break

The efficiency factor was obtained from data on the operating time of heavy equipment during the project. In this study, the measurements were conducted directly in the field by observing and recording the non-productive time of the equipment. The method used for this measurement was stopwatch timing and work sampling, which involved recording the time when the equipment stopped operating and the time when it resumed activity. Observations were made on the duration of equipment downtime (in minutes) within a one-hour period or 60 minutes. The detailed measurement records can be found in the appendix.

The observed efficiency factors of the equipment on the first day are summarized in the table below. These values were derived from field observations, as documented in the Appendix. The following table presents an example of the recap of the average downtime for each piece of equipment during the first day of observation.

Table 5. 5 Observation of Heavy Equipment Non-Productive Time Day 1

Equipment	Equipment Type	Session	Idle Time	Average
Excavator	Zoomlion ZE215E	Morning	5	7.33
		After noon	12	
		evening	5	
Dump Truck	Toyota	Morning	20	23.33
		After noon	23	
		evening	27	

Continuous Table 5. 5 Observation of Heavy Equipment Non-Productive Time Day 1

Equipment	Equipment Type	Session	Idle Time (minute)	Average (minute)
	Mitsubishi	Morning	15	25
		After noon	30	
		evening	30	
	Hino Dutro	Morning	30	32.33
		After noon	32	
		evening	35	
	Isuzu	Morning	10	14.27
		After noon	28	
		evening	24	
Bulldozer	Zoomlion ZDX160-3	Morning	23	20.667
		After noon	15	
		evening	16	
Sheepsfoot	XCMG XS3EPD	Morning	20	16.33
		After noon	23	
		Evening	6	
Vibratory Roller	QCMG XS113E	Morning	15	13.33
		After noon	10	
		Evening	15	

For example, the Idle time calculation for the Zoomlion ZE215E Excavator is as follows:

Idle time in one hour

Average idle time during the morning session = 5 minutes

Average idle time during the afternoon session =12 minutes

Average idle time during the evening session = 5 minutes

Idle time average $= \frac{5+12+5}{3}$

= 7.333 minutes.

Base on the data above, the average downtime (minutes) and average effective working time (minutes) were obtained. From these results, the average efficiency factor of the heavy equipment can be calculated by comparing the average downtime to the total time within one hour.

$$\begin{aligned}
 \text{Total average Idle time} &= \frac{7.333+7.67+7+6.33+6.33}{5} \\
 &= 6.93 \text{ minute} \\
 \text{Average effective working time} &= 60 - 6.93 \\
 &= 53.067 \text{ minute}
 \end{aligned}$$

Based on the above calculations, it can be observed that the average effective working time for the excavator is 53.0666 minutes. In this study, similar observations and calculations were conducted for the other types of heavy equipment over a five-day observation period. A summary of the total productive working time of the heavy equipment is presented below

Table 5. 6 Summary of Heavy Equipment Productive Time

Equipment	Observation Time	Average	Effective Time (minute)
Excavator	Day 1	7.33	53.0666
	Day 2	7.67	
	Day 3	7	
	Day 4	6.33	
	Day 5	6.33	
	Average	6.93	
DT Isuzu	Day 1	17.00	45.733
	Day 2	15.00	
	Day 3	15.67	
	Day 4	8.33	
	Day 5	15.33	
	Average	14.27	

Continuous Table 5. 6 Summary of Heavy Equipment Productive Time

Equipment	Observation Time	Average	Effective Time (minute)
DT Toyota	Day 1	12.33	43.583
	Day 2	17.33	
	Day 3	20.33	
	Day 4	10.00	
	Day 5	14.33	
DT Mitsubishi	Average	16.42	45.1333
	Day 1	13.67	
	Day 2	20.67	
	Day 3	21.00	
	Day 4	10.33	
	Day 5	12.33	
	Average	17.33	
DT Hino Dutro	Day 1	14.00	46.666
	Day 2	11.00	
	Day 3	17.00	
	Day 4	11.67	
	Day 5	13.00	
	Average	13.33	
Bulldozer	Day 1	15.67	45.6
	Day 2	11.67	
	Day 3	21.33	
	Day 4	9.67	
	Day 5	13.67	
	Average	14.40	
Sheepsfoot	Day 1	13.33	48.6667

Continuous Table 5. 6 Summary of Heavy Equipment Productive Time

Equipment	Observation Time	Average	Effective Time (minute)
DT Toyota	Day 2	7.33	43.583
	Day 3	11.33	
	Day 4	12.33	
	Day 5	12.33	
	Average	11.33	
Vibratory Roller	Day 1	16.33	48.467
	Day 2	8.00	
	Day 3	14.33	
	Day 4	6.67	
	Day 5	12.33	

Based on the data above, the average idle time (minutes) and the average effective working time (minutes) were obtained. From these results, the average efficiency factor of the heavy equipment can be calculated based on the average idle time within one hour. As an example, the following is the calculation of the efficiency factor for the excavator.

$$\begin{aligned}
 \text{Average idle time} &= \frac{7.333+7.67+7+6.33+6.33}{5} \\
 &= 6.93 \text{ minute} \\
 \text{Average effective time} &= 60 - 6.93 \\
 &= 53.06667 \text{ minute} \\
 \text{Efficiency time} &= \frac{\text{Average effective time}}{60} \times 100\% \\
 &= \frac{53.06667}{60} \times 100\% \\
 &= 0.8844
 \end{aligned}$$

The results of the recapitulation of the calculation of the heavy equipment work efficiency factor can be seen in the table below

Table 5. 7 Recapitulation of Heavy Equipment Work Efficiency Factors

Heavy Equipment Types	Effective Time	Work Efficiency (E)
Excavator	53.0667	0.8844
DT Isuzu	45.733	0.7622
DT Toyota	43.583	0.7264
DT Mitsubishi	45.133	0.7522
DT Hino Dutro	46.667	0.7778
Bulldozer	45.6	0.76
Sheep footer	48.6667	0.8111
Vibrator Roller	48.4667	0.807
Average	47.115	0.7852

Based on the recapitulation in the table above, the average productive time of each equipment is 47.115 minutes, with an average efficiency factor (E) is 0.7852.

5.2.5 Estimation of Heavy Equipment Usage Costs

The cost estimation for heavy equipment utilization in this embankment project was derived from interviews conducted with the equipment operators. The subcontractor responsible for the project execution employs privately owned heavy machinery, thereby limiting the cost components to operator wages and fuel expenses. In contrast, for the dump truck operations, the payment scheme is based on the number of hauling trips, where the agreed-upon cost already encompasses both the operator remuneration and the fuel consumption costs. In addition, the executing company subsequently delivers and sells the soil, compacted by volume, to PT. Adhi Karya. This transaction is carried out based on the agreed unit volume price for compacted soil.

The following table presents the operator wages, fuel requirements, fuel prices, and the operator wages for dump trucks per trip. The data were obtained through direct inquiries with the project executors and the heavy equipment operators

Table 5. 8 List of Heavy Equipment Usage Cost

Heavy Equipment	Operator Fee per day	Fuel per liter	Fuel per hour
Excavator	Rp. 250.000,00	Rp. 6.800	20 liters
Bulldozer	Rp. 275.000,00	Rp. 6.800	18 liters
Sheepsfoot Roller	Rp. 225.000,00	Rp. 6.800	12 liters
Vibratory Roller	Rp. 225.000,00	Rp. 6.800	12 liters
Dump Truck	Rp. 90.000,00 per trip		-

(Source: PT. MAP, 2025)

Based on the data summarized in the table, a detailed cost calculation was subsequently carried out to determine the total expenses associated with heavy equipment operations. The calculation takes into account operator wages, fuel consumption, fuel prices, as well as the dump truck operator cost per trip.

1. Excavator

Fuel expenditure	=	Rp. 6,800.00 (Table 5.8)
	=	Rp. 6,800.00 x 20 liters x 7 hours
	=	Rp. 952,00.00 per day
Operator remuneration	=	Rp. 250,000.00 per day
Overall cost	=	Rp. 1,202,000.00 per day

2. Dump Truck

Dump truck merk	=	Toyota
	=	Mitsubishi
	=	Hino Dutro
	=	Isuzu

Unit Cost per trip = Rp. 90,000.00 (Table 5.8)

3. Bulldozer

Fuel expenditure = Rp. 6,800.00 (table 5.8)
 = Rp. 6,800.00 x 18 liters x 7 hours
 = Rp. 856,800.00 per day
 Operator remuneration = Rp. 275,000.00 per day
 Overall cost = Rp. 1,131,800.00 per day

4. Sheepsfoot Roller

Fuel expenditure = Rp. 6,800.00 (Table 5.8)
 = Rp. 6,800.00 x 12 liters x 7 hours
 = Rp. 571,200.00 per day
 Operator remuneration = Rp. 225,000.00 per day
 Overall cost = Rp. 796,200.00 per day

5. Vibratory Roller

Fuel expenditure = Rp. 6,800.00 (Table 5.8)
 = Rp. 6,800.00 x 12 liters x 7 hours
 = Rp. 571,200.00 per day
 Operator remuneration = Rp. 225,000.00 per day
 Overall cost = Rp. 796,200.00 per day

5.3 Calculation of Heavy Equipment Productivity

In the embankment work at the Exit area STA 0+000 – STA 0+600, heavy equipment is utilized to enhance the efficiency and effectiveness of the construction process. The calculation of heavy equipment productivity is carried out to determine the working capacity of each unit and to identify the optimal equipment combination.

The results of the heavy equipment productivity calculation for this project are presented as follows

5.3.1 Excavator

In this study, the observed excavator is a Zoomlion ZE215E model. Its function is to excavate material and load it into the Dump Truck. The observation results can be found in the Appendix. The observations were conducted by recording the digging time, swing-to-load time, dumping time, and swing-to-empty time for three cycles each during the morning, afternoon, and evening sessions. These times were then averaged to obtain the average digging time, average dumping time, average swing-to-load time, and average swing-to-empty time. An example of the recorded cycle time on the first day is presented below. In addition, the data were collected under actual field conditions to ensure accuracy and reliability. The results of these measurements form the basis for calculating the productivity of the excavator. Furthermore, the consistency of the recorded data across different time periods helps to minimize bias in the productivity analysis.

Table 5. 9 Excavator Cycle Time Day 1

Session	Cycle	Digging time (s)	Swing Time (s)	Dumping Time (s)	Swing Back Time (s)
Morning	1	8.93	4.35	3.02	4.77
	2	5.3	4.6	4.07	5.04
	3	4.36	4.26	3.96	4.67
Afternoon	1	6.02	4.73	3.03	4.66
	2	7	4.91	4.08	4.37
	3	7.56	4.74	4.39	4.91
Evening	1	15.19	4.64	3.59	6.68
	2	4.21	4.55	3.37	4.22
	3	4.49	4.23	3.57	4.78

The table below presents a summary of the average Excavator cycle time recorded over a 5-day observation period.

Table 5. 10 Recapitulation of Excavator Cycle Time

Observation Time	Digging time (s)	Swing Time (s)	Dumping Time (s)	Swing Back Time (s)	Digging time (s)
Day 1	7.007	4.557	3.676	4.9	20.139
Day 2	6.572	4.154	3.819	4.131	18.676
Day 3	8.24	4.66	3.648	4.674	21.222
Day 4	8.331	4.270	5.424	4.807	22.832
Day 5	7.564	4.602	5.876	4.978	23.02

The following is the detailed calculation of Excavator productivity on the first day of observation.

Bucket capacity (V)	=	1 m ³	(Table 5.4)
Cycle Time (CT)			
- Digging Time (t1)	=	7.007	s (Table 5.9)
- Swing to Dumping Time (t2)	=	4.557	s (Table 5.9)
- Dumping Time (t3)	=	3.676	s (Table 5.9)
- Swing back time (t4)	=	4.9	s (Table 5.9)
Total Cycle time (CT)	=	0.336	minute
Correction Factor (Fk)			
- Work efficiency (E)	=	0.884	(Table 5.7)
- Working condition	=	0.84(Very good)	(Table 3.4)
- Bucket fill factor	=	0.9	(Table 3.5)
- Factor Bucket	=	0.8	(Table 3.6)
Total Correction Factor	=	0.64476	

$$\begin{aligned}
 \text{Total Trip (T)} &= \frac{60}{0.336} \\
 &= 178.7586 \quad \text{Trip/hour}
 \end{aligned}$$

$$\begin{aligned}
 \text{Productivity (Q)} &= V \times T \times Fk \text{ (Equation 3.8)} \\
 &= 1 \times 178.7586 \times 0.64476 \\
 &= 115.2564 \, m^3/\text{hour}
 \end{aligned}$$

The summarized results of the excavator productivity calculations are presented in the table below.

Table 5. 11 Recapitulation of Excavator Productivity Calculation

Type of Heavy Equipment	Observation Time	Productivity (m3/hour)
Excavator	Day 1	115.256
	Day 2	124.280
	Day 3	109.373
	Day 4	101.661
	Day 5	100.752
Average Productivity		110.2644

Based on the recap of the calculations, the average productivity of the excavator is $110.2644 \, m^3/\text{hour}$ with a bucket capacity is $1 \, m^3$.

5.3.2 Dump Truck

In this study, the observed Dump Trucks consist of Toyota with a capacity of $9.8 \, m^3$, Mitsubishi with capacity of $10 \, m^3$, Hino Dutro with capacity of $9.6 \, m^3$, and Isuzu with capacity of $9.6 \, m^3$. The primary function of these Dump Trucks is to transport embankment material from the quarry to the embankment site.

1. Toyota

The observations were conducted by recording the Loading time, loaded time, unloading time and unloading travel time for three cycles each during the morning, afternoon, and evening sessions. These times were then averaged to obtain the average Loading time, average loaded time, average unloading time and average unloading travel time. An example of the recorded cycle time on the first day is presented below. The following presents the cycle time of the Toyota Dump Truck on the first day of observation.

Table 5. 12 Cycle Time of Toyota Dump Truck Day One

Session	Cycle	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)
morning	1	2.79	31	0.500	15.2
	3	2.98	29	0.467	16.1
	4	2.96	32	0.500	15.7
After noon	1	3.59	37	0.483	16.5
	2	3.16	35	0.483	15.4
	3	3.33	33	0.433	17
Evening	1	2.82	32	0.500	16.3
	2	4.33	30	0.617	15.6
	3	2.79	33	0.567	17.2
Average		3.194	32.444	0.506	16.111
Cycle Time (minute)		52.256			

The detailed productivity calculations for the Toyota dump truck on the first day of observation are presented below.

Bed length	L	=	3.85	m (Table 5.4)
Bed width	W	=	1.85	M (Table 5.4)
Bed height	H	=	1.38	M (Table 5.4)

Capacity	V	=	9.8	m^3 (table 5.4)
Efficiency	E	=	0.762	(Table 5.5)
Distance	Dt	=	11	Km
Loading time	T1	=	3.194	Minute (Table 5.12)
Loaded travel time	T2	=	32.444	Minute (Tabel 5.12)
Unloading Time	T3	=	0.506	Minute (Table 5.12)
Unloading travel time	T4	=	16.111	Minute (Table 5.12)
Cycle Time	CT	=	52.256	Minute (Tabel 5.12)

$$\begin{aligned}
 \text{Productivity} \quad (Q) &= V \times \frac{60}{CT} \times E \text{ (Equation 3.10)} \\
 &= 9.8 \times \frac{60}{52.256} \times 0.762 \\
 &= 8.6023 \, m^3/\text{hour}
 \end{aligned}$$

Based on the analysis, the productivity of the Toyota dump truck on the first day was $8.6023 \, m^3/\text{hour}$. The observation of cycle time data and productivity analysis conducted on the Toyota dump truck were also carried out for the other three dump truck brands. The following presents the recapitulation of the Toyota dump truck cycle times observed over a five-day period. This initial result serves as a benchmark for evaluating daily productivity fluctuations and overall operational efficiency.

Table 5. 13 Recapitulation of the Average Cycle Time of the Toyota Dump Truck

Time	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)	Loading Time (minute)
Day 1	3.194	32.444	0.506	16.111	3.194

Continuous Table 5. 13 Recapitulation of the Average Cycle Time of the Toyota Dump Truck

Time	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)	Loading Time (minute)
Day 2	3.202	29.978	0.493	16.167	3.202
Day 3	3.152	32.156	0.563	16.211	3.152
Day 4	3.137	32.033	0.465	16.278	3.137
Day 5	3.218	32.467	0.470	16.244	3.218

Based on the cycle time data presented above, the productivity of each cycle was then calculated. The following is the recapitulation of the productivity calculations for the Toyota dump truck

Table 5. 14 Recapitulation of Productivity Toyota Dump Truck

Heavy Equipment	Observation Time	Productivity (m³/hour)
Toyota	Day 1	8.602
	Day 2	9.019
	Day 3	8.630
	Day 4	8.659
	Day 5	8.579
Average		8.698

Based on the recapitulation of the calculations, the average productivity of the Toyota Dump Truck with capacity of 9.8 m^3 is $8.698 \text{ m}^3/\text{hour}$.

2. Mitsubishi

The observations were conducted by recording the Loading time, loaded time, unloading time and unloading travel time for three cycles each during the morning, afternoon, and evening sessions. These times were then averaged to obtain the average Loading time, average loaded time, average unloading time

and average unloading travel time. An example of the recorded cycle time on the first day is presented below. The following presents the cycle time of the Mitsubishi Dump Truck on the first day of observation.

Table 5. 15 Cycle Time of Mitsubishi Dump Truck Day 1

Session	Cycle	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)
Moring	1	5.02	24	0.43	15.2
	2	2.72	33	0.45	16
	3	2.84	36	0.43	17.1
After noon	1	3.3	35	0.50	18.3
	2	3.59	37	0.50	15.6
	3	4.13	35	0.43	16.4
evening	1	2.44	35	0.58	17
	2	2.68	32	0.40	19.2
	3	3.08	34	0.63	18
Average		3.311	33.444	0.485	16.978
Cycle Time (minute)		54.219			

The detailed productivity calculations for the Mitsubishi dump truck on the first day of observation are presented below.

Bed length	L	=	3.9	m (Table 5.4)
Bed width	W	=	1.9	m (Table 5.4)
Bed height	H	=	1.45	m (Table 5.4)
Capacity	V	=	10.7	m^3 (table 5.3)
Efficiency	E	=	0.752	(Table 5.7)
Distance	Dt	=	11	Km
Loading time	T1	=	3.311	Minute (Table 5.15)

Loaded travel time	T2	=	33.444	Minute (Table 5.15)
Unloading Time	T3	=	0.485	Minute (Table 5.15)
Unloading travel time	T4	=	16.978	Minute (Table 5.15)
Cycle Time	CT	=	54.219	Minute (Table 5.15)

$$\begin{aligned}
 \text{Productivity (Q)} &= V \times \frac{60}{CT} \times E \text{ (Equation 3.10)} \\
 &= 10.7 \times \frac{60}{54.219} \times 0.752 \\
 &= 8.944 \text{ m}^3/\text{hour}
 \end{aligned}$$

The observation of cycle time data and the productivity analysis conducted on the Mitsubishi dump truck on the first day were also carried out for the other dump truck brands. The following presents the recapitulation of the Mitsubishi dump truck cycle times observed over a five-day period.

Table 5. 16 Recapitulation of Mitsubishi Cycle Time

Time	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)	Loading Time (minute)
Day 1	3.311	33.444	0.485	16.978	3.311
Day 2	3.296	34.089	0.546	17.489	3.296
Day 3	3.282	33.133	0.448	17.489	3.282
Day 4	3.239	33.889	0.470	18.400	3.239
Day 5	3.559	35.389	0.454	18.533	3.559

Based on the cycle time data presented above, the productivity of each cycle was then calculated. The following is the recapitulation of the productivity calculations for the Mitsubishi dump truck.

Table 5. 17 Recapitulation of Mitsubishi Productivity

Heavy Equipment	Observation Time	Productivity (m ³ /hour)
Mitsubishi	Day 1	8.944
	Day 2	8.750
	Day 3	8.922
	Day 4	8.660
	Day 5	8.370
Average		8.729

Based on the recapitulation of the calculations, the average productivity of the Mitsubishi dump truck with a capacity of 10.7 m^3 is $8.729 \text{ m}^3/\text{hour}$.

3. Hino Dutro

The observations were conducted by recording the Loading time, loaded time, unloading time and unloading travel time for three cycles each during the morning, afternoon, and evening sessions. These times were then averaged to obtain the average Loading time, average loaded time, average unloading time and average unloading travel time. An example of the recorded cycle time on the first day is presented below. The following presents the cycle time of the Hino Dutro Dump Truck on the first day of observation.

Table 5. 18 Cycle Time of the Hino Dutro Day 1

Session	Cycle	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)
Morning	1	2.88	31	0.450	16
	2	2.9	24	0.450	15.5
	3	2.97	31.5	0.500	17
After noon	1	2.99	29	0.467	15.7
	2	3	34	0.500	16.4
	3	3	35	0.500	17.8

Continuous Table 5. 18 Cycle Time of the Hino Dutro Day 1

Session	Cycle	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)
Evening	1	3.02	33	0.683	15.6
	2	3.04	28.7	0.650	16
	3	3.05	30.6	0.583	18.1
Average		2.983	30.756	0.531	16.456
Cycle Time (minute)		50.726			

The detailed productivity calculations for the Mitsubishi dump truck on the first day of observation are presented below.

Bed length	L	=	3.85	m (Table 5.4)
Bed width	W	=	1.85	m (Table 5.4)
Bed height	H	=	1.35	m (Table 5.4)
Capacity	V	=	9.6	m^3 (table 5.4)
Efficiency	E	=	0.778	(Table 5.7)
Distance	Dt	=	11	Km
Loading time	T1	=	2.983	Minute (Table 5.18)
Loaded travel time	T2	=	30.756	Minute (Table 5.18)
Unloading Time	T3	=	0.531	Minute (Table 5.18)
Unloading travel time	T4	=	16.456	Minute (Table 5.18)
Cycle Time	CT	=	50.726	Minute (Table 5.18)

$$\text{Productivity (Q)} = V \times \frac{60}{CT} \times E \text{ (Equation 3.7)}$$

$$= 9.6 \times \frac{60}{50.726} \times 0.777$$

$$\text{Productivity} = 8.846 \text{ m}^3/\text{hour}$$

The observation of cycle time data and the productivity analysis conducted on the Mitsubishi dump truck on the first day were also carried out for the other dump truck brands. The following presents the recapitulation of the Hino Dutro dump truck cycle times observed over a five-day period.

Table 5. 19 Recapitulation of Hino Dutro Cycle Time

Time	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)	Loading Time (minute)
Day 1	2.983	30.756	0.531	16.456	2.983
Day 2	2.981	31.633	0.487	16.533	2.981
Day 3	2.929	32.022	0.546	16.722	2.929
Day 4	2.920	32.333	0.489	16.844	2.920
Day 5	2.998	31.167	0.491	17.111	2.998

Based on the cycle time data presented above, the productivity of each cycle was then calculated. The following is the recapitulation of the productivity calculations for the Hino Dutro dump truck.

Table 5. 20 Recapitulation of Hino Dutro Productivity

Heavy Equipment	Observation Time	Productivity
Hino Dutro	Day 1	8.846
	Day 2	8.950
	Day 3	9.602
	Day 4	9.535
	Day 5	9.686
Average		9.324

Based on the recapitulation of the calculations, the average productivity of the Hino Dutro dump truck with a capacity of 9.6 m^3 adalah sebesar $9.324 \text{ m}^3/\text{hour}$.

4. Isuzu

The observations were conducted by recording the Loading time, loaded time, unloading time and unloading travel time for three cycles each during the morning, afternoon, and evening sessions. These times were then averaged to obtain the average Loading time, average loaded time, average unloading time and average unloading travel time. An example of the recorded cycle time on the first day is presented below. The following presents the cycle time of the Isuzu Dump Truck on the first day of observation

Table 5. 21 Cycle Time of Isuzu Dump Truck Day 1

Session	Cycle	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)
Moring	1	2.76	30	0.450	14.5
	2	3.01	30	0.433	15.2
	3	3.23	33	0.500	15
	1	3.07	36	0.433	15.5
	2	3.19	34	0.517	16.1
	3	3.23	33	0.500	15
	1	3.43	32	0.867	16.2
	2	3.58	32	0.617	14.9
	3	3.25	34	0.333	15.8
Average		3.149	32.667	0.509	15.333
Cycle Time (minute)			51.658		

The detailed productivity calculations for the Isuzu dump truck on the first day of observation are presented below.

Bed length	L	=	3.85	m (Table 5.4)
Bed width	W	=	1.85	m (Table 5.4)
Bed height	H	=	1.35	m (Table 5.4)
Capacity	V	=	9.6	m^3 (table 5.4)
Efficiency	E	=	0.726	(Table 5.7)
Distance	Dt	=	11	Km
Loading time	T1	=	3.149	Minute (Table 5.21)
Loaded travel time	T2	=	32.667	Minute (Table 5.21)
Unloading Time	T3	=	0.509	Minute (Table 5.21)
Unloading travel time	T4	=	15.333	Minute (Table 5.21)
Cycle Time	CT	=	51.333	Minute (Table 5.21)
Productivity	(Q)	=	$V \times \frac{60}{CT} \times E$ (Equation 3.7)	

$$= 9.6 \times \frac{60}{51.333} \times 0.726$$

$$= 8.112 \text{ } m^3/\text{hour}$$

The observation of cycle time data and the productivity analysis conducted on the Mitsubishi dump truck on the first day were also carried out for the other dump truck brands. The following presents the recapitulation of the Isuzu dump truck cycle times observed over a five-day period

Table 5. 22 Recapitulation of Isuzu Cycle Time

Time	Loading Time (minute)	Loaded travel time (minute)	Unloading time (minute)	Unloading travel time (minute)	Loading Time (minute)
Day 1	3.149	32.667	0.509	15.333	3.149
Day 2	3.252	33.144	0.506	15.422	3.252
Day 3	3.166	32.800	0.489	15.844	3.166
Day 4	3.189	33.100	0.502	15.411	3.189
Day 5	3.173	32.711	0.517	15.430	3.173

Based on the cycle time data presented above, the productivity of each cycle was then calculated. The following is the recapitulation of the productivity calculations for the Hino Dutro dump truck.

Table 5. 23 Recapitulation of Isuzu Productivity

Heavy Equipment	Observation Time	Productivity (m ³ /hour)
Isuzu	Day 1	8.112
	Day 2	8.950
	Day 3	8.954
	Day 4	8.971
	Day 5	9.035
Average		8.804

Based on the recapitulation of the calculations, the average productivity of the Isuzu dump truck with a capacity of 9.6 m³ is 8.804 m³/hour.

5.3.3 Bulldozer

In this study, the observed bulldozer is the Zoomlion ZDX160-3 model. The primary function of this bulldozer is to push and level the material unloaded by the dump trucks.

Table 5. 24 Cycle Time of Bulldozer Day 1

Time	Session	Forward Time (s)	Distance (m)	Forward Speed (m/s)	Reverse Time (s)	Distance (m)	Reverse Speed (m/s)	Gear Shifting (s)
Morning	1	35	50	1.429	50	16	3.13	1.20
	2	35	50	1.429	50	18	2.78	1.50
	3	36	50	1.389	50	20	2.50	1.80
	4	34	50	1.471	50	25	2.00	1.90
	5	35	50	1.429	50	16	3.13	1.60
	6	39	50	1.282	50	14	3.57	1.30
	7	36	50	1.389	50	17	2.94	1.70

The following presents the recapitulation of the average cycle time of the bulldozer over the five days of observation.

Table 5. 25 Recapitulation of Bulldozer Cycle Time

Session	Forward Time (s)	Distance (m)	Forward Speed (m/s)	Reverse Time (s)	Distance (m)	Reverse Speed (m/s)	Gear Shifting (s)	Cycle Time (s)
1	39.73	50	1.26	18.57	50	2.69	1.96	60.62
2	40.97	50	1.22	18.20	50	2.75	1.6	60.77
3	44.43	50	1.13	19.00	50	2.63	1.73	60.16
4	39.27	50	1.27	18.90	50	2.65	1.73	59.9
5	42.27	50	1.18	17.07	50	2.93	1.75	61.09

The detailed productivity calculations for the bulldozer on the first day of observation are presented below.

Blade height	H	=	1.1	m (table 5.4)
Blade Length	L	=	4.5	m (table 5.4)
	W	=	1.5	m (table 5.4)
Blade capacity	V1	=	$\frac{WHL}{2}$	(Equation 3.11)
		=	$\frac{(1.5 \times 1.1) \times 1.1 \times 4.5}{2}$	
		=	4.084	
Efficiency	E	=	0.76	
Distance	J	=	50	m
Forward Speed	F	=	75.503	m/minute
Reverse Speed	R	=	161.580	m/minute
Fixed Time	Z	=	0.0327	minute
Cycle Time	CT	=	1.004	minutes
Operator Qualification		=	1	
Material Type		=	0.9	
Efficiency	E	=	0.76	

$$\begin{aligned}
 \text{Correction Factor} \quad CF &= 0.684 \\
 \text{Amount of Trip} \quad T &= 59.74112 \text{ trip/hour} \\
 \text{Productivity} \quad (Q) &= V \times T \times CF \text{ (Equation 3.12)} \\
 &= 4.084 \times 59.74112 \times 0.76 \\
 &= 166.874 \text{ m}^3/\text{hour}
 \end{aligned}$$

The recapitulation of the bulldozer productivity calculations can be seen in the table below.

Table 5. 26 Recapitulation of Bulldozer Productivity

Heavy Equipment	Observation Time	Productivity (m3/hour)
Bulldozer	Day 1	166.874
	Day 2	165.483
	Day 3	154.317
	Day 4	167.886
	Day 5	164.625
Average Productivity		163.837

Based on the recapitulation of the calculations, the average productivity of the bulldozer is $163.837 \text{ m}^3/\text{hour}$ with blade capacity 4.084 m^3 .

5.3.4 Vibrator Roller

In this study, the observed vibratory roller is the Zoomlion QCMG XS113E model. The primary function of this vibratory roller is to compact and finish the soil surface that has previously been compacted by the sheep foot roller.

Table 5. 27 Cycle Time of Vibrator Roller Day 1

Time	Session	Time per single pass (s)	Distance (m)
Morning	1	35	50

Continuous Table 5.28 Cycle Time of Vibrator Roller Day 1

Time	Session	Time per single pass (s)	Distance (m)
Morning	2	34	50
	3	32	50
	4	35	50
	5	35	50
	6	40	50
	7	30	50
	8	38	50
	9	32	50
	10	37	50
After noon	1	32	50
	2	38	50
	3	33	50
	4	33	50
	5	39	50
	6	35	50
	7	30	50
	8	33	50
	9	36	50
Evening	1	39	50
	2	41	50
	3	36	50
	4	46	50
	5	38	50
	6	31	50
	7	33	50
	8	35	50
	9	37	50
	10	30	50
Average		35.233	50

The following presents the recapitulation of the average speed of the vibratory roller over the five days of observation.

Table 5. 28 Recapitulation of Average Speed of Vibratory Roller

Heavy Equipment	Observation Time	Time per single pass (s)	Distance (m)	Average Speed (km/hour)
Vibrator Roller	Day 1	35.233	50	5.109
	Day 2	34.867	50	5.163
	Day 3	44.200	50	4.072
	Day 4	42.967	50	4.189
	Day 5	44.233	50	4.069

Based on interviews with the field supervisor and in accordance with the earthwork method, it was identified that the pavement thickness is 2 m, with each layer having a thickness of 15 cm, compacted through six passes. The rolling speed is calculated by dividing the compaction distance (m) by the time per single pass (s), and subsequently converted into km/hour.

Compaction Width	W	=	2.14	m
Passing	P	=	6	m
Rolling Speed	S	=	5.109	Km/hour
Layer Height	H	=	20	cm
Efficiency	E	=	0.808	(Table 5.5)

$$\begin{aligned}
 \text{Productivity (Q)} &= \frac{10 \times W \times S \times H \times E}{N} \text{ (Equation 3.8)} \\
 &= \frac{10 \times 2.14 \times 5.1088 \times 20 \times 0.808}{6} \\
 &= 294.377 \text{ m}^3/\text{hour}
 \end{aligned}$$

The recapitulation of the vibratory roller productivity calculations can be seen in the table below.

Table 5. 29 Recapitulation of Vibratory Productivity

Heavy Equipment	Observation Time	Productivity (m ³ /hour)
Vibrator Roller	Day 1	294.376537
	Day 2	297.472275
	Day 3	234.657617
	Day 4	241.393328
	Day 5	234.480784
Average Productivity		260.476

Based on the recapitulation of the calculations, the average productivity of the vibratory roller is $260.476 \text{ m}^3/\text{hour}$.

5.3.5 Sheep Footer

In this study, the observed sheepsfoot roller is the Zoomlion XCMG XS3EPD model. The primary function of this equipment is to compact and break down soil clumps that have been previously spread by the bulldozer. The following presents the observation results of time and distance for a single pass of the sheep foot roller on the first day.

Table 5. 30 Cycle Time of Sheepsfoot Roller Day 1

Time	Session	Time per single pass (s)	Distance (m)
Morning	1	1.79	50
	2	1.79	50
	3	1.72	50
	4	1.67	50
	5	1.92	50
	6	1.79	50
	7	1.79	50
	8	1.72	50

Continuous Table 5. 31 Cycle Time of Sheepsfoot Roller Day 1

Time	Session	Time per single pass (s)	Distance (m)
	9	1.79	50
	10	1.92	50
Afternoon	1	1.56	50
	2	1.92	50
	3	2.17	50
	4	1.56	50
	5	2.50	50
	6	2.50	50
	7	2.08	50
	8	2.17	50
	9	1.56	50
	10	1.56	50
Evening	1	2.00	50
	2	1.92	50
	3	2.08	50
	4	1.85	50
	5	2.00	50
	6	1.92	50
	7	1.85	50
	8	2.00	50
	9	1.92	50
	10	2.08	50
Average		1.88	50

The following presents the recapitulation of the average speed of the sheep foot roller over the five days of observation.

Table 5. 31 Recapitulation of Sheepsfoot Roller Average Speed

Heavy Equipment	Observation Time	Time per single pass (s)	Distance (m)	Average Speed (m/s)
Vibrator Roller	Day 1	26.633	50	6.758
	Day 2	27.633	50	6.514
	Day 3	26.067	50	6.905
	Day 4	25.667	50	7.013
	Day 5	24.900	50	7.229

Based on the data obtained from specifications, field observations, and interviews, the productivity calculation of the sheep foot roller can be seen as follows.

Compaction Width	W	=	2.3	m
Passing	P	=	8	m
Rolling Speed	S	=	6.758	Km/hour
Layer Height	H	=	20	cm
Efficiency	E	=	0.811	(Table 5.5)

$$\begin{aligned}
 \text{Productivity (Q)} &= \frac{10 \times W \times S \times H \times E}{N} \text{ (Equation 3.7)} \\
 &= \frac{10 \times 2.3 \times 6.758 \times 20 \times 0.811}{8} \\
 &= 315.2065 \text{ m}^3/\text{hour}
 \end{aligned}$$

The recapitulation of the sheep foot roller productivity calculations can be seen in the table below.

Table 5. 32 Recapitulation of Sheepsfoot Roller Productivity

Heavy Equipment	Observation Time	Productivity (m ³ /hour)
Sheep Footer	Day 1	315.206508
	Day 2	303.799759
	Day 3	322.058824
	Day 4	327.077922
	Day 5	337.148594
Average Productivity		321.058

Based on the recapitulation of the calculations, the average productivity of the vibratory roller is 321.058 $m^3/hour$. The following presents the recapitulation of productivity for each heavy equipment that has been calculated.

After obtaining the productivity values for each type of heavy equipment through cycle time observations and subsequent calculations, the results were compiled to provide a comprehensive overview. This recapitulation presents the productivity of all heavy equipment observed during the study, allowing for a clear comparison across different equipment types. The summary of these productivity calculations is presented in the table below

Table 5. 33 Recapitulation of Each Heavy Equipment

Heavy Equipment	Productivity (m ³ /hour)
Excavator	110.2644
Dump truck Toyota	8.699
Dump truck Mitsubishi	8.729
Dump Truck Hino Dutro	9.324
Dump Truck Isuzu	8.804

Continuous Table 5.36 Recapitulation of Each Heavy Equipment

Heavy Equipment	Productivity (<i>m</i>³/hour)
Bulldozer	163.837
Sheepsfoot Roller	321.058
Vibratory Roller	260.476

5.4 Analysis of Alternative Heavy Equipment Combinations

5.4.1 Existing Condition

In the landfill work at the project site, several combinations of heavy equipment are utilized according to the existing field conditions. These combinations are analyzed based on the calculated productivity of each piece of equipment. Based on the collected data, various alternative combinations can be evaluated to assess the effectiveness and efficiency of equipment utilization. The following presents the calculation of heavy equipment combinations under the existing field conditions.

1. Excavator

Volume	= 122187.149 <i>m</i> ³
Unit	= 2 units (Table 5.4)
Productivity	= 110.264 <i>m</i> ³ /hour (Table 5.11)
Total productivity in an hour	= Productivity x unit = 110.264 <i>m</i> ³ /hour x 2 = 220.5288 <i>m</i> ³ /hour
Working duration (days)	= $\frac{Volume}{total\ P\ per\ hour\ x\ working\ hour}$ = $\frac{122187.149}{220.5288 \times 7}$
Working hours	= 80 days
Equipment cost per day	= Rp. 1,202,00.00
Total equipment cost	= Rp. 192,320,000.00

2. Dump Truck

Duration Analysis

Volume	=	122187.1494 m^3
Effective hour	=	7 hours
Toyota Productivity	=	8.698 m^3 /hour (Table 5.14)
Mitsubishi Productivity	=	8.729 m^3 /hour (Table 5.17)
Isuzu Productivity	=	8.804 m^3 /hour (Table 5.20)
Hino Dutro Productivity	=	9.324 m^3 /hour (Table 5.23)
Average Productivity	=	8.889 m^3 /hour
per hour		
Amount of trip	$\frac{60}{CT \text{ (minute)}}$	= $\frac{60}{52.783}$
		= 1 trip per hour
Total trip per day		= Trip per hour x unit x working hour x unit excavator
		= 1 x 12 x 7 x 2
		= 168 trip/day
Amount of units DT	$\frac{Excavator \text{ Prod}}{DT \text{ Prod}}$	= $\frac{110.2644}{8.889}$
		= 12 units for 1 excavator
		= 24 units for 2 excavators
Working hours (days)	$\frac{Volume}{Productivity \text{ per day}}$	= $\frac{122187}{8.889 \times 24 \times 7}$
		= 80 days
Cost per trip		= Rp. 90,000.00
Total cost		= Rp. 11,800,000.00 x 80 days
		Rp. 1,239,840,00.00

3. Bulldozer

Volume	$= 122187.1494 \text{ m}^3$
Unit	$= 1 \text{ unit (Table 5.4)}$
Productivity	$= 163.836954 \frac{\text{m}^3}{\text{hour}}$ (Table 5.28)
Total productivity per hour	$= \text{Productivity} \times \text{unit}$ $= 163.836954 \text{ m}^3/\text{hour} \times 1$ $= 163.836954 \frac{\text{m}^3}{\text{hour}}$
Working hours (day)	$= \frac{V}{\text{total P per hour} \times \text{working hour}}$ $= \frac{122187.149}{163.836954 \times 7}$
Working hours (day)	$= 107 \text{ days}$
Cost per day	$= \text{Rp. } 1,131,800.00$
Total cost	$= \text{Rp. } 121,102,600.00$

4. Vibratory Roller

Volume	$= 122187.1494 \text{ m}^3$
Unit	$= 1 \text{ unit (Table 5.4)}$
Productivity	$= 260.476 \frac{\text{m}^3}{\text{hour}}$
Total productivity per hour	$= \text{Productivity} \times \text{unit}$ $= 260.476 \text{ m}^3/\text{hour} \times 1$ $= 260.476 \frac{\text{m}^3}{\text{hour}}$
Working hours (day)	$= \frac{\text{Volume}}{\text{total P per hour} \times \text{working hour}}$ $= \frac{122187.1494}{260.476 \times 7}$
Working hours (day)	$= 68 \text{ days}$
Cost per day	$= \text{Rp. } 796,200.00$
Total Cost	$= \text{Rp. } 54,141,600.00$

5. Sheep Footer

Volume	= 122,187.1494 m^3
Unit	= 1 unit
Productivity	= 321.058 $\frac{m^3}{hour}$
Total productivity per hour	= Productivity x unit = 321.058 $m^3/hour$ x 1 = 321.058 $\frac{m^3}{hour}$
Working hours (day)	= $\frac{Volume}{total\ P\ per\ hour\ x\ working\ hour}$ = $\frac{122,187}{321.058 \times 7}$
Working hours (day)	= 55 days
Cost per day	= Rp. 796,200.00
Total cost	= Rp. 43,791,000.00

Based on the calculation of duration and cost under the existing conditions for each piece of equipment, the recapitulation is presented in the following table.

Table 5. 34 Recapitulation of Working Hour and Total Cost Existing

Heavy Equipment	Total Working Hour	Total Cost
Excavator	80 days	Rp. 192,320,000.00
Dump Truck	80 days	Rp. 1,239,840,00.00
Bulldozer	107 days	Rp. 121,102,600.00
Sheep Foot	84 days	Rp. 43,791,000.00
Vibratory Roller	68 days	Rp. 54,141,600.00
Total	107 days	Rp 1,651,195,200.00

Based on the above recapitulation, it can be identified that the Bulldozer serves as the bottleneck under the existing condition. Consequently, the total time required to complete the earthwork with a loose volume of 122,187.1494 m^3 is 107

days. Furthermore, the total cost under the existing condition amounts to Rp1,651,195,200.00, with the largest portion attributed to Dump Trucks, due to a different payment or rental system compared to the other equipment.

5.4.2 Analysis of Alternative Combination 1

The following are several combinations of heavy equipment used in embankment operations under the alternative combination 1 at the project site, which will be analyzed based on the calculated productivity of each equipment. From the collected data, various alternatives can be evaluated by comparing the productivity results of the individual heavy equipment

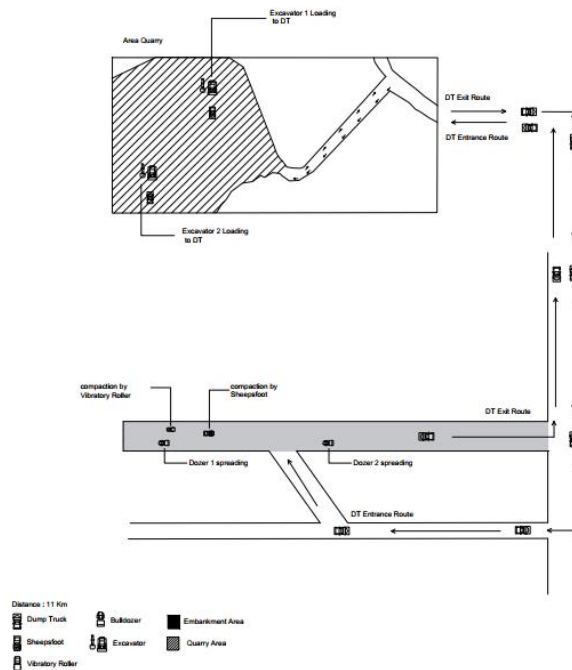


Figure 5. 12 Illustration of Heavy Equipment Movement Alternative 1

At quarry, two excavators are employed, including two excavators with a bucket capacity of 1.2 m³ each. To transport the soil from the extraction site to the fill location, four types of dump trucks are used: Isuzu with a 9.6 m³ bed, Mitsubishi with a 10 m³ bed, Hino Dutro with a 9.8 m³ bed, and Toyota with a 9.8 m³ bed. Two bulldozers are used to level the material delivered by the dump trucks. For compaction, one sheepfoot roller and one vibratory roller are utilized.

The following presents the calculation of equipment combinations under the existing field conditions, which will be analyzed based on equipment productivity and rental costs

a. Excavator

The total cost calculation for the Excavator in Alternative 1 can be seen in the calculation below.

Volume	= 122187.149 m^3
Unit	= 2 units
Productivity	= 110.264 $m^3/hour$
Total productivity in an hour	= Productivity x unit = 110.264 $m^3/hour$ x 2 = 220.528 $m^3/hour$
Working duration (days)	= $\frac{Volume}{total\ P\ per\ hour\ x\ working\ hour}$ = $\frac{122187.149}{220.528 \times 7}$
Working hours	= 80 days
Equipment cost per day	= Rp. 1,202,00.00
Total equipment cost	= Rp. 96,160,000.00

b. Dump Truck

The total cost calculation for the Dump Truck in Alternative 1 can be seen in the calculation below.

Duration Analysis

Volume	= 122187.1494 m^3
Effective hour	= 7 hours
Toyota Productivity	= 8.698 $m^3/hour$ (Table 5.14)
Mitsubishi Productivity	= 8.729 $m^3/hour$ (Table 5.17)
Isuzu Productivity	= 8.804 $m^3/hour$ (Table 5.21)
Hino Dutro Productivity	= 9.324 $m^3/hour$ (Table 5.24)

$$\begin{aligned}
\text{Average Productivity per hour} &= 8.889 \text{ m}^3/\text{hour} \\
\text{Amount of trip} \frac{60}{CT \text{ (minute)}} &= \frac{60}{52.783} \\
&= 1 \text{ trip per hour} \\
\text{Total trip per day} &= \text{Trip per hour} \times \text{unit} \times \text{working hour} \times \text{unit excavator} \\
&= 1 \times 12 \times 7 \times 2 \\
&= 168 \text{ trip/day} \\
\text{Amount of units DT} \frac{Excavator \text{ Prod}}{DT \text{ Prod}} &= \frac{110.2644}{8.889} \\
&= 12 \text{ units for 1 excavator} \\
&= 24 \text{ units for 2 excavators} \\
\text{Working hours (days)} \frac{Volume}{Productivity \text{ per day}} &= \frac{122187}{8.889 \times 24 \times 7} \\
&= 80 \text{ days} \\
\text{Cost per trip} &= \text{Rp. } 90,000.00 \\
\text{Total cost} &= \text{Rp. } 11,800,000.00 \times 80 \text{ days} \\
&= \text{Rp. } 1,239,840,00.00
\end{aligned}$$

c. Bulldozer

The calculation of the total cost for Bulldozer alternative 1 can be observed in the following analysis.

$$\begin{aligned}
\text{Total Equipment} &= 2 \\
\text{(n)} & \\
\text{Volume} &= 122187 \text{ m}^3 \\
\text{Productivity per hour (Q)} &= 163.837 \text{ m}^3/\text{hour} \\
\text{Total productivity} &= Q \times n \\
&= 163.837 \times 2 \\
&= 327.674 \text{ m}^3/\text{hour}
\end{aligned}$$

$$\begin{aligned}
 \text{Working duration} &= \frac{\text{Volume}}{\text{prod per hour} \times \text{working hour}} \\
 (\text{day}) &= \frac{122187}{327.647 \times 7} \\
 \text{Working hour} &= 54 \text{ days} \\
 (\text{day}) & \\
 \text{Cost per day} &= \text{Rp. 1,131,800.00} \\
 \text{Total cost} &= \text{Rp. 122,234,400.00}
 \end{aligned}$$

d. Sheepsfoot Roller

The calculation of the total cost for Sheepsfoot Roller alternative 1 can be observed in the following analysis.

$$\begin{aligned}
 \text{Total Equipment (n)} &= 1 \\
 \text{Volume} &= 154358 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 321.058 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n \\
 &= 321.058 \times 1 \\
 &= 321.058 \text{ m}^3/\text{hour} \\
 \text{Working duration (day)} &= \frac{\text{Volume}}{\text{Prod per hour} \times \text{working hour}} \\
 &= \frac{122187}{321.058 \times 7} \\
 \text{Working hour (day)} &= 55 \text{ days} \\
 \text{Cost per day} &= \text{Rp. 796,200} \\
 \text{Total cost} &= \text{Rp. 43,791,000.00}
 \end{aligned}$$

e. Vibratory Roller

The calculation of the total cost for Vibratory Roller alternative 1 can be observed in the following analysis.

$$\text{Total Equipment (n)} = 1$$

$$\begin{aligned}
 \text{Volume} &= 12218187 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 182.577 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n \\
 &= 260.476 \times 1 \\
 &= 260.476 \text{ m}^3/\text{hour} \\
 \text{Working hour (hour)} &= \frac{\text{Volume}}{\text{Produksi seluruh alat}} \\
 &= \frac{1221817}{260.476 \times 7} \\
 \\
 \text{Working hour (day)} &= 68 \text{ days} \\
 \text{Cost per day} &= \text{Rp. } 796,200 \\
 \text{Total cost} &= \text{Rp. } 54,141,600
 \end{aligned}$$

Based on the data and analysis, the recapitulation of time and cost for alternative 1 is obtained as follows.

Table 5. 35 Recapitulation of Alternative Combination 1

Heavy Equipment	Units	Work Durations (day)	Cost per day	Effective hour	Total Cost
Excavator	2	80	Rp. 1,202,000.00	7	Rp. 192,320,000.00
Dump Truck	24	82	Rp. 90,000.00	7	Rp. 1,239,840,000.00
Dozer	2	54	Rp 1,131,800.00	7	Rp. 122,234,400.00
Sheep Footer	1	55	Rp. 796,200.00	7	Rp 54,141,600.00
Vibrator Roller	1	68	Rp. 796,200.00	7	Rp. 43,791,000.00
Total					Rp. 1,652,327,000

In combination alternative 1, the project duration is determined to be 82 days with a total cost of Rp. 1,652,327.00. The primary distinction compared to the existing condition lies in the addition of one unit each of the Dozer. The addition of this dozer unit is based on the existing calculation, where the bottleneck lies in the

dozer. Therefore, by adding one dozer unit, the project duration is reduced from 107 days to 82 days. This represents a decrease of -23% percent. However, in terms of cost, it increases from Rp. 1,651,195,200.00 rupiah to Rp. 1,652,327,000.00 rupiah, or by approximately 0.069% percent. The following presents the detailed differences between the alternatives 1 and the existing conditions.

Difference in work = 107 days – 82 days

duration

= 11 days

Duration = $\frac{82 - 107}{107 \text{ days}} \times 100\%$
comparison

= -23%

Cost comparison = $\frac{\text{Rp. } 1,652,237,000 - 1,651,195,000}{\text{Rp. } 1,651,195,200,000} \times 100\%$

= 0.069%

Table 5. 36 Time Schedule for Alternative 1

Heavy Equipment			1				2				3			
			1	2	3	4	1	2	3	4	1	2	3	4
Excavator	1	80												
Dump Truck	1	80												
Bulldozer	1	54												
Sheepsfoot	1	55												
Vibratory Roller	2	69												

In this embankment work, on the first day the excavators and dump trucks immediately operate for the full 7 hours, excavating and transporting material. The bulldozers can only begin after about 4 hours, since they must wait for enough material to accumulate, so they are effectively active for only 3 hours on that day. The sheepsfoot roller starts once the first layer has been spread by the bulldozers, while the vibratory roller does not operate at all on the first day and only begins on

the second day. Starting from the second day, all equipment works in parallel under the *start-to-start* principle. Excavators and dump trucks run continuously, bulldozers spread the material, the sheepsfoot roller compacts the areas just spread, and the vibratory roller performs finishing compaction. These activities overlap in different areas, so each stage does not need to wait for the previous one to be fully completed. In terms of duration, the bulldozers finish by day 54, the sheepsfoot roller by day 55, the vibratory roller by day 69, the excavators by day 80, and the dump trucks by day 82. Therefore, the overall work for Alternative 1 is considered complete on day 82, since the dump trucks are the last to finish.

5.4.3 Analysis of Alternative Combination 2

The following are several combinations of heavy equipment used in embankment operations under the alternative combination 2 at the project site, which will be analyzed based on the calculated productivity of each equipment. From the collected data, various alternatives can be evaluated by comparing the productivity results of the individual heavy equipment.

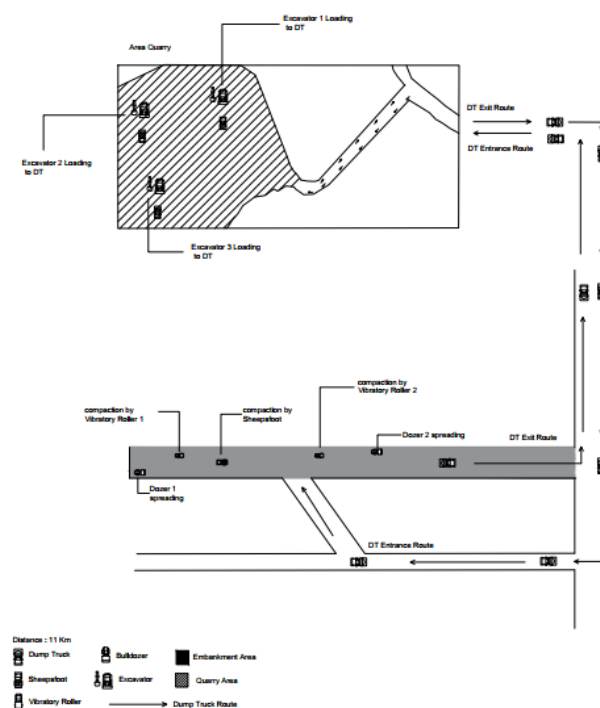


Figure 5. 13 Illustration of Heavy Equipment Alternative 2

At quarry, three excavators are employed, including two excavators with a bucket capacity of 1.2 m³ each. To transport the soil from the extraction site to the fill location, four types of dump trucks are used: Isuzu with a 9.6 m³ bed, Mitsubishi with a 10 m³ bed, Hino Dutro with a 9.8 m³ bed, and Toyota with a 9.8 m³ bed. Two bulldozers are used to level the material delivered by the dump trucks. For compaction, one sheepsfoot roller and one vibratory roller are utilized.

The following presents the calculation of equipment combinations under the existing field conditions, which will be analyzed based on equipment productivity and rental costs

a. Excavator

The total cost calculation for the Excavator in Alternative 2 can be seen in the calculation below.

Unit (n)	=	3
Volume	=	122187 m ³
Productivity per hour (Q)	=	110.264 m ³ /hour (Table 5.11)
Productivity all equipment	=	Q x n
	=	110.264 x 3
	=	330.793 m ³ /hour
Working hour (hour)	=	$\frac{Volume}{Productivity\ all\ equipment}$
	=	$\frac{122187}{333.945 \times 7} \times 7$
Cost per hour	=	53 days
Total cost	=	Rp. 191,118,00.00

b. Dump Truck

The total cost calculation for the Dump Truck in Alternative 2 can be seen in the calculation below.

Duration Analysis

Volume	=	122187.1494 m ³
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Effective hour	=	7 hours
Toyota Productivity	=	$8.698 \text{ m}^3/\text{hour}$ (Table 5.14)
Mitsubishi Productivity	=	$8.729 \text{ m}^3/\text{hour}$ (Table 5.17)
Isuzu Productivity	=	$8.804 \text{ m}^3/\text{hour}$ (Table 5.21)
Hino Dutro Productivity	=	$9.324 \text{ m}^3/\text{hour}$ (Table 5.24)
Average Productivity per hour	=	$8.889 \text{ m}^3/\text{hour}$
Amount of trip	$\frac{60}{CT \text{ (minute)}}$	= $\frac{60}{52.783}$
		= 1 trip per hour
Total trip per day		= Trip per hour x unit x working hour x unit excavator
		= $1 \times 12 \times 7 \times 3$
		= 252 trip/day
Amount of units DT	$\frac{Excavator \text{ Prod}}{DT \text{ Prod}}$	= $\frac{110.2644}{8.889}$
		= 12 units for 1 excavator
		= 48 units for 3 excavators
Working hours (days)	$\frac{Volume}{Productivity \text{ per day}}$	= $\frac{122187}{8.889 \times 48 \times 7}$
		= 55 days
Cost per trip		= Rp. 90,000.00
Total cost		= Rp. 90,000 x 252 x 55 days
		Rp. 1,247,400,000.00

c. Bulldozer

The calculation of the total cost for Bulldozer alternative 2 can be observed in the following analysis.

$$\text{Total Equipment} = 2$$

(n)

$$\text{Volume} = 122187 \text{ m}^3$$

$$\begin{aligned}
\text{Productivity per hour (Q)} &= 163.837 \text{ m}^3/\text{hour} \\
\text{Total productivity} &= Q \times n \\
&= 163.837 \times 2 \\
&= 327.674 \text{ m}^3/\text{hour} \\
\text{Working duration (day)} &= \frac{\text{Volume}}{\text{prod per hour} \times \text{working hour}} \\
&= \frac{122187}{327.647 \times 7} \\
\text{Working hour (day)} &= 54 \text{ days} \\
\text{Cost per day} &= \text{Rp. 1,131,800.00} \\
\text{Total cost} &= \text{Rp. 122,234,400.00}
\end{aligned}$$

d. Sheepsfoot Roller

The calculation of the total cost for Sheepsfoot Roller alternative 2 can be observed in the following analysis.

$$\begin{aligned}
\text{Total Equipment (n)} &= 1 \\
\text{Volume} &= 122187.1494 \text{ m}^3 \\
\text{Productivity per hour (Q)} &= 321.058 \text{ m}^3/\text{hour} \\
\text{Total productivity} &= Q \times n \\
&= 321.058 \times 1 \\
&= 321.058 \text{ m}^3/\text{hour} \\
\text{Working duration (day)} &= \frac{\text{Volume}}{\text{Prod per hour} \times \text{working hour}} \\
&= \frac{122187}{321.058 \times 7} \\
\text{Working hour (day)} &= 55 \text{ days} \\
\text{Cost per day} &= \text{Rp. 796,200} \\
\text{Total cost} &= \text{Rp. 43,791,000.00}
\end{aligned}$$

e. Vibratory Roller

The calculation of the total cost for Vibratory Roller alternative 2 can be observed in the following analysis.

$$\begin{aligned}
 \text{Total Equipment (n)} &= 2 \\
 \text{Volume} &= 12218187 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 260.476 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n \\
 &= 260.476 \times 2 \\
 &= 520.952 \text{ m}^3/\text{hour} \\
 \text{Working hour (hour)} &= \frac{\text{Volume}}{\text{Produksi seluruh alat}} \\
 &= \frac{1221817}{520.952 \times 7} \\
 \text{Working hour (day)} &= 34 \text{ days} \\
 \text{Cost per day} &= \text{Rp. 796,200} \\
 \text{Total cost} &= \text{Rp. 54,141,600.00}
 \end{aligned}$$

Based on the data and analysis, the recapitulation of time and cost for alternative 2 is obtained as follows.

Table 5. 37 Recapitulation of Analysis Combination 2

Heavy Equipment	Units	Work Durations (day)	Cost per day	Effective hour	Total Cost
Excavator	3	53	Rp. 1,202,000.00	7	Rp. 191,118,000.00
Dump Truck	36	55	Rp. 90,000.00	7	Rp. 1,247,400,000
Dozer	2	54	Rp 1,131,800.00	7	Rp. 122,234,400.00
Sheep Footer	2	34	Rp. 796,200.00	7	Rp 54,141,600.00
Vibrator Roller	1	55	Rp. 796,200.00	7	Rp 43,791,000.00
Total					Rp.1,658,685,000.00

In combination alternative 2, the project duration is determined to be 55 days with a total cost of Rp 1,658,685,000. The primary distinction compared to the existing condition lies in the addition of units for each type of equipment. The project duration is reduced from 107 days to 55 days. This represents a decrease of -49% percent. However, in terms of cost, it increases from Rp. 1,651,195,200.00 rupiah to Rp. 1,658,685,000 rupiah, or by approximately 0.454% percent.

Difference in work = 107 days – 55 days
duration

Duration = $\frac{55 - 107}{107 \text{ days}} \times 100\%$
comparison

= -49%

Cost comparison = $\frac{\text{Rp. } 1,658,685,000 - 1,651,195,200}{\text{Rp. } 1,651,195,200} \times 100\%$

= 0.454%

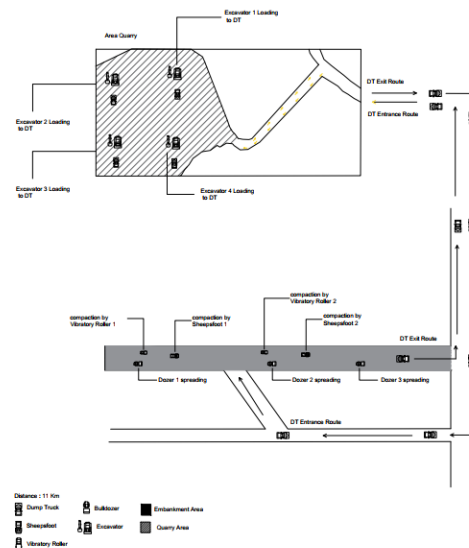
Table 5. 38 Time Schedule for Alternative 2

			1				2				3			
			1	2	3	4	1	2	3	4	1	2	3	4
Excavator	1	8 0												
Dump Truck	1	8 0												
Bulldozer	1	5 4												
Sheepsfoot ter	1	5 5												
Vibratory Roller	2	6 9												

On the first day, excavators and dump trucks immediately operate for the full 7 hours. Bulldozers begin working after a 4-hour delay, so they are only active for about 3 hours on the first day. The sheepsfoot rollers can start once the first layer has been spread, while the vibratory roller does not operate on day one and only begins on day two. From the second day onward, all equipment works in parallel. Excavators and dump trucks continuously supply and transport material, bulldozers

spread it, sheepsfoot rollers perform the initial compaction, and the vibratory roller completes the final compaction. Each activity overlaps in different work fronts, minimizing waiting time between tasks. Regarding duration, the sheepsfoot rollers finish by day 34, bulldozers by day 54, excavators by day 53, dump trucks by day 55, and the vibratory roller by day 56 (since it starts on day two). Thus, the overall work for Alternative 2 is considered complete on day 56, with dump trucks and the vibratory roller as the last equipment to finish.

5.4.4 Analysis of Alternative Combination 3



a. Excavator

The total cost calculation for the Excavator in Alternative 3 can be seen in the calculation below.

Unit (n)	= 4
Volume	= 122187 m^3
Productivity per hour (Q)	= $110.264 \text{ m}^3/\text{hour}$
Productivity all equipment	= Q x n
	= 110.264×4
	= $441.058 \text{ m}^3/\text{hour}$

$$\begin{aligned}
 \text{Working duration (day)} &= \frac{\text{Volume}}{\text{Productivity all equipment}} \\
 &= \frac{122187}{441.058 \times 7}
 \end{aligned}$$

$$\text{Cost per hour} = 40 \text{ days}$$

$$\text{Total cost} = \text{Rp. } 192,320,000.00$$

b. Dump Truck

The total cost calculation for the Dump Truck in Alternative 3 can be seen in the calculation below.

Duration Analysis

$$\text{Volume} = 122187.1494 \text{ m}^3$$

$$\text{Effective hour} = 7 \text{ hours}$$

$$\text{Toyota Productivity} = 8.698 \text{ m}^3/\text{hour} \text{ (Table 5.14)}$$

$$\text{Mitsubishi Productivity} = 8.729 \text{ m}^3/\text{hour} \text{ (Table 5.17)}$$

$$\text{Isuzu Productivity} = 8.804 \text{ m}^3/\text{hour} \text{ (Table 5.21)}$$

$$\text{Hino Dutro Productivity} = 9.324 \text{ m}^3/\text{hour} \text{ (Table 5.22)}$$

$$\text{Average Productivity} = 8.889 \text{ m}^3/\text{hour}$$

per hour

$$\text{Amount of trip} = \frac{60}{CT \text{ (minute)}} = \frac{60}{52.783}$$

$$= 1 \text{ trip per hour}$$

$$\text{Total trip per day} = \text{Trip per hour} \times \text{unit} \times \text{working hour} \times \text{unit excavator}$$

$$= 1 \times 12 \times 7 \times 4$$

$$= 336 \text{ trip/day}$$

$$\text{Amount of units DT} = \frac{\text{Excavator Prod}}{\text{DT Prod}} = \frac{110.2644}{8.889}$$

$$= 12 \text{ units for 1 excavator}$$

$$= 48 \text{ units for 3 excavators}$$

$$\begin{aligned}
 \text{Working hours (days)} &= \frac{\text{Volume}}{\text{Productivity per day}} = \frac{122187}{8.889 \times 48 \times 7} \\
 &= 41 \text{ days} \\
 \text{Cost per trip} &= \text{Rp. } 90,000.00 \\
 \text{Total cost} &= \text{Rp. } 90,000 \times 336 \times 41 \text{ days} \\
 &= \text{Rp. } 1,239,840.000.00
 \end{aligned}$$

c. Bulldozer

The calculation of the total cost for Bulldozer alternative 3 can be observed in the following analysis.

$$\begin{aligned}
 \text{Total Equipment (n)} &= 3 \\
 \text{Volume} &= 122187 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 163.8369 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n \\
 &= 163.8369 \times 3 \\
 &= 491.511 \text{ m}^3/\text{hour} \\
 \text{Working duration (day)} &= \frac{\text{Volume}}{\text{Produksi seluruh alat}} \\
 &= \frac{122187}{491.511 \times 7} \times 7 \\
 \text{Working hour (day)} &= 36 \text{ days} \\
 \text{Cost per day} &= \text{Rp. } 1,131,800.00 \\
 \text{Total cost} &= \text{Rp. } 122,235,200
 \end{aligned}$$

d. Sheepsfoot Roller

The calculation of the total cost for Sheepsfoot Roller alternative 3 can be observed in the following analysis.

$$\begin{aligned}
 \text{Total Equipment (n)} &= 2 \\
 \text{Volume} &= 122187 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 321.058 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n
 \end{aligned}$$

$$\begin{aligned}
 &= 321.058 \times 2 \\
 &= 642.116 \text{ m}^3/\text{hour} \\
 \text{Working duration (day)} &= \frac{\text{Volume}}{\text{Produksi seluruh alat}} \\
 &= \frac{122187}{642.116 \times 7} \times 7 \\
 \text{Working hour (day)} &= 28 \text{ days} \\
 \text{Cost per day} &= \text{Rp. } 796,200 \\
 \text{Total cost} &= \text{Rp. } 44,587,200.00
 \end{aligned}$$

e. Vibratory Roller

The calculation of the total cost for Vibratory Roller alternative 3 can be observed in the following analysis.

$$\begin{aligned}
 \text{Total Equipment (n)} &= 2 \\
 \text{Volume} &= 12218187 \text{ m}^3 \\
 \text{Productivity per hour (Q)} &= 260.476 \text{ m}^3/\text{hour} \\
 \text{Total productivity} &= Q \times n \\
 &= 260.476 \times 2 \\
 &= 520.952 \text{ m}^3/\text{hour} \\
 \text{Working hour (hour)} &= \frac{\text{Volume}}{\text{Produksi seluruh alat}} \\
 &= \frac{1221817}{520.952 \times 7} \\
 \text{Working hour (day)} &= 34 \text{ days} \\
 \text{Cost per day} &= \text{Rp. } 796,200 \\
 \text{Total cost} &= \text{Rp. } 54,141,600.00
 \end{aligned}$$

Based on the data and analysis, the recapitulation of time and cost for alternative 3 is obtained as follows.

Table 5. 39 Recapitulation of Analysis Combination 3

Heavy Equipment	Units	Work Durations (day)	Cost per day	Effective hour	Total Cost
Excavator	4	40	Rp. 1,202,000.00	7	Rp. 192,320,000.00
Dump Truck	48	41	Rp. 90,000.00	7	Rp. 1,239,840,000
Dozer	3	36	Rp 1,131,800.00	7	Rp. 122,234,400.00
Sheep Footer	2	34	Rp. 796,200.00	7	Rp. 54,141,600.00
Vibrator Roller	2	28	Rp. 796,200.00	7	Rp. 44,587,200.00
Total					Rp. 1,653,123,200

In combination alternative 3, the project duration is determined to be 41 days with a total cost of Rp 1,653,123,000. The primary distinction compared to the existing condition lies in the addition of units for each type of equipment. The project duration is reduced from 107 days to 41 days. This represents a decrease of -62% percent. However, in terms of cost, it increases from Rp. 1,651,195,200 rupiah to Rp. 1,653,123,200 rupiah, or by approximately 0.117% percent.

Difference in work = 107 days – 48 days
duration

Duration = $\frac{41 - 107}{107 \text{ days}} \times 100\%$
comparison

= -62%

Cost comparison = $\frac{\text{Rp. 1,653,123,000} - \text{1,651,195,000}}{\text{Rp. ,1,651,195,200}} \times 100\%$

= 0.117%

Table 5. 40 Time Schedule for Alternative 3

			1				2				3			
			1	2	3	4	1	2	3	4	1	2	3	4
Excavator	1	8 0												
Dump Truck	1	8 0												
Bulldozer	1	5 4												
Sheepsfoot ter	1	5 5												
Vibratory Roller	2	6 9												

On the first day, excavators and dump trucks operate for the full 7 hours. Bulldozers start after a 4-hour delay, so they are active for about 3 hours. The sheepsfoot rollers begin once the first spread is completed, while the vibratory rollers do not operate on day one and only start from day two. From the second day onward, all equipment works simultaneously. Excavators and dump trucks maintain continuous loading and hauling, bulldozers spread the material, sheepsfoot rollers compact the freshly spread areas, and vibratory rollers carry out the finishing compaction. These operations overlap across different sections, ensuring steady workflow without waiting for full completion of the previous task. In terms of duration, sheepsfoot rollers finish by day 34, bulldozers by day 36, excavators by day 40, vibratory rollers by day 29, and dump trucks by day 41. Therefore, the overall work for Alternative 3 is considered complete on day 41, with dump trucks being the last equipment to finish.

5.4.5 Comparative Analysis of Alternatives Combinations

The analysis indicates that differences in duration and cost are influenced by the number of heavy equipment units. In the existing condition, 2 Excavators, 1 Dozers, 1 Sheepsfoot Rollers, 1 Vibratory Rollers, and 24 Dump Trucks are utilized, resulting in 107 days and a total cost of Rp 1,651,195,200

Alternative 1 adds one unit for Bulldozer, reducing the duration to 82 days with a cost of Rp 1,652,327,000. Alternative 2 increases Dump Trucks to 36 units,

excavator 2 units, and vibratory roller 2 units, yielding 55 days and Rp 1,658,685,000. Alternative 3 combines both adjustments, achieving 48 days with a cost of Rp 1,653,123,200

Table 5. 41 Comparison of Work Duration and Total Time for Each Combination

Combination	Work Duration	Duration Comparison	Total Cost	Cost Comparison
Existing	107		Rp 1,651,195,200.00	
Combination 1	82	-23%	Rp 1,652,327,000.00	0.069%
Combination 2	55	-49%	Rp 1,658,685,000.00	0.454%
Combination 3	41	-62%	Rp 1,653,123,200.00	0.117%

The difference in duration can be observed more clearly in the following figure, which illustrates the comparison of project completion times.

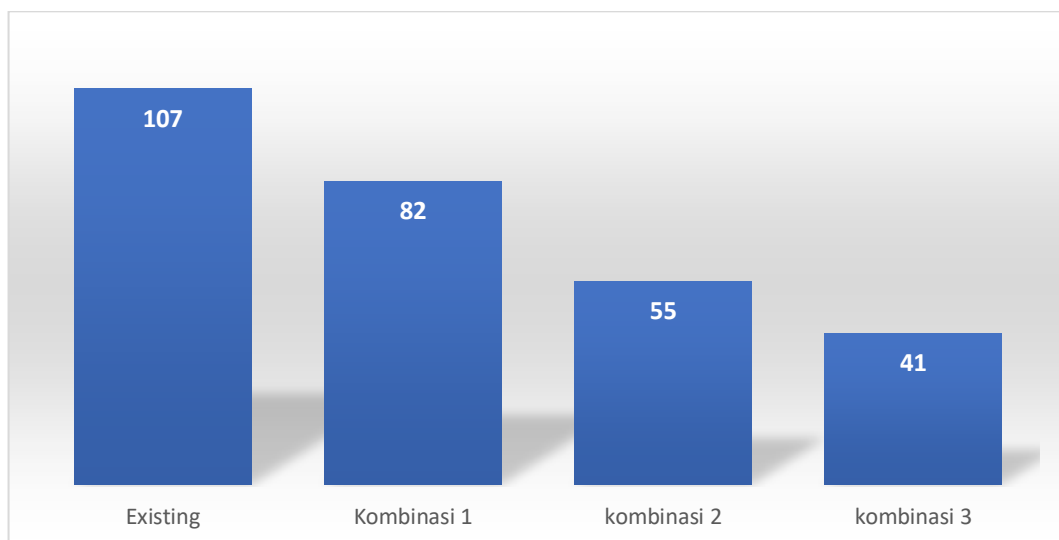


Figure 5. 14 Chart Comparison of Work Duration for Each Combination

From the duration comparison chart above, the existing condition demonstrates the longest completion time of 107 days. By increasing the number of equipment units in the simulated alternatives, the project duration can be significantly reduced. Alternative 1 shortens the time to 82 days represents decrease of -23%, Alternative 2 to 55 days represents a decrease of 49%, and Alternative 3 achieves the fastest completion at 41 days and represents a decrease of 62%. This indicates that the greater the number of equipment units utilized, particularly Excavators and Dump Trucks, the more efficient the project completion becomes. Therefore, Alternative 3 is considered the most optimal option in terms of duration acceleration.

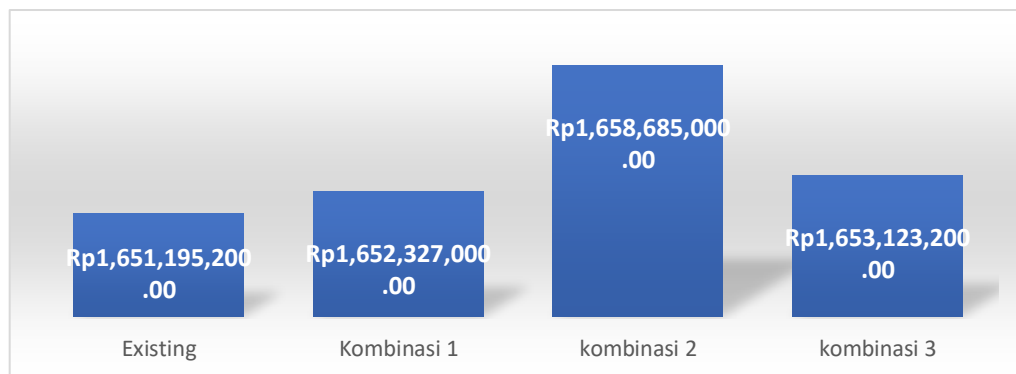


Figure 5. 15 Chart Comparison of Total Cost for Each Combination

In terms of total cost, the existing condition requires Rp. 1,651,195,200. In Alternative 1, the project cost increases to Rp. 1,652,327,000, representing an additional about 0.069% compared to the existing cost. In Alternative 2, the total project cost rises more significantly to Rp. 1,658,685,000, with an increase of approximately 0.454% over the existing condition. Meanwhile, in Alternative 3, the required total cost is Rp. 1,653,123,200, which is increase about 0.117% compared to the existing condition. Thus, from the cost perspective, Alternatives 1 and 3 are relatively more efficient because they require only a very small additional expense, while Alternative 2, although providing the significant reduction in project duration, but requires the highest additional cost at 0.454% over the existing condition.

Thus, in terms of duration, Alternative 3 is the most optimal choice as it reduces the project duration by more than half compared to the existing condition. From the

perspective of cost, Alternatives 1 and 3 are more efficient since the increase is only 0.069% and 0.117% which is significantly lower than Alternative 2. Overall, Alternative 3 provides the most advantageous combination, offering the most significant time reduction with only a very small additional cost.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study examines the productivity and cost analysis of heavy equipment utilization in earthwork embankment projects, with the aim of evaluating the existing condition and comparing it with several alternative combinations of equipment units. The analysis was conducted by calculating project duration and equipment rental costs based on variations in the number of Excavators, Dump Trucks, Dozers, Vibratory Rollers, and Sheep Foot Rollers employed. The findings provide insights into the impact of equipment quantity on both time and cost efficiency in embankment works.

1. The productivity analysis showed the following average performance (per unit): excavator 110.26 m³/hour, dump truck 8.89 m³/hour, bulldozer 163.84 m³/hour, sheepsfoot roller 321.06 m³/hour, and vibratory roller 260.48 m³/hour. These figures represent the effective productivity values after accounting for cycle time, efficiency, and jobsite conditions on the Yogyakarta–Bawen Toll Road embankment work. This analysis provides a clear picture of the contribution and efficiency of each equipment type to the overall earthwork process.
2. Three alternative equipment combinations were simulated. Alternative 1 (2 excavators, 24 dump trucks, 2 bulldozers, 1 sheepsfoot, 1 vibratory) required 82 working days. Alternative 2 (3 excavators, 36 dump trucks, 2 bulldozers, 2 sheepsfoot, 1 vibratory) reduced the duration to 55–56 working days. Alternative 3 (4 excavators, 48 dump trucks, 3 bulldozers, 2 sheepsfoot, 2 vibratory) achieved the shortest duration of 41 working days. Therefore, in terms of project completion time, Alternative 3 is the most suitable.
3. Cost analysis indicated that increasing the number of equipment units significantly raised operational expenses. Alternative 1 resulted in the lowest

project cost, Alternative 2 required higher investment, and Alternative 3, although fastest in duration, was the most expensive option due to the large number of units involved. Hence, in terms of minimizing cost, Alternative 1 is the most suitable.

6.2 Recommendation

Based on the results of the analysis and calculations, the following conclusions and recommendations can be presented:

1. The determination of the number of heavy equipment units must carefully consider the balance between reducing project duration and controlling costs, in order to avoid inefficiency as well as delays.
2. The composition of equipment needs to be aligned with the productivity of each unit to minimize idle time, particularly between excavators and dump trucks. In this regard, it is recommended that dump trucks with larger capacities be utilized, as the payment system is based on the number of trips. This approach can reduce the total number of trips required, thereby increasing cost efficiency.
3. The planning of equipment deployment should also take into account site conditions such as hauling distance, soil characteristics, and weather conditions, as these external factors directly influence productivity, project duration, and overall costs.

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APPENDIX

Appendix 1 Cycle Time Excavator Day 1

[illegible]

Appendix 2 Cycle Time Excavator Day 2

[illegible]

Appendix 3 Cycle Time Excavator Day 3

Pengamatan Produktivitas Excavator		Nama Proyek		Ujungpeta - Busan Toll Road		
		Lokasi		Peta 501		
		Hari Pengamatan		Hari 3		
Spesifikasi Excavator						
Merk Excavator	Komatsu					
Tipe Excavator	PC240LC					
Ukuran Excavator	Bucket 1 m ³					
Kondisi Alat	Baik					
Bahan Bakar	20 Liter / jam					
Upah Operator	Rp. 250.000					
Sesi	Jam	Siklus	Gali (detik)	Putar Isi (detik)	Buang (detik)	Putar Kosong (detik)
Pagi	08:00 - 11:00	1	5:33	4:13	3:44	4:19
		2	11:57	4:18	3:17	4:03
		3	5:18	4:04	3:31	4:51
Pagi	11:00 - 14:00	1	5:15	3:19	3:04	2:6
		2	5:03	4:19	3:14	5:48
		3	7:47	3:29	3:04	4:10
Siang	14:00 - 16:00	1	4	4:5	2:57	2:5
		2	4:04	4:25	3:21	4:8
		3	11:12	4:24	6:03	4:12
Rata-Rata			6:572	4:184	3:84	4:19
Waktu Siklus Rata-rata			18:477			
Mengetahui Staff Lapangan/Proyek						Catatan
 (Nur Khair)						

Appendix 4 Cycle Time Excavator Day 4

Pengamatan Produktivitas Excavator		Nama Proyek		Ujungpeta - Busan Toll Road		
		Lokasi		Peta 501		
		Hari Pengamatan		Hari 4		
Spesifikasi Excavator						
Merk Excavator	Komatsu					
Tipe Excavator	PC240LC					
Ukuran Excavator	1 m ³					
Kondisi Alat	Baik					
Bahan Bakar	20 Liter / jam					
Upah Operator	Rp. 250.000					
Sesi	Jam	Siklus	Gali (detik)	Putar Isi (detik)	Buang (detik)	Putar Kosong (detik)
Mening	08:00 - 11:00	1	3:39	2:31	6:34	3:38
		2	8:45	3:01	3:36	3:08
		3	6:13	4:36	7:21	3:15
Apitroom	11:00 - 14:00	1	4:18	4:31	5:03	6:18
		2	8:26	4:08	4:39	3:33
		3	9:08	4:49	7:02	3:19
Sudutry	14:00 - 16:00	1	8:12	3:16	3:51	3:15
		2	3:51	4:13	5	3:45
		3	24:61	5:35	5:14	5:65
Rata-Rata			8:53	4:190	3:44	4:367
Waktu Siklus Rata-rata			12:032			
Mengetahui Staff Lapangan/Proyek						Catatan
 (Nur Khair)						

Appendix 5 Cyle Time Excavator Day 5

Pengamatan Produktivitas Excavator		Nama Proyek		Ujungkutan- Dusun Tol Rend		
Lokasi		Peta		Arah		
Hari Pengamatan		Day 5				
Spesifikasi Excavator						
Merk Excavator	Tomijon					
Tipe Excavator	7E51C					
Ukuran Excavator	1 m ³					
Kondisi Alat	Baik					
Bahan Bakar	20L / jam					
Upah Operator	Rp. 140.000					
Sesi	Jam	Siklus	Gali (detik)	Putar Isi (detik)	Buang (detik)	Putar Kosong (detik)
Morning	08:00 - 11:00	1	3:39	2:31	6:34	3:38
		2	4:35	3:01	3:30	3:08
		3	4:33	4:36	7:31	3:15
Afternoon	11:00 - 01:00	1	4:18	4:31	5:03	6:38
		2	8:26	4:08	4:39	5:33
		3	9:08	4:49	7:05	3:19
Evening	14:00 - 18:00	1	8:22	5:26	3:51	3:15
		2	8:31	4:53	5	3:45
		3	24:61	5:35	5:141	5:65
Rata-Rata			8:31	4:30	3:44	4:30
Waktu Siklus Rata-rata			12:00			
Mengetahui Staff Lapangan/Proyek					Catatan	
 (Nur Huda)						

Appendix 6 Cycle Time Dump Truck Toyota Day 1

Pengamatan Produktivitas SheepsFoot		Nama Proyek		Ujungkutan- Dusun Tol Rend	
Lokasi		Peta		Arah	
Hari Pengamatan		Day 1			
Spesifikasi Sheepsfoot					
Merk Alat	XCMG X558D				
Tipe Alat					
Ukuran Alat	2.5 x 1.5				
Kondisi Alat	Baik				
Bahan Bakar	12L / jam				
Upah Operator	Rp. 225.000				
		Waktu Siklus			
Waktu	Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)	
Morning	Apikman	1	18	80	1.33
		2	18	80	1.33
		3	19	80	1.32
		4	30	80	1.60
		5	26	80	1.41
		6	28	80	1.33
		7	28	80	1.32
		8	29	80	1.33
		9	28	80	1.33
		10	26	80	1.33
Evening	1	1	26	80	1.33
		2	25	80	1.33
		3	25	80	1.33
		4	25	80	1.33
		5	26	80	1.33
Mengetahui Staff Lapangan/Proyek					
 (Nur Huda)					

Appendix 7 Cyle Time Dump Truck Toyota Day 2

Pengamatan Produktivitas SheepsFoot		Nama Proyek		Uppskatu- Dusun Taji, Pacel	
		Lokasi		Area 4th	
		Hari Pengamatan		Day 1	
Spesifikasi Sheepsfoot					
Merk Alat	XCMG X558D				
Tipe Alat					
Ukuran Alat	2.5 x 1.5				
Kondisi Alat	Baik				
Bahan Bakar	12.6 / jam				
Upah Operator	Rp. 225.000				
Waktu Siklus					
Waktu		Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)
Mening	Apikmen	1	18	80	1.75
1	1	2	18	80	1.75
2	2	3	19	80	1.72
3	3	4	30	80	1.60
4	4	5	26	80	1.54
5	5	6	28	80	1.75
6	6	7	28	80	1.72
7	7	8	29	80	1.72
8	8	9	28	80	1.75
9	9	10	26	80	1.75
10	10	1	28	80	1.75
Downing 1	6	2	26	80	1.75
2	7	3	23	80	1.75
3	8	4	21	80	2.45
4	9	5	20	80	1.60
5	10	6	20	80	2.40
Mengetahui Staff Lapangan/Proyek					
 (Nur Hidayat)					

Appendix 8 Cyle Time Dump Truck Toyota Day 3

Pengamatan Produktivitas SheepsFoot		Nama Proyek		Uppskatu- Dusun Taji, Pacel	
		Lokasi		Area 4th	
		Hari Pengamatan		Day 1	
Spesifikasi Sheepsfoot					
Merk Alat	XCMG X558D				
Tipe Alat					
Ukuran Alat	2.5 x 1.5				
Kondisi Alat	Baik				
Bahan Bakar	12.6 / jam				
Upah Operator	Rp. 225.000				
Waktu Siklus					
Waktu		Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)
Mening	Apikmen	1	18	80	1.75
1	1	2	18	80	1.75
2	2	3	19	80	1.72
3	3	4	30	80	1.60
4	4	5	26	80	1.54
5	5	6	28	80	1.75
6	6	7	28	80	1.72
7	7	8	29	80	1.72
8	8	9	28	80	1.75
9	9	10	26	80	1.75
10	10	1	28	80	1.75
Downing 1	6	2	26	80	1.75
2	7	3	23	80	1.75
3	8	4	21	80	2.45
4	9	5	20	80	1.60
5	10	6	20	80	2.40
Mengetahui Staff Lapangan/Proyek					
 (Nur Hidayat)					

Appendix 9 Cyle Time Dump Truck Toyota Day 4

Pengamatan Produktivitas SheepsFoot		Nama Proyek	Uppiyah - Dusun Tel. Daud	
		Lokasi	Area 4A	
		Hari Pengamatan	Day 4	
Spesifikasi Sheepsfoot				
Merk Alat	XCMG X558D			
Tipe Alat				
Ukuran Alat	2.5 x 1.5			
Kondisi Alat	Baik			
Bahan Bakar	12.6 / jam			
Upah Operator	Rp. 225.000			
Waktu Siklus				
Waktu	Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)
Mening	Apikman	1	18	60
1	1	2	18	60
2	2	3	19	60
3	3	4	30	60
4	4	5	26	60
5	5	6	28	60
6	6	7	28	60
7	7	8	29	60
8	8	9	28	60
9	9	10	26	60
10	10	1	28	60
Downing	2	2	26	60
1	1	3	23	60
2	2	4	21	60
3	3	5	20	60
4	4	6	20	60
5	10	5	20	60
Mengetahui Staff Lapangan/Proyek				
<div></div> <div>(Nur Hidar)</div>				

Appendix 10 Cyle Time Dump Truck Toyota Day 5

Pengamatan Produktivitas SheepsFoot		Nama Proyek	Uppiyah - Dusun Tel. Daud	
		Lokasi	Area 4A	
		Hari Pengamatan	Day 5	
Spesifikasi Sheepsfoot				
Merk Alat	XCMG X558D			
Tipe Alat				
Ukuran Alat	2.5 x 1.5			
Kondisi Alat	Baik			
Bahan Bakar	12.6 / jam			
Upah Operator	Rp. 225.000			
Waktu Siklus				
Waktu		Sesi	Waktu dalam 1 lintasan (detik)	Kecepatan (m/s)
Mening	Apikman	1	18	60
1	1	2	18	60
2	2	3	19	60
3	3	4	30	60
4	4	5	26	60
5	5	6	28	60
6	6	7	28	60
7	7	8	29	60
8	8	9	28	60
9	9	10	26	60
10	10	1	28	60
Downing	1	2	26	60
1	2	3	23	60
2	3	4	21	60
3	4	5	20	60
4	5	6	20	60
5	10			2.40
Mengetahui Staff Lapangan/Proyek				
<div> (Nur Hidar)</div>				

Appendix 11 Cycle Time Dump Truck Mitsubishi Day 1

Pengamatan Produktivitas Dump Truck		Nama Proyek		Gedung - Papan 11. Bnd	
		Lokasi		Sml	
		Hari Pengamatan		Dag 1	
Spesifikasi Dump Truck					
Merk Dump Truck	Mitsubishi				
Tipe Dump Truck	-				
Ukuran Dump Truck	10 m ³				
Kondisi Alat	Baik				
Bahan Bakar	-				
Upah Operator	Rp. 100				
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang Kembali (menit)
Pagi	08.00 - 11.00	1	1.05	14	0.45
		2	1.12	15	0.41
		3	1.04	16	0.43
Siang	11.00 - 13.00	1	1.15	15	0.40
		2	1.02	17	0.40
		3	1.13	18	0.43
Sore	14.00 - 16.00	1	1.01	15	0.40
		2	1.00	17	0.40
		3	1.08	14	0.43
Rata-Rata			1.11	14.44	0.435
Waktu Siklus Rata-rata					16.98
Mengetahui Staff Lapangan/Proyek					Catatan
 (Nur Kholis)					

Appendix 12 Cycle Time Dump Truck Mitsubishi Day 2

Pengamatan Produktivitas Dump Truck		Nama Proyek		Gedung - Papan 11. Bnd	
		Lokasi		Sml	
		Hari Pengamatan		Dag 2	
Spesifikasi Dump Truck					
Merk Dump Truck	Mitsubishi				
Tipe Dump Truck	-				
Ukuran Dump Truck	10 m ³				
Kondisi Alat	Baik				
Bahan Bakar	-				
Upah Operator	Rp. 100 / m ³				
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang Kembali (menit)
Pagi	08.00 - 11.00	1	1.05	14	0.45
		2	1.11	15	0.42
		3	1.10	15	0.41
Siang	11.00 - 13.00	1	1.11	16	0.46
		2	1.15	16	0.45
		3	1.05	14	0.45
Sore	14.00 - 16.00	1	1.15	15	0.41
		2	1.08	14	0.41
		3	1.15	16	0.40
Rata-Rata			1.11	15.00	0.44
Waktu Siklus Rata-rata					17.00
Mengetahui Staff Lapangan/Proyek					Catatan
 (Nur Kholis)					

Appendix 13 Cycle Time Dump Truck Mitsubishi Day 3

Pengamatan Produktivitas Dump Truck		Nama Proyek		Spesifikasi Dump Truck			
		Lokasi		Sungai Kato - Pasir 121 km			
		Hari Pengamatan		Des 3			
Merk Dump Truck	Mitsubishi						
Tipe Dump Truck	-						
Ukuran Dump Truck	10 m ³						
Kondisi Alat	Baik						
Bahan Bakar	-						
Upah Operator Sesi	Rp. 20.000 / hr						
	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)	
Pagi	08.00 - 11.00	1	4.30	71	0.5	14.5	
		2	3.51	75	0.5	14.5	
		3	3.50	73	0.4	14	
Siang	11.00 - 14.00	1	3.51	78	0.6	14.5	
		2	3.55	76	0.45	14.5	
		3	3.51	74	0.45	14.5	
Sore	14.00 - 16.00	1	3.55	73	0.61	14.5	
		2	3.55	71	0.61	14.5	
		3	3.55	70	0.50	14.4	
Rata-Rata			3.56	74.05	0.46	14.09	
Waktu Siklus Rata-rata							
Mengetahui Staff Lapangan/Proyek				Catatan			
							
(Nur Kholid)							

Appendix 14 Cycle Time Dump Truck Mitsubishi Day 4

Pengamatan Produktivitas Dump Truck			Nama Proyek				
			Lokasi		Siti		
			Hari Pengamatan		Day 4		
Spesifikasi Dump Truck							
Merk Dump Truck		Mitsubishi					
Tipe Dump Truck		-					
Ukuran Dump Truck		10 m ³					
Kondisi Alat		Baik					
Bahan Bakar		-					
Upah Operator		Rp. 20.000 / hr					
Sesi		Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	}		1	4.50	71.6	0.53	14.8
			2	2.61	51.8	0.45	14.46
			3	2.51	70.4	0.5	14.6
Siang	}		1	3.49	71.2	0.5	14.44
			2	3.44	71.6	0.43	14.60
			3	4.21	72.1	0.43	14.74
Sore	}		1	2.46	71.1	0.43	14.50
			2	2.43	71.4	0.53	14.60
			3	2.5	71.8	0.43	14.70

Appendix 15 Cycle Time Dump Truck Mitsubishi Day 5

Pengamatan Produktivitas Dump Truck		Nama Proyek				
		Lokasi		Are. 5m		
		Hari Pengamatan		Des 5		
Spesifikasi Dump Truck						
Merk Dump Truck	Mitsubishi					
Tipe Dump Truck	-					
Ukuran Dump Truck	10. m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator Sesi	Rp. 78.000					
	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi		1	3.03	0.40	2.1	11.5
		2	3.03	0.40	2.1	11.5
		3	2.39	0.41	2.1	11.7
Pekan		1	3.38	0.41	2.3	18.5
		2	3.36	0.41	2.1	20.4
		3	3.33	0.38	2.8	15.7
Sore		1	2.66	0.41	2.5	11.3
		2	2.53	0.43	2.2	18.6
		3	2.78	0.43	2.2	22
Rata-Rata			3.13	0.41	2.1	15.5
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek					Catatan	
 C. Nur Hous						

Appendix 16 Cycle Time Dump Truck Isuzu Day 1

Pengamatan Produktivitas Dump Truck		Nama Proyek				
		Lokasi		Are. 5m		
		Hari Pengamatan		Des 5		
Spesifikasi Dump Truck						
Merk Dump Truck	Mitsubishi					
Tipe Dump Truck	-					
Ukuran Dump Truck	10. m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator Sesi	Rp. 78.000					
	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi		1	3.03	0.40	2.1	11.5
		2	3.03	0.40	2.1	11.5
		3	2.39	0.41	2.1	11.7
Pekan		1	3.38	0.41	2.3	18.5
		2	3.36	0.41	2.1	20.4
		3	3.33	0.38	2.8	15.7
Sore		1	2.66	0.41	2.5	11.3
		2	2.53	0.43	2.2	18.6
		3	2.78	0.43	2.2	22
Rata-Rata			3.13	0.41	2.1	15.5
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek					Catatan	
 C. Nur Hous						

Appendix 17 Cycle Time Dump Truck Isuzu Day 2

Pengamatan Produktivitas Dump Truck		Nama Proyek				
		Lokasi		Des. 501		
		Hari Pengamatan		Minggu 1		
Spesifikasi Dump Truck						
Merk Dump Truck	Isuzu					
Tipe Dump Truck						
Ukuran Dump Truck	9.6 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator Sesi	Rp. 42.000					
	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	08.00 - 11.00	1	2.05	11.11	0.153	14.3
		2	2.10	11.40	0.523	14.3
		3	2.25	12.10	0.515	15.2
Siang	11.00 - 13.00	1	2.11	11.10	0.5	14.6
		2	2.21	11.10	0.487	14.9
		3	2.25	11.20	0.483	15.4
Sore	14.00 - 16.00	1	2.41	11.50	0.463	16.3
		2	2.21	11.20	0.50	16.3
		3	2.25	12.10	0.480	14.3
Rata-Rata			2.152	11.44	0.506	15.422
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek					Catatan	
<div> (Nur Icholus)</div>						

Appendix 18 Cycle Time Dump Truck Isuzu Day 3

Pengamatan Produktivitas Dump Truck		Nama Proyek				
		Lokasi		Ara 501		
		Hari Pengamatan		20/11/23		
Spesifikasi Dump Truck						
Merk Dump Truck	Isuzu					
Tipe Dump Truck	-					
Ukuran Dump Truck	9.6 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator Sesi	Rp. 42.000					
	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	08.00 - 11.00	1	2.09	10.2	0.400	14.3
		2	2.06	10.2	0.383	14
		3	2.11	10.4	0.413	14.4
Siang	11.00 - 13.00	1	2.05	10.1	0.5	14
		2	2.11	10.5	0.413	14.6
		3	2.11	10.9	0.407	14.8
Sore	14.00 - 16.00	1	2.44	11.9	0.433	15
		2	2.03	10.1	0.41	14.3
		3	2.25	10	0.410	14.3

Appendix 19 Cycle Time Dump Truck Isuzu Day 4

Pengamatan Produktivitas Dump Truck		Nama Proyek		Ujungpandan-Banjar Toll Road		
		Lokasi		Kec. Sakti		
		Hari Pengamatan		Des 4		
Spesifikasi Dump Truck						
Merk Dump Truck	Isuzu					
Tipe Dump Truck	-					
Ukuran Dump Truck	3.6 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator	Rp. 92.000					
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	08.00 - 11.00	1	2.45	18.5	0.400	15.7
		2	2.06	18.2	0.385	15
		3	2.11	18.6	0.415	15.5
Siang	11.00 - 13.00	1	2.05	20.1	0.390	15
		2	2.13	18.5	0.463	15.5
		3	2.11	21.2	0.47	15
Sore	14.00 - 16.00	1	2.14	21.5	0.480	15.3
		2	2.03	20.1	0.41	14.3
		3	2.15	20	0.450	15
Rata-Rata			2.164	18.800	0.409	15.244
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek						Catatan
 Nur Kholis						

Appendix 20 Cycle Time Dump Truck Isuzu Day 5

Pengamatan Produktivitas Dump Truck		Nama Proyek		Ujungpandan-Banjarbaru Toll Road		
		Lokasi		Kec. Sakti		
		Hari Pengamatan		Des 5		
Spesifikasi Dump Truck						
Merk Dump Truck	Isuzu					
Tipe Dump Truck						
Ukuran Dump Truck	3.6 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator	Rp 92.000					
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	08.00 - 11.00	1	2.00	17.1	0.4	15.3
		2	2.15	18.2	0.45	15.5
		3	2.00	17.8	0.35	15.2
Siang	11.00 - 13.00	1	2.15	18	0.463	15.44
		2	2.16	18.5	0.503	15.79
		3	2.2	18.2	0.463	15.2
Sore	14.00 - 16.00	1	2.11	18.2	0.463	15.8
		2	2.6	18	0.460	19
		3	2.20	17.7	0.483	16
Rata-Rata			2.173	17.71	0.47	15.450
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek					Catatan	
 (Nur Kholis)						

Appendix 21 Cycle Time Dump Truck Hino Dutro Day 1

[illegible]

Appendix 22 Cycle Time Dump Truck Hino Dutro Day 2

Pengamatan Produktivitas Dump Truck		Nama Proyek Lokasi Hari Pengamatan		"Sungai - Bagan" Tail Road Ata 544 Des 2		
Spesifikasi Dump Truck						
Merk Dump Truck	Hino Duro					
Tipe Dump Truck						
Ukuran Dump Truck	9,8 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator	Rp. 00					
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Des	08:00 - 11:00	1	2:5	23	0:40	14:5
		2	3:16	25	0:45	15:2
		3	3:1	23:2	0:50	16
Sesi	11:00 - 13:00 13:00 - 14:00	1	3:05	26	0:45	15:3
		2	2:59	25	0:50	15:8
		3	3:8	25	0:50	16
Sesi	14:00 - 16:00	1	2:35	28:8	0:45	16:6
		2	3:23	28:9	0:50	16:9
		3	3:11	28:8	0:45	16:5
Rata-Rata			2:58	3:14	0:48	16:53
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek					Catatan	
 (Nur Indris)						

Appendix 23 Cycle Time Dump Truck Hino Dutro Day 3

Pengamatan Produktivitas Dump Truck		Nama Proyek		Ujungpala - Bawen Tol Pand		
		Lokasi		Arao Srit		
		Hari Pengamatan		Day 3		
Spesifikasi Dump Truck						
Merk Dump Truck	Hino Dutro					
Tipe Dump Truck	-					
Ukuran Dump Truck	9.8 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator	Rp. 52.000 / hrp					
Sesi						
Pagi	08.00 - 11.00	1	2.49	30	0.410	16.3
		2	2.42	30	0.385	17.1
		3	2.35	33.8	0.363	15.8
Siang	11.00 - 14.00	1	2.49	33	0.5	16.2
	13.00 - 14.00	2	2.05	38	0.5	17
		3	2.08	33	0.433	16.3
Sore	14.00 - 16.00	1	2.53	34.4	0.37	15.9
		2	2.42	35.1	0.333	16.1
		3	2.42	38.9	0.4	16.2
					</	

Appendix 24 Cycle Time Dump Truck Hino Dutro Day 4

Pengamatan Produktivitas Dump Truck		Nama Proyek		Grogzjaban - Bawen Tol Pand		
		Lokasi		Arao Srit		
		Hari Pengamatan		Day 4		
Spesifikasi Dump Truck						
Merk Dump Truck	Hino Dutro					
Tipe Dump Truck	-					
Ukuran Dump Truck	9.8 m ³					
Kondisi Alat	Baik					
Bahan Bakar	-					
Upah Operator	Rp. 52.000 / hrp					
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Pagi	08.00 - 11.00	1	2.34	38.5	0.413	15.4
		2	2.37	30.1	0.467	14.3
		3	2.03	35	0.350	17.9
Siang	11.00 - 14.00	1	2.31	34.3	0.485	16.2
		2	2.31	32.4	0.400	16.8
		3	2.42	30.9	0.357	15.9
Sore	14.00 - 16.00	1	2.49	32.2	0.400	16.6
		2	3.32	34.8	0.433	17.1
		3	2.38	35	0.393	18
Rata-Rata			2.510	33.738	0.409	16.044
Waktu Siklus Rata-rata						
Mengetahui Staff Lapangan/Proyek						Catatan
						
(Nur Khidit)						

Appendix 25 Cycle Time Dump Truck Hino Dutro Day 5

Pengamatan Produktivitas Dump Truck		Nama Proyek		Uyungjaya - Gunung Tali Road		
		Lokasi		Ara 5 th		
		Hari Pengamatan		Dah 5		
Spesifikasi Dump Truck						
Merk Dump Truck	Hino					
Type Dump Truck						
Ukuran Dump Truck	9.8 m ³					
Kondisi Alat	baik					
Bahan Bakar	-					
Upah Operator	Rp. 22.000					
Sesi	Jam	Siklus	Waktu Muat (menit)	Waktu Angkut (menit)	Waktu Buang (menit)	Waktu Kembali (menit)
Morning	08.00 - 11.00	1	2.08	20.9	0.6	11.6
		2	2.05	20.8	0.45	11.6
		3	2.1	20.6	0.45	11.4
Afternoon	11.00 - 12.00 13.00 - 14.00	1	3.05	31.2	0.45	16.1
		2	2.8	31.2	0.40	16.1
		3	2.74	30.7	0.40	16.0
Evening	14.00 - 16.00	1	3.09	30.1	0.45	15.8
		2	3.35	31	0.45	16.3
		3	3.24	30.3	0.45	15.6
			2.998	29.3	0.44	11.11
Rata-Rata Waktu Siklus Rata-rata			3.1	31.12		
Mengetahui Staff Lapangan/Proyek						
<div></div> <div>(Nur Khalis)</div>						
Catatan						

Appendix 26 Cycle Time Bulldozer Day 1

Pengamatan Produktivitas		Nama Proyek		Yogyakarta - Bantul Tali Bund			
Excavator		Lokasi		Pena 5th			
		Hari Pengamatan		Diyg 4			
Spesifikasi Excavator							
Mark Excavator	7700000						
Type Excavator	7500000						
Ukuran Excavator	1 m ³						
Kondisi Alat	Baik						
Bahan Bakar	200 / jam						
Upah Operator	Rp. 100.000						
Sesi	Jam	Siklus	Gali (detik)	Putar isi (detik)	Buang (detik)	Putar Kosong (detik)	
Morning	08:00 - 11:00	1	3:30	2:30	6:30	3:30	
		2	3:45	3:00	3:30	3:00	
		3	3:35	3:30	3:30	3:15	
Afternoon	11:00 - 03:00	1	4:10	4:30	5:00	6:00	
		2	3:45	4:30	3:30	3:30	
		3	3:45	4:30	3:30	3:30	
Evening	19:00 - 21:00	1	3:30	3:30	3:30	3:30	
		2	3:30	3:30	3:30	3:30	
		3	3:30	3:30	3:30	3:30	
Rata-Rata			3:30	3:30	3:30	3:30	
Waktu Siklus Rata-rata			12:00				
Mengetahui Staf Lapangan/Proyek							Catatan
							
(Nur Idrus)							

Appendix 27 Cycle Time Bulldozer Day 2

Pengamatan Produktivitas Bulldozer		Nama Proyek		Uruslah - Baur Tol Pad			
		Lokasi		Ara. Gal			
		Hari Pengamatan		Day 2			
Spesifikasi Bulldozer							
Merk Bulldozer	Zamkon 90 (10-3)						
Tipe Bulldozer	Crawler Dozer						
Ukuran Blade							
Kondisi Alat	Baik						
Bahan Bakar	10 L / jam						
Upah Operator	Rp. 35.000						
Waktu Siklus							
Sesi	Jam	Jarak Angkut	Maju (detik)	Kecepatan maju (m/detik)	Mundur (detik)	Kecepatan Mundur (m/detik)	Ganti persneling (detik)
Pagi 08.00 - 11.00							
1	08	30	44	1.34	18	2.08	1.44
2	08	30	34	1.47	13	2.05	1.34
3	08	30	44	1.34	15	2.22	1.44
4	08	30	43	1.43	14	2.22	1.44
5	08	30	40	1.46	14	2.28	1.3
6	08	30	40	1.46	14	2.22	2.24
7	08	30	43	1.41	17	2.24	1.88
8	08	30	44	1.36	16	2.00	1.43
9	08	30	45	1.33	12	4.17	1.44
10	08	30	43	1.43	15	2.33	1.73
Siang 11.00 - 12.00							
1	11	30	40	1.38	16	3.13	1.42
2	11	30	43	1.36	15	3.05	2.01
3	11	30	46	1.41	15	3.33	1.91
4	11	30	41	1.49	12	2.77	2.32
5	11	30	43	1.43	14	2.48	1.21
Rata-rata							
Waktu Siklus rata-rata							
Mengetahui Staff Lapangan/Proyek						Catatan	
 (Nur Hani)							

Appendix 28 Cycle Time Bulldozer Day 3

Pengamatan Produktivitas Bulldozer		Nama Proyek		Uruslah - Baur Tol Pad			
		Lokasi		Ara. Gal			
		Hari Pengamatan		Day 2			
Spesifikasi Bulldozer							
Merk Bulldozer	Zamkon 90 (10-3)						
Tipe Bulldozer	Crawler Dozer						
Ukuran Blade							
Kondisi Alat	Baik						
Bahan Bakar	10 L / jam						
Upah Operator	Rp. 35.000						
Waktu Siklus							
Sesi	Jam	Jarak Angkut	Maju (detik)	Kecepatan maju (m/detik)	Mundur (detik)	Kecepatan Mundur (m/detik)	Ganti persneling (detik)
Pagi 08.00 - 11.00							
1	08	30	44	1.34	18	2.08	1.44
2	08	30	34	1.47	13	2.05	1.34
3	08	30	44	1.34	15	2.22	1.44
4	08	30	43	1.43	14	2.22	1.44
5	08	30	40	1.46	14	2.28	1.3
6	08	30	40	1.46	14	2.22	2.24
7	08	30	43	1.41	17	2.24	1.88
8	08	30	44	1.36	16	2.00	1.43
9	08	30	45	1.33	12	4.17	1.44
10	08	30	43	1.43	15	2.33	1.73
Siang 11.00 - 12.00							
1	11	30	40	1.38	16	3.13	1.42
2	11	30	43	1.36	15	3.05	2.01
3	11	30	46	1.41	15	3.33	1.91
4	11	30	41	1.49	12	2.77	2.32
5	11	30	43	1.43	14	2.48	1.21
Rata-rata							
Waktu Siklus rata-rata							
Mengetahui Staff Lapangan/Proyek						Catatan	
 (Nur Hani)							

Appendix 29 Cycle Time Bulldozer Day 4

Pengamatan Produktivitas Bulldozer		Nama Proyek		Uppasulabo - Bauri Titi Dad			
		Lokasi		Ara. Gal			
		Hari Pengamatan		Day 4			
Spesifikasi Bulldozer							
Merk Bulldozer	Zamkon 90 (10-3)						
Tipe Bulldozer	Crawler Dozer						
Ukuran Blade							
Kondisi Alat	Baik						
Bahan Bakar	10 L / jam						
Upah Operator	Rp. 35.000						
Waktu Siklus							
Sesi	Jam	Jarak Angkut	Maju (detik)	Kecepatan maju (m/detik)	Mundur (detik)	Kecepatan Mundur (m/detik)	Ganti persneling (detik)
Morning 08.00 - 11.00							
1		20	44	1.136	18	2.78	1.44
2		20	34	1.471	13	3.85	1.33
3		20	44	1.136	15	3.33	1.41
4		20	43	1.163	14	3.21	1.43
5		20	40	1.160	14	3.48	1.3
6		20	40	1.160	12	3.23	2.34
7		20	43	1.11	17	3.94	1.81
8		20	44	1.136	12	2.00	1.43
9		20	45	1.11	12	4.17	1.44
10		20	43	1.163	15	3.33	1.73
Afternoon 11.00 - 11.00							
1		20	40	1.20	16	3.13	1.42
2		20	43	1.136	15	3.85	2.01
3		20	46	1.111	12	3.33	1.91
4		20	41	1.194	12	2.77	2.32
5		20	43	1.163	14	2.98	1.21
Rata-rata							
Waktu Siklus rata-rata							
Mengetahui Staff Lapangan/Proyek						Catatan	
 (Nur Hani)							

Appendix 30 Cycle Time Bulldozer Day 5

Pengamatan Produktivitas Bulldozer		Nama Proyek		Uppasulabo - Bauri Titi Dad			
		Lokasi		Ara. Gal			
		Hari Pengamatan		Day 5			
Spesifikasi Bulldozer							
Merk Bulldozer	Zamkon 90 (10-3)						
Tipe Bulldozer	Crawler Dozer						
Ukuran Blade							
Kondisi Alat	Baik						
Bahan Bakar	10 L / jam						
Upah Operator	Rp. 35.000						
Waktu Siklus							
Sesi	Jam	Jarak Angkut	Maju (detik)	Kecepatan maju (m/detik)	Mundur (detik)	Kecepatan Mundur (m/detik)	Ganti persneling (detik)
Morning 08.00 - 11.00							
1		20	44	1.136	18	2.78	1.44
2		20	34	1.471	13	3.85	1.33
3		20	44	1.136	15	3.33	1.41
4		20	43	1.163	14	3.21	1.43
5		20	40	1.160	14	3.48	1.3
6		20	40	1.160	12	3.23	2.34
7		20	43	1.11	17	3.94	1.81
8		20	44	1.136	12	2.00	1.43
9		20	45	1.11	12	4.17	1.44
10		20	43	1.163	15	3.33	1.73
Afternoon 11.00 - 11.00							
1		20	40	1.20	16	3.13	1.42
2		20	43	1.136	15	3.85	2.01
3		20	46	1.111	12	3.33	1.91
4		20	41	1.194	12	2.77	2.32
5		20	43	1.163	14	2.98	1.21
Rata-rata							
Waktu Siklus rata-rata							
Mengetahui Staff Lapangan/Proyek						Catatan	
 (Nur Hani)							

Appendix 31 Cycle Time Sheepsfoot Roller Day 1

Pengamatan Produktivitas SheepsFoot		Nama Proyek	Uppskatu- Dusun Tdi Dend	
		Lokasi	Area 4A	
		Hari Pengamatan	Day 1	
Spesifikasi Sheepsfoot				
Merk Alat	XCMG X558D			
Tipe Alat				
Ukuran Alat	2.5 x 1.5			
Kondisi Alat	Baik			
Bahan Bakar	12.6 / jam			
Upah Operator	Rp. 225.000			
Waktu Siklus				
Waktu	Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)
Mening	Apikmen			
1	1	1	18	60
2	2	2	18	60
3	3	3	19	60
4	4	4	20	60
5	5	5	26	60
6	6	6	28	60
7	7	7	28	60
8	8	8	29	60
9	9	9	28	60
10	10	10	26	60
11	11	11	28	60
12	12	12	26	60
13	13	13	25	60
14	14	14	25	60
15	15	15	26	60
16	16	16	26	60
17	17	17	25	60
18	18	18	25	60
19	19	19	26	60
20	20	20	26	60
21	21	21	26	60
22	22	22	26	60
23	23	23	26	60
24	24	24	26	60
25	25	25	26	60
26	26	26	26	60
27	27	27	26	60
28	28	28	26	60
29	29	29	26	60
30	30	30	26	60
31	31	31	26	60
32	32	32	26	60
33	33	33	26	60
34	34	34	26	60
35	35	35	26	60
36	36	36	26	60
37	37	37	26	60
38	38	38	26	60
39	39	39	26	60
40	40	40	26	60
41	41	41	26	60
42	42	42	26	60
43	43	43	26	60
44	44	44	26	60
45	45	45	26	60
46	46	46	26	60
47	47	47	26	60
48	48	48	26	60
49	49	49	26	60
50	50	50	26	60
51	51	51	26	60
52	52	52	26	60
53	53	53	26	60
54	54	54	26	60
55	55	55	26	60
56	56	56	26	60
57	57	57	26	60
58	58	58	26	60
59	59	59	26	60
60	60	60	26	60
61	61	61	26	60
62	62	62	26	60
63	63	63	26	60
64	64	64	26	60
65	65	65	26	60
66	66	66	26	60
67	67	67	26	60
68	68	68	26	60
69	69	69	26	60
70	70	70	26	60
71	71	71	26	60
72	72	72	26	60
73	73	73	26	60
74	74	74	26	60
75	75	75	26	60
76	76	76	26	60
77	77	77	26	60
78	78	78	26	60
79	79	79	26	60
80	80	80	26	60
81	81	81	26	60
82	82	82	26	60
83	83	83	26	60
84	84	84	26	60
85	85	85	26	60
86	86	86	26	60
87	87	87	26	60
88	88	88	26	60
89	89	89	26	60
90	90	90	26	60
91	91	91	26	60
92	92	92	26	60
93	93	93	26	60
94	94	94	26	60
95	95	95	26	60
96	96	96	26	60
97	97	97	26	60
98	98	98	26	60
99	99	99	26	60
100	100	100	26	60
Mengetahui Staff Lapangan/Proyek				
<div> (Nur Hidar)</div>				

Appendix 32 Cycle Time Vibratory Roller Day 1

Pengamatan Produktivitas SheepsFoot		Nama Proyek	Uppskatu- Dusun Tdi Dend	
		Lokasi	Area 4A	
		Hari Pengamatan	Day 1	
Spesifikasi Sheepsfoot				
Merk Alat	XCMG X558D			
Tipe Alat				
Ukuran Alat	2.5 x 1.5			
Kondisi Alat	Baik			
Bahan Bakar	12.6 / jam			
Upah Operator	Rp. 225.000			
Waktu Siklus				
Waktu	Sesi	Waktu dalam 1 lintasan (detik)	Jarak Pemadatan (m)	Kecepatan (m/s)
Mening	Apikmen			
1	1	1	18	60
2	2	2	18	60
3	3	3	19	60
4	4	4	20	60
5	5	5	26	60
6	6	6	28	60
7	7	7	28	60
8	8	8	29	60
9	9	9	28	60
10	10	10	26	60
11	11	11	28	60
12	12	12	26	60
13	13	13	25	60
14	14	14	25	60
15	15	15	26	60
16	16	16	26	60
17	17	17	25	60
18	18	18	25	60
19	19	19	26	60
20	20	20	26	60
21	21	21	26	60
22	22	22	26	60
23	23	23	26	60
24	24	24	26	60
25	25	25	26	60
26	26	26	26	60
27	27	27	26	60
28	28	28	26	60
29	29	29	26	60
30	30	30	26	60
31	31	31	26	60
32	32	32	26	60
33	33	33	26	60
34	34	34	26	60
35	35	35	26	60
36	36	36	26	60
37	37	37	26	60
38	38	38	26	60
39	39	39	26	60
40	40	40	26	60
41	41	41	26	60
42	42	42	26	60
43	43	43	26	60
44	44	44	26	60
45	45	45	26	60
46	46	46	26	60
47	47	47	26	60
48	48	48	26	60
49	49	49	26	60
50	50	50	26	60
51	51	51	26	60
52	52	52	26	60
53	53	53	26	60
54	54	54	26	60
55	55	55	26	60
56	56	56	26	60
57	57	57	26	60
58	58	58	26	60
59	59	59	26	60
60	60	60	26	60
61	61	61	26	60
62	62	62	26	60
63	63	63	26	60
64	64	64	26	60
65	65	65	26	60
66	66	66	26	60
67	67	67	26	60
68	68	68	26	60
69	69	69	26	60
70	70	70	26	60
71	71	71	26	60
72	72	72	26	60
73	73	73	26	60
74	74	74	26	60
75	75	75	26	60
76	76	76	26	60
77	77	77	26	60
78	78	78	26	60
79	79	79	26	60
80	80	80	26	60
81	81	81	26	60
82	82	82	26	60
83	83	83	26	60
84	84	84	26	60
85	85	85	26	60
86	86	86	26	60
87	87	87	26	60
88	88	88	26	60
89	89	89	26	60
90	90	90	26	60
91	91	91	26	60
92	92	92	26	60
93	93	93	26	60
94	94	94	26	60
95	95	95	26	60
96	96	96	26	60
97	97	97	26	60
98	98	98	26	60
99	99	99	26	60
100	100	100	26	60
Mengetahui Staff Lapangan/Proyek				
<div></div> <div>(Nur Hidar)</div>				

Appendix 33 Observation of Heavy Equipment Non-Productive Time Day 1

Nama Proyek : Ujungbatan - Bawen Toll Road
 Lokasi : Area 5A
 Hari Pengamatan : Day 1
 Pengamat : Wafiq Nur Satri

Heavy Equipment	Sesi Pengamatan	Waktu berhenti (min)	Rata-rata	Keterangan
Excavator	Pagi	5	$\frac{5+0+5}{3}$	The operator broke a bucket
	Siang	12		
	Sore	5	$\frac{5+0+5}{3}$	
DT Isuzu	Pagi	10	$\frac{10+10+10}{3}$	Anti
	Siang	11		
	Sore	11	$\frac{10+10+10}{3}$	
DT Toyota	Pagi	10	$\frac{10+10+10}{3}$	Anti
	Siang	13		
	Sore	11	$\frac{10+10+10}{3}$	
DT Mitsubishi	Pagi	15	$\frac{15+15+15}{3}$	Anti
	Siang	20		
	Sore	10	$\frac{15+15+15}{3}$	
DT Hino Dutro	Pagi	10	$\frac{10+10+10}{3}$	Anti
	Siang	12		
	Sore	11	$\frac{10+10+10}{3}$	
Dozer	Pagi	13	$\frac{13+13+13}{3}$	waiting for material
	Siang	3		
	Sore	11	$\frac{13+13+13}{3}$	
Sheepsfoot	Pagi	15	$\frac{15+15+15}{3}$	waiting for material
	Siang	10		
	Sore	15	$\frac{15+15+15}{3}$	
Vibratory Roller	Pagi	10	$\frac{10+10+10}{3}$	waiting for material
	Siang	13		
	Sore	10	$\frac{10+10+10}{3}$	
MENGETAHUI STAFF LAPANGAN/PROYEK			CATATAN	
				
(Nur Kholis)				

Appendix 34 Observation of Heavy Equipment Non-Productive Time Day 2

Nama Proyek : Ujungbatan - Bawen Toll Road
 Lokasi : Day 2 Area 5A
 Hari Pengamatan : Day 2
 Pengamat : Wafiq Nur Satri

Heavy Equipment	Sesi Pengamatan	Waktu berhenti	Rata-rata	Keterangan
Excavator	Pagi	0	$\frac{0+0+0}{3}$	waiting to be in action at position
	Siang	10		
	Sore	5	$\frac{0+0+0}{3}$	
DT Isuzu	Pagi	12	$\frac{12+12+12}{3}$	Anti
	Siang	18		
	Sore	11	$\frac{12+12+12}{3}$	
DT Toyota	Pagi	11	$\frac{11+11+11}{3}$	Anti
	Siang	10		
	Sore	15	$\frac{11+11+11}{3}$	
DT Mitsubishi	Pagi	8	$\frac{8+8+8}{3}$	Anti
	Siang	11		
	Sore	11	$\frac{8+8+8}{3}$	
DT Hino Dutro	Pagi	8	$\frac{8+8+8}{3}$	Anti
	Siang	18		
	Sore	15	$\frac{8+8+8}{3}$	
Dozer	Pagi	11	$\frac{11+11+11}{3}$	waiting for material
	Siang	15		
	Sore	5	$\frac{11+11+11}{3}$	
Sheepsfoot	Pagi	8	$\frac{8+8+8}{3}$	waiting for material
	Siang	6		
	Sore	8	$\frac{8+8+8}{3}$	
Vibratory Roller	Pagi	5	$\frac{5+5+5}{3}$	waiting for material
	Siang	15		
	Sore	11	$\frac{5+5+5}{3}$	
MENGETAHUI STAFF LAPANGAN/PROYEK			CATATAN	
 (Nur Kholis)				

Appendix 35 Observation of Heavy Equipment Non-Productive Time Day 3

Nama Proyek : Ujung Genteng - Kawasan Tirta Ponds
 Lokasi : Dug-2 Area Esol
 Hari Pengamatan : Rabu
 Pengamat : Wafiq Nur Bidin

Heavy Equipment	Sesi Pengamatan	Waktu berhenti	Rata-rata	Keterangan
Excavator	Pagi	8	$8 + 10 + 5$	waiting to be in motion and position
	Siang	10	$\frac{3}{3}$	
	Sore	5	$\frac{1}{1.667}$	
DT Isuzu	Pagi	12	$12 + 10 + 15$	Aditi
	Siang	18	$\frac{3}{3}$	
	Sore	31	$\frac{1}{12.333}$	
DT Toyota	Pagi	17	$17 + 10 + 15$	Aditi
	Siang	20	$\frac{3}{3}$	
	Sore	25	$\frac{1}{1.111}$	
DT Mitsubishi	Pagi	8	$8 + 10 + 15$	Aditi
	Siang	31	$\frac{3}{3}$	
	Sore	24	$\frac{1}{1.416}$	
DT Hino Dutro	Pagi	8	$8 + 10 + 15$	Aditi
	Siang	18	$\frac{3}{3}$	
	Sore	25	$\frac{1}{10.333}$	
Dozer	Pagi	11	$11 + 15 + 25$	waiting for maintenance
	Siang	15	$\frac{3}{3}$	
	Sore	5	$\frac{1}{11.667}$	
Sheepsfoot	Pagi	8	$8 + 10 + 15$	waiting for maintenance
	Siang	6	$\frac{3}{3}$	
	Sore	8	$\frac{1}{8}$	
Vibratory Roller	Pagi	5	$5 + 15 + 14$	waiting for maintenance
	Siang	15	$\frac{3}{3}$	
	Sore	4	$\frac{1}{2.777}$	
MENGETAHUI STAFF LAPANGAN/PROYEK			CATATAN	
 (Nur Kholis)				

Appendix 36 Observation of Heavy Equipment Non-Productive Time Day 4

Nama Proyek : Ujung Genteng - Kawasan Tirta Ponds
 Lokasi : Dug-2 Area Esol
 Hari Pengamatan : Kamis
 Pengamat : Wafiq Nur Bidin

Heavy Equipment	Sesi Pengamatan	Waktu berhenti	Rata-rata	Keterangan
Excavator	Pagi	8	$8 + 10 + 5$ $\frac{3}{3}$	waiting to be in motion and position
	Siang	10	$\frac{1}{1.667}$	
	Sore	5		
DT Isuzu	Pagi	12	$12 + 10 + 15$ $\frac{3}{3}$	Aditi
	Siang	18	$\frac{1}{12.333}$	
	Sore	31		
DT Toyota	Pagi	17	$17 + 10 + 15$ $\frac{3}{3}$	Aditi
	Siang	20	$\frac{1}{1.111}$	
	Sore	25		
DT Mitsubishi	Pagi	8	$8 + 10 + 15$ $\frac{3}{3}$	Aditi
	Siang	31	$\frac{1}{1.416}$	
	Sore	24		
DT Hino Dutro	Pagi	8	$8 + 10 + 15$ $\frac{3}{3}$	Aditi
	Siang	18	$\frac{1}{10.333}$	
	Sore	25		
Dozer	Pagi	11	$11 + 15 + 25$ $\frac{3}{3}$	waiting for maintenance
	Siang	15	$\frac{1}{11.667}$	
	Sore	5		
Sheepsfoot	Pagi	8	$8 + 10 + 15$ $\frac{3}{3}$	waiting for maintenance
	Siang	6	$\frac{1}{8}$	
	Sore	8		
Vibratory Roller	Pagi	5	$5 + 15 + 14$ $\frac{3}{3}$	waiting for maintenance
	Siang	15	$\frac{1}{2.777}$	
	Sore	4		
MENGETAHUI STAFF LAPANGAN/PROYEK			CATATAN	
 (Nur Kholis)				

Appendix 37 Observation of Heavy Equipment Non-Productive Time Day 5

Nama Proyek : Ujung Genteng - Bowen Toll Road
 Lokasi : Dugur Area 201
 Hari Pengamatan : 04/02
 Pengamat : Wafiq Nur Bidi

Heavy Equipment	Sesi Pengamatan	Waktu berhenti	Rata-rata	Keterangan
Excavator	Pagi	8	$8:10-15$ 3	uang 10 di 10 maka ke pushon
	Siang	10		
	Sore	5	$1:16:13$	
DT Isuzu	Pagi	12	$12:10-15$ 3	Adi
	Siang	18		
	Sore	31	$1:12:15$	
DT Toyota	Pagi	13	$13:10-15$ 3	Adi
	Siang	20		
	Sore	15	$1:14$	
DT Mitsubishi	Pagi	8	$8:10-15$ 3	Adi
	Siang	31		
	Sore	24	$1:14:15$	
DT Hino Dutro	Pagi	8	$8:10-15$ 3	Adi
	Siang	18		
	Sore	15	$1:10:15$	
Dozer	Pagi	11	$11:15-15$ 3	uang 10 di 10 maka ke pushon
	Siang	15		
	Sore	5	$1:16:13$	
Sheepsfoot	Pagi	8	$8:10-15$ 3	uang 10 di 10 maka ke pushon
	Siang	6		
	Sore	8	$1:10:15$	
Vibratory Roller	Pagi	5	$5:15-15$ 3	uang 10 di 10 maka ke pushon
	Siang	15		
	Sore	4	$1:11:15$	
MENGETAHUI STAFF LAPANGAN/PROYEK			CATATAN	
				
(Nur Kholis)				

Appendix 38 Summary of Properties Testing Results



RANGKUMAN HASIL PENGUJIAN PROPERTIES

**QUARY :
GUNUNG KWAGON**

(PERIODE : 22 Februari 2025 - 28 Februari 2025)

1. Maksud dan Tujuan
 Untuk menguji sifat fisik atau indeks properties yang meliputi Kapadatan Laboratorium, kadar air, berat jenis tanah, atterberg limit, daya dukung tanah, analisa saringan. Sebagai kontrol / pengendalian mutu di lapangan.

II. Jenis Pengujian

- Indeks Properties
 - * Kadar air untuk tanah SNI 1965 : 2008
 - * Berat Jenis Tanah SNI 1964 : 2008
 - * Batas Cair Tanah SNI 1967 : 2008
- Tabel klasifikasi tanah (USCS) SNI 03 6371-2000
- Kapadatan tanah (Standard Proctor) SNI 1742 : 2008
- Analisa Saringan SNI 3423 : 2008
- CBR Laboratorium SNI 1744 : 2012
- Pengujian Dilapangan
 - * DCP Test SEM PU No. 04/SE/M/2010
 - * Sandcone Test SNI 2838:2011
 - * CBR Lapangan SNI 1738:2011

III. Hasil Test

- Kapadatan tanah (Standard Proctor)
 - * Kadar Air Optimum : 12.66 %
 - * y Dry Max : 1.832 gr/cm³
 - * Berat Jenis : 2.554 gr/cm³
- Atterberg Limit
 - * Batas Cair (LL) : 35.09 %
 - * Plastic Limit : 30.16 %
 - * Plasticity Index : 5.73 %
- * Type Material : GM - Kerikil Lempung dengan Pasir
- CBR Laboratorium (Soaked)
 - * 95% yD MAXIMUM : 1.740 gr/cm³
 - * CBR : 12.24 %
- Analisa Saringan

No Saringan	% Lolos	Persentase kandungan
# 3/8"	100.00	Gravel 37.68
# 4	75.70	Sand 31.64
# 10	62.32	Silt 28.54
# 60	52.53	Clay 2.14
# 200	30.68	Activity 0.19

Diketahui Oleh :
 PT. Jasa Marga Ingg - Bowen

Diperiksa & Diuji Oleh :
 PT. Eskapindo Matra KSO PT. JKG

Dijadikan Oleh :
 ADRI-MTM, KSO

Appendix 39 Research Time Schedule

No	Uraian Kegiatan	Jam Kerja (Hour)	1				2				3				4				5				6			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A	Preparation																									
	Literature Study	20	2	2	2	2	2	2	2	2	2	2														
B	Data Collection																									
	Secondary data collection	20											10	10												
	conducting heavy equipment specification interviews	35													7	7	7	7	7							
	Observation and Recording of Working Hours of Each Equipm	35													7	7	7	7	7							
C	Data Processing and Analysis																									
	Data Processing	20																	10	10						
	Data Analysis	30																		10	10	10				
D	Compile the Final Project Report																									
	Temporary Report	15																					10	5		
	Finalized Report	15																						10	5	
	Total	190																								
	Weekly Plan (Hour)		2	2	2	2	2	2	2	2	2	2	10	10	14	14	14	14	14	10	20	10	10	10	15	5
	Cumulative		2	4	6	8	10	12	14	16	18	20	30	40	54	68	82	96	110	120	140	150	160	170	185	190