Analysis of productivity and the need for heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun)

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Abstract. Grade B aggregate foundation layers are part of the road foundation that is located between subgrade and grade A foundation layers. The function of grade B aggregate foundation layers is to minimize the spread of loads to the subgrade. Road infrastructure is one of the factors that support an area development. Road improvements aimed to improve the social economy and open access to isolated areas of considerable potential for the development of natural resources. This research analyses productivity and the need for 5 types of heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun). Noted that heavy equipment specifications were used in project site same as the planned. The results showed that based on time schedule and project volume in this research can be completed properly and on time if using 5 units of dump trucks and 1 unit each for wheel loader, vibratory roller, motor grader and water tank truck, with productivity for wheel loader is 125.42 m^3, dump truck is 2.69 m^3, vibratory roller is 87.15 m^3, motor grader is 57.24 m^3 and water tank truck is 71.14 m^3.

1. Introduction
Roads are defined as all parts of the road, including auxiliary buildings and their equipment intended for public traffic, which are on the surface of the land, above the surface of the land, below the surface of the land and/or water and above the water level, except railroads and roads cable [1]. While local roads are public roads that serve the function of local transportation with the characteristics of short distance travel, low average speed and the number of entry roads is not limited [2]. Pekan Gedang road section in Batang Asai District Sarolangun is an old road which in 2018 has been upgraded to a local road with a road length of 1 km, width of the road body is 6 meters, type of road is 1/2 UD and can be burdened by vehicle loads heaviest up to 8 tons.

The increase in the Pekan Gedang road section is related to the existing conditions in the form of macadam pavement layers which are often badly damaged due to annual landslides due to very high rainfall. Repairing parts of the damaged road continually cost so much that the Ministry of Public Works

of the Jambi Province in the field of Bina Marga initiated the road improvement activities for Region VIII in the Sarolangun Regency, namely opening new roads by cutting hills.

Cost, quality, time and work safety factors are benchmarks of project performance in achieving success [3]. Grade B aggregate foundation layers work as part of this project has a total work volume of 1,200 m^3. The definition of aggregate is a major component of highway pavement material which contains 90 – 95% of the rupture area, it comes from nature or through processing [4]. The foundation layers' work is assisted by the use of 5 types of heavy equipments, namely wheel loader, dump truck, vibratory roller, motor grader and water tank truck. Heavy equipment is an important factor in construction work that has a large scale of work. The purpose of using heavy equipment is to facilitate humans in doing work, so that maximum results can be achieved in a short time. Errors in the allocation of heavy equipment can cause work to become problematic, have an impact on the quality of work and scheduled implementation of work [5].

The work sequence of the combination of heavy equipments above in carrying out work in a mechanical way starts with:

    i.   Wheel loader; function to loads grade B aggregates into a dump truck at base camp or road project in the site.
    ii.   Dump truck; function to transports grade B aggregates to the site.
    iii.   Vibratory roller; function to compacts on grade B aggregates that have been soaked in water by a water tank truck.
    iv.   Motor grader; function to extends grade B aggregates on the road that has been prepared.
    v.   Water tank truck; function to flushes grade B aggregates evenly that have spread across the road site.

The infrastructure development is an important aspect for the overall development of country. The major problem frequently faced by contractor in the selection of most suitable equipment [6]. "Construction Equipment (CE)" or "Heavy Equipment" refers to heavy-duty self-propelled vehicles, specially designed for executing construction tasks. Its use has a signifcant importance in the successful realisation of civil projects. Therefore, represents a major capital investment for the construction industry [7]. In highway projects most of the activities nowadays are equipment oriented and require only very meagre amount of participation from the unskilled and semi-skilled labourers. Only high skilled manpower and operators of the equipments are required to execute the job and the productivity of the operators can be determined from the productivity of the respective equipments [8]. It's important to have a proper management for maintenance, work schedule, fuel consumption and idle time [9]. As for each type of machine having a completely different cycle time phase. Therefore, studying cycle time statistics and cycle time frequency distribution curves is important [10].

The location of the work, the field of work, the type of work and the time of completion of the work are considered in the process of selecting the type of equipment needed [11]. In addition, the type of material, the volume of work and the ability to work of heavy equipment also influence [12]. The use of heavy equipments that is not right with the conditions and employment situation will affect the low productivity of the equipment and not achieving the predetermined schedule or target [13]. Many found a significant increase in the use of heavy equipment at construction sites as a form of business to meet the demand in the past few decades [14].

By paying attention to the problems that occur, it is concluded that the heavy equipment used in a project is influenced by the productivity of the equipment to the volume of work to be carried out, while the amount of equipment needed depends on the time available, site conditions, weather conditions, equipment efficiency, equipment capacity, number equipment and equipment operator capabilities [3]. Therefore, the authors make a research of the formulation of how much productivity (production capacity) per hour of heavy equipment and how much the need for heavy equipment used in grade B aggregate foundation layers work with a total volume of 1,200 m^3.

2. Method of Research

This type of research is quantitative data study, which is a type of data that can be measured (measurable) or calculated directly as a variable number or number that describe a case or object of research, about productivity and the need for heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun) in 2018.

Data sources in this research consisted of primary data and secondary data. The primary data were obtained using the approach and direct observation in the project site by field observations and interviews, while the secondary data obtained of important documents from owner, contractor, supervising consultant and other sources related to this research. Secondary data collection aimed to obtain information, such as complete project implementation data, heavy equipments data and grade B aggregate foundation layers work data.

The research site is shown in Figure 1:

Figure 1. Research Site

2.1 Preparation Phase

There are several steps taken at preparation phase, namely:

   i.   Formulating research, research objectives, define the methods to be used and explore the literature, do literature study by reading the lecture subjects, reference books related to a research report.
   ii. Collected project data that will be made as object of research, such as site data from contractor, relevant government institutions as project owners, consultant and other sources related to the execution of the project.
   iii. To support the research conducted interviews with parties related to the project.

In processing data to determine productivity and the need for heavy equipment on grade B aggregate foundation layers work, there are formulations and specifications that are used, namely:

2.1.1 Wheel Loader

The calculation for production capacity per hour can be calculated according to equation (1) and the specifications of wheel loaders used are as tabulated in Table 1.

$$Q = \frac{V \ x \ F_b \ x \ F_a \ x \ 60}{T_s \ x \ Bip/Bil} \qquad (1)$$

The following notation is used to formulate the production capacity of wheel loader:

Q = The production capacity per hour (m^3)
V = Capacity of bucket (m^3)
F_b = Bucket factor

F_a = Equipment efficiency factor
T_s = Cycle time (minute)

Table 1. Specifications of wheel loaders used.

Specification	Description
Brand of heavy equipment	Caterpillar
Type of heavy equipment	Cat 914 G
Heavy equipment power (HP)	95 HP
Bucket capacity (Cp)	1.4 m^3
Heavy equipment age (A)	5 years
Working hours for 1 year (W)	2000 hours

2.1.2 Dump Truck

The calculation for the production capacity per hour can be calculated based on equation (2) and the specification of dump truck used is as displayed in Table 2.

$$Q = \frac{V \ x \ F_a \ x \ 60}{D \ x \ T_s} \qquad (2)$$

The following notation is used to formulate the production capacity of dump truck:

V = Capacity of tub (ton)
F_k = Materials development factor
F_a = Equipment efficiency factor
60   = Conversion from hours into minute
D = Weight of material (loose materials) (ton/m^3)
T_s = Cycle time (minute)
        = $T_1 + T_2 + T_3 + T_4$

Table 2. Specifications of dump truck used.

Brand of heavy equipment	Hino
Type of heavy equipment	Dutro 130 HD
Heavy equipment power (HP)	130 HP
Dump capacity (Cp)	6 m^3
Heavy equipment age (A)	5 years
Working hours for 1 year (W)	2000 hours

2.1.3 Vibratory Roller

The production capacity per hour can be calculated based on equation (3) and specifications of vibratory rollers used is as shown in Table 3.

$$Q = \frac{(b_e \ x \ v \ x \ 1000) \ x \ t \ x \ F_a}{n} \qquad (3)$$

The following notation is used to formulate the production capacity of vibratory roller:

b_e = Effective width of compaction wheel
        = $b - b_o$ (overlap) (m)
b = Effective width of compaction (m)
b_o = Overlap width (m)

t	= Compaction thickness (m)
v	= Equipment average speed (km/hour)
n	= Number of tracks (track)
F_a	= Equipment efficiency factor
	(use 0.83 for good condition)
1000	= Conversion from km into m

Table 3. Specifications of vibratory rollers used.

Brand of heavy equipment	Sakai
Type of heavy equipment	Sakai SV525D
Heavy equipment power (HP)	82 HP
Equipment capacity (Cp)	7.1 tons
Heavy equipment age (A)	5 years
Working hours for 1 year (W)	2000 hours

2.1.4 Motor Grader

The production capacity per hour can be calculated as in equation (4) and specifications of motor graders used is tabulated in Table 4.

$$Q = \frac{L_h \; x \; (n \; (b - b_o)) \; x \; F_a \; x \; 60}{N \; x \; n \; x \; T_s}$$

(4)

The following notation is used to formulate the production capacity of motor grader:

L_h	= Length of overlay (m)
b_o	= Overlap width (m)
F_a	= Equipment efficiency factor
n	= Number of tracks (track)
N	= Number of lane (lane)
b	= Effective width of blade
60	= Conversion from hours into minute
T_1	= One time track
	= *(LH x 60) / (v x 1000)* (minute)
T_2	= Other time (minute)
T_s	= Cycle time (minute)

Table 4. Specifications of motor graders used.

Brand of heavy equipment	Caterpillar
Type of heavy equipment	Cat 120 K
Heavy equipment power (HP)	125 HP
Heavy equipment age (A)	5 years
Working hours for 1 year (W)	2000 hours
Brand of heavy equipment	Caterpillar

2.1.5 Water Tank Truck

The production capacity per hour can be calculated as in equation (5) and the specifications of water tank truck used is as displayed in Table 5.

$$Q = \frac{P_a \; x \; F_a \; x \; 60}{W_c \; x \; 1000}$$

(5)

The following notation is used to formulate the production capacity of water tank truck:

W_c = The need of water per m³ solid materials (m³)

P_a = Capacity of water pump
(use 100 liters/minute)

F_a = Equipment efficiency factor

60 = Conversion from hours into minute

1000 = Conversion from km into m

Table 5. Specifications of water tank truck used.

Brand of heavy equipment	Mitsubishi
Type of heavy equipment	Canter HD 125 PS
Heavy equipment power (HP)	125 HP
Tank capacity (V)	4000 liters
Heavy equipment age (A)	5 years
Working hours for 1 year (W)	2000 hours

2.1.6 Total Heavy Equipment Need

To determine the need allocation of necessary heavy equipment in road construction project in this research, there are elements that need to be considered which are allocation assumption of heavy equipments (units), volume of work (m³), production capacity of heavy equipments (m³), and working hours for 1 year (days)

In this research, working hours specified for grade B aggregate foundation layers work on time schedule is a guideline for allocating working day of each machine. First, determined working days based on largest to smallest production capacity of heavy equipment with assumption there is only one heavy equipment can be calculated according to equation (6).

$$t = \frac{Q}{V}$$

(6)

where t is the working days (hour), Q is the production capacity (m³) and V is the volume of work (m³). Once obtained each working days then calculate the summary of heavy equipment working days. The number of working days must be less than or equal to the working days on time schedule. In this case, heavy equipment with smallest production capacity must be considered because that smallest one needs more working days to fit same working days in time schedule.

2.2 Process Phase

There are several steps taken at process phase, namely:

i.   Calculating the productivity (production capacity) of heavy equipment on grade B aggregate foundation layers work.

ii.   Calculating the demand of heavy equipment on grade B aggregate foundation layers work.

2.3 Final Phase
At this last stage, the research procedure is make conclusion from analysis results of productivity and the need for heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun).

3. Result and Discussion

3.1 Project Volume Data
The implementation of work for the improvement of Pekan Gedang Road (Batang Asai) – Muaro Talang District, Sarolangun, in 2018 by Ministry of Public Works and Public Housing in Jambi Province consists of several types of work as set out in Table 6 below:

Table 6. Project Volume Data

No	Type of Work	Unit	Volume	%
1	Mobilization	Ls	1.00	0.85
2	Excavation for drainage channel and water channel	m^3	59.00	0.06
3	Ordinary excavation	m^3	321.80	0.30
4	Soft stone excavation	m^3	1,120.00	2.76
5	Selection fill from excavation	m^3	263.00	0.31
6	Road set up	m^3	6,000.00	0.38
7	Grade B aggregate foundation layers	m^3	1,200.00	16.94
8	Concrete quality: fc' 25 Mpa (K.300)	m^3	31.10	1.35
9	Concrete quality: fc' 20 Mpa (K.240)	m^3	972.00	48.47
10	Concrete quality: fc' 15 Mpa (K.180)	m^3	50.40	1.77
11	Concrete quality: fc' 10 Mpa (K.120)	m^3	7.00	0.20
12	Reinforcing steel: BJ 24 plain	kg	56,599.50	26.61
	Total			100.00

In this research, discussion is limited for grade B aggregate foundation layers work with a total volume of 1,200 m^3.

3.2 Wheel Loader
The production capacity calculation of wheel loader can be seen in the Table 7.

Table 7. The Production Capacity Calculation Recapitulation of Wheel Loader

No	Data	Code	Coefficient	Quantity	Unit
	Data of Project				
1	Solid weight of grade B aggregate	Bip	–	1.80	ton/m^3
2	Loose weight of grade B aggregate	Bil	–	1.60	ton/m^3
3	Effective working hours per day	T_k	–	7.00	hour
	Data of Wheel Loader				
1	Capacity of bucket	V	–	1.40	m^3
2	Bucket factor	F_b	0.85	–	–
3	Equipment efficiency factor	F_a	0.83	–	–
4	Cycle time	T_s	–	0.45	minute
5	Production capacity per hour				
		Q	–	125.42	m^3

	$Q \quad = \dfrac{V \; x \; F_b \; x \; F_a \; x \; 60}{T_s \; x \; Bip/Bil}$				
6	Production capacity per day				
	$Q_h \quad = T_k \; x \; Q$	Q_h	–	877.96	m^3

Based on the calculation results in Table 2 and specifications of the heavy equipment used, wheel loader production capacity is 125.42 m³/hour and 877.96 m³/day. Within 1 day the wheel loader works with effective working hours of 7 hours.

3.3 Dump Truck
The production capacity calculation of dump truck can be seen in the Table 8.

Table 8. The Production Capacity Calculation Recapitulation of Dump Truck

No	Data	Code	Coefficient	Quantity	Unit
	Data of Project				
1	Capacity of dump truck	Q_1	–	118.37	m^3
	Data of Dump Truck				
1	Dump capacity (on site)	V	–	4.80	ton
2	Equipment efficiency factor	F_a	0.80	–	–
3	Average speed of loads vehicle	v_1	–	10.00	km/hour
4	Average speed of empty vehicle	v_2	–	15.00	km/hour
5	Loading time: $(V \; x \; 60)/(Q_1 \; x \; Bil)$	T_1	–	1.52	minute
6	Loads vehicle time: $(L/v_1) \; x \; 60$	T_2	–	30.00	minute
7	Empty vehicle time: $(L/v_2) \; x \; 60$	T_3	–	20.00	minute
8	Etc, like unloading material time	T_4	–	2.00	minute
9	Cycle time: $T_1 + T_2 + T_3 + T_4$	T_s	–	53.52	minute
10	Production capacity per hour	Q	–	2.69	m^3
11	Production capacity per day				
	$Q_h \quad = T_k \; x \; Q$	Q_h	–	18.83	m^3

Based on the calculation results in Table 3 and specifications of dump truck used, the production capacity of dump truck is 2.69 m³/hour and 18.83 m³/day, in 1 day the dump truck works with effective working hours is 7 hour.

3.4 Vibratory Roller
The production capacity calculation of vibratory roller can be seen in the Table 9.

Table 9. The Production Capacity Calculation Recapitulation of Vibratory Roller

No	Data	Code	Coefficient	Quantity	Unit
1	Average speed of vehicle	v	–	1.50	km/hour
2	Effective width of compaction wheel	b_e	–	0.70	m
3	Overlap width	b_o	–	0.30	m
4	Effective width of compaction	b	–	1.00	m
5	Equipment efficiency factor	F_a	0.83	–	–
6	Number of tracks	n	–	2.00	track
7	Production capacity per hour	Q	–	87.15	m^3
8	Production capacity per day				
	$Q_h \quad = T_k \; x \; Q$	Q_h	–	610.05	m^3

Based on the results of calculations in Table 4 and specifications of vibratory roller used, vibratory roller production capacity is 87.15 m³/hour and 610.05 m³/day, in 1 day vibratory roller working with effective working hours is 7 hour.

3.5 *Motor Grader*
The production capacity calculation of vibratory roller can be seen in the Table 10.

Table 10. The Production Capacity Calculation Recapitulation of Motor Grader

No	Data	Code	Coefficient	Quantity	Unit
1	Length of overlay	L_h	–	1,000.00	m
2	Effective width of blade	b	–	1.00	m
3	Overlap width	b_o	–	0.30	m
4	Equipment efficiency factor	F_a	0.83	–	–
5	Average speed of vehicle	v	–	2.50	km/hour
6	Number of tracks	n	–	6.00	track
7	Number of lane	N	–	1.00	lane
8	Cycle time	T_s	–	29.00	minute
9	Leveling 1 track: *(L_h x 60) / (v x 1000)*	T_1	–	24.00	minute
10	Etc	T_2	–	5.00	minute
11	Production capacity per hour	Q	–	57.24	m^3
12	Production capacity per day				
	$Q_h = T_k \; x \; Q$	Q_h	–	400.69	m^3

Based on the calculation in Table 5 and the specifications of the motor grader used, the production capacity of motor grader is 57.24 m³/hour and 400.69 m³/day, in 1 day the motor grader work with effective working hours is 7 hours.

3.6 *Water Tank Truck*
The production capacity calculation of water tank truck can be seen in the Table 11.

Table 11. The Production Capacity Calculation Recapitulation of Water Tank Truck

No	Data	Code	Coefficient	Quantity	Unit
1	Tank capacity	V	–	4.00	m^3
2	The need of water per m^3 solid materials	W_c	–	0.07	m^3
3	Capacity of water pump	P_a	–	100.00	liter/ minute
4	Equipment efficiency factor	F_a	0.83	–	–
5	Production capacity per hour	Q	–	71.14	m^3
6	Production capacity per day				
	$Q_h = T_k \; x \; Q$	Q_h	–	498.00	m^3

Based on the calculation in Table 6 and the specifications of the water tank truck used, the production capacity of the water tank truck is 71.14 m³/hour and 498.00 m³/day, in 1 day the water tank truck works with effective working hours is 7 hours.

3.7 *Total Heavy Equipment Needed*
The calculation of total heavy equipment needed can be seen in the Table 12.

Table 12. The Calculation Recapitulation of Total Heavy Equipment Needed

No	Data	Wheel Loader	Dump Truck	Vibratory Roller	Motor Grader	Water Tank Truck
1	Heavy equipment needed (unit)	1	5	1	1	1
2	Volume of work (m^3)	1,200	1,200	1,200	1,200	1,200
3	Production capacity (m^3/day)	877.96	86.05	610.05	400.69	498.00
4	Working day (day)	1.37	13.94	1.97	2.99	2.41
5	Working day (day) (rounded)	2	14	2	3	3

The results of the calculations in Table 7 can be seen that total heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun) in 2018 with a total volume of 1,200 m^3 based on time schedule consist of wheel loader needs 1 unit, dump truck needs 5 units, vibratory roller needs 1 unit, motor grader needs 1 unit and water tank truck needs 1 unit.

4. Conclusion

The use of heavy equipment is required for large-scale construction work. The goal is to make it easier for humans to do work in order to obtain maximum good results within a certain period of time. In addition, the accuracy in choosing the type and combination of heavy equipment greatly affects the quality of the work. Heavy equipment used in a project is also influenced by two important things, namely the productivity of the heavy equipment to the volume of work to be done and the amount of heavy equipment needed in the field. The number of heavy equipment required depends on the time available, field conditions, weather conditions, heavy equipment efficiency, heavy equipment capacity, number of heavy equipment and the ability of the heavy equipment operator.

From the results of the analysis, the results obtained that the productivity of heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun) consists of production capacity per hour for wheel loader is 125.42 m^3, production capacity per hour for dump truck is 2.69 m^3, production capacity per hour for vibratory roller is 87.15 m^3, production capacity per hour for motor grader is 57.24 m^3 and production capacity per hour for water tank truck is 71.14 m^3.

From the results of the analysis, the results obtained that the productivity of heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun) consists of production capacity per hour for wheel loader is 125.42 m^3, production capacity per hour for dump truck is 2.69 m^3, production capacity per hour for vibratory roller is 87.15 m^3, production capacity per hour for motor grader is 57.24 m^3 and production capacity per hour for water tank truck is 71.14 m^3. The results showed that production capacity per hour of each heavy equipment on grade B aggregate foundation layers work in accordance with project time schedule.

In calculating the needs for heavy equipment on grade B aggregate foundation layers work (case study: Pekan Gedang road section, Batang Asai – Muaro Talang District, Sarolangun), all data needed are the aggregate volume of class B, the production capacity of the heavy equipment and the time to carry out the work specified in the work schedule (time schedule). Time schedule for grade B aggregate foundation layers work in this research is 4 weeks or 24 work days or 168 hours, where 1 effective working day is 7 hour. From the calculation results, it can be seen that total heavy equipment needed on grade B aggregate foundation layers work for 1,200 m^3 project volume which consists of Wheel loader needs 1 unit, Dump truck needs 5 units, Vibratory roller needs 1 unit, Motor grader needs 1 unit and Water tank truck needs 1 unit.

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