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OPTIMIZING OF HEAVY EQUIPMENT IN EARTH WORK FOR THE PROBOLINGGO - BANYUWANGI TOLL ROAD PROJECT PACKAGE 1

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ABSTRAK

Studi ini berfokus pada pekerjaan timbunan dan galian dalam proyek Jalan Tol Probolinggo – Banyuwangi Paket 1 pada STA 0+000 sampai STA 5+000 merupakan infrastruktur berskala besar yang melibatkan penggunaan berbagai jenis alat berat dengan kapasitas operasional dan biaya sewa yang berbeda-beda. Keterlambatan proyek terjadi sebagian karena penggunaan alat yang kurang efisien dan pengelolaan yang tidak optimal. Untuk mengatasi masalah ini, studi ini bertujuan mengoptimalkan pemilihan dan alokasi alat berat dengan menganalisis total biaya, mengidentifikasi jenis alat yang paling ekonomis, serta menentukan jumlah unit alat yang dibutuhkan secara optimal. Analisis dilakukan berdasarkan data sekunder seperti volume pekerjaan, rencana kerja, spesifikasi teknis (RKS), biaya sewa alat berat, volume pekerjaan galian sebesar 4,980.13 m3 dan volume pekerjaan timbunan 1.349.805,44 m3 , serta kurva-S proyek sebagai acuan jadwal dan kemajuan pekerjaan. Melakukan perbandingan antara perhitungan manual dan menggunakan program linier metode simpleks menggunakan aplikasi LINDO. Hasil analisis menunjukkan bahwa total biaya optimal untuk penggunaan alat berat pada pekerjaan galian adalah sebesar Rp. 204.426.192,00, Dengan jumlah alat berat 2 Unit excavator KOMATSU PC 200-8, 7 Unit dump truck HINO 500 FC 110 JS HD. Dan Untuk pekerjaan timbunan zona 1 adalah sebesar Rp.44.904.150.323,00, with the heavy equipment used is 3 unit excavator SANY SY285H, 38 unit dump truck Hino Dutro 130 HD, 2 unit motor grader Hidromek 330MG, 4 unit tandem roller Bomag BW 161 AD–50, 4 unit water tank truck Isuzu NMR 71. Timbunan zona 2 Rp 32.087.623.131,00, dengan alat berat yang digunakan 3 unit excavator SANY SY285H, 26 unit dump truck Hino Dutro 130 HD, 2 unit motor grader Hidromek 330MG, 3 unit tandem roller Bomag BW 161 AD–50, dan 3 unit water tank truck Isuzu NMR 71.
Kata kunci : *optimasi, galian, timbunan*

ABSTRACT

This study focuses on excavation and embankment works on the Probolinggo–Banyuwangi Toll Road Project, Package 1, from STA 0+000 to STA 5+000. As a large-scale infrastructure project, it involves the use of various heavy equipment, each with distinct operational capacities and rental costs. Delays have occurred partly due to inefficient equipment usage and suboptimal management. To address this, the study aims to optimize the selection and allocation of heavy equipment by analyzing total costs, identifying the most economical types of equipment, and determining the optimal number of units required. The analysis uses secondary data, including work volumes, implementation plans, technical specifications, rental prices, excavation volume of 4,980.13 m3, embankment volume of 1,349,805.44 m3, and the project's S-curve as a reference for scheduling and progress monitoring. Optimization is conducted through a comparison between manual calculations and linear programming using the LINDO application. The results indicate that the optimal total cost for excavation work is IDR 204,426,192.00, utilizing 1 unit of KOMATSU PC 200-8 excavator and 7 units of HINO 500 FC 110 JS dump trucks. For embankment work in Zone 1, the optimal cost is IDR 44,904,150,323.00 with 3 SANY SY285H excavators, 38 Hino Dutro 130 HD dump trucks, 2 Hidromek 330MG motor graders, 4 Bomag BW 161 AD–50 tandem rollers, and 4 Isuzu NMR 71 water tank trucks. In Zone 2, the total cost is IDR 32,087,623,131.00, using 3 SANY SY285H excavators, 26 dump trucks, 2 motor graders, 3 tandem rollers, and 3 water tank trucks. This optimization ensures cost-efficiency, proper equipment allocation.
***Keywords** : optimization, excavation, embankment*

1. INTRODUCTION

The Probolinggo–Banyuwangi Toll Road, part of the Trans-Java network, spans 175.40 km and is expected to boost regional economic development by improving travel efficiency and logistics access. Earthwork is a critical component of the Probolinggo–Banyuwangi Toll Road Project, particularly in Package 1, which spans 12 km. Excavation work are carried out to remove unsuitable soil.

Both embankment and excavation activities represent a substantial portion of the project's total workload. As key structural and preparatory elements, they must be executed efficiently to ensure the project progresses according to schedule and meets the targeted standards of budget, quality, and occupational health, safety, and environmental (OHSE) compliance.

The construction of roads, particularly toll roads, requires proper planning and supervision. One of the most critical early stages in toll road development is the execution of excavation and embankment works. These activities rely heavily on the use of heavy equipment to improve efficiency and accelerate progress. However, improper use of heavy equipment can significantly affect the quality and outcomes of the work. Therefore, the deplopment of heavy machinery must be carefully analyzed to achieve optimal results minimizing costs without compromising the project timeline.

Based on the aforementioned background and issues, the objectives of this study are as follows:

1. What is the productivity of each type of heavy equipment?
2. What are the alternative combinations of heavy equipment for the embankment and excavation work?
3. What are the operational costs of each heavy equipment used in the embankment and excavation work?
4. How does the comparison between the manual heavy equipment calculation and the optimization calculation using the LINDO application?
5. Which combination is the most optimal from the calculation comparison?

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

1. Calculating the productivity of each heavy equipment used in excavation and embankment work
   a. Excavator
   $$Q = \frac{V \; x \; Fb \; x \; Fa \; x \; 60}{Ts \; x \; Fv} \quad (1)$$
   Description:
   V = Bucket capacity; m3
   Fb = Bucket factor
   Fa = Equipment efficiency factor
   Fv = Conversion factor
   Ts = Cycle time; minutes
   b. Dump Truck
   $$Q = \frac{V \; x \; Fa \; x \; 60}{Ts \; x \; Fk} \quad (2)$$
   Description:
   V = Bucket capacity; m3
   Fk = Swell factor
   Fa = Equipment efficiency factor
   Ts = Cycle time; minutes
   c. Motor Grader
   $$Q = \frac{Lh \; x \; (n(b-bo)+bo) \; x \; t \; x \; Fa \; x \; 60}{Ts \; x \; n \; x \; N} \quad (3)$$
   Description:
   Lh = spreading length; m
   bo = overlap width; m
   Fa = work efficiency factor
   t = compacted layer thickness
   N = number of passes
   n = number of cuts per pass
   V = average speed; km/hour
   b = effective blade width; m
   60 = hour-to-minute conversion factor
   c. Tandem Roller
   $$Q = \frac{V \; x \; 1000 \; x \; (Nx(b-bo)+bo) x \; t \; Fa}{n \; x \; N} \quad (4)$$
   Description:
   V = Average operating speed; km/hour
   N = Number of passes
   b = effective compaction width
   bo = overlap width
   Fa = equipment efficiency factor
   t = spreading thickness
   c. Tandem Roller
   $$Q = \frac{pa \; x \; Fa \; 60}{1000 \; x \; Wc} \quad (5)$$
   Description:
   pa = water pum capacity
   Fa = equipment efficiency factor
   Wc = Water requirement per m3
2. Determining alternative combinations of heavy equipment used for each work item.the Probolinggo–Banyuwangi Toll Road Project Package 1
3. The operational costs of each heavy equipment used in the embankment work and excavation work .the Probolinggo–Banyuwangi Toll Road Project Package 1
   a. Fuel Requirement
   b. Fuel Price
   c. Rental cost
   d. Operational cost
4. Calculating the number of heavy equipment units both manually and through the application of the simplex method, using the LINDO software as a computational tool to support optimization analysis in a structured and systematic manner.
5. Based on the comparison of calculations, the most optimal combination is the one that achieves the lowest operational cost while fulfilling the required project volume and time constraints.

2. METHODOLOGY

The object of this research is the Probolinggo–Banyuwangi Toll Road Project, Package 1. Data collection was conducted by obtaining supporting information in the form of secondary data sourced from the project. The data used in this study includes the specifications of the embankment, the plant schedule for embankment activities, the embankment and excavation volumes from STA 0+000 to STA 5+000, a unit price analysis, and the standard unit prices for goods and services in the Probolinggo region. After collecting the secondary data, analysis and data processing were carried out to optimize the utilization of heavy equipment. The overall research methodology is illustrated in the following flowchart.

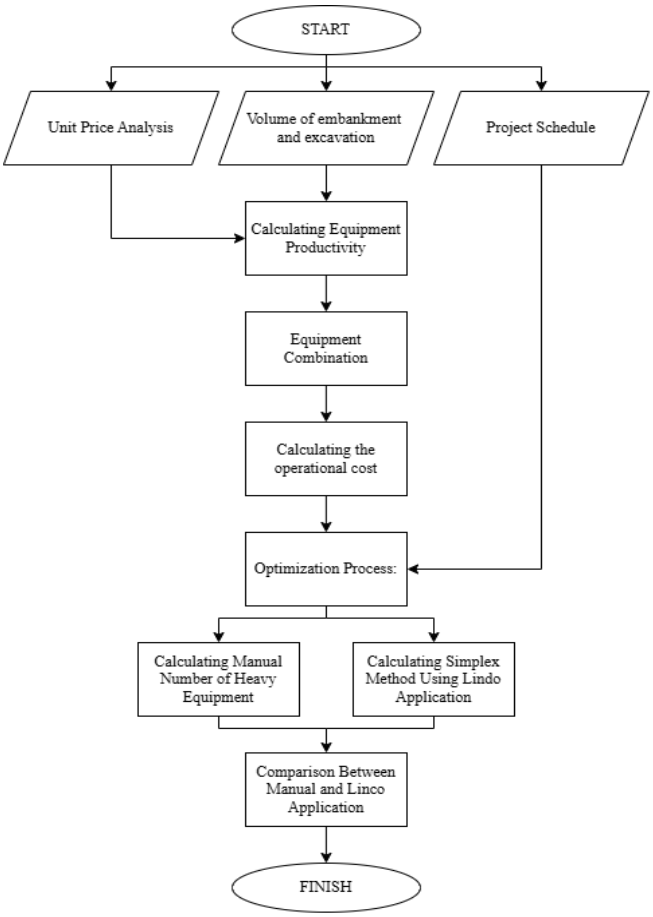

Figure 1. Research Flowchart

3. RESULTS AND DISCUSSION

Work Volume

In the implementation of the Probolinggo–Banyuwangi Toll Road Project, Package 1, the work volumes for each item start STA 0+000 to STA 5+000, particularly excavation and embankment, are not calculated independently but are obtained directly from project provided data.

Table 1. Work Volume

Work Description	STA	Volume	Unit
Excavation	0+000 – 5+000	4.981,13	m3
Embankment (Zone 1)	0+000 – 2+500	737.077,49	m3
Embankment (Zone 2	2+500 – 5+000	612.797,66	m3

Types of Heavy Equipment

In In selecting the equipment to be used for excavation and embankment work in the implementation of the Probolinggo–Banyuwangi Toll Road Project, Package 1, it is important to consider the types of work activities involved and their sequence according to the construction process.

1. Excavation work involves the use of heavy equipment to strip the existing soil surface, excavate the material, and haul the material from the project site to the designated disposal area.
2. Embankment work involves the use of heavy equipment to excavate soil from the quarry, load it onto hauling equipment for transport to the project site, and then spread, compact, and water the material to meet the required specifications

Table 2. Types of Heavy Equipment

Code	Equipment	Brand
EX1	Excavator	KOMATSU PC 200
EX2	Excavator	SANNY SY285H
DT1	Dump Truck	Hino dutro 130 HD
DT2	Dump Truck	HINO 500 (FC 110 JS)
MG1	Motor Grader	Hidromek 330MG
MG2	Motor Grader	Komatsu GD535-5
TR1	Tandem Roller	Bomag BW 161 AD
WT1	Water Tank Truck	ISUZU NMR 71

Heavy Equipment Productivity Calculation

Each type of heavy equipment used has a different productivity rate. The productivity of the equipment is calculated using Equations 1, 2, and 3. The results of the productivity calculations for the heavy equipment are presented in Tables 4 and 5.

Table 3. Equipment Productivity in Excavation Work

No	Type	Productivity	Unit	Description
1	EX 1	118,64	m3/hour	-
2	EX 2	158,19	m3/hour	-
3	DT 1	22,57	m3/hour	EX 1
4	DT 1	30,99	m3/hour	EX 2
5	DT 2	24,23	m3/hour	EX 1
6	DT 2	34,22	m3/hour	EX 2

Table 4. Equipment Productivity in Embankment Work

No	Type	Productivity	Unit	Description
1	EX 1	154,07	m3/hour	-
2	EX 2	205,43	m3/hour	-
3	DT 1	11,59	m3/hour	EX 1
4	DT 1	17,15	m3/hour	EX 2
5	DT 2	12,29	m3/hour	EX 1
6	DT 2	17,87	m3/hour	EX 2
7	MG 1	261,45	m3/hour	-
8	MG 2	378,84	m3/hour	-
9	TR 1	128,37	m3/hour	-
10	WT 1	142,29	m3/hour	-

Alternative Combination of Heavy Equipment

Each The alternative combinations of heavy equipment are selected based on the full range of equipment types and their respective specifications. These combinations are planned as part of the optimization process to determine the most effective and efficient equipment selection for the Probolinggo–Banyuwangi Toll Road Construction Project, Package 1. This decision is based on the large volume of work, the limited project area, and the interdependence of each type of equipment for specific work activities. The determination of alternative heavy equipment combinations can be seen in

Table 5. Equipment Combinations in Excavation Work

No	Alternative Combination	Excavator	Dump Truck
1	Comb.1	EX1	DT1
2	Comb.2	EX1	DT2
3	Comb.3	EX2	DT1
4	Comb.4	EX2	DT2

Table 6. Equipment Combinations in Embankment Work

No	Alternative Combination	EX	DT	MG	TR	WT
1	Comb.1	EX1	DT1	MG1	TR1	WT1
2	Comb.2	EX1	DT1	MG2	TR1	WT1
3	Comb.3	EX1	DT2	MG1	TR1	WT1
4	Comb.4	EX1	DT2	MG2	TR1	WT1
5	Comb.5	EX2	DT1	MG1	TR1	WT1
6	Comb.6	EX2	DT1	MG2	TR1	WT1
7	Comb.7	EX2	DT2	MG1	TR1	WT1
8	Comb.8	EX2	DT2	MG2	TR1	WT1

Alternative Combination of Heavy Equipment

Each type of heavy equipment incurs rental and operational costs as well as mobilization expenses for field use therefore, these costs must be calculated

Example of the calculation cost operational excavation wor combination 1

Excavator KOMATSU PC 200-8

Fuel requirement = (0,125 s/d 0,175 liter/HP/hour) x HP
= 0,15 x 155
= 23,25 liter/hour

Fuel cost = 23,25 liter/hour x Fuel cost
= 23,25 liter/hour x Rp. 6.800,-/liter
= Rp. 158.100,00,-/hour

Rental Cost = Rp. 548.102,00,-/hour

Operational Cost = Rp. 158.100,00 + Rp. 548.102,00
= Rp. 706.225,25,-/hour x 35 hour
= Rp. 24.717.833,75/ Equipment

Table 7. Excavation Work Operational Cost

No	Type Equipment	Cost Operational/Equipment
1	EX1	Rp.24.717.833,75
2	EX2	Rp.33.293.207,50
3	DT1	Rp.19.691.682,50
4	DT2	Rp.29.005.605,50

Table 8. Embankment Work Operational Cost

No	Type Equipment	Cost Operational/Equipment
1	EX1	Rp.1.137.022.652,50
2	EX2	Rp.1.367.234.395,00
3	DT1	Rp.905.817.395,00
4	DT2	Rp.1.334.257.715,00
5	MG1	Rp.677.359.602,00
6	MG2	Rp.693.784.017,50
7	TR1	Rp.362.540.927,00
8	WT1	Rp.894.320.304,50

Optimization Process

The optimization process is divided into two approaches: manual calculation and the application of the simplex method. Calculating the number of heavy equipment units is carried out using both methods, with the LINDO

Manual Calculation of Heavy Equipment for Excavation Work

The number of excavators can be determined using the formula below. The following is an example of the excavator quantity calculation in Combination 1, which utilizes EX1.

1. Excavator

$$N = \frac{Daily\ Productivity}{Productivity\ Excavator/day} \quad (6)$$

Daily productivity get from Volume/Duration, and for Productivity Excavator get from previous calculation, so:

$N = \frac{78{,}91\ m3/days}{830{,}49\ m3/days} = 0{,}09 \approx 1/\text{day}$

2. Dump Truck

Meanwhile, to calculate the number of dump trucks, it is necessary to first determine the loading time value of EX1.

$$Cms = \frac{Bucket\ DT\ Capacity}{Bucket\ EX\ Capacity} \times Tc\ Excavator \quad (7)$$

$$M = \frac{Cmt}{n\ x\ Cms} \quad (8)$$

Table 9. Manual Calculation of Excavation Work

M = Number of Dump Truck
Cms = Cycle Time Loaders
Cmt = DT Cycle time

$$M = \frac{11{,}03\ sec}{2{,}2667\ sec}\ x\ 1 = 5$$

Combination	Number of		Total Cost
	EX	DT	
1	1	5	Rp.640.516.740,50
2	1	4	Rp.731.849.527,50
3	1	6	Rp.787.505.173,00
4	1	4	Rp.776.441.211,00

Therefore, the number of equipment units for Combination 1 can be determined as follows:

EX1 = 1 Unit
DT1 = 5 Unit

Manual Calculation of Heavy Equipment for Embankment Work

The number of excavators can be determined using the formula below. The following is an example of the excavator quantity calculation in Combination 1, which utilizes EX1,MG1,TR1,WT1:

1. Excavator, Motor Grader, Tandem Roller, Water Truck use **formula 6**
2. Dump Truck use **formula 7,8**

Table10. Manual Calculation of Embankment Work

Combination	Number of Heavy Equipment					Total Cost
	EX	DT	MG	TR	WT	
Comb.1	3	28	2	3	4	Rp.34.261.798.844,00
Comb.2	3	28	1	3	4	Rp.33.600.863.656,50
Comb.3	3	20	2	3	4	Rp.35.584.066.084,00
Comb.4	3	20	1	3	4	Rp.34.923.130.896,50
Comb.5	3	38	2	3	4	Rp.44.010.635.021,50
Comb.6	3	38	1	3	4	Rp.43.349.699.834,00
Comb.7	3	25	2	3	4	Rp.42.978.865.716,50
Comb.8	3	25	1	3	4	Rp.42.285.081.699,00

Combination	Number of Heavy Equipment					Total Cost
	EX	DT	MG	TR	WT	
Comb.1	3	28	1	3	3	Rp.33.221.898.314,50
Comb.2	3	28	1	3	3	Rp.33.238.322.729,50
Comb.3	3	20	1	3	3	Rp.34.544.165.554,50
Comb.4	3	20	1	3	3	Rp.34.560.589.969,50
Comb.5	3	25	1	3	3	Rp.29.827.864.962,00
Comb.6	3	25	1	3	3	Rp.29.844.289.377,00
Comb.7	2	17	1	3	3	Rp.29.881.235.657,00
Comb.8	2	17	1	3	3	Rp.29.881.235.657,00

Optimization of Heavy Equipment Utilization (Linear Programming Using the Simplex Method with LINDO Application) Excavation Work

1. Determination of Decision Variables
   X1 = Number of Excavator
   X2 = Number of Dump Truck
2. Determination of Objective Function
   Minimize = 128532995,50X1+102396749X2
3. Determination of Constraint Function
   118,64.X1 ≥ 11.40
   22,57.X2 ≥ 11.40
   X1 ≤ 4
   X2 ≤ 40
   0,09.X1 ≤ 182
   0,5X2 ≤ 182
4. Determination of Non Negativity Constraints
   X1≥0
   X2≥0

   The results of the heavy equipment utilization optimization per hour can be seen in the

VARIABLE	VALUE	REDUCED COST
X1	0.096089	0.000000
X2	4.000000	0.000000

Figure 2. Result from LINDO Excavation Work

EX1 = 1 Unit
DT1 = 4 Unit
Zmin = Rp.128.532.995,501+Rp.102.396.749,00 . 4
= Rp.538.119.991,50

Table 11. Result of Optimization Excavation Work

Combi-nation	Heavy Equipment		Cost Total
	EX	DT	
1	1	4	Rp.538.119.991,50
2	1	3	Rp.581.020.394,50
3	1	5	Rp.685.108.424,00
4	1	3	Rp.776.441.211,00

Optimization of Heavy Equipment Utilization (Linear Programming Using the Simplex Method with LINDO Application) Embankment Work

1. Determination of Decision Variables
   X1 = Number of Excavator
   X2 = Number of Dump Truck
   X3 = Number of Motor Grader
   X4 = Number of Tandem Roller
   X5 = Number of Water Tank Truck
2. Determination of Objective Function
   Minimize = 1137022652X1 + 905817395X2 + 677359602 X3 + 362540927X4 + 894320304X5
3. Determination of Constraint Function
   154,07.X1 ≥ 457,77
   11,95.X2 ≥ 457,77
   261,45.X3 ≥ 457,77
   128,37.X4 ≥ 457,77
   142,29.X5 ≥ 457,77
   X1 ≤ 4
   X2 ≤ 40
   2,97X1 ≤ 1610
   38,31X2 ≤ 1610
   1,75X2 ≤ 1610
   3,57X2 ≤ 1610
   3,22X2 ≤ 1610
4. Determination of Non Negativity Constraints
   X1≥0
   X2≥0
   X3≥0
   X4≥0
   X5≥0

   The results of the heavy equipment utilization optimization per hour can be seen in the

VARIABLE	VALUE	REDUCED COST
X1	2.971182	0.000000
X2	38.307114	0.000000
X3	1.750889	0.000000
X4	3.566020	0.000000
X5	3.217162	0.000000

Figure 3. Result from LINDO Embankment Work

EX1 = 1 Unit
DT1 = 39 Unit
MG1 = 2 Unit
TR1 = 4 Unit
WT1 = 4 Unit
Zmin = Rp. 1.137.022.652. 3 + Rp. 905.817.395. 39 + Rp. 677.359.602. 2 + Rp. 362.540.927. 4 + Rp. 894.320.304. 4. 4
Zmin = Rp. 45.120.110.489,00

Table 12. Result of Optimization Excavation Work

Combination	Number of Heavy Equipment					Total Cost
	EX	DT	MG	TR	WT	
Comb.1	3	39	2	4	4	Rp.45.120.110.489,00
Comb.2	3	39	2	4	4	Rp.45.152.959.319,00
Comb.3	3	27	2	4	4	Rp.45.818.190.391,00
Comb.4	3	27	2	4	4	Rp.45.851.039.219,00

Comb.5	3	38	2	4	4	Rp.44.904.150.323,00
Comb.6	3	38	2	4	4	Rp.44.936.001.155,00
Comb.7	3	26	2	4	4	Rp.46.032.222.583,00
Comb.8	3	26	2	4	4	Rp.46.056.070.415,00

Combination	Number of Heavy Equipment					Total Cost
	EX	DT	MG	TR	WT	
Comb.1	3	32	2	3	3	Rp.37.522.527.493,00
Comb.2	3	32	2	3	3	Rp.37.555.376.323,00
Comb.3	3	23	2	3	3	Rp.39.225.298.300,00
Comb.4	3	23	2	3	3	Rp.39.258.148.128,00
Comb.5	2	31	2	3	3	Rp.35.940.128.934,00
Comb.6	2	31	2	3	3	Rp.35.972.977.764,00
Comb.7	2	22	2	3	3	Rp.37.939.144.377,00
Comb.8	2	22	2	3	3	Rp.37.972.993.209,00

Comparasion between Manual and LINDO Aplication and make Heavy Equipment Strategy

1. Excavation Work

   Among the several alternative combinations of heavy equipment tested, Combination 1 generated by LINDO is selected as the most optimal alternative. The details of this combination are as follows:

   EX(Komatsu PC 200-8) = 2 Unit
   DT (Hino Dutro 130 HD) = 7 Unit
   Cost =Rp.204.426.192,00

   The construction method is carried out continuously from STA 0+000 to STA 5+000. The excavator excavates the material in layers according to the designed elevation and slope stability. The excavated material is then transported by dump trucks to the designated disposal area.
2. Embankment Work Zone 1

   Among the several alternative combinations of heavy equipment tested, Combination 5 generated by LINDO is selected as the most optimal alternative. The details of this combination are as follows:

   EX (SANY SY285H) = 3 Unit
   DT (Hino Dutro 130 HD) = 38 Unit
   MG (Hidromek 330MG) = 2 Unit
   TR (Bomag BW 161 AD-50) = 4 Unit
   WT (Isuzu NMR 71) = 4 Unit
   Cost = Rp. 44.904.150.323,00

   The embankment work in Zone 1 and Zone 2, from STA 0+000 to STA 2+500 with an estimated volume of 737,007.8 m^3, will be carried out progressively in 500-meter segments starting from STA 0+000. Three excavators will load material at the quarry into 38 dump trucks for transport to the site. At the embankment area, two motor graders will spread the material, while four tandem rollers and four water tank trucks will handle compaction.
3. Embankment Work Zone 2

   Among the several alternative combinations of heavy equipment tested, Combination 5 generated by Calculating Manual is selected as the most optimal alternative. The details of this combination are as follows:

   EX (SANY SY285H) = 3 Unit
   DT (Hino Dutro 130 HD) = 26 Unit
   MG (Hidromek 330MG) = 2 Unit
   TR (Bomag BW 161 AD-50) = 3 Unit
   Water Tank (Isuzu NMR 71) = 3 Unit
   Cost = Rp. 32.087.623.131,00

   The embankment work in Zone 2, from STA 2+500 to STA 5+000 with an estimated volume of 612,797.66 m^3, will be carried out progressively in 500-meter segments starting from STA 2+500. 2 excavators will load material at the quarry into 25 dump trucks for transport to the site. At the embankment area, 1 motor graders will spread the material, while 3 tandem rollers and 3 water tank trucks will handle compaction.

4. CONCLUSION

The optimization of heavy equipment usage for excavation and embankment work on the Probolinggo–Banyuwangi Toll Road Project, Package 1 STA 0+000 to STA 5+000, was analyzed by comparing manual calculations and the simplex method using LINDO. The results are as follows:

1. Productivity Calculation can be obtion from **table 3 and table 4**
2. Alternative Combination can be obtain from **table 5, and table 6**
3. Operatonal Cost can be obtain from **table 7, table 8**

4. Calculating the number of heavy equipment units both manually and through the application of the simplex method, using the LINDO can obatain from **table 9,10,11,12**
5. Determining the optimal combination of heavy equipment based on both manual calculations and optimization using LINDO software. The selection is not solely based on the lowest operational cost, but also considers the suitability of the equipment quantity with the construction method, as described below:
   a. Excavation Work
      Combination 1 using LINDO application with operational cost Rp. 538.119.991,50, with the heavy equipment used is 1 Unit excavator KOMATSU PC 200-8, 4 Unit dump truck Hino Dutro 130 HD.
   b. Embankment Work Zone 1
      Combination 5 using LINDO application with operational cost Rp.44.904.150.323,00, with the heavy equipment used is 3 unit excavator SANY SY285H, 38 unit dump truck Hino Dutro 130 HD, 2 unit motor grader Hidromek 330MG, 4 unit tandem roller Bomag BW 161 AD–50, 4 unit water tank truck Isuzu NMR 71.
   c. Embankment Work Zone 2
      Combination 5 manual calculation with operational cost Rp 32.087.623.131,00, with the heavy equipment used 3 unit excavator SANY SY285H, 26 unit dump truck Hino Dutro 130 HD, 2 unit motor grader Hidromek 330MG, 3 unit tandem roller Bomag BW 161 AD–50, dan 3 unit water tank truck Isuzu NMR 71.

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