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Analysis of Heavy Equipment Quantity using Quantitative Methods Software (QM) for Windows V5 on Road Infrastructure Works

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ABSTRACT

Data from the Geological Agency, Ministry of Energy and Mineral Resources (ESDM) in 2018, Indonesia has 37 billion tons of coal with proven reserves of 20.11 billion tons and estimated reserves of 17.02 billion tons. The total reserves increased by 12 billion tons compared to the previous year. To increase production and reserve coal, it is necessary to build mine roads to connect other mining areas. One of them is the work of transporting soil material for road embankment work. The constraints that are often encountered are limited resources and high cost of equipment. Therefore it is necessary to optimize the need for heavy equipment using Quantitative Methods Software (QM) for Windows V5. The data used in this study are primary data taken from the interview process and data in the form of related secondary documents, namely the RAB, Scheduling, SPK and other documents. The tools that will be used and optimized are a lot of digging and loading equipment such as Excavator PC400 with a bucket capacity of 2.6 m^3, Excavator PC300 with a bucket capacity of 1.8 m^3, Excavator with a bucket capacity of 0.8 m^3 and a Dump Truck with a body capacity of 22.3 m^3 as transportation equipment. The results of the research data analysis show that the most optimal number of tools needed for the road works is 1 PC300 Excavator unit, 1 PC200 unit and 3 Dump Truck (ADT) units for a work volume of 99.626 m^3 and the optimal work duration is 814 hours and the labor cost is Rp. 2,781,227,681. Excavator with a bucket capacity of 0.8 m^3 and a Dump Truck with a body capacity of 22.3 m^3 as transportation equipment. The results of the research data analysis show that the most optimal number of tools needed for the road works is 1 PC300 Excavator unit, 1 PC200 unit and 3 Dump Truck (ADT) units for a work volume of 99.626 m^3 and the optimal work duration is 814 hours and the labor cost is Rp. 2,781,227,681. Excavator with a bucket capacity of 0.8 m^3 and a Dump Truck with a body capacity of 22.3 m^3 as transportation equipment. The results of the research data analysis show that the most optimal number of tools needed for the road works is 1 PC300 Excavator unit, 1 PC200 unit and 3 Dump Truck (ADT) units for a work volume of 99.626 m^3 and the optimal work duration is 814 hours and the labor cost is Rp. 2,781,227,681.

Keyword: Dump Truck, Excavator, Infrastructure, Optimization, QM Software V5.

Introduction

Studies, exploration and utilization of metallurgical coal in Indonesia have not been carried out much both in terms of resources and exploitation [1-9]. Indonesia is one of the largest thermal coal producers in the world. Coal resources in Indonesia also have the potential to produce metallurgical coal which can encourage investment in this sector. **Table 1** is data on coal production, exports,

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consumption and prices from 2014 to 2019 [10].

Table 1. Coal Production, Export, Consumption and Prices

	2014	2015	2016	2017	2018	2019
Production (in million tonnes)	458	461	456	461	425	400
Export (in million tonnes)	461	375	365	364	311	160
Domestic (in million tonnes)	76	86	91	97	114	240
Price (HBA) (USD/tonne)	72.6	60.1	61.8	na	na	na

One of the supporting jobs for coal production is the coal hauling road infrastructure. The infrastructure project includes road embankment work. Heavy equipment for earthmoving work for embankment projects, both for preliminary work for road work and building construction, requires equipment in large quantities, especially for excavators and other types of heavy equipment conveyance (dump truck) [11-19].

Figure 1. Mining infrastructure work [19]

The analytical method used to calculate the number of the most effective tools for the following road works is to use the Quantitative Method (QM) Software V5 is software as a tool optimization to calculate the optimal cost, time and number of tools needed to carry out road embankment work on the project above. QM for Windows is a combination of the previous DS and POM for Windows programs, so more modules are available in QM for Windows compared to the POM for Windows program. However, there are modules that can only be used with the POM program for Windows or only with the DS program for Windows, but not with QM for Windows [20-22]. Therefore, it can be concluded that the purpose of this analysis is to determine the optimal number of tools, both excavators and dump trucks for coal road project work in order to obtain a combination of the right and efficient use of tools. And the cost of work becomes as economical as possible.

Methods

Project

A project is a series of interconnected activities with specific starting and ending points and outcomes. Projects are usually cross-functional organizations with varying levels of expertise from different professions and organizations. According to [22]: Projects are jobs that have the following characteristics:

a. The start and finish times are planned.
b. It is a work unit that can be separated from the others.
c. The number of items and volume of work is large and the relationship between activities is complex.

The main cycle of the project can be seen in the following flowchart:

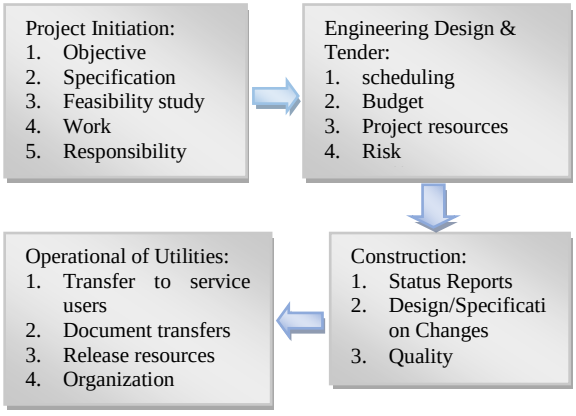

Figure 2. Cycle of a construction project [22]

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Road infrastructure

There is no classification of roads within the mining area, but in general they can be divided into mine roads (mine shafts, ports, or entrances to the dumps) and mine roads (roads around the mining area). Both roads have almost the same structure as regular highways, the only difference being that they have almost no asphalt or concrete surfaces. This is because heavy equipment often crosses the mine road. The design of mine roads and haul roads must consider entry and exit locations, crossing widths, super-elevations, and so on.

In the phase during the earthwork implementation stage to prepare the subsoil according to the planned schedule, determine the work method that will be used by the contractor to complete each work within the planned time. The procedure determination should cover the proposed procedure, including the allocation and details of equipment, materials and personnel. The work proposed by the contractor, in this case earthwork specifically for embankments, must be submitted to the field manager for approval prior to commencement of work. work. Material for road embankments is taken from a quarry which is a predetermined source of material taking. Mining road infrastructure can be seen in **Figure 3**.

Figure 3. Mining road [1]

Heavy equipment

1. Excavators

Excavator (backhoe) is a heavy equipment that is usually used to dig the ground and transport soil or other materials into trucks. Excavators or what Indonesians call dupes are the most common tools in projects because of their different functions. Apart from digging the ground, excavators have other functions such as moving heavy materials, leveling the ground, lowering foundation blocks, dredging rivers, and others. The shape of the excavator is shown in **Figure 4**.

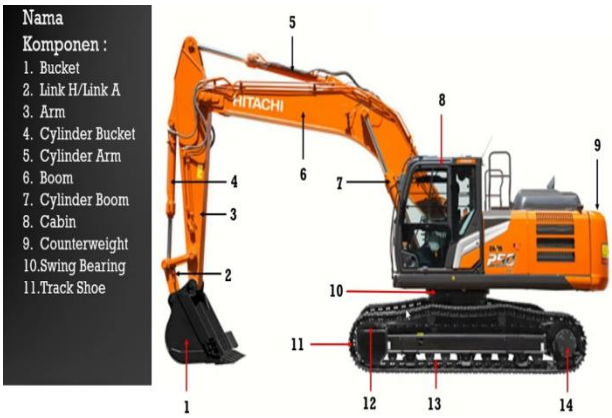

Figure 4. Excavators [1]

Excavator productivity is the ability to produce loading equipment which can be calculated using the following formula:

$Q = (qx\ 60 \times E)/Cms$ where $q = ql \times K$ (1)

Where :

Q : Production per hour (m^3 /hour)
q : Production per cycle (m^3)
cms : Loading tool cycle time (minutes)
E : Work efficiency
ql : Bucket capacity
K : Bucket fill factor

Furthermore, the excavator cycle time is calculated by the formula:

$cms = tm + tpb + tb + tpk$ (2)

Where :

tm :Wbucket loading time (digging time), tm
tpb :Wload play time (swing loaded time)
tb :Wdumping time
but :Wturn back time (swing empty time)

Table 2. Bucket Fill Factor [20]

Factor Bucket (Back Hoe)		
Excavation Conditions		Factor Buckets
Easy	Soft clay soil (ordinary)	1.2 - 1.1

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Currently	Loose soil mixed with gravel	1.1 - 1.0
It's kinda hard	Hard rock, traces of light explosions	1.0 - 0.8
Difficult	Hard rock, blast marks	0.9 - 07

2. Dump Trucks

Dump trucks are basically used to transport materials from one place to another. For loading, loading and recharging must be assisted by excavators or other tools, while unloading dump truck loads works alone. These materials include coal, packed earth, sand, crushed rock, nickel, iron ore, and even waste. The rear dumper is used to transport the piled and excavated materials. Material excavated by loading aids is loaded into a dump truck and disposed of in the TPA or TPA road construction area. To calculate the total hourly output of several dump trucks doing the same job, it can be calculated using a mathematical equation. The shape of the dump truck can be seen in **Figure 5**.

Figure 5. Dump Trucks [1]

The production capacity of the conveyance can be calculated by the formula:

P = (C x 60 x E)/Cmt where C = nx ql x K (3)

Where:

P : Production per hour (m^3 /hour)
C : Production per cycle (m^3)
cmt : Dump truck cycle time, loading, cargo travel, dumping, retracting travel (minutes)
E : Work efficiency factor
n : Number of cycles of the excavator filling the dump truck
ql : Bucket capacity
K : Bucket fill factor

And for the dump truck cycle time it consists of 5 time components, namely:

cmt = tl + th + td + tr + tw (4)

tl :loading time
th :transport time
td : demolition time
tr :return time , tr
tw : waiting time / queue

Equipment Cost

The use of heavy equipment basically must be considered the economics of a tool including the consequences of costs that must be incurred. The costs included in the cost of heavy equipment expenses are equipment rental costs, mobilization and demobilization costs, and operator wage costs. Construction equipment driven by internal combustion engines requires fuel and lubricating oil, which must also be considered as operational costs.

1. Fuel

The amount of fuel for heavy equipment that uses gasoline or diesel varies. On average, those using gasoline are 0.06 gallons per horse-power per hour, while diesel fuel consumes 0.04 gallons per horse-power per hour. The value obtained is then multiplied by the operating factor. The amount of fuel consumption per unit time will depend heavily on the power specifications of the heavy equipment according to the type issued by the manufacturer or the manual book of the tool itself.

2. Wages

The amount of wages for operators/helpers on excavators, bulldozers, motor graders, vibrator rollers and drivers/coachers on dump trucks depends on the location of work, the company concerned, the regulations in force at the location, and the work contract between the two parties. Basically wages for workers are calculated in the amount of money paid per hour worked (Rp/hour).

3. Calculation of Lubricating Oil Usage

The calculation of the use of lubricant per hour is usually based on the amount of operating time and the duration of the lubricant change. The replacement of lubricating oil is usually done every 100 to

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200 hours. The estimated cost of lubricant per hour is calculated as follows:

Qp = (fx Hp x 0.006)/7.4+ c/t (5)

Where:

Qp : Lubricant usage per hour

f : Operating factor

Mobile phone : Horsepower of the engine

c : crankcase capacity

t: duration of use of lubricant (replacement)

4. Mobilization and Demobilization Costs

Heavy equipment that is rented from a place, requires transportation costs for the equipment to the project site and transportation costs for the equipment back to its place of origin. For certain heavy equipment, a special vehicle is even needed to lift the heavy equipment to the project location and vice versa. These necessary costs include mobilization and demobilization costs.

5. Equipment Maintenance and Care Costs

The fundamental difference between maintenance and maintenance is the size of the job. Major repairs will affect the depreciation value of the tool and the life of the tool. The cost of maintenance and maintenance of the tool is assumed to be 100% of the depreciation of the tool (straight-line method) for 5 years (Rostiyanti, 2008). For wheeled equipment such as dump trucks, there is an additional fee for using the tires according to the specified service life.

Calculation of Equipment Cost Components consisting of ownership costs and operational costs. Analysis of the unit price of tools for earthmoving work requires operator or driver wage data, tool specifications including engine power, tool work capacity (m^3), tool economic life (from the manufacturer), working hours in one year, and tool prices. Another factor is the equipment investment component including bank interest rates, tool insurance, specific tool factors such as the bucket factor for excavators, the acquisition price of tools, and loaders, and others.

Excavator and Dump Truck Productivity

Tool requirements are calculated based on the volume and duration of work. Some of the analysis indicators needed to obtain the number of tool requirements include:

Technical data indicators of work

a. Job volume = 99.626 m^3
b. Duration = 4 Months 120 Days 960 Hours≅≅

The amount of ADT required for each type of backhoe varies. According to (Wedhanto, 2009) the efficiency value (e) of the tool is 83%. Then from the productivity of each excavator it can be known the number of ADT units needed. The following is the calculation of productivity and the need for ADT units:

Is known:

a. Tool efficiency (e) →83%
b. Bucket Correction Factor (k) →1
c. Cycle Time Loading Excavators (CT)
d. 400 PCs→127.65 hours
e. PC 300→139.05 hours
f. PCs 200→140.85 hours
g. Load Cycle Time ADT Tool (CT ADT)
h. ADTPC 400→2.26 hours
i. ADTPC 300→2.29 hours
j. ADTPC 200→2.12 hours
k. Excavator Bucket Capacity
l. 400 PCs →2.6m3
m. PC 300 →1.8m3
n. PCs 200 →0.8m3
o. ADT Vessel (Bak) Capacity →22.3 m3

The productivity of each excavator or backhoe tool is:

1. PC Productivity 400
   = (Bucket Capacity)x(k)x(e)xCT PC 400
   = 2.6 x 1 x 83% x 127.65
   = 275.49 m^3/hour
2. PC Productivity 300
   = (Bucket Capacity)x(k)x(e)xCT PC 300
   = 1.8 x 1 x 83% x 139.05
   = 207.74 m^3/hour
3. PC Productivity 200
   = (Bucket Capacity)x(k)x(e)xCT PC 300
   = 0.8 x 1 x 83% x 140.85
   = 93.52 m^3/hour

ADT productivity for each excavator as follows:

1. ADT-PC 400 productivity
   = CT PC ADT 400 x Capacity ADT

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= 2.26 x 22.3
= 50.35 m^3/hour

2. ADT-PC 300 productivity
= CT PC ADT 300 x Capacity ADT
= 2.29 x 22.3
= 51.10 m^3/hour

3. ADT-PC 200 productivity
= CT PC ADT 200 x Capacity ADT
= 2.12 x 47.30
= 50.35 m^3/hour

Then the ADT requirement for each excavator tool is as follows:

1. ADT for 400 PCs = $\frac{\text{Productivity PC400}}{\text{Productivity ADT-PC400}} = \frac{275,49}{50,35}$
= 5.47 units~6 units

2. ADT for 300 PCs = $\frac{\text{Productivity PC300}}{\text{Productivity ADT-PC300}} = \frac{207,74}{51,10}$
= 4.07 units~4 units

3. ADT for 200 PCs = $\frac{\text{Productivity PC200}}{\text{Productivity ADT-PC200}} = \frac{93,52}{47,30}$
= 1.98 units~2 units

Quantitative Method for Windows V5

QM for Windows V5 stands for Quantitative Method, software found in operations management textbooks. QM for Windows is a combination of the previous DS and POM for Windows, so QM for Windows provides more modules compared to POM for Windows. The screen shown in **Figure 6**.

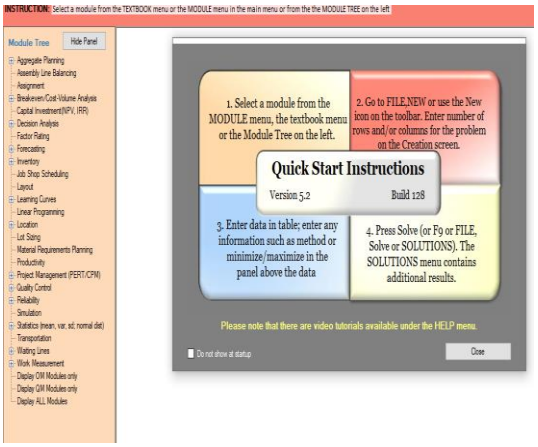

Figure 6. Interface QM for Windows V5

The steps for running the QM For Windows program are:

1) Select the File - New menu, then a screen will appear as shown below.
2) Create a title to solve this problem by filling in the Title section. If the title is not filled, the QM for Windows program creates its own title according to the default (comment).
3) Enter the limit amount by clicking on the icon in the Limit amount field.
4) Enter the number of variables by clicking the tick in the column Number of variables.
5) Select the desired destination from the Destination section. If the desired goal is to maximize, select "maximize" and vice versa, if the desired goal is to minimize, select "minimize".
6) Then click OK.
7) Write a number in the box that corresponds to the question.
8) Finish by clicking the button on the toolbar or on the File - Solve menu or by pressing the F9 key on the keyboard.
9) If you find that the question information needs to be corrected, click the button on the toolbar or click the File – Edit menu.
10) Don't forget to save this working file using the File - Save menu or by pressing Ctrl+S.

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This analysis is carried out to obtain the required number of transportation equipment to be used according to the type and specification using cycle time data and equipment capacity as well as optional loading equipment and to obtain an economical cost for the work. Next, create a mathematical model using the linear programming method as a step in setting constraints related to decision variables and functions of the number of conveyances and loading equipment to be used as well as economical costs.

Based on the formulation of the problem, the linear program equation contains, among others:

1. Decision variable

The resulting decision variable is Xi, namely the number of excavators of a certain type of heavy excavator used. There are 3 Xi variables in this study, namely:

X1→PC 400 excavators
X2→PC 300 excavators
X3→PC 200 excavators

2. Objective Function

The resulting objective function is to determine the minimum tool cost incurred by this work. The equation formed in the objective function can be seen from the following formula:

Minimize Z =C1.X1 + C2 . X2 + C3.X3 (6)

Where :

Z → Total cost of equipment for excavator/PC and articulated dump truck/ADT (Rp/Hour)
C1→ Total rental costs for excavators (PC400) and articulated dump trucks/ADT, operator fees, hourly fuel costs (Rp/hour)
C2→ Total rental costs for excavators (PC300) and articulated dump trucks/ADT, operator fees, hourly fuel costs (Rp/hour)
C3→ Total rental costs for excavators (PC200) and articulated dump trucks/ADT, operator fees, hourly fuel costs (Rp/hour)
X1→ Required number of PC400 excavators or backhoes (units)
X2→ Required number of PC300 excavators or backhoes (units)
X3→ Number of PC200 excavator or backhoe required (units)

3. Constraint Function

Constraints include cost constraints, time constraints, constraints on the number of tools and constraints on tool productivity. From the results of mathematical modeling, goal setting and problem threshold determination can be constructed in the following form:

- Production Cost (A1)
  C1.X1 + C2.X2 + C3.X3 ≤ Total Amount of Production Cost (Rp/hour) (7)
- Work Volume (A2)
  Σ Excavator/PC Productivity (m³/hour). Xi ≤ Total Productivity (m³/hour) (8)
- Time (A3 to A5)
  Σ Excavator/PC Production Time (hours). Xi ≤ Total Duration (hours) (9)
- Number of Excavators/PC (A6 to A8)
  1 x Xi ≤ Excavator Productivity/PC(m³/h)/Total Productivity (m³/h) (10)
- Excavator/PC Productivity (A9 to A11)
  Excavator/PC Productivity (m³/hour). Xi ≤ Total Productivity (m³/hour) (11)

4. Articulated Dump truck (ADT) Tool Requirement Function

The function of knowing the need for tools for transport trucks (ADT) is to determine the number of tools to be used based on the number and type of excavator or backhoe needed. To get the number of units of ADT tools, you can use the following equation:

Σ ADT coefficient x Xi (12)

Results and Disscussion

Analysis of the QM v5 software using a work volume of 99.626m3 with a duration of 960 hours is as follows:

Table 3. Analysis of QM V5

	X1	X2	X3		RHS	Dual
Maximize	9931209	7509472	3636717			
Constraint 1	9931209	7509472	3636717	<=	5707739	0
Constraint 2	264470	199431	89780	<=	99626	37,65
Constraint 3	960	0	0	<=	960	0
Constraint 4	0	960	0	<=	960	0
Constraint 5	0	0	960	<=	960	0
Constraint 6	1	0	0	<=	,38	0
Constraint 7	0	1	0	<=	,5	0
Constraint 8	0	0	1	<=	1,11	0
Constraint 9	275	0	0	<=	59,3	0
Constraint 10	0	208	0	<=	59,3	0
Constraint 11	0	0	94	<=	59,3	2724,44
Solution	0	,22	,63		3912925	

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The results of research data processing for a total work volume of 99,626 m3 with a duration of 960 hours, the equipment needed during the project period is as follows:

PC400 = 0.00 ~0 Units
PC200 = 0.63~1 Unit
PC300 = 0.22~1 Unit
ADT = 2.13~3 Unit

Table 4. Optimization Results of Road Construction Time and Cost Based on the Number of Equipment

No Item Pek	Volume Pekerjaan (m3)	Jenis Alat (unit)	Produktivitas (m3/Jam)	Durasi Pekerjaan Dalam Kontrak (jam)	Durasi Pekerjaan Optimal Hasil QM Analysis (jam)	Biaya (Rp/Jam)	Jumlah Alat Hasil QM Analysis (unit)	Jumlah Alat Round Up (unit)	Biaya QM Analysis (Rp)
1	99.626	PC400	275,49	960	206	Rp 1.304.206	0,00	0,00	-
		PC300	207,74		609	Rp 1.090.477	0,21	1,00	224.131.550
		PC200	93,52			Rp 513.963	0,63	1,00	312.858.567
		ADT				Rp 1.577.149	2,13	3,00	2.244.237.564
Volum e=	99.626	m3		Durasi =	814	Jam			REKAPITULASI
									TOTAL 2.781.227.681
									RENCANA5.479.430.000
									DEVIASI 2.698.202.319
									% -49,24%

From **Table 4**, the optimization results are obtained by using excavators and dump trucks, namely the road work time is 814 hours from the planned time of 960 hours. And the total cost of implementation to Rp. 2,781,227,681 of the initial planned cost of Rp. 5,479,430,000. The percentage of the difference in costs that can be saved is 49.24% with a nominal value of Rp. 2,698,202,319.

Conclusions

The need for heavy equipment for the construction of coal mine roads must be planned as efficiently as possible. In order to optimize the tools used, primary data is taken from the interview process and secondary data in the form of related documents, namely budget plans, scheduling, SPK and other documents. The results of the analysis using the QM for Windows v5 software show that the optimal number of tools needed for the road works is 1 unit of Excavator PC300, 1 unit of PC200 and 3 units of Dump Truck (ADT) for a work volume of 99,626m3 and the optimal work duration is 814 hours and work costs Rp. 2,781,227,681.

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Author Contributions

The authors' contributions to the paper are as follows: study conception, design, analysis, and interpretation of results: ZC, RFA, PDW; data collection: YM, RA, RKK, ERF; draft manuscript preparation: ZC. All authors have reviewed the results and approved the final version of the manuscript.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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