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Efficiency Analysis of the Combination of Heavy Equipment Use in Excavation and Landfill Work in Road Construction Projects

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Abstract: An efficient heavy equipment management system is needed to complete a earthwork on time. This study aims to analyze the productivity and efficiency of the combination of heavy equipment used in excavation and heap work. Heavy equipment productivity is calculated based on cycle time in the field and its needs are calculated based on the volume of the weekly plan. After that, an efficient combination of heavy equipment planning is carried out for excavation and heaping work. The method of calculating heavy equipment needs uses a theoretical approach, with cycle time adjustments based on operational conditions in the field. Efficiency analysis and heavy equipment selection are carried out based on the idle time of the smallest heavy equipment. The Optimal cut-fill Pairing and Sequencing (OPS) method is used to create a scheme of excavation and heaping work. The results of the analysis showed that the most efficient combination of heavy equipment used in excavation work of 14,467.66 BCM every week was 4 units of Kobelco PC 200 excavators, 2 units of Kobelco SK 330 excavators, and 10 units of Hino 500 dump trucks. Meanwhile, in the backfill work of 5,423.96 CCM every week, 1 unit of Komatsu D68ESS bulldozer, 1 unit of Sakai SV512TF sheepfoot roller, and 1 unit of Sakai vibro roller SV512TF are needed. This combination is chosen based on the value of the smallest idle time. With proper planning, high work efficiency, operational cost savings, and project completion are achieved according to the set schedule.

Keywords: Heavy Equipment, Productivity, Idle Time, Efficiency, Combination.

Introduction

In the construction of project X, many challenges must be faced, such as difficult terrain conditions, accessibility, resources, security and safety (Kausari). This project includes several works, such as excavation, heaping, bridges, drainage, and road pavement work. Excavation and heaping are the primary focus of this project's construction because they involve a considerable volume of work. There is a lot of excavation work that is deep enough to reach a depth of approximately 20 (twenty) meters, as well as high hoarding work, which requires a prolonged duration.

Hard rocks dominate the type of excavated material in this project, so a blasting process is required to break the parent rock so excavation work can be carried out. In addition, difficult terrain conditions in the form of high cliffs and steep valleys with extreme topography make the excavation work process less than optimal. With this, adequate human resources and equipment are needed, with the proper methods (Hidayat, 2022) (Damayanti et al., 2023).

Heavy equipment is a vital resource on large construction jobs (Sherafat et al., 2020). Using heavy equipment will produce practical, economical, and perfect work. A practical and economical heavy equipment management system is needed to complete the earthwork on time (S. S. Lee et al., 2018). Heavy equipment management involves the planning, implementation, and control of heavy equipment used in the construction of a construction project (Kurniawati & Putra, 2024). Using heavy equipment without a sound and correct equipment management system will result in project delays that can cause additional costs and losses. Thus, analysing the effectiveness of heavy equipment use is very important to identify and evaluate for a project's success (Febrianti & Zulyaden, 2017).

The selection of heavy equipment must be adjusted to several things such as the type of project, project location, capital and so on. The data used in calculating the efficiency of heavy equipment includes heavy equipment specifications, transverse cut drawings, work schedules and volumes of excavation and heaping work (Asshiddiqie et al., 2020). This is done to produce a research that is in accordance with the original conditions (Sarmada et al., 2022).

Based on this background, the researcher studied the productivity and combination of heavy equipment used in excavation and stockpile work in Project X. This study aims to provide information about the efficient combination of heavy equipment when used in excavation and stockpile work.

The steps in the calculation of the efficiency of the combination of heavy equipment are as follows:

1. Determine the volume of the work plan.
2. Identify the duration of the job.
3. Identify the type, number and function of existing heavy equipment.
4. Survey of the heavy equipment cycle time according to its type.
5. Perform productivity calculations for each type of heavy equipment. This productivity calculation refers to the PUPR Ministerial Regulation No. 11 2013. (Indonensia, 2013)
   a. Excavator

$$Q = \frac{V \times \Sigma n \times F_b \times F_a \times 60}{(T_{s1} \times \Sigma n) + T_w}$$

Information:

Q = Excavator production capacity (m^3/hour)
V = Bucket capacity (m^3)
F_b = Bucket factor (m^3)
F_a = Tool efficiency factor
T_s = Cycle time (minutes)
T_w = Dump truck time takes loading position (minutes)

Σn = Average number of buckets
60 = multiply 1 hour by minutes

b. Dump Truck

$$Q = \frac{V \times \Sigma n \times F_a \times 60}{T_s}$$

Information:
Q = Dump truck production capacity (m^3)
V = Bucket capacity (m^3)
Σn = Number of buckets
F_a = Tool efficiency factor
T_s = Cycle time (minutes)
60 = multiply 1 hour by minutes

c. Bulldozer

$$\text{Q} = \frac{l \times (n(L - L_0) + L_0) \times F_b \times F_m \times F_a \times 60}{N \times n \times T_s}$$

Information:
Q = Production for leveling (m^2/hour)
F_b = Blade factor (generally easy, taken 1)
F_a = Tool efficiency factor
F_m = Blade tilt factor (taken 1 for flat, 1.2 for -15% drop, 0.7 to climb +15%)
L = Blade width (m)
T_s = Cycle time (minutes)
60 = multiply 1 hour by minutes
L_0 = Overlap width (m)
l = Stripping distance
W = Width of stripping area
n =Number of track columns (columns)
N =Number of stripping pass columns (pass)

d. Sheepfoot Roller

$$\text{Q} = \frac{(b_e \times v \times 1000) \times t \times Fa}{n}$$

Information:
Q = Production every hour (m^3/hour)
b_e = Effective width of compaction (m)
t = Compaction thickness (m)
v = Average speed of the appliance (km/h)
n = Number of passes
Fa = Tool efficiency factor
1000 = Multiplication from km to m

e. Vibro Roller

$$Q = \frac{(b_e \times v \times 1000) \times t \times Fa}{n}$$

Information:

Q = Production every hour (m^3/hour)
b_e = Effective width of compaction (m)
t = Compaction thickness (m)
v = Average speed of the appliance (km/h)
n = Number of passes
Fa = Tool efficiency factor
1000 = Multiplication from km to m

1. Determine the location of excavation, heap, and disposal work.
2. Analyse the needs of heavy equipment.
3. Carry out excavation, heap work, and disposal.

Methodology

Planning heavy equipment combinations can be carried out after obtaining the productivity of each heavy equipment used, the needs of heavy equipment, and the volume of the heap excavation work plan in Project X. Combining heavy equipment planning is carried out to obtain the most efficient tools possible (Arga Rumbyarso, 2023).

The research method used in this study is the quantitative descriptive method. Quantitative method is a method with data expressed in numbers or the form of numbers (Djollong, 2014) To plan the combination of heavy equipment in excavation and hoarding work, a mathematical approach based on operational efficiency is used, with priority given to the equipment that has the lowest idle time to maximize productivity and avoid wasting resources. With this, the most efficient combination of heavy equipment is obtained and according to the needs in the field. This approach allows the evaluation of various tool usage scenarios based on production capacity, working time, and number of tools, so that optimal and realistic planning results can be obtained (Putra, 2025).

The method used to create a scheme for using heavy equipment in excavation and stockpile work is the Optimal Cut-Fill Pairing and Sequencing (OPS) method. The earthwork optimisation method is classified into equipment fleet planning (EFP) and earth allocation planning (EAP). EFP identifies the most profitable types of equipment, calculates anticipated earthwork productivity, calculates the optimal amount of equipment and allocates equipment at the right time and place on schedule (Gwak et al., 2018).

Result and Discussion

Work Plan Volume

In executing Project X work, the volume of work on each work item must be calculated. The volume of the plan to be used as a calculation of the efficiency of the use of heavy equipment is taken in the 25th week. The researcher took the volume of work plans for the week because there was more heavy equipment than in the previous weeks. In addition, excavation and stockpiling activities during the week are classified as the largest. The volume of the excavation and stockpile work plan in week 25 can be seen in the Table 1.

Table 1. Planned volume of excavation and embankment work week 25

Soil Conditions	Unit	Total Volume	Weight of Work	Weight of the Week 25th	Volume of Work Week 25th
Excavation					
Common Excavation	m^3	81.569,77	1,48	0,03	1.653,44
Soft Stone Excavation	m^3	162.670,04	7,12	0,15	3.427,04
Stone Excavation	m^3	422.539,69	36,96	0,77	8.802,91
Excavation for Drainage Ditches and Drains	m^3	9.145,50	0,165	0,01	554,27
				Total	14.437,66
Common Fill					
Common Fill from Excavation Result	m^3	261.555,45	4,34	0,09	5.423,96

Based on Table 1, in the 25th week there was a total volume of excavation work of 14,437.66 m^3 and of the heap work of 5,423.96 m^3.

Type and Number of Heavy Equipment

The selection of tools to be used in the implementation of excavation and heap work of Project X, needs to consider what work takes place in accordance with the order of the type of work.

1. Excavation requires heavy equipment to dredge the soil (digging) and carry materials (hauling) from the excavation site to the disposal area.
2. Landfill work requires heavy equipment to dredge soil from the excavation site into heavy equipment brought to the project site (hauling), where it is levelled and compacted.

Table 2. Heavy Equipment Recapitulation

Function	Heavy Equipment	Brand and Type	Capacity	Number of Tools
Excavation	Excavator	Kobelco SK 200	0.8 m^3	5
		Kobelco SK 330	1.4 m^3	4
		Kobelco SK 520	3.1 m^3	2
Hauling	Dump Truck	Hino 500	22 m^3	15
Perata	Bulldozer	Komatsu D68ESS	2.58 m^3	2
		Komatsu D85ESS	4.85 m^3	1
		Caterpillar D8R	10.71 m^3	1

Function	Heavy Equipment	Brand and Type	Capacity	Number of Tools
Compaction	Sheepfoot Roller	Sakai SV512TF	2.13 m	1
	Vibro roller	Sakai SV512TF	2.13 m	1
		Sakai SV515TF	2.13 m	1

Table 2 regarding the results of the recapitulation of heavy equipment summarizes the types of heavy equipment used based on their function, brand and type of equipment, work capacity, and the number of units available. There are 5 units of PC 200 excavators with a capacity of 0.8 m^3, 4 units of SK 330 excavators with a capacity of 1.4 m^3, and 2 units of SK 520 excavators with a capacity of 3.1 m^3. In the material transportation work, 15 units of Hino 500 dump trucks with a transport capacity of 22 m^3 were used. In the groundwater leveling work, 4 units of bulldozers of various brands and capacities were used, namely 2 units of Komatsu D68ESS with a capacity of 2.58 m^3, 1 unit of Komatsu D85ESS with a capacity of 4.85 m^3, and 1 unit of Caterpillar D8R with a capacity of 10.71 m^3. As for the compaction work, there are three units of compacting equipment, namely 1 unit of sheepfoot roller, and 2 units of vibro, each with a drum width of 2.13 meters.

Cycle Time of Heavy Equipment

In the implementation of heavy equipment, planning needs to consider cycle time, which is an essential aspect and cannot be ignored (Sokop et al., 2018) (H.-C. Lee et al., 2018). The cycle time is adjusted to real conditions in the field, such as the type of material, mileage, terrain conditions, and operator capabilities (Kaprina et al., 2018). The goal is to produce realistic, efficient, and by the project's operational needs (Fadri et al., 2024) (Prasmoro & Hasibuan, 2018). Details of the cycle time of the observation results of each heavy equipment used in the excavation and stacking work can be seen in Table 3-5

Table 3. Excavator Cycle Time

Types of excavators	Cycle Time (sec)	Cycle Time (minutes)
Kobelco SK 200 Excavator	19,7	0,328
Kobelco SK 330 Excavator	22,7	0,362
Kobelco SK 520 Excavator	24,4	0,407

Table 3 presents cycle time data for three types of Kobelco brand excavators, namely SK 200, SK 330, and SK 520. The Kobelco SK 200 Excavator has the fastest cycle time of 19.7 seconds, the Kobelco SK 330 Excavator has a cycle time of 22.7 seconds, and the Kobelco SK 520 Excavator has the longest cycle time of 24.4 seconds.

Table 4. Dump Truck Cycle Time

	Duration	Unit
A dump truck, when filled	8,90	Km/h
A dump truck when empty	15,07	Km/h
Duration of dumping	1,09	Minute
Duration of loading preparation	1,18	Minute

Table 4 shows the operating time and speed of a dump truck in the work cycle. When loaded, the dump truck moves slower at a speed of 8.90 km/h, and when empty the speed increases to 15.07 km/h. The process of discharging the load takes 1.09 minutes, while the preparation of the filling takes 1.18 minutes. This data is important for calculating the total cycle time and productivity of the conveyor.

Table 5. Average Excavator Bucket Count

Types of Excavator	Cycle Time (sec)
Kobelco SK 200 Excavator	19,7
Kobelco SK 330 Excavator	22,7
Kobelco SK 520 Excavator	24,4

Table 5 lists the average bucket fill cycle times for the three types of Kobelco excavators. SK 200 has the fastest cycle time of 19.7 seconds, followed by SK 330 with a cycle time of 22.7 seconds and SK 520 with a cycle time of 24.4 seconds. This difference reflects the increased capacity and size of the tool, whereas larger excavators take longer per cycle but move more volume of material.

Heavy Equipment Productivity

The use of heavy equipment is influenced by several aspects such as the selection of heavy equipment, the condition of the heavy equipment, the operator of the heavy equipment, and the condition of the work environment (Prasetiyo & Priyanto, 2023) (Handayani, 2017). The heavy equipment used in the project has different levels of productivity, depending on the type of equipment, capacity, operational conditions in the field, and the work efficiency of each unit (Prima & Hafudiansyah, 2022). The results of these productivity calculations reflect the ability of each tool to complete a specific volume of work in a given unit of time, such as cubic meters every hour (m^3/hour). This information is the basis for making decisions regarding the most efficient combination of heavy equipment. Details of the productivity calculation results for each heavy equipment used in excavation and heaping work can be seen in Table 6.

Table 6: Heavy Equipment Productivity

Heavy Equipment	Brand and Type	Productivity every hour	Unit	Daily productivity	Unit
Excavator	Kobelco SK 200	38,14	m^3/hour	419,51	m^3/day
	Kobelco SK 330	52,58	m^3/hour	581,24	m^3/day
	Kobelco SK 520	80,59	m^3/hour	886,52	m^3/day
Dump Truck	Hino 500	36,75	m^3/hour	404,28	m^3/day
Bulldozer	Komatsu D68ESS	531,99	m^2/hour	5851,87	m^2/day
	Komatsu D85ESS	679,88	m^2/hour	7478,73	m^2/day
	Caterpillar D8R	710,25	m^2/hour	7812,74	m^2/day
Sheepfoot Roller	Sakai SV512TF	273,4	m^3/hour	3007,4	m^3/day
Vibro roller	Sakai SV512TF	273,4	m^3/hour	3007,4	m^3/day
	Sakai SV515TF	273,4	m^3/hour	3007,4	m^3/day

Based on the results of the calculation of heavy equipment productivity, the productivity results of each tool used in project X were obtained. In the excavation work, 3 types of excavators with different capacities are used. The Kobelco PC 200 excavator has a productivity of 38.14 m^3/h, the Kobelco SK 330 excavator has a productivity of 52,58 m^3/h, and the Kobelco SK 520 excavator has a productivity of 80,59 m^3/h. For dump truck transport equipment, the Hino 500 type has a productivity of 36,75 m^3/h. In the ground leveling work, 3 types of bulldozers are used with various brands and capacities. The Komatsu D68ESS bulldozer has a productivity of 531,99 m^2/h, the Komatsu D85ESS bulldozer has a productivity of 679,88 m^2/h, and the Caterpillar D8R bulldozer has a productivity of 531,99 m^2/h. As for compaction work, there are two types of compaction tools, namely sheepfoot rollers, and vibro rollers. These compactors each have a productivity of 273.4 m^3/hour.

Heavy Equipment Needs

Planning of heavy equipment needs is carried out systematically by considering the volume of work that has been designed, the characteristics of the project terrain, and the availability of the type and number of heavy equipment in the field. This process aims to ensure that all construction activities can run efficiently, on time, and within budget (Novty, 2018). The analysis of heavy equipment selection is not only based on capacity and technical specifications, but also considers overall operational efficiency. The main priority is given to heavy equipment that has the lowest idle time, in order to maximize productivity in the field and minimize waste of fuel, time, and human resources (Thayeb, 2015). The following is presented with details of the needs of each heavy equipment to be used.

Excavator

The calculation of excavator needs is carried out by referring to the productivity of each type of tool, which has been calculated based on field conditions, type of work, and tool capacity. For each work site, the selection of the excavator type is carried out taking into account the lowest idle time or idle time. In this way, the utilization of heavy equipment can be optimized thereby reducing resource wastage and increasing the effectiveness of work in the field (Suharyanto & Erfanto, 2020). The following is a calculation of excavator needs based on the smallest idle time:

Table 7. Calculation of Excavator Needs

Type of work	Type of heavy equipment	Daily productivity (m^3/h)	Volume of work	Plan complated (day)	daily production plan	heavy equipment activities Total	heavy equipment activities Duration of work	daily production (m^3/day)	Daily working hours	Idle Time (h)	Use
2	3	4	5	6	7 = 5/6	8	9 = 7/(4x8)	10 = 4x8x9	11	12 = 11-9	13
Cut	Excavator										
	Kobelco PC 200	38.14				1	7.87	300.00	11	3.13	
Cut 1	Kobelco SK 330	52.84	1800	6	300.00	1	5.68	300.00	11	5.32	PC 200
	Kobelco SK 520	80.59				1	3.72	300.00	11	7.28	
	Kobelco PC 200	38.14				1	9.18	350.00	11	1.82	
Cut 2	Kobelco SK 330	52.84	2100	6	350.00	1	6.62	350.00	11	4.38	PC 200
	Kobelco SK 520	80.59				1	4.34	350.00	11	6.66	
	Kobelco PC 200	38.14				1	9.18	350.00	11	1.82	
Cut 3	Kobelco SK 330	52.84	2100	6	350.00	1	6.62	350.00	11	4.38	PC 200
	Kobelco SK 520	80.59				1	4.34	350.00	11	6.66	
	Kobelco PC 200	38.14				1	9.18	350.00	11	1.82	
Cut 4	Kobelco SK 330	52.84	2100	6	350.00	1	6.62	350.00	11	4.38	PC 200
	Kobelco SK 520	80.59				1	4.34	350.00	11	6.66	
	Kobelco PC 200	38.14				1	13.11	500.00	11	-2.11	
Cut 5	Kobelco SK 330	52.84	3000	6	500.00	1	9.46	500.00	11	1.54	SK 330
	Kobelco SK 520	80.59				1	6.20	500.00	11	4.80	
	Kobelco PC 200	38.14				1	13.11	500.00	11	-2.11	
Cut 6	Kobelco SK 330	52.84	3000	6	500.00	1	9.46	500.00	11	1.54	SK 330
	Kobelco SK 520	80.59				1	6.20	500.00	11	4.80	

Based on Table 7 regrading the analysis of the calculation of excavator needs for excavation work at six locations. To achieve the efficiency of the use of heavy equipment, the selection is based on the smallest idle time. The results of the analysis show that in excavation 1 the Kobelco PC 200 excavator was selected with the smallest idle time of 3.13

hours/day, in excavation 2 the Kobelco PC 200 excavator was selected with the smallest idle time of 1.82 hours/day, in excavation 3 the Kobelco PC 200 excavator was selected with the smallest idle time of 1.82 hours/day, in excavation 4 the Kobelco PC 200 excavator was selected with the smallest idle time of 1.82 hours/day, in excavation 5 the Kobelco SK 330 excavator with the smallest idle time of 1.54 hours/day was selected, and in excavation 6 the Kobelco SK 330 excavator was selected with the smallest idle time of 1.54 hours/day.

Dump Truck

In calculating the need for a dump truck, the distance travelled by the dump truck from the material loading location to the dumping location is the basis for calculating the travel duration. Therefore, the location of the material loading and the location of dumping are determined. The area for planning the combination of heavy equipment in excavation and landfill work was taken starting from STA 0+200 to 3+900. Excavated materials that have poor quality and are not needed will be disposed of, and good quality materials will be used as waste. The placement of the excavation location and the number of dump trucks needed for each excavation tool can be seen in the Table 9.

Table 8. Calculation of Dump Truck Needs

Type of work	Type of heavy equipment	Daily productivity (m³/h)	Volume of work	Plan complated (day)	daily production plan	heavy equipment activities: Total	heavy equipment activities: Duration of work	daily production (m³/day)	Daily working hours	Idle Time (h)	Use
2	3	4	5	6	7 = 5/6	8	9 = 7/(4x8)	10 = 4x8x9	11	12 = 11-9	13
Cut	Excavator										
Cut 1	Hino 500	36.75	1800	6	300.00	1	8.16	300.00	11	2.84	1 DT
Cut 2	Hino 500	34.18	2100	6	350.00	1	10.24	350.00	11	0.76	1 DT
Cut 3	Hino 500	18.56	2100	6	350.00	1	18.85	350.00	11	-7.85	2 DT
						2	9.43	350.00	11	1.57	
Cut 4	Hino 500	22.40	2100	6	350.00	1	15.62	350.00	11	-4.62	2 DT
						2	7.81	350.00	11	3.19	
Cut 5	Hino 500	25.82	3000	6	500.00	1	19.36	500.00	11	-8.36	2 DT
						2	9.68	500.00	11	1.32	
Cut 6	Hino 500	35.32	3000	6	500.00	1	14.16	500.00	11	-3.16	2 DT
						2	7.08	500.00	11	3.92	

Based on Table 8 regrading the analysis of the calculation of dump truck needs for excavation work at six locations. To achieve the efficiency of the use of heavy equipment, the selection is based on the smallest idle time. The results of the analysis show that in excavation 1, 1 unit of Hino 500 dump truck is needed with the smallest idle time of 2.84 hours/day; in excavation 2, 1 unit of Hino 500 dump truck is needed with the smallest idle time of 0.76 hours/day; in excavation 3, 2 unit of Hino 500 dump truck is needed with the smallest idle time of 1.57 hours/day; in excavation 4, 2 unit of Hino 500 dump truck is needed with the smallest idle time of 3.19 hours/day; in excavation 5, 2 unit of Hino 500 dump truck is needed with the smallest idle time of 1.32 hours/day; and in excavation 6, 2 unit of Hino 500 dump truck is needed with the smallest idle time of 3.92 hours/day.

Bulldozer

Bulldozer Use The use of bulldozers in this project is divided into 2 types of work, namely leveling work and stripping or cleaning of areas. However, this study only discusses heavy equipment in excavation and stockpile work. Therefore, the calculation of the need for a bulldozer is only carried out for the groundwater leveling work. There are 3 types of bulldozers that will be analyzed in this study, the following is a calculation of bulldozer needs:

Table 9. Calculation of Bullozer Needs

Type of work	Type of heavy equipment	Daily productivity (m^3/h)	Volume of work	Plan complated (day)	daily production plan	heavy equipment activities Total	Duration of work	daily production (m^3/day)	Daily working hours	Idle Time (h)	Use
2	3	4	5	6	7 = 5/6	8	9 = 7/(4x8)	10 = 4x8x9	11	12 = 11-9	13
	Bulldozer										
	Komatsu D68ESS	531.99	4910	6	818.33	1	1.54	818.33	11	9.46	Komatsu D68ESS
	Komatsu D85ESS	679.88				1	1.20	818.33	11	9.80	
	Caterpillar D8R	710.25				1	1.15	818.33	11	9.85	

Based on Table 9 regrading the results of the calculation of the need for heavy equipment for landfill leveling work, the Komatsu D68ESS bulldozer was chosen because it produces the least idle time of 9.48 hours/day, compared to other types.

Roller

Based on the analysis of roller calculations on the compaction of the landfill at one landfill location, the selection of the type of heavy equipment is based on the smallest idle time value to achieve maximum efficiency.

Table 10. Calculation of Roller Needs

Type of work	Type of heavy equipment	Daily productivity (m^3/h)	Volume of work	Plan complated (day)	daily production plan	heavy equipment activities Total	Duration of work	daily production (m^3/day)	Daily working hours	Idle Time (h)	Use
2	3	4	5	6	7 = 5/6	8	9 = 7/(4x8)	10 = 4x8x9	11	12 = 11-9	13
	Roller										
	Sheepfoot Roller	273.402	4910	6	818.33	1	2.99	818.33	11	8.01	
	Vibro Roller	273.402				1	2.99	818.33	11	8.01	

Based on Table 10 regrading the results of the calculation of the need for heavy equipment for the landfill leveling work, 1 unit of sheepfoot roller and vibro roller are needed. Idle time is 8.01 hours/day.

Heavy Equipment Combinations

After calculating the need for heavy equipment based on the planned work volume, taking into account the minimum idle time, the optimal number of heavy equipment for each work location is obtained. From the results of the analysis, the most efficient combination of heavy equipment was determined, thus supporting the smooth implementation of the project as a whole. Heavy equipment is needed for excavation work as many as 4 unit of PC 200 excavator, 2 unit of SK 330 excavator, 10 unit of dump truck. For the backfill work1 unit of Komatsu D68ESS Bulldozer, 1 unit of sheepfoot roller, and 1 unit of vibro roller are needed

Simulation of Excavation and Landfill Work

The combination of heavy equipment in excavation and stockpile work was simulated using the Optimal Cut-Fill Pairing and Sequencing (OPS) method. The OPS method in this study is divided into two parts: the plan for the most efficient use of heavy equipment and the planning of land allocation for excavation and stockpile work. The plan for using the tool has been analysed in previous calculations. Only a model of the excavation and heap work is made in this step.

In making this excavation and heap work scheme, the unit of soil volume is symbolised with the help of prisms to make it easier in making modeling. The volume of one prism has been determined and has the same volume value for excavation and backfill work. Each prism represents a soil volume of 1500 BCM. The following is the number of soil prisms needed for each type of material for excavation and heaping work:

Table 11. Number of Excavation and Stockpile Prism Needs

Location	Volume Material (BCM)			Volume	Number of Prisms		
	Common Exc	Soft Stone & Stone Exc	Fill	(BCM)	Common Exc	Soft Stone & Stone Exc	Fill
a	b	c	d	e	f = b/e	g = c/e	h = d/e
3+000 - 3+100	2906.55	33548.88	95.89	1500.00	2	22	-
3+100 - 3+200	274.93	382.66	4081.68	1500.00	-	-	3
3+200 - 3+300	158.33	144.91	10444.10	1500.00	-	-	7
3+300 - 3+400	2430.44	13268.48	188.81	1500.00	2	9	-
3+400 - 3+500	906.35	1847.86	7440.25	1500.00	-	1	5
3+500 - 3+600	821.65	5533.39	5137.01	1500.00	1	4	3
3+600 - 3+700	1304.11	9580.46	-	1500.00	1	6	-
3+700 - 3+800	721.04	1375.00	5635.90	1500.00	-	1	4
3+800 - 3+900	344.13	2172.94	9954.90	1500.00	-	2	7
3+900 - 4+000	2365.00	10780.06	322.91	1500.00	2	7	-
Total	12232.53	78634.64	43301.45		8.00	52.00	29.00

Based on the Table 11, the number of prisms is obtained based on the type of soil and its location. In STA 3+000 to 4+000, the total number of prisms of common excavated material prisms is 8 prisms, stone excavation materials are 52 prisms, and heapment materials are 29 prisms. Once the number of prisms for each soil type and their location are determined, the prisms are arranged and adjusted based on the volume and location of the soil in each STA. This soil prism is then arranged based on the amount of soil volume and its location to make a scheme of excavation and heap work as shown in the Figure 1.

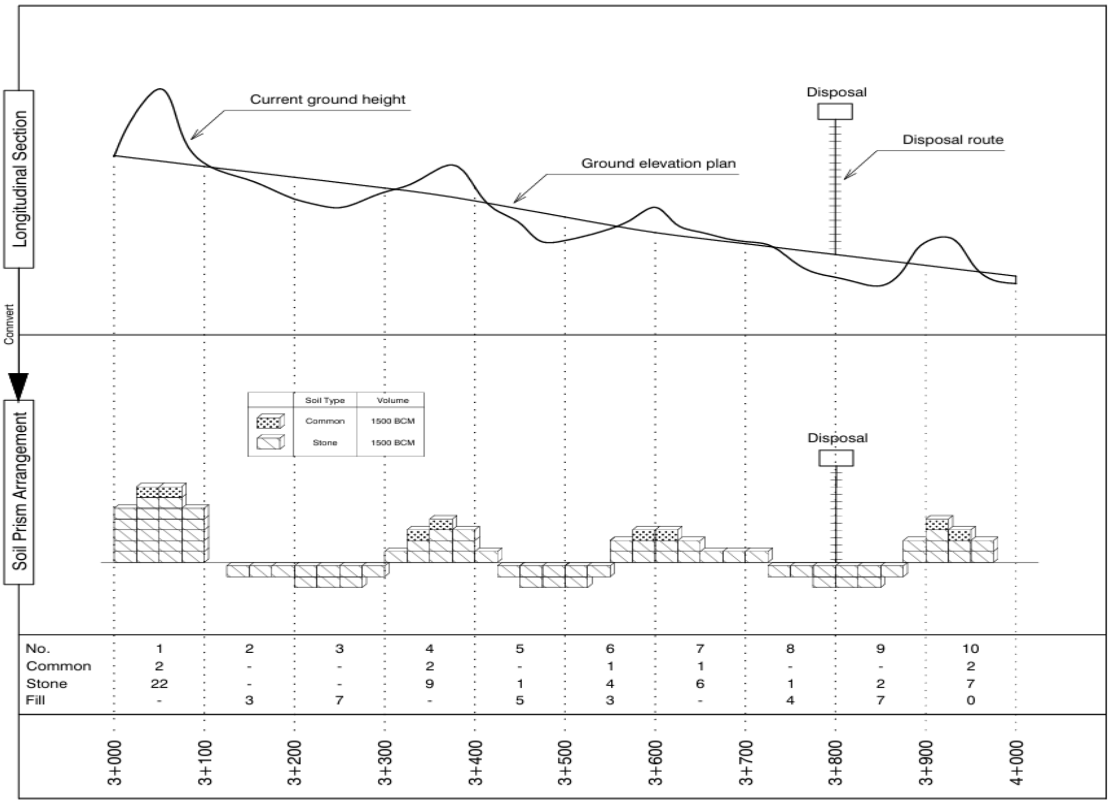

Figure 1. Preparation of Soil Prisms in Excavation and Embankment Work Schemes

To prepare a visual and systematic excavation and heap work scheme, the combination of heavy equipment calculated in advance will be positioned at the work sites by the layout planning in the field. This placement considers the efficiency of tool movement, ease of access, and smooth workflow. In the scheme, the operational flow is indicated with the help of a red directional line that describes the movement of materials from the excavation site to the disposal area or landfill. In the Figure 2, excavation and stockpile schemes are displayed based on the most efficient combination of heavy equipment, as determined through productivity analysis and operational planning.

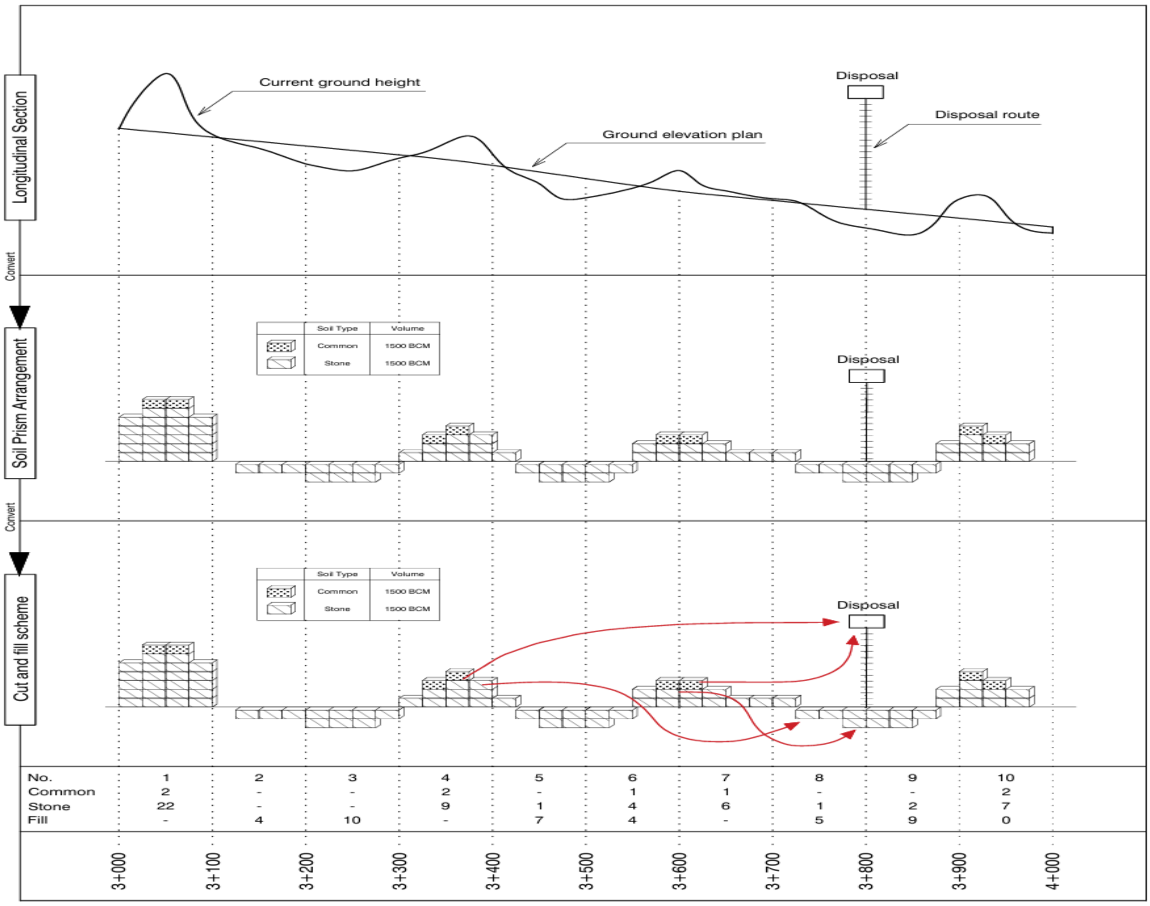

Figure 2. Excavation and Heap Work Scheme

Discussion

Based on the results of the analysis and discussion of the efficiency of the use of heavy equipment in excavation and heaping work at Project X, for excavation work of 14467.66 BCM per week, 4 unit of PC 200 excavator, 2 unit of SK 330 excavator, 10 unit of dump trucks are needed. Meanwhile, to complete the pile work with a work volume of 5423.96 CCM in one week, 1 unit of Komatsu D68ESS bulldozer, 1 unit of Sakai SV512TF sheepfoot roller, and 1 unit of Sakai SV512TF vibro roller are needed.

The excavation and stockpile work can be said to be less efficient compared to the amount of heavy equipment available in the project. This is due to the use of tools that exceed the actual needs in the field, so several units of heavy equipment should not be needed. These inefficiencies can lead to increased operational costs, such as fuel, maintenance, and equipment rental, without significantly contributing to increased productivity.

This combination is chosen based on the calculation of tool capacity, productivity, and synchronisation between tools to avoid excessive idle time. The use of 4 units of Kobelco PC 200 excavators and 2 units of Kobelco SK 330 excavators is considered to be able to achieve the target weekly excavation volume at a speed that meets the needs of the project, while 10 units of dump trucks are sufficient to accommodate and transport excavated materials continuously without causing queues or transportation delays. The Komatsu D68ESS bulldozer is used to level and spread the backfill material, while two types of rollers, namely sheepfoot rollers and vibro rollers, ensure that the soil compaction process runs optimally according to technical specifications. With this configuration, work efficiency is increased, operational costs can be reduced, and the duration of excavation and landfill work can be completed according to the project schedule that has been set.

Conclusion

From the results of the discussion on the efficiency of the use of heavy equipment in excavation and heaping work in Project X, it can be concluded that the most efficient combination of heavy equipment based on the smallest idle time consists of 4 units of Kobelco PC 200 excavators, 2 units of Kobelco SK 330 excavators, 10 units of Hino 500 dump trucks, 1 unit of Komatsu D68ESS bulldozers, 1 unit of Sakai SV512TF sheepfoot rollers, and 1 unit of Sakai SV512TF vibro rollers. When compared to the amount of heavy equipment available in the project, the excavation and stockpile work can be said to be less efficient. This is due to the use of tools that exceed the actual needs in the field, so several units of heavy equipment should not be needed.

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