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Optimization of Heavy Equipment Capabilities in The Framework of Productivity and Coal Mining Business Sustainability: Case Study of East Kalimantan Mining Area

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Abstract
Coal mining business is now faced with various challenges such as export restrictions policy, an increase in value added products, and the decline in market prices of products. To be able to compete, mining companies are expected to increase productivity and efficiency and make continuous improvements in the production process. In the mining process, the availability of equipment and dump truck unloading tool will determine the sustainability of production that have an impact on productivity and efficiency. The purpose of this study was to optimize the production of coal mining in the context of the efficient use of equipment using the match factor, queues, and linear programming. The research location is in the area of the mining concession contractor KTD Corp is in the village of Embalut, District Tenggarong Seberang, Kertanegara Kutai Regency, East Kalimantan in October-November 2015. Unloading equipment used backhoe excavator is 5 units and 32 units of dump trucks. The simulation results match factor generated by the method optimal dump truck needs 26 units, while the queuing method and linear programming as much as 25 units of dump truck. The results of production optimization with linear programming method produced mining productivity of 1,208 BCM of overburden per hour with the optimum cost of $ 0,909/BCM.

Keywords: Linear Programming Method, Match Factor Method, Production Optimize, Queuing Method

1. Introduction

1.1 Introduction

The coal mining industry has been an industrial sector that has played a major role in supporting national development. The coal mining sector supports regional economic development, creates jobs, contributes to state revenues, brings in foreign exchange through exports, and supports electrification and national energy security.

However, the role and sustainability of the coal mining industry is very vulnerable to the volatility of commodity prices and also global economic developments (APBI, 2012).

On the other hand, since the enactment of the Minister of Trade Regulation No. 39/M-DAG/PER/7/2014 regarding restrictions on coal exports in the 2015-2030 period, a maximum of 425 million tons per year has an impact on the sustainability of companies in the coal mining sector. Therefore coal mining companies are required to increase productivity and efficiency, increase the use of technology and make innovations, especially those related to operational processes. Optimization of production is one of the fundamental things in order to achieve optimal production results (Susanti, 2012).

As one of the owners of coal mining concessions in East Kalimantan, Kitadin Corporation (KTD Corp) must achieve the planned overburden and coal production targets. The achievement of overburden production for the January-September 2015 period was 5,353,458 Bank Cubic Meters (BCM) from the planned total production of 6,009,000 BCM or only 89%. The failure to achieve this production target is due to the inadequate utilization and productivity of the main mining equipment, namely heavy equipment excavators and dump trucks in supporting the mining process. This can be seen from the water flow lost opportunity in Figure 1, lost opportunity can be seen in productivity and utilization. Lost opportunity from productivity was -455,983 BCM while from utilization was -328,308 BCM, while the gained opportunity in availability was +128,748 BCM (RML's Internal Report, 2015).

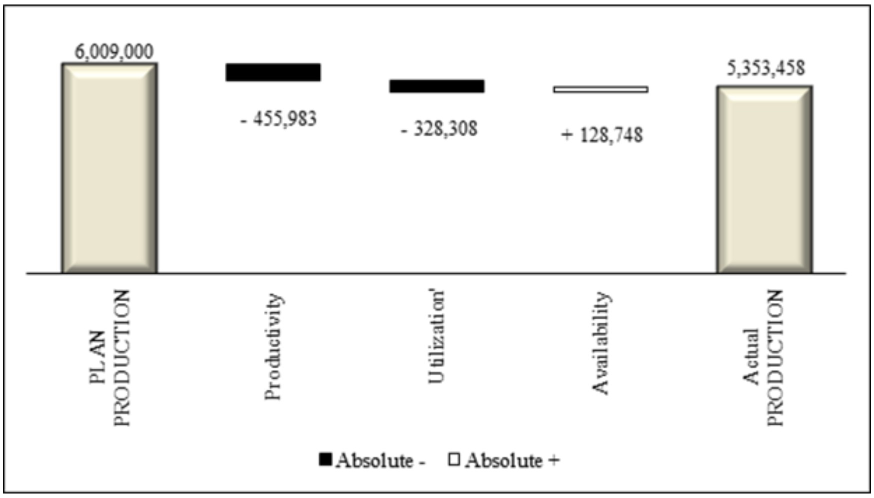

Figure 1: Water flow loss opportunity overburden production during January-September 2018

Less than optimal heavy equipment productivity can hurt the company. Heavy equipment productivity depends on bucket capacity, bucket factor, cycle time, and production correction factors (Sujatmiko, 2015). Optimization of production in mining can be done in various ways, namely optimizing the production capacity of heavy equipment, working time efficiency, and so on (Ilahi *et al*., 2014). Optimization of heavy equipment production capability is the most important factor considering the costs incurred in mining operations are mostly generated by heavy equipment operational activities (Rahadian, 2011). According to Burt (2008), optimization of production in mining can increase productivity. Among the various optimization methods and equipment selection and increasing productivity of the mining industry are match factor methods, queuing theory, linear programming, and simulation (Burt, 2008).

The most popular linear programming method used by researchers to optimize production schedules (Adadzi, 2013; Franik & Franik, 2009; Kumar, 2014; Morley, 2013; Nel *et al*., 2011; Newman *et al*., 2010; Shawki *et al*, 2009) and minimizing production costs (Adadzi, 2013; Bascetin & Ercelebi, 2009; Franik & Franik, 2009; Morley *et al*., 2012; Savic & Jancovic, 2006). Some researchers propose the use of the queuing method to evaluate the dump truck cycle for optimization of production schedules (Alkass, 2003; Cetin, 2004; Coronado, 2014; May, 2012). The match factor method is used by several researchers to determine the optimal number of trucks (Caccetta & Burt, 2013; Choudhary, 2015; Morley, 2012; Nageshwaraniyer, 2013). A match factor value of more than one indicates that the truck is inefficient and unproductive because of the queue time for the dump truck, on the other hand, the match factor of less than one makes the excavator wait for the dump truck for a long time (Caccetta & Burt, 2013). Some researchers try to combine linear programming and queuing methods (Bascetin & Ercelebl, 2009; Cetin, 2004; Coronado, 2014; Sahoo, 2012) or linear programming and match factors (Morley, 2012; Nel, 2011).

This study try to analyze the optimization of overburden production in coal mining in the mining area of PT.X Samarinda, East Kalimantan using the match factor method, the queuing method and the linear programming method. The objectives are 1) determine the optimal dump truck requirement planning for coal mining at PT.X Jobsite KTD, 2) determine optimal production at coal mining at RML CORP Jobsite KTD, and 3) determine minimum production costs for coal mining at PT.X Jobsite KTD.

2. Theoretical Review

2.1 Cycle Time

Cycle time is the time required for a device to perform a certain activity from start to finish and be ready to start over. In any mechanical earth moving activity, mechanical tools work according to a certain pattern, which in principle consists of several cycle time components, movements in one cycle time (Choudhary, 2015).

Excavator cycle times consist of digging, swinging loaded, spilling, swinging empty. The dump truck cycle time consists of time to be filled to the full by the excavator, transporting it to a full body, taking a position for spilling, spilling material, returning to the front with an empty load and taking a position to be refilled. The following is the calculation equation for the excavator and dump truck cycle times.

$$CT_E = DgT + SLT + DpT + SET \quad (1)$$

Where:

CT_E : Cycle Time Excavator (second)
DgT : Digging Time Excavator (second)
SLT : Swing Load Time Excavator (second)
DpT : Passing Time Excavator (second)
SET : Swing Empty Time Excavator (second)

$$CT_{DT} = LT + HLT + SDT + DT + RT + QT + SLT \quad (2)$$

Where:

CT_{DT} : Cycle Time Dump Truck (second)
LT : Loading Time Dump Truck (second)
HLT : Hauling Load Time Dump Truck (second)
SDT : Spotting Dump Time Dump Truck (second)
DT : Dumping Time Dump Truck (second)
RT : Returning Time Dump Truck (second)
QT : Queueing Time Dump Truck (second)
SLT : Spotting Load Time Dump Truck (second)

2.2 Excavators and Dump Trucks Productions

Information on production targets and production of heavy equipment per unit will determine the number of equipment needed according to capacity, the type of material to be handled, and the level of ease of operation and maintenance. The excavator's production capability can be calculated using the following formula:

$$P_E = 60/CT_E \times BC \times BFF \times WE \times SF \quad (3)$$

Where:

P_E : Excavator Production (BCM/Hour)
CT_E : Cycle Time Excavator (minute)

BC : Bucket Capacity (m^3)
BFF : Bucket Fill Factor (%)
WE : Work Efficiency (%)
SF : Swell Factor
The production capacity of a dump truck can be calculated using the following formula:
P_{DT} = 60/CTDT x n x BC x BFF x WE x N x SF (4)

Where:
P_{DT} : Dump Truck Production (BCM/Hour)
CT_{DT} : Cycle Time Dump Truck (minute)
n : Bulk Amounts
BC : Bucket Capacity (m^3)
BFF : Bucket Fill Factor (%)
WE : Work Efficiency (%)
N : Number of Dump Trucks (unit)
SF : Swell Factor

2.3 Production Costs

According to Mohutsiwa and Musingwini (2015), mining production costs are costs incurred from mining operations which are divided into fixed costs and variable costs. Fixed costs include depreciation, interest and taxation. Variable costs include fuel costs, repair costs, and labor costs. In general, production costs can be measured by the total cost divided by the production produced, which is usually in USD / BCM.

The production costs can be divided according to the activities in a company's business processes. According to Lind (2001), the production cost per activity is often referred to as Activity Based Costing (ABC). In coal mining, Activity Base Costing is also commonly used. Some examples of Activity Base Costing in coal mining, especially in operations such as at PT. X (Engineering RML, 2018).

2.4 Match Factor (MF)

The compatibility factor is usually used to determine the number of dump trucks that are suitable (compatible) in serving one excavator unit (Burt, 2008). The compatibility factor of the excavator and dump truck can be formulated as follows (Morgan & Peterson, 1968 in Burt, 2008):

$$MF = \frac{NDT \times CTDT}{NE \times CTE} \quad (5)$$

Where:
MF : Match Factor
N_{DT} : Number of Dump Trucks (unit)
CT_{DT} : Cycle Time Dump Truck
N_E : Number of Excavators (unit)
CT_E : Cycle Time Excavator

If the results of the calculation are obtained MF less than 1, means the excavator will often be idle, if MF equal to 1 then no excavator and dump truck are idle, and if MF larger than 1 means the dump truck will often idle.
The number of dump trucks needed to serve one excavator unit can be found using the compatibility factor formula above, with several assumptions that must be made, namely the number of digging tools is 1 and the value of MF equal to 1. So the above formula can be simplified to become:

$$N_{DT} = \frac{CTDT}{CTE} \quad (6)$$

Where:
N_{DT} : Number of Dump Trucks (unit)

CT_{DT} : Cycle Time Dump Truck
CT_E : Cycle Time Excavator

2.5 Queueing Method

The queuing theory can be used to statistically analyze the cost of dump trucks and loading equipment required for a number of trucks so that the optimum number of trucks can be determined. In addition, the queuing theory can also provide an overview of the optimum production that can be achieved with the least cost. The application of queuing theory can take the example of a loading device used to serve several trucks, where this truck will transport the cargo to the destination, dump it, and return to the loading place for further loading (May, 2012). The queuing model in dump truck services can be described as follows:

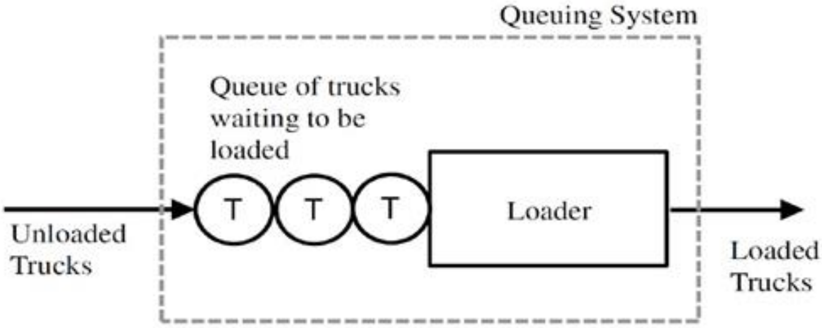

Figure 2: Loader and Dump Truck queueing system

Based on the queuing theory, it can be calculated the probability value of no dump trucks in the queue with the following equation (May, 2012).

$$Po\,(Na, x) = \frac{\frac{e^{-x} x^{Na}}{Na\,!}}{P\,(Na\,x)} = \frac{p\,(Na, x)}{P\,(Na, x)} \quad (7)$$

Where:
P0 (Na, x) : Zero trucks queueing probability
r : Average truck arrival time, r = 1/Ta
e : Natural logarithm constant (2,71828)
m : Average service per hour, m = 1/Ts
Na : Amount of Truck in a fleet
Ta : Truck cycle time, exclude loading time (hour), 1/r
x : Amount of Trucks required in a fleet, x = m/r
Ts : Truck loading time (hour), 1/m
p : Poisson Cummulative Distribution

In open pit mining operations, the dump truck moves from the loading point to the dumping location and back, sometimes stopping for a short break at the waste dump or regularly going to the fuel station and to park up for shift change. In other conditions, you have to wait at the loading point or waste dump and queue at the fuel station. This situation is due to variations in load times, loading running time, waste dumping time, return time and various time intervals between trucks arriving in the area. The existence of road repairs and work by other tools along the route also affects this variation (May, 2015).

This waiting time will reduce production capacity. This will increase if a dump truck unit is added to an existing system and no changes are made to the system. For example, if there is no change in truck mileage, the addition of these units will cause the productivity of the dump truck to decrease and the productivity of the excavator to increase. This estimated waiting time is important in designing and selecting equipment for new pits as well as estimating the travel time of trucks both loaded and empty (May, 2015). The amount of waiting time can be calculated using following equation:

W = (TL + STD + DT + TE) – (N-1)(STL + LT) (8)

Where:
W : Waiting Time
TL : Travel Time Charged
STD : Positioning time at the material dump site
DT : Material dump time
TE : Empty time travel
N : Required amount of trucks
STL : Positioning time at loading location
LT : Material charged travel

3. Research Design

The research location is located in the mining contractor working area in the KTD Corp concession, namely in Embalut Village, Tenggarong Seberang District, Kutai Kertanegara Regency, East Kalimantan. This location can be reached by road from Balikpapan ± 2.5 hours' drive. PT. KTD - Embalut covering an area of 2,973 hectares. The boundaries of the area with latitude 0o18'25,8 " LS - 0o22'30 "LS to longitude 117o5'0" East Longitude - 117o7'49,9 "East Longitude. In the north it is bordered by Bangun Rejo Village and to the west it is bordered by Embalut Village.

Mining activities carried out are in an open pit system, usually this type is applied to coal deposits that have thick layers and is carried out by making benchmarks. The stages in coal mining activities at PT. X are (1) land clearing, (2) top soil removal, (3) ripping and dozing, (4) stripping the overburden (overburden removal), (5) excavating and transporting coal, (6) transporting overburden to overburden to disposal, (7) transporting coal to stock pile/crusher (coal hauling to crusher/stockpile), (8) coal transportation to port and shipment, and (9) reclamation as can be seen in Figure 3.

The data used in this study consisted of primary data and secondary data. Primary data in this study are excavator cycle times and dump truck cycle times obtained from direct observations in the field. Secondary data in the form of a map of the location of the activity, the target volume of coal overburden removal work, dump truck rental prices, and other supporting data related to this study were obtained from companies and other relevant agencies.

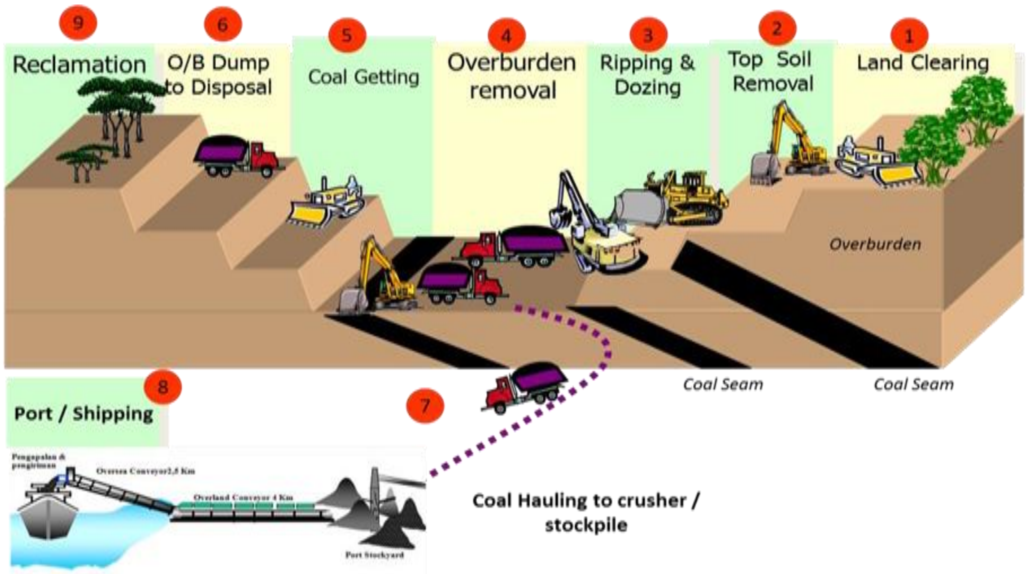

Figure 3: Mining activity

In the initial stage, data suitability testing (Poisson distribution), data adequacy test, data normality test, and data uniformity test were carried out with the help of Minitab 16 and IBM SPSS Statistics 24 software. If the data test results are declared feasible, the next step is data processing and data analysis using following steps.

1. Determine the optimal number of dump trucks in the following manner:
   a. Calculating dump truck needs with the Match Factor method.
   b. Calculating the need for dump trucks with the queuing method with the following stages:
      - The queue model used is a single service (M/M/1), the population is assumed to be unlimited and only served by 1 excavator with first come first served service discipline.
      - Calculating the optimization of the number of dump trucks using the queuing theory (M/M/1) according to equation (7), while the calculation of the excavator waiting time is used equation (8).
   c. Counting the number of dump trucks using the linear programming method. Data processing steps are carried out by determining the decision variables, limitations, and objectives. Furthermore, the data is processed in the POM for Windows software program.
2. Determine the optimal amount of production
   a. Calculating the optimal amount of production using the match factor method. Based on the optimal number of dump trucks using the match factor method, the total production amount can be calculated using equations (3) and (4).
   b. Calculating the optimal amount of production using queuing and linear programming methods. Based on the optimal number of dump trucks using queuing and linear programming methods, the total production amount can be calculated. The ideal production can be determined by calculating the productivity of the dump truck multiplied by the number of units.
3. Determining the minimum production costs
   Based on the calculation of the number of dump trucks and production using the match factor, queuing and linear programming methods, the dump truck production costs can be calculated according to the cost of the equipment per hour for each method.

This analysis is used in examining the magnitude of the contribution shown by the path coefficient on each path diagram of the causal relationship between independent variables on moderation and its impact on the dependent variable. Path analysis is a technique for estimating the effect of the independent variable on the dependent variable from a set of observed correlations, providing a pattern of causal relationships between variables. This path analysis technique will be used in testing the amount of contribution (contribution) shown by the path coefficient on each path diagram of the causal relationship between the independent variable on moderation and its impact on the dependent variable. Correlation and regression analysis which is the basis for calculating the path coefficient. There are three stages in conducting path analysis, namely formulating hypotheses and structural equations, calculating the path coefficient based on the regression coefficient, calculating the path coefficient individually.

4. Results and Discussion

4.1 Main Mining Equipment

All materials are loaded by the excavator (loading tool) with the Komatsu PC 400 type loader. The material is then transported by a dump truck with the Volvo brand FM 370 type. The excavator and dump truck are the main mining equipment in RML Corporation's operational activities. A total of 6 units of excavators with 5 units of ready status (ready to work) 1 unit of breakdown status (damaged in repair), 32 units of dump trucks with 27 units ready and 5 units breakdown.

The capacity of the PC 400 bucket is 2.0 BCM, while the vessel is 10,8 BCM. The excavator tool costs USD 60,8/hour and the dump truck costs USD 30,5/hour. The productivity target for Komatsu PC 400 units is 240 BCM/hour with a total production target per hour of 1200 BCM. The target production cost for loading activities is 0,256 USD/BCM and for hauling costs 0,677 USD/BCM so that the total production cost of loading and transporting is 0,933 USD/BCM. Based on data obtained from Engineering RML CORP, the assumption that the filling factor for the Komatsu PC 400 bucket is 90%, the vessel by the excavator is 100%, and the excavator and dump truck work efficiency factor is 0,75.

4.2 Excavator and Dump Truck Cycle Time calculations

Cycle time for excavators and dump trucks is obtained from direct observations in the field. Cycle time data were collected and validated through data sufficiency test, data uniformity and data normality (Wignjosoebroto, 2008 in Noor, 2011) with the help of Minitab 16 software. The test results showed that the data used was sufficient, uniform and normally distributed (Figure 4). The average excavator and dump truck cycle times are presented in Table 1 and Table 2.

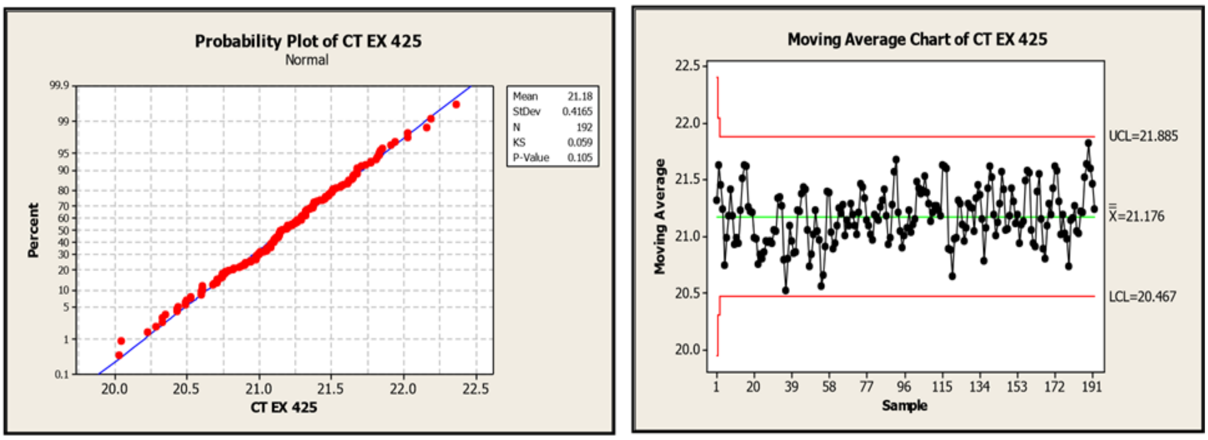

Figure 4: Normality and uniformity test result of cycle time data EX 441 with Minitab16

Table 1: Average Excavator cycle time

Unit	Digging (seconds)	Swing Load (seconds)	Passing (seconds)	Swing Empty (seconds)	Total (seconds)
EX 441	5,70	5,01	4,94	5,53	21,18
EX 442	5,91	5,82	4,11	4,62	20,47
EX 443	5,61	5,27	5,05	5,79	21,71
EX 444	6,05	5,34	3,36	4,32	19,07
EX 445	6,53	5,81	4,48	4,31	21,12

Table 2: Average Dump Truck cycle time (in seconds, unless stated otherwise)

Unit	Distance (meter)	Queueing Time	Spotting Load Time	Loading Time	Hauling Load Time	Spotting Dump Time	Dumping Time	Returning Time	Total Cycle Time	
									With Queueing	Without Queueing
EX 441	1800	39,62	10,81	127,06	276,86	18,80	29,63	227,03	729,80	690,19
EX 442	1200	21,68	15,43	122,80	220,19	22,81	39,14	146,10	588,14	566,46
EX 443	1400	15,19	27,60	130,30	266,04	33,16	35,76	168,82	676,86	661,68
EX 444	1300	15,49	35,78	114,42	199,19	20,78	41,12	201,53	628,31	612,82
EX 445	1300	27,84	23,22	127,20	195,24	17,92	39,22	207,01	628,31	609,81

4.3 Excavator Waiting Time and Dump Truck Queue Time

Distribution of data on the number of dump truck arrivals in each excavator in the field is tested by means of a suitability test (goodness of fit) with the help of IBM SPSS Statistics 20 software. The test results show that the data for dump truck arrivals is Poisson distributed (Table 3). All significance values are greater than 0,05, so it can be concluded that all the truck arrival data for each excavator have a Poisson distribution.

Table 3: Poisson distribution test result

		EX 421	EX 442	EX 443	EX 444	EX 445
N		32	35	31	31	31
Poisson Parametera,b	Mean	1,500	1,371	1,032	1,000	0,9032
Most Extreme Differences	Absolute	0,191	0,225	0,227	0,239	0,212
	Positive	0,191	0,160	0,115	0,135	0,132
	Negative	(0,152)	(0,225)	(0,227)	(0,239)	(0,212)
Kolmogorov-Smirnov Z		1,081	1,332	1,265	1,330	1,179
Asymp. Sig. (2-tailed)		0,193	0,057	0,082	0,058	0,124

Based on the calculations and simulations carried out (formula 13), the amount of optimum waiting time for each dump truck fleet that is placed at each location is presented in Table 4. When the condition of the dump truck excess unit conditions, it allows queues to occur at each excavator. The queuing time for dump trucks can be seen in Table 5.

Table 4: Excavator EX 441 wait time (in minutes, unless stated otherwise)

Transport Time	Loading Time	No. of DT (Unit)	Excavator Waiting Time
9,21	2,298	1	9,21
9,21	2,298	2	6,91
9,21	2,298	3	4,61
9,21	2,298	4	2,31
9,21	2,298	5	0,01
9,21	2,298	6	(2,28)
9,21	2,298	7	(4,58)

Table 5: Actual dump truck EX441 queueing time

Excavator Unit	DT Queueing Time	DT Cycle Time with Queueing	DT Cycle Time without Queueing
425	0,66	12,16	11,50
429	0,36	9,80	9,44
430	0,25	11,28	11,03
431	0,26	10,47	10,21
432	0,46	10,63	10,16

The comparison of overburden production by dump trucks with queues and without queues can be seen in Table 6. This potential for increased production can be optimized by reducing queuing times.

Table 6: Dump Truck (DT) production with and without queueing

Excavator Unit	Vessel Capacity	DT Efficiency	Number of DT	DT Production (minute)	
				With Queueing	Without Queueing
EX 441	10,8	0,75	6	39,96	42,25
EX 442	10,8	0,75	5	49,58	51,48
EX 443	10,8	0,75	6	43,08	44,07
EX 444	10,8	0,75	5	46,41	47,58
EX 445	10,8	0,75	5	45,73	47,82

4.4 Determination of the Optimal Number of Dump Trucks

Optimal Determination of the number of dump trucks is evaluated by the match factor method, the queuing method and the linear programming method. The optimal number of dump trucks is expected to provide optimal production at the most efficient cost possible.

4.5 Match Factor (MF) Method

Based on the calculation of the number of excavators, the number of dump trucks, excavator cycle time and dump truck cycle time, the match factor can be calculated. By using the assumption of match factor equal to 1, the number of dump trucks needed is 25 units, while the actual number is 27 units, which means that it can reduce dump trucks by 2 units.

Table 7: Number of dump truck simulation with Match Factor equal to 1

Excavator Unit	**Actual number of DT (unit)**	**Actual MF**	**DT requirement unit**	
			MF Simulation = 1	**Rounding**
EX 441	6	1,100	5,43	5
EX 442	5	1,080	4,61	5
EX 443	6	1,180	5,08	5
EX 444	5	0,930	5,35	5
EX 445	5	1,040	4,80	5
Total	**27**		**25,27**	**25**

4.6 Queueing Method

The calculation of the number of dump trucks using the match factor method does not take into account the possibility of queuing time or ideal waiting time, so to find out more about the optimal number of dump trucks at each excavator it is also necessary to optimize production based on the occurrence of queuing times and waiting times that occur. , by using the queuing theory, the optimal number of tools will be obtained.

The waiting time for EX 425 is shown in Table 8, the condition without waiting time is shown in the number of dump trucks 6 units. Thus, based on the waiting time, the optimal number of dump trucks is 6 units. When calculating the waiting time for all excavators, the number of dump trucks for each excavator can be determined and the total dump trucks as a whole. The results of the calculation of the optimal number of dump trucks based on waiting time can be seen in Table 9. Therefore, based on the waiting time, the optimal number of dump trucks is 26 units.

Table 8: Queueing time for excavator EX 441

Number of DT	**P_0**	**$1\text{-}P_0$**	**Waiting time (minute)**	**Production (BCM/hours)**
0	1,000	0,000	0,00	0,000
1	0,792	0,208	9,21	47,78
2	0,616	0,384	6,91	88,15
3	0,457	0,543	4,61	124,60
4	0,320	0,680	2,31	156,05
5	0,209	0,791	0,01	181,56
6	0,126	0,874	(2,28)	200,68
7	0,069	0,931	(4,58)	213,69
8	0,034	0,966	(6,88)	221,63

Table 9: Optimal DT with queueing time

Excavator Unit	DT Optimal Amount
EX 441	6
EX 442	5
EX 443	5
EX 444	5
EX 445	5
Total	**26**

4.7 Linear Programming Method

Determining the optimal number of dump trucks with the aim of increasing production with minimum costs can also be done by the Linear Programming (LP) method. The following is the objective function and the constraints for optimizing the number of trucks:
The objective function is the minimization of dump truck production costs.

$Z = 0{,}7219\ X_1 + 0{,}5925\ X_2 + 0{,}6921\ X_3 + 0{,}6410\ X_4 + 0{,}6378\ X_5$ (9)

With boundaries as follow:
$X_1 + X_2 + X_3 + X_4 + X_5 \leq 27$
$42{,}25\ X_1 \geq 240$
$51{,}48\ X_2 \geq 240$
$44{,}07\ X_3 \geq 240$
$47{,}58\ X_4 \geq 240$
$47{,}82\ X_5 \geq 240$
$X_i \geq 0$
$P_j \geq 0$

Where:
C_i : Cost per Dump trucks (i = 1, 2, 3, 4, 5)
X_i : Sum of DT EX (i = 1, 2, 3, 4, 5)
P_j : Dump truck production unit (j = 1, 2, 3, 4, 5)

The optimal solution for the calculation results with the linear programming method using POM for Windows can be seen in Table 10, the result is the total number of DT is 26 units.

Table 10: Number of Dump Trucks as a result from LP program POM for Windows

Variable	LP simulation unit POM for Windows	LP simulation unit POM for Windows (integer)
X_1 (441)	5,681	6,0
X_2 (442)	4,662	5,0
X_3 (443)	5,446	5,0
X_4 (444)	5,044	5,0
X_5 (445)	5,019	5,0
Optimal Value (Z)	**17,066**	**26,0**

4.8 Optimal Dump Truck Needs Planning

The results of the optimization of dump truck needs with the match factor method, the queuing method and the linear programming method are not much different. The optimal number of dump trucks with the match factor method is 25 units with the distribution of each excavator getting 5 dump trucks. Whereas with the queuing method and the linear programming method, a total of 26 dump trucks were obtained with the spread of 1 excavator unit (EX 425) getting 6 dump trucks, and other excavators (EX 429, EX 430, EX 431, EX 432) got 5 dump trucks. The number of dump trucks which originally actually totaled 27 units can be reduced by 2 units from the results of the analysis using the match factor method or as much as 1 unit by the queuing method and linear programming. Thus, 1 dump truck unit should be allocated to another work area.

The factors that influence the planning of dump truck needs include 1) excavator productivity, 2) dump truck productivity, 3) excavator and dump truck conditions, 4) number of excavators, and 5) number of dump trucks. The productivity or production per hour of this excavator has an effect in determining the productivity of the dump truck which ultimately determines the number of dump trucks. The excavator's productivity is influenced by the excavator's cycle time, work efficiency, bucket fill factor, and bucket capacity.

Dump truck productivity has the most influence on the number of dump trucks, where with the same excavator production volume, the higher the productivity of the dump truck, the less the number of dump trucks needed, and vice versa. The condition of the availability of excavators and dump trucks that are ready to work will affect the calculation of the optimization simulation. The actual number of excavators has an effect on the number of dump trucks serving it to determine the distribution of each dump truck with a limited number, while the actual number of dump trucks has an effect on the optimization of the limited allocation of dump trucks.

4.9 Productivity Comparison

The results of dump truck productivity calculations can be seen in Table 11. Based on this table, it can be seen that all methods produce the same total productivity of 233 BCM/hour, the amount of production is able to exceed the actual production, which is 225 BCM/hour.

Table 11: Productivity comparison of each dump truck

Excavator Unit	**Actual**	**Dump Truck Total Productivity (BCM/Hour)**		
		Match Factor	**Queueing Method**	**Linear Programming Method**
EX 441	40	42	42	42
EX 442	50	51	51	51
EX 443	43	44	44	44
EX 444	46	48	48	48
EX 445	46	48	48	48
Total	**225**	**233**	**233**	**233**

From the results of the productivity of each dump truck then multiplied by the number of dump trucks per method. The comparison of the production volume of each method can be seen in Table 12. Based on this table, it can be seen that the total production volume that exceeds the production target of 1200 BCM/hour is the queue method and linear programming, which is 1208 BCM/hour, the production volume simulation method the match factor did not reach the target. When compared with the previous actual production increased by 1 BCM/hour, from 1207 BCM/hour to 1208 BCM/hour.

Table 12: Total production volume Dump Truck comparison

Excavator Unit	**Production Target**	**Actual**	**Dump Truck Total Production (BCM/Hour)**		
			Match Factor Method	**Queueing Method**	**Linear Programming Method**
EX 441	240	240	211	253	253
EX 442	240	248	257	257	257
EX 443	240	258	220	220	220
EX 444	240	232	238	238	238

EX 445	240	229	239	239	239
Total	**1200**	**1207**	**1165**	**1207**	**1207**

4.10 Determination of Minimum Production Costs

Based on the calculation of the number of dump trucks and overburden production, the dump truck production costs can then be calculated so that the minimum production costs are known. The calculation of the production cost of transportation activities (hauling cost) based on the number of DT and DT production using the Match Factor method can be seen in Table 13. As an illustration, the cost of DT EX 425 per unit is 30,5 USD / hour with a production of 211 BCM/hour and the number of DT of 5 units will result in a production cost of 0,72 USD/BCM. The total production cost for the EX 425 excavator is the hauling cost plus the loading cost of 1.01 USD/BCM.

The calculation of the production cost of transportation activities (hauling cost) based on the number of DT and production of DT for the queuing method and the linear programming method is the same as in Table 14. The efficient production cost (loading and hauling cost) is 0,909 USD/BCM.

Table 13: Production cost using Match Factor method

Excavator Unit	**Excavator Cost per unit (USD/BCM)**	**DT Cost per unit (USD/BCM)**	**Total Hauling Cost**			**Loading Cost (USD/BCM)**	**Total Cost (USD/BCM)**
			DT Amount		**DT Production (USD/BCM)**		
			Unit	**BCM/Hour**			
EX 441	60,8	30,5	5	211	0,72	0,29	1,01
EX 442	60,8	30,5	5	257	0,59	0,24	0,83
EX 443	60,8	30,5	5	220	0,69	0,28	0,97
EX 444	60,8	30,5	5	238	0,64	0,26	0,90
EX 445	60,8	30,5	5	239	0,64	0,25	0,89
TOTAL			**25**	**1165**	**0,657**	**0,262**	**0,919**

Table 14: Production cost using Queueing Method and LP Method

Excavator Unit	**Excavator Cost per Unit (USD/BCM)**	**DT Cost per Unit (USD/BCM)**	**Number of DT (unit)**	**DT Total Production (BCM/Hour)**	**Hauling Cost (USD/BCM)**	**Loading Cost (USD/BCM)**	**Total Cost (USD/BCM)**
EX 441	60,80	30,50	6	253	0,720	0,240	0,960
EX 442	60,80	30,50	5	257	0,590	0,240	0,830
EX 443	60,80	30,50	5	220	0,690	0,280	0,970
EX 444	60,80	30,50	5	238	0,640	0,260	0,900
EX 445	60,80	30,50	5	239	0,640	0,250	0,890
TOTAL			**26**	**1207**	**0,657**	**0,252**	**0,909**

4.11 Minimal Production Costs

The ultimate goal of production optimization is to optimize limited resources by achieving production optimization in accordance with the efficiency of production costs. Thus the main factor to consider is the production cost factor for each calculation method. Based on the number of dump trucks and the production produced by each method, the production costs for efficient or minimal hauling costs can be determined. The comparison of the production costs of each method can be seen in Table 17. Based on the results of the comparison, it can be seen that the most efficient cost is shown by the linear programming method and the queue, which is 0,909 USD/BCM or has succeeded in reducing production costs (hauling cost and loading cost) from 0,935 USD/BCM to 0,909 USD/BCM or a decrease of 2.69% of the actual production cost, while the initial target was 0,933 USD/BCM.

Table 15: Dump Truck (hauling) production cost comparison

Excavator Unit	Hauling Cost (USD/BCM)				
	Plan	**Actual**	**Match Factor Method**	**Queueing Method**	**LP Method**
EX 441	0,677	0,763	0,722	0,722	0,722
EX 442	0,677	0,615	0,592	0,592	0,592
EX 443	0,677	0,708	0,692	0,692	0,692
EX 444	0,677	0,657	0,641	0,641	0,641
EX 445	0,677	0,667	0,638	0,638	0,638
TOTAL	**0,677**	**0,682**	**0,657**	**0,657**	**0,657**

Table 16: Excavator/loading production cost comparison

Excavator Unit	Loading Cost (USD/BCM)				
	Plan	**Actual**	**Match Factor Method**	**Queueing Method**	**LP Method**
EX 441	0,256	0,254	0,288	0,240	0,240
EX 442	0,256	0,245	0,236	0,236	0,236
EX 443	0,256	0,235	0,276	0,276	0,276
EX 444	0,256	0,262	0,256	0,256	0,256
EX 445	0,256	0,266	0,254	0,254	0,254
TOTAL	**0,256**	**0,252**	**0,262**	**0,252**	**0,252**

Table 17: Production total cost (USD/BCM) comparison (loading & hauling)

Plan	**Actual**	**Match Factor Method**	**Queueing Method**	**LP Method**
0,933	1,017	1,010	0,962	0,962
0,933	0,860	0,829	0,829	0,829
0,933	0,943	0,968	0,968	0,968
0,933	0,919	0,897	0,897	0,897
0,933	0,933	0,892	0,892	0,892
0,933	0,935	0,919	0,909	0,909

Based on the above analysis, the linear programming method is better for use in production optimization simulations with optimal use of transportation equipment. This can be seen from the production that is close to the target and efficient production costs. Thus the linear programming method can provide better results in optimizing the use of conveyances, so that linear programming can be used as an alternative in determining the most optimum number of conveyances to achieve production targets.

This research succeeded in reducing the cost of transportation equipment by reducing the number of transportation equipment from 27 units to 25 units using the match factor method and 26 units using the queuing method and linear programming, in addition to reducing the production costs (hauling cost and loading cost) of originally 0,935 USD/BCM became 0,909 USD/BCM or a decrease of 2,7% of the actual production cost, while the initial target was 0,933 USD/BCM. The application of the results of this analysis will benefit the mining industry, especially mining contractors, because it can reduce the production costs of operational activities in the mine.

5. Conclusion

Planning for the optimal number of dump trucks needed for the removal of overburden material based on the match factor method for excavators is 25 units, based on the queuing method for each excavator, 26 units are needed, while with the linear programming method for each excavator there are 26 units. Thus, if the previous actual unit used 27 units, efficiency can be made as much as 1-2 units of DT which can be allocated to other work areas.

The optimal production for overburden material removal based on the match factor method is 1,166 BCM/hour, with the queuing method is 1,208 BCM/hour, and based on the linear programming method is 1,208 BCM/hour. Thus the optimal production is the queuing method and the linear programming method with 1,208 BCM/hour which best fits the production target of 1,200 BCM/hour.

The efficient production cost for the removal of overburden material based on the match factor method is 0,919 USD/BCM, based on the queuing method is 0,909 USD/BCM, and the linear programming method is 0,909 USD/BCM. Thus, the efficient production cost with the linear programming method with 0,909 USD/BCM is still below the target production cost of 0,933 USD/BCM.

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