The Productivity of Heavy Equipment in Embankment Work Method on Toll Road Development Project

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Abstract

The purpose of this research is to evaluate the productivity and cost of heavy equipment on embankment work in 27 km toll road development project in DKI Jakarta–West Java area and the cause of the different value of productivity from the planning. This research was conducted with quantitative method and analysed by comparing the calculation of productivity and costs based on survey result and theoretical data in an undisturbed and disturb conditions. This resulted that the productivity and cost of heavy equipment based on theoretical data in an undisturbed condition had better productivity and lower costs than productivity and costs based on survey in an undisturbed and disturb conditions. The different productivity value was caused by the dump truck that did not follow applicable regulations in compaction process and the after-rain condition that creates water puddles on site hence affected the heavy equipment's productivity.

Keywords
Productivity of heavy equipment, heavy equipment, cost of the productivity, productivity of embankment work, construction management.

1. Introduction
In this era, Indonesia rapidly developing the economy and social welfare, starting from the construction of public transportation facilities such as the Jakarta-Bandung high-speed train, Jakarta MRT, Jakarta LRT to the construction of toll roads in Indonesia. One of the ongoing infrastructure developments is the 27 km Toll Road Project in the DKI Jakarta – West Java Region which plays a role in the development and operator of toll roads for the length expansion of toll roads throughout Indonesia. The toll road corridor has fast traffic growth and the volume of traffic passing through the toll road has exceeded capacity. Therefore, in order to support and accommodate traffic growth in the Toll Road Corridor in the DKI Jakarta – West Java area, PT. Jasa Marga is building a new toll road development parallel to the Jakarta-Cikampek toll road.

The implementation of construction work is always related to heavy equipment used by humans in doing work that is considered unproductive if done without the help of these tools. Construction projects certainly require heavy equipment to facilitate the work because heavy equipment is one of the most important things so that the project can achieve the target, so to produce optimal work, accurate planning is needed so that it can be achieved with optimal cost and execution time. Therefore, an analysis of the use of heavy equipment is needed in order to obtain the right alternative for heavy equipment for the construction of a project (Handoko, 2017; Miharja, 2019). One of the important works in toll road projects is earthworks. so, it is necessary to choose the right heavy equipment according to the type of work depending on the conditions, terrain, and performance of the equipment itself, but if the selection of heavy equipment is not by the work, progress will cause delays in achieving targets and inflated costs.

Therefore, productivity of heavy equipment, scheduling, and the selection of heavy equipment for each type of work are very important so that operating capabilities can be optimal and mutually support other equipment considering that heavy equipment costs very expensive and the performance or contribution is quite dominant on the project (Supit, 2020). Based on previous research, hourly productivity of each heavy equipment used to work on the aggregate B foundation layer works according to the project time schedule (Dwiretnani, 2020). In addition, when the calculation uses the theoretical method, the combination of 5 to 8 has an efficient productivity compared to other combinations

(Dewi et al., 2019). In terms of time, the heavy equipment does not exceed the time schedule and early finish (Aoliya, 2018). In this research, when the project entered the planning phase or stage of working on the embankment to be compacted at STA 59+400 – 59+500, there were differences in productivity values based on the project plan data and survey data, so the research on the productivity of heavy equipment is needed to find out causes of productivity differences. In this research, when the project entered the planning phase or stage of working on the embankment to be compacted at STA 59+400 – 59+500, there were differences in productivity values based on the project plan data and survey data, so the research on the productivity of heavy equipment is needed to find out causes of productivity differences.

2. Research Methodology

This research begins by collecting data with observation method through surveys to the field to collect data: cycle time, distance, speed of the heavy equipment, and efficiency. This observation was done during an undisturbed and disturbed phase of the project condition. In this paper, the definition of disturb and undisturbed does not mean the condition of the soil, instead it refers to the condition of the heavy equipment productivity cycle during observation and separately, as a definition for material condition.

In the heavy equipment productivity cycle in this paper, a disturbed condition means that during a project cycle there is interferences such as rain, unforeseen delays, deteriorating road condition, and other elements that disturb a heavy equipment productivity cycle. An undisturbed condition means that during the heavy equipment productivity cycle, there are little to no interferences, and if there are any, it was negligible. A material can be defined as undisturbed if they are in a natural state in accordance with their initial conditions and can be defined as disturbed if the material is in a loose state caused by heavy equipment or material that has been moved from its original state [2]. The size of the soil in this condition is usually referred to as the state of the soil that is still natural. Other secondary data such as documents from companies was also collected. The related data required consists of two sources, primary data by direct observation such as cycle time, speed of the heavy equipment, working time and efficiency, and secondary data by collecting documents from related companies, previous research journals, Unit Price Analysis, Regulation of the Minister of Public Works and Public Housing Number 28/PRT/M/2016, standard specifications of heavy equipment, and Journal of Unit Prices of Construction Building Materials, and Interior edition 39 of 2020. After the data is collected, calculate the productivity and costs in disturbed and undisturbed conditions to find the value of productivity, costs, and analyzed the causes of different heavy equipment value from project plan and survey data. Conclusion of this research is to be able to find the causes of differences in productivity values based on survey data and theoretical data. The research methods can be seen on Figure 1.

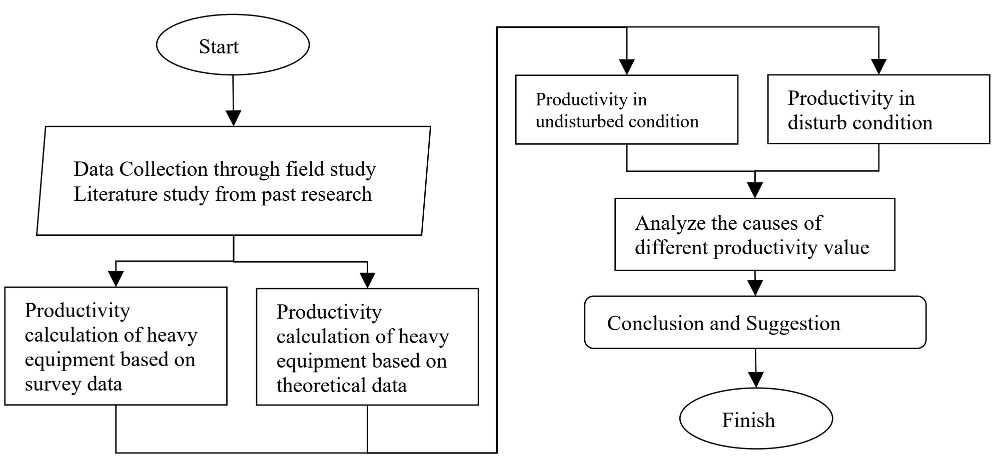

Figure 1. Research Methodology

2.1 Productivity Calculation

The calculation of heavy equipment productivity based on survey data in undisturbed and disturbed condition, and productivity based on theoretical data in undisturbed condition. Calculation of productivity based on survey data use data that obtained through direct surveys to the field, such as data on speed, distance, efficiency of the tool, and the length of working hours of the tool. For unit prices, the calculation uses the Journal of Unit Prices was used, and for the equation for each heavy equipment, including its efficiency and factor can be found through the ministerial regulations. The specification for heavy equipment can be seen on Table 1.

Table 1. Specifications of heavy equipment (data from project)

Specification	Description			
	Excavator	Dump Truck	Bulldozer	Compactor
Brand	Kobelco	Hino	Komatsu	Bomag
Type	SK200	FM 260 JD	D65E-12	BW211D-40
Horsepower	160 HP	260 HP	180 HP	133 HP
Capacity	1m^3	30m^3	1944m^3	2.1 m
Age	5 years	5 years	5 years	5 years

2.1.1 Excavator

The calculation for productivity of excavator can be calculated according to equation (1) and the specification in Table 1.

$$Q = \frac{V \times F_b \times F_a \times 60}{T_{s1} \times F_v} \tag{1}$$

Where:
Q = Productivity per hour (m^3/hour)
V = Bucket capacity (m^3)
F_b = Bucket factor
F_a = Heavy equipment efficiency
60 = Conversion from hour to minute
F_v = Conversion factor
T_{s1} = Cycle time, $T_s = \sum_{n-1}^{n} T_n$ (minute)

2.1.2 Dump Truck

The calculation for productivity of dump truck can be calculated according to equation (2) and the specification in Table 1.

$$Q = \frac{V \times F_a \times 60}{T_s \times D} \tag{2}$$

Where:
Q = Productivity per hour (m^3/hour)
V = Bucket capacity (m^3)
F_a = Heavy equipment efficiency
60 = Conversion from hour to minute.
T_s = Cycle time, $T_s = \sum_{n-1}^{n} T_n$ (minute)
D = Weight of material (ton/m^3)

2.1.3 Bulldozer

The calculation for productivity of bulldozer can be calculated according to equation (3) and the specification in Table 1.

$$Q = \frac{q \times F_b \times F_m \times F_a \times 60}{T_s} \tag{3}$$

Where:
Q = Productivity per hour (m^3/hour)

q = Blade capacity, $q = L \times H^2$ (m^3)
F_b = Blade factor
F_m = Tilt blade factor (grade), (1 for flat, 1.2 for down -15%, 0.7 for climb +15%)
F_a = Heavy equipment efficiency
60 = Conversion from hour to minute.
T_s = Cycle time, $T_s = \sum_{n-1}^{n} T_n$ (minute)

2.1.4 Bulldozer

The calculation for productivity of compactor can be calculated according to equation (4) and the specification in Table 1.

$$Q = \frac{(b_e \times v \times 1000) \times t \times F_a}{n} \quad (4)$$

Where:
Q = Productivity per hour (m^3)
b_e = Effective width of compaction, $b_e = b - b_o$ (m)
b = Effective width of compaction (m)
b_o = Overlap width (m)
v = Average speed (km/hour)
t = Compaction thickness (m)
1000 = Conversion from km into m
F_a = Heavy equipment efficiency
n = Number of passing

2.1 Cost Calculation

a. Cost of fuel for heavy equipment
The cost of how much the heavy equipment consumes fuel in liters/hour.

$$H = (12.00 - 15.00)\ \% \times HP \quad (5)$$

Where:
H = Heavy equipment's fuel (liter/hour)
HP = Horsepower or machine capacity of heavy equipment
12.00% = Light working condition
15.00% = Heavy working condition

b. Cost of oil for heavy equipment
Equation for the cost of how much the heavy equipment use oil in liters/hour based on machine capacity.

$$I = (2.5 \text{ until } 3)\ \% \times HP \quad (6)$$

Where:
I = Heavy equipment's oil consumption (liter/hour)
HP = Horsepower or machine capacity of heavy equipment
2,5% = Light working condition
3% = Heavy working condition

c. Cost of operator
Cost of operator are adjusted to each region and how to calculate the cost is in accordance with the working hours of the heavy equipment used

d. Overhead and profit
Overhead or general fee are indirect costs incurred to support the realization of the project progress, or costs that are calculated as operational costs. Profit cost includes the cost of work risk during the implementation and maintenance period in the work contract.

3. Result and Discussion

This section comprises of analysis of the productivity and cost of heavy equipment based on survey and theoretical data in undisturbed and disturbed condition heavy equipment to carry out embankment work on the 27 km Toll Road in the DKI Jakarta - West Java Region.

3.1 Productivity of Heavy Equipment

The productivity of Heavy Equipment was found using data gathered from observation and calculations found on section 2. The productivity for one cycle can be seen in the Table 2.

Table 2. Example of The Productivity Calculation of Heavy Equipment in an Undisturbed Condition

Data	Notation	Quantity					Unit
		Excavator	Dump Truck	Bulldozer	Sheepfoot Roller	Vibratory Roller	
Productivity per hour	Q	119, 2715	51,3780	17,3139	79,3333	91,3750	m^3/hour
Productivity per day	Q_D	954,1700	429,0900	138,5100	634,6700	731,0000	m^3/day
Coefficient per m^3	C	0,0084	0,0195	0,0578	0,0126	0,0109	hour

Based on Table 2, the calculation results of excavator productivity is 119.2715 m^3/hour equal to 954.1700 m^3/day, the dump truck productivity is 51.3780 m^3/hour equal to 429.0900 m^3/day, the bulldozer productivity is 17.3139 m^3/hour equal to 138.5100 m^3/day, the sheep foot roller productivity is 79.3333 m^3/hour equal to 634.6700 m^3/day, and the vibratory roller productivity is 91.3750 m^3/hour equal to 731.0000 m^3/day. The value of heavy equipment productivity per day is obtained from productivity per hour multiplied by the working hours of heavy equipment in 1 day with 8 working hours.

On Table 2, there is the value of coefficient. This value is used to calculate the cost of productivity for each cycle. Coefficient can be calculated using equation from the attachment of ministerial regulation no 28 2016. The table 2 is an example of the results, the recapitulation can be seen on the sub section below.

3.2 Calculation of Productivity Cost for One Cycle

The example calculation of productivity cost for one cycle can be seen in the Table 3. The data for the calculation was gathered from many different sources, for the equation it is from ministerial regulation no 28 2016, the price is from Journal of Unit Prices of Construction Building Materials, and Interior edition 39 of 2020, the cycle was gathered through direct observation, and the specification of the heavy equipment was gathered through the contractors on the project site.

Table 3. Cost of Productivity for One Cycle

No.	Description	Unit	Quantity	Unit Price	Total Price					
					Man Power	**Equipment**	**Fuel and Oil**	**Material**	**Total**	**Notes**
1	**Man Power**									
-	Foreman	day	0.000235	Rp194.274	46					
-	Handyman	day	0	Rp147.643	0					
-	Worker	day	0.02	Rp157.643	3153					
	Excavator Operator	Hours	0.0084	Rp194.274	1632					
	Dozer Operator	Hours	0.0578	Rp194.274	11229					
	Dt Driver	Hours	0.0195	Rp194.274	3788					
	Vibratory Operator	Hours	0.010944	Rp194.274	2126					
	Sheepfoot Operator	Hours	0.0126	Rp194.274	2448					
				Sub Total	24422				Rp24.422	
2	**Heavy Equipment**									
-	Excavator 80 - 140 hp kav. 0,7 m3	Hours	0.0084	Rp150.000		252				
-	Buldozer	Hours	0.0578	Rp210.000		2428				
-	Dump Truck 30 M3	Hours	0.0195	Rp150.000		585				
-	Vibrator Roller Kap. 12 ton	Hours	0.010944	Rp140.530		308				
-	Sheep Foot Roller	Hours	0.0126	Rp140.530		354				
					Sub Total	3927			Rp3.927	
3	**Fuel and Oil**									
-	Solar (industri)	Liter	2.393921	Rp12.000			28727			
-	Oli	Liter	0.07605	Rp30.000			2282			
						Sub Total	31009		Rp31.009	
4	**Material**									
-	Embankment Soil	M3	1.3	Rp180.000				234000		
							Sub Total	234000	Rp234.000	
								Total	Rp293.358	(Q)
5	**Overhead + Profit** (7% + 3% = 10%) 10% x (Q)								Rp29.336	
								Grand Total	Rp322.694	(B)
								Harga Satuan	Rp322.694	

Based on Table 3, Total cost for one cycle of productivity is Rp323,316 per hour and total cost per day is Rp2,586,528. The value for the total cost of heavy equipment productivity is obtained from the total cost per hour multiplied by the working hours of heavy equipment in 1 day with 8 working hours.

3.3 Recapitulation of Productivity and Cost of Heavy Equipment

The recapitulation of productivity and cost based on observation survey data in undisturbed and disturbed condition of the heavy equipment productivity cycle and compared with the theoretical data in undisturbed condition for embankment work of 1 layer and project data. Based on the table, there are 6 cycles for embankment work of 1 layer and 1 cycle consisting of excavator, dump truck, bulldozer, sheep foot roller, and vibratory roller.

Table 4. Recapitulation of Productivity and Cost of Heavy Equipment Based on Survey Data in Undisturbed Condition

No	Heavy Equipment	Type	Productivity		Cost	
			m3/hour	m3/day	By Hour	By day
1	Excavator	Kobelco SK 200	119.2715	954.17	Rp 322.694	Rp 2.581.552
	Dump Truck	Hino FM 260 JD	51.3780	411.02		
	Bulldozer	Komatsu D65E-12	17.3139	138.51		
	Sheepfoot	Bomag BW 211D-40	79.3333	634.67		
	Vibratory Roller	Bomag BW 211D-40	91.3750	731.00		
2	Excavator	Kobelco SK 200	121.5765	972.61	Rp 322.980	Rp 2.583.840
	Dump Truck	Hino FM 260 JD	51.0200	408.16		
	Bulldozer	Komatsu D65E-12	17.2065	137.65		
	Sheepfoot	Bomag BW 211D-40	79.3333	634.67		
	Vibratory Roller	Bomag BW 211D-40	88.7778	710.22		
3	Excavator	Kobelco SK 200	121.4600	971.68	Rp 322.401	Rp 2.579.208
	Dump Truck	Hino FM 260 JD	50.7607	406.09		
	Bulldozer	Komatsu D65E-12	17.2065	137.65		
	Sheepfoot	Bomag BW 211D-40	79.3333	634.67		
	Vibratory Roller	Bomag BW 211D-40	79.3333	634.67		
4	Excavator	Kobelco SK 200	118.4710	947.77	Rp 324.624	Rp 2.596.992
	Dump Truck	Hino FM 260 JD	48.0517	384.41		
	Bulldozer	Komatsu D65E-12	17.3139	138.51		
	Sheepfoot	Bomag BW 211D-40	81.2222	649.78		
	Vibratory Roller	Bomag BW 211D-40	75.5556	604.44		
5	Excavator	Kobelco SK 200	115.8787	927.03	Rp 324.861	Rp 2.598.888
	Dump Truck	Hino FM 260 JD	48.0517	384.41		
	Bulldozer	Komatsu D65E-12	17.3139	138.51		
	Sheepfoot	Bomag BW 211D-40	79.3333	634.67		
	Vibratory Roller	Bomag BW 211D-40	75.5556	604.44		
6	Excavator	Kobelco SK 200	115.6257	925.01	Rp 322.652	Rp 2.581.216
	Dump Truck	Hino FM 260 JD	48.5615	388.49		
	Bulldozer	Komatsu D65E-12	17.3847	139.08		
	Sheepfoot	Bomag BW 211D-40	83.1111	664.89		
	Vibratory Roller	Bomag BW 211D-40	79.3333	634.67		

Based on Table 4, Total cost for heavy equipment productivity based on survey data in undisturbed condition for embankment work of 1 layer is Rp15.521.696. The value for the total cost of heavy equipment productivity is obtained from the total price per hour multiplied by the working hours of heavy equipment in 1 day with 8 working hours.

Table 5. Recapitulation of Productivity and Cost of Heavy Equipment Based on Survey data in Disturbed Condition

No	Heavy Equipment	Type	Productivity		Cost	
			m3/hour	m3/day	By Hour	By day
1	Excavator	Kobelco SK 200	116.1328	929.06	Rp 331,300	Rp 2,650,400
	Dump Truck	Hino FM 260 JD	44.2215	353.77		
	Bulldozer	Komatsu D65E-12	16.1817	129.45		
	Sheepfoot	Bomag BW 211D-40	60.2727	482.18		
	Vibratory Roller	Bomag BW 211D-40	64.6000	516.80		
2	Excavator	Kobelco SK 200	114.8732	918.99	Rp 331,684	Rp 2,653,472
	Dump Truck	Hino FM 260 JD	43.6764	349.41		
	Bulldozer	Komatsu D65E-12	16.2289	129.83		
	Sheepfoot	Bomag BW 211D-40	61.8182	494.55		
	Vibratory Roller	Bomag BW 211D-40	61.2000	489.60		
3	Excavator	Kobelco SK 200	109.6409	877.13	Rp 332,625	Rp 2,661,000
	Dump Truck	Hino FM 260 JD	41.0793	328.63		
	Bulldozer	Komatsu D65E-12	16.3187	130.55		
	Sheepfoot	Bomag BW 211D-40	61.8182	494.55		
	Vibratory Roller	Bomag BW 211D-40	62.9000	503.20		
4	Excavator	Kobelco SK 200	112.6735	901.39	Rp 330,704	Rp 2,645,632
	Dump Truck	Hino FM 260 JD	43.6764	349.41		
	Bulldozer	Komatsu D65E-12	16.4068	131.25		
	Sheepfoot	Bomag BW 211D-40	64.9091	519.27		
	Vibratory Roller	Bomag BW 211D-40	64.6000	516.80		
5	Excavator	Kobelco SK 200	109.1888	873.51	Rp 332,572	Rp 2,660,576
	Dump Truck	Hino FM 260 JD	40.9263	327.41		
	Bulldozer	Komatsu D65E-12	16.3148	130.52		
	Sheepfoot	Bomag BW 211D-40	63.3636	506.91		
	Vibratory Roller	Bomag BW 211D-40	62.9000	503.20		
6	Excavator	Kobelco SK 200	109.6409	877.13	Rp 332,478	Rp 2,659,824
	Dump Truck	Hino FM 260 JD	40.1045	320.84		
	Bulldozer	Komatsu D65E-12	16.4487	131.59		
	Sheepfoot	Bomag BW 211D-40	66.4545	531.64		
	Vibratory Roller	Bomag BW 211D-40	61.2000	489.60		

Based on Table 5, Total cost for heavy equipment productivity based on survey data in undisturbed condition for embankment work of 1 layer is Rp15.930.904. The value for the total cost of heavy equipment productivity is obtained from the total price per hour multiplied by the working hours of heavy equipment in 1 day with 8 working hours. The results in graphical form can be seen on Figure 2.

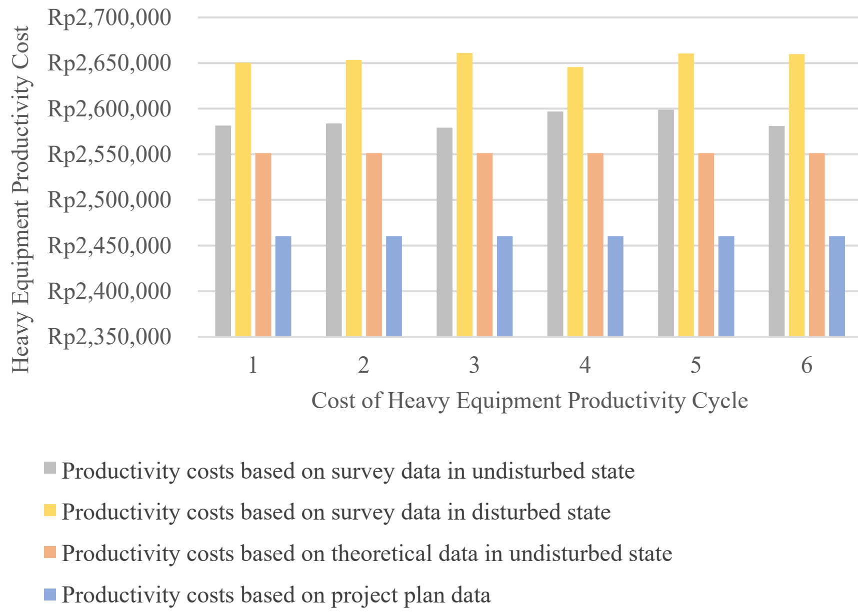

Figure 2. Productivity Cost Calculation and Observation

4. Conclusion and Suggestion

4.1 Conclusion

Conclusion Based on the results of productivity and costs of heavy equipment on 27 km Toll Road Construction project in the DKI Jakarta – West Java Region, the value of productivity in disturbed condition based on survey data has a lower value than the productivity of heavy equipment in an undisturbed condition based on survey data and theoretical data. The following is the conclusion of this research:

1. For the productivity of heavy equipment value, it can be concluded that: the calculation of productivity from observation survey in undisturbed condition is closer to the productivity based on theoretical value and known data values from the equipment's specifications, but the productivity in disturbed condition is lower than the others. Meaning that more care and preparation is needed to for this, and the calculation on the planning stage need to be more pessimistic to counter the actual outcome of heavy equipment productivity.
2. The cost of productivity from each cycle can be concluded as: the cost in undisturbed condition is close to the calculated cost using theoretical value and known data values from the equipment's specifications. But the value of those two is still higher than those planned by the project, meaning the planned calculation is most likely overly optimistic. Lastly the cost of productivity during the disturbed condition is higher than the rest, meaning it is very important to anticipate it, and not being overly optimistic on the planned calculation.
3. Another conclusion is that there are factors that cause the difference in productivity values between the planned data and survey data, such as there are several dump trucks that pass the compaction work while it is in progress, so the compactor must repeat the compaction work again. Then, the condition of the field after the rain causes puddles of water on the compaction surface. so you have to add the number of passes from the vibratory roller and sheep foot roller so that puddles are reduced or lost.

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