Analysis of Heavy Equipment Usage for Inlet Conduit Work on Cijurey Dam Project Package 1

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ABSTRACT

Earth excavation work is inseparable from the use of heavy equipment, where job performance is expected to be completed quickly and at minimal cost. Therefore, it is necessary to calculate equipment productivity to determine the most efficient combination of heavy equipment. The productivity of heavy equipment is determined based on the cycle time of each tool, which varies depending on the size of the equipment and the type of material being handled. The method used involves comparing the productivity of heavy equipment by observing the cycle time required to complete the work. The productivity comparison results are then used to determine the most efficient equipment needs and the estimated costs required to complete the job. Equipment fleet efficiency can be achieved when the difference in productivity between tools is significantly large. This efficiency affects the project's duration, equipment costs, or both. In this study, the efficiency of heavy equipment in the earth excavation work of the Cijurey Dam inlet area is analyzed through a change in equipment combination, from two excavators and four dump trucks to three excavators and four dump trucks. The results show that this new equipment fleet combination (fleet 3) leads to a work time acceleration of up to 80 working hours and a cost reduction of Rp97,543,226.67. Therefore, selecting the right combination of heavy equipment plays a crucial role in improving the efficiency of both time and cost in earth excavation projects.

Keywords: Cycle Time, Dam, Efficiency, Heavy Equipment, Productivity

1. INTRODUCTION

One of the government's efforts to support the Indonesian people is through dam construction, which plays a crucial role in ensuring sustainable water resources. These dams are designed to preserve both the quality and quantity of water, allowing long-term use without degradation. Dams serve as a vital source of clean water for communities, not only for everyday needs but also for agriculture. Sufficient access to clean water contributes significantly to better public health and enhances overall living standards. The Cijurey Dam, for example, was built in response to the recurring floods of the Citarum River, which often overflowed due to increasing water volume.

Several factors drove the decision to construct the Cijurey Dam. The frequent and severe flooding in areas such as Karawang and Bekasi posed a serious threat. In addition, population growth and economic development in the region have increased demand for water and electricity. The high hydroelectric potential of the Cijurey River also offers an opportunity to produce clean energy and reduce reliance on fossil fuels. With full government support, the project has become a national priority. The overarching aim is to balance energy and water demands with environmental preservation.

Within dam construction, the inlet plays a vital role as it regulates incoming water flow, ensuring structural stability and water distribution. The inlet work is categorized as critical and influences the design of the entire dam. Activities such as excavation using equipment like excavators, breakers, and dump trucks must be optimized to prevent project delays. Therefore, this study focuses on analyzing the use of heavy equipment in the excavation of the dam inlet, particularly in terms of equipment quantity and cost-effectiveness in the field.

2. THEORY AND METHODS

2.1 Theory

2.1.2 Heavy Equipment

In earth excavation work, a KOBELCO SK 200 excavator is used, equipment with a 0,8 m^3 bucket. According to [4], the excavator's cycle time consists of four components (Excavating time, Loaded swing time, Dumping time, Empty swing time). The formula for excavator cycle time is shown in Equation (2.1)

$$C_{ms} = t_m + t_{pb} + t_b + t_{pk} \tag{2.1}$$

Informations:

C_{ms} = excavator cycle time (s)	t_b = dumping time (s)
t_m = bucket loading time (s)	t_{pk} = empty swing time (s)
t_{pb} = loaded swing time (s)	

According to [4], a dump truck is a vehicle used to transport materials such as soil, sand, and other construction materials that have been loaded by an excavator into the rear bed, over medium to long distances (500 meters or more). The cycle time can be seen in Equation (2.2).

$$C_{mt} = (n \times C_{ms}) + t_a + t_b + t_k + t_c \tag{2.2}$$

Informations:

C_{mt} = Dump truck cycle time	t_a = Hauling time
n = Number of cycles required by the excavator	t_b = Unloading time
	t_k = Return time
C_{ms} = Excavator cycle time	t_c = Queuing time

2.1.3 Equipment Productivity

The productivity of an excavator, dump truck, and based on volume can be calculated using Equation (2.3):

$$Q = \frac{(q \times 3600 \times E)}{Cms} \quad ; \quad Q = \frac{(C \times 60 \times E \times N)}{Cmt} \quad ; \quad Q = \frac{Vt}{tk} \tag{2.3}$$

Informations:

Q = Production per hour (m^3/hour)	N = Number of dump trucks operating
q = Production per cycle (m^3)	Cmt = Dump truck cycle time (minutes)
E = Work efficiency	Vt = Volume at disposal area (m^3)
Cms = Excavator cycle time (seconds)	tk = Working time (hours)

2.1.4 Tool Cost

Tool costs are divided into two categories: ownership costs and operating costs. The depreciation formulas are shown in Equations (2.8) and (2.9).

$$Dk = R \times (1 - R)^{(k-1)} \times P \quad (2.8)$$

$$Bk = (1 - R)^{(k-1)} \times P \quad (2.9)$$

Where:

Dk = Annual depreciation at the beginning of the year
Bk = Annual depreciation at the end of the year
R = Depreciation rate
k = Year number
P = Equipment price

2.1.4.2 Ownership Cost

Ownership cost is calculated by summing depreciation cost, capital interest, insurance, and tax. Depreciation cost is obtained by subtracting the salvage value from the equipment price (excluding tires), then dividing by total operating hours [7].

Capital interest, insurance cost, tax cost is calculated using Equation (2.11):

$$A = \frac{\frac{N+1}{2N} x c2 x Z1}{U}; \qquad B = \frac{\frac{N+1}{2N} x c2 x Z2}{U}; \qquad C = \frac{\frac{N+1}{2N} x c2 x Z3}{U} \quad (2.11)$$

Where:

A = Capital interest cost (Rp/hour)
N = Equipment economic life (years)
c2 = Equipment price excluding tires (Rp)
Z1 = Capital interest rate (%)
U = Total operating hours
B = Insurance cost (Rp/hour)
Z2 = Insurance rate (%)
C = Tax cost (Rp/hour)
Z3 = Tax rate (%)

2.1.4.3 Operating Cost

Operating cost is calculated by summing the operator wage, assistant operator wage, fuel consumption, lubricant consumption, workshop cost, and maintenance cost [9]. All values are expressed in rupiah per hour to obtain the total operating cost per hour.

2.2 Methods

This study is a work study that analyzes heavy equipment productivity through direct field data collection. The observation process follows the flow shown in Fig. 1, beginning with recording 30 cycle time samples through direct observation and measuring excavation volumes based on surveyor reports at the disposal area. Field productivity data is then compared with theoretical productivity based on AHSP standards from the Indonesian Ministry of Public Works. A one-way ANOVA test is used to determine whether there is a significant difference between field productivity and theoretical standards from two unrelated data groups. Continued to calculate the analysis of heavy equipment use by comparing productivity between heavy equipment used to then determine the more optimal heavy equipment *fleet* to use.

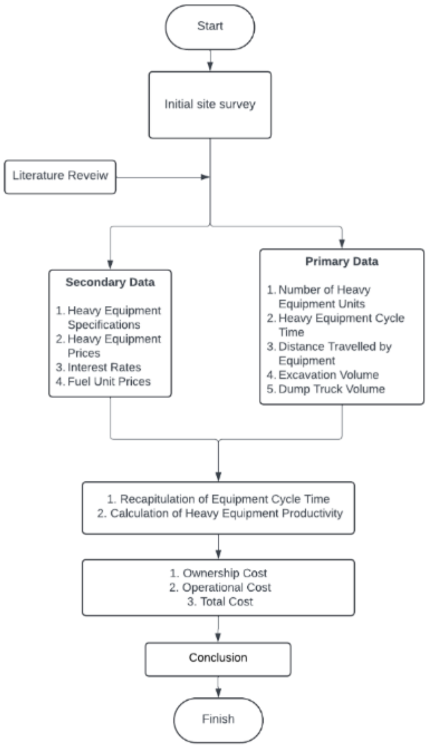

Fig. 1 Flowchart of research impementation

3. RESULTS AND DISCUSSION

In its implementation, 30 samples of cycle time of each working tool were taken. Cycle time data can be seen from Table 1.

Table 1. Heavy Equipment Cycle Time Data

Tool	Sample									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Excavator (s)	18	19	19	15	18	17	16	20	15	19
Dump truck (minutes)	17,90	18,18	17,62	13,92	14,40	13,18	13,23	22,32	13,70	21,27
Tool	**Sample**									
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Excavator (s)	15	17	17	16	17	18	15	15	17	18
Dump truck (minutes)	13,58	21,27	17,90	13,23	17,62	22,32	13,70	14,40	13,92	18,18
Tool	**Sample**									
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Excavator (s)	17	15	17	18	16	20	21	15	19	15
Dump truck (minutes)	13,18	17,62	13,58	22,32	18,18	14,40	13,18	13,92	17,90	13,23

The average cycle time values from the obtained data are:

1. *The excavator* has a cycle time of 17.13 seconds.
2. *Dumptruck* has a cycle time of 16.31 minutes.

Figure 2. Heavy Equipment Fleet

By conducting a data homogeneity test using the one-way anova method, the cycle time that appears can be used as the basis for calculation. The one-way anova homogeneity test produces data as shown in Table 2.

Table 2. Anova Test

SK	JK	db	KT	F_{count}	F_{table}
Treatment	10,127	1	10,127	1,527	4,007
Error	384,426	58	6,628		
Total	394,553	59			

Based on the one-way ANOVA test, the F value is lower than the F table, indicating acceptance of H0 and data homogeneity. Subsequent calculations using PUPR Regulation No. 1 of 2022 determined the productivity of the excavator and dump truck (Table 3).

Table 3. Heavy Equipment Tool Productivity

Aspect	**Type and coefficient**	**Unit**	**Aspect**	**Type and coefficient**	**Unit**
Excavator			**Dump Truck**		
Type	Cobelco SK 200		Brand	HINO 500 FM 260 TI	
Capacity	0,8	m^3	Type	HINO 500 FM 260 TI	
Buquet Factor (BFF)	0,9		Capacity	25	m^3
Working Efficiency (E)	0,83		Efisiency Factor	0,83	
Working Hours/Day	8	hours	Distance	1000	m
Soil Type	Clay		Tool Condition	Good	
Digging time	5,80	s	Excavator capacity	79,472	m^3/hour
Turning time	5,00	s	Excavator cycle time	0,286	Min
Exhaust time	2,60	s	DT Cycle time	16,31	min
Tool rotating angle	90	°	Productivity	42,403	m^3/hour
Production/cycle (P)	0,72	m^3	Productivity/day	339,225	m^3/day
Cycle time (CT)	17,13	s			
	0,29	min			
Hourly production	(VxFbxFax60) / (Ts_2xFk)				
	79,47	m^3/h			
Production/day	635,78	m^3/day			

From the total volume of excavation results, namely 30250 m³ divided by 240 working hours, the productivity of the excavator in the field is 126,042 m³/hour with the number of excavators as many as two pieces. The dump truck field productivity value is 193,427 m³/hour for four dump trucks. With the comparison of plan productivity and field productivity, the efficiency of heavy equipment comparison can be seen in Table 4.

Table 4. Comparison of Tool Productivity

No	Tool Type	Productivity (m^3/hour)	Comparison (unit)	
			Excavator	*Dump truck*
1	*Excavator*	63,021	1	1,30
2	*Dumptruck*	48,357		

The comparison result show that efficiency can be achieved by changing the heavy equipment fleet, as long as the change reduces time and cost, which is calculated based on the hourly cost after 1,25% depreciation using the declining balance method (Table 5).

Table 5. Depreciation

Excavator			Dump Truck		
k	Dk	Bk	k	Dk	Bk
0		Rp1.500.000.000	0		Rp1.283.000.000
1	Rp375.000.000	Rp1.125.000.000	1	Rp320.750.000	Rp962.250.000
2	Rp281.250.000	Rp843.750.000	2	Rp240.562.500	Rp721.687.500
3	Rp210.937.500	Rp632.812.500	3	Rp180.421.875	Rp541.265.625
4	Rp158.203.125	Rp474.609.375	4	Rp135.316.406	Rp405.949.219
5	Rp118.652.344	Rp355.957.031	5	Rp101.487.305	Rp304.461.914

Price calculations refer to the Bogor Regent Regulation 2024 and field prices, with equipment cost divided into ownership and operational costs, where details of ownership costs are presented in Table 6.

Table 6. Ownership Cost

No	Aspek	Excavator			Dump Truck		
		%	Coef	Unit	%	Coef	Unit
1	a. Tool Price (including attachment)		Rp1.500.000.000			Rp1.283.000.000	
	b. Tire price		-	tracksoe		Rp500.000.000	
	c. Tool price without tire		Rp1.500.000.000			Rp783.000.000	
2	Residual value	0			30	Rp384.900.000	
	Residual value of equipment (DBM)		Rp355.957.031				
3	a. Tool cost over lifetime		Rp1.500.000.000			Rp398.100.000	
	b. Depreciation		Rp95.336,91			Rp33.175	
4	Capital interest		Rp45.000	/hour		Rp11.745	/hour
	Isurance		Rp5.625	/hour		Rp2.936,25	/hour
	Tax		Rp18.750	/hour		Rp9.787,50	/hour
Total Owning Cost			Rp164.711,91	/hour		Rp57.643,75	/hour

Based on the cost of ownership, the detailed calculation of equipment operating costs can be seen in Table 7.

Table 7. Operating Costs

Aspect	Value	
	Excavator	Dumptruck
Fuel Comsumption	Rp237.000	Rp87.150
Lubricating Oil Consumption	Rp25.272	Rp41.587
Workshop Cost	Rp17.500	Rp14.968
Maintenance Cost	Rp56.250	Rp48.113
Operator Cost	Rp43.179	Rp43.179
Helper Cost	Rp26.169	Rp26.169
Total Operational Cost	Rp168.370	Rp174.016

From the above calculations, it can be analyzed the hourly cost requirements of the heavy equipment fleet. The calculation on the heavy equipment fleet can seen in Table 8.

Table 8. Cost of Fleet

Fleet	Type	Unit	Productivity (m3/h)	Producviti vy x Unit (m3/h)	Combination (m3/h)	Cost/hour (Rp)	Cost/hour x Unit (Rp)	Total Cost Combination
1	Excavator	2	63,02	126,042	126,042	561.400	1.122.799,83	Rp2.342.090,16
	Dumptruck	4	48,357	193,427		304.823	1.219.290,33	
2	Excavator	2	63,02	126,042	126,042	561.400	1.122.799,83	Rp2.037.267,58
	Dumptruck	3	48,357	145,070		304.823	914.467,75	
3	Excavator	3	63,021	189,063	189,063	561.400	1.684.199,74	Rp2.903.490,08
	Dumptruck	4	48,357	193,427		304.823	1.219.290,33	

The total cost and working time required for each of the three heavy equipment fleets to complete the work were calculated and are presented in Table 9.

Table 9. Fleet Efficiency

Fleet	1	2	3
Combination Productivity (m^3/h)	126,042	126,042	189,063
Excavation Volume	30250	30250	30250
JTotal working hours	240	240	160
Total of work weeks	3	3	2
Cost of combination	Rp562.101.639	Rp488.944.219	Rp464.558.412

With the same work volume, a comparison of heavy equipment fleets reveals differences in cost efficiency and working time. Fleet 1 (field conditions) took 240 hours at a cost of Rp562,101,639. Fleet 2, a simulation with fewer dump trucks, reduced the cost to Rp488,944,219 without changing working time, as excavator productivity remained the key factor. Fleet 3, simulated with more excavators (three excavators and four dump trucks), shifted the determining factor to dump trucks, cutting working time to 160 hours and cost to Rp464,558,412. This fleet combination improves work efficiency and project sustainability.

4. CONCLUSIONS

Based on the analysis results, it can be concluded that the excavation work in the soil inlet area of the Cijurey Dam Package 1 can still be carried out efficiently using heavy machinery, with fleet 3 consisting of 3 excavators and 4 dump trucks identified as the most efficient combination, resulting in a work execution time of 80 hours and a cost efficiency of IDR 97,543,226.67; this finding provides a practical reference for optimizing heavy equipment planning in similar dam construction projects and offers a foundation for further research in improving operational efficiency in Civil Engineering practices.

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