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Optimization of Heavy Equipment Costs in Coal Mining Overburden Production Using Match Factor and Linear Programming

Rizkyah Erwanda[1*], Ari Yanuar Ridwan[1], Prafajar Suksessannp Muttaqin[2]

[1]*Industrial Engineering Faculty of Industrial Engineering Telkom University Telecommunication Street 1, Terusan Buahbatu-Bojongsoang, Bandung, Indonesia*
[2]*Logistics Engineering Faculty of Industrial Engineering Telkom University Telecommunication Street 1, Terusan Buahbatu-Bojongsoang, Bandung, Indonesia*
[*]*Corresponding author. Email: kiaerwnd@student.telkomuniversity.ac.id*

ABSTRACT
The coal mining industry is currently facing challenges in terms of the establishment of export restrictions and the drop in coal prices. In order to compete, companies are required to increase their productivity and efficiency. Optimizing heavy equipment productivity is an essential factor in improving cost efficiency. In Pit 2 West Banko, there are 21 units of Belaz 75135 dump truck and 3 units of Shovel Excavator Komatsu PC 3000E-6 spread over 3 fleet. In the 4th quarter of 2020, the overburden production target is 3,480,000 BCM, however, only 2,859,794 BCM or 82.18 percent was achieved. The reason why the production target was unable to be accomplished is because of the waiting time of the excavator as indicated by the match factor value of less than one. This study aims to minimize overburdened production costs by determining the optimal number of dump trucks using match factor and linear programming methods. As the results of calculations with these two methods, it is necessary to add 5 units of dump trucks with different distributions. Based on the Match Factor method, the total production achieved is 4,194,256 BCM with a cost of Rp 6,483 /BCM. Meanwhile, based on the linear programming method of 4,214,835 BCM for at Rp 6,462 /BCM.

Keywords: *Mining, Heavy Equipment, Match Factor, Linear Programming*

1. INTRODUCTION

Indonesia still has a high dependence on fossil fuels, namely oil, coal, and natural gas. The percentage of dependence is on coal 34.6%, oil 33.8%, and natural gas 23.9% [1]. The mining sector is currently one of the main sectors driving the wheels of the economy in Indonesia, this indication can be seen from the contribution of state revenues from the ESDM sector [2]. However, the role and sustainability of the coal mining industry are very vulnerable to the volatility of commodity prices and global economic developments [3], [4].

In addition, since September 1, 2014, the Ministry of Trade (2014) issued the Minister of Trade Regulation (Permendag) Number 39/M-DAG/PER/7/2014 concerning Provisions for Exports and Coal Products [5]. The Minister of Trade Regulation limits coal production to a maximum of 425 million tons per year during 2015-2030. This has an impact on companies in the coal mining sector to continue to push production as optimally and efficiently as possible, increasingly fierce market competition and competitive companies compete with each other to provide the best products at relatively low prices [6]. Optimization of production in mining can be done in several ways, including optimizing the productivity of heavy equipment excavators and dump trucks, work time efficiency, and so on [7]. Optimizing the productivity of heavy equipment is the most important factor to get the operational costs to a minimum, considering that the costs incurred in mining operations are dominated by heavy equipment operational activities [8].

As one of the owners of coal mining concessions in South Sumatra, PT XYZ must achieve the planned overburden and coal production targets. The achievement of overburden production in the quarter 4th of 2020 was 2,859,794 BCM (Bank Cubic Meter) from the planned total production of 3,480,000 BCM or only achieved 82.18 percent. The non-achievement of the production target was caused by the non-optimal productivity of the main mining equipment, namely heavy excavators and dump trucks in supporting the mining process. It was concluded by looking at the existing conditions where the productivity of heavy equipment excavators and dump trucks that were used did not meet expectations. The productivity of excavators in the 4th quarter of 2020 respectively was 823 BCM/Hour, 788 BCM/Hour, and 801 BCM/Hour from the planned productivity of 950 BCM/Hour. As for the planned productivity of the dump truck, it is 115 BCM/hour, but the realization recorded is 94.8 BCM/hour, 104.5 BCM/hour, and 92 BCM/hour. With the productivity targets not being achieved, it causes production costs to not be achieved as expected.

The linear programming method is one of the methods that dominate the literature for equipment selection to minimize production costs[9]–[12]. Several theories were also developed, one of which is the match factor method which is useful for seeing the productivity of digging and loading equipment and determining the optimal number of trucks [7], [10], [13]. A match factor value of more than one indicates queuing time for dump trucks, whereas a value of less than one indicates waiting time for excavators [14].

This study focuses on analyzing the cost optimization of overburden production in Pit 2 West Banko PT XYZ by using match factor and linear programming methods. The objectives are 1) to determine optimal dump truck requirements planning for coal mining at Pit 2 West Banko PT XYZ, 2) determine optimal production at coal mining at Pit 2 West Banko PT XYZ, and 3) determine optimal production costs for coal mining at PT XYZ. Pit 2 West Banko PT XYZ.

1.1 Literature Review

1.1.1 Cycle Time

Cycle time is the time it takes for a tool to carry out certain activities from start to finish and is ready to start again. The circulation time has a very important influence on the production of work tools because the circulation time becomes a variable in the calculation of the number of ritases that can be carried out in one working hour[4]. The smaller the circulation time, the greater the amount of productivity that will be produced. Mechanical devices work according to a certain pattern which in principle consists of several components of movement in one cycle of cycle time which can be calculated as follows [7]:

- Excavator Cycle Time

$$CT = DgT + SLT + Dpt + SET \quad (1)$$

Where CT is the cycle time (seconds), DgT is the digging time (seconds), SLT is the swing load time (seconds), Dpt is the passing time (seconds), and SET is the swing empty time (seconds).

- Dump Truck Cycle Time

$$CT = LT + HLT + SDT + DT + RT + QT + SL \quad (2)$$

Where CT is the cycle time (seconds), LT is the load time (seconds), HLT is the hauling load time (seconds), SDT is the spotting dump time (seconds), DT is the dumping time (seconds), RT is the returning time (seconds), QT is the queuing time (seconds), and SLT is the spotting load time (seconds).

1.1.2 Productivity of Excavator and Dump Truck Equipment

Production is the process of making goods or services that transform inputs into outputs [11]. Meanwhile, tool productivity is the ability of heavy equipment to complete work which is calculated at one time which is influenced by time capacity, time factor, cycle, and production correction factor [13]. The production capability of excavators and dump trucks can be calculated using the following formula [15]:

- Excavator Production

$$Q = \frac{q1\ x\ K\ x\ 3600\ x\ E}{Cm} \quad (1)$$

Where Q is the productivity (BCM/hour), q1 is the bucket capacity (BCM), K is the bucket factor, E is the job efficiency, Cm is the cycle time (seconds).

- Dump Truck Production

$$Q = \frac{n\ x\ q1\ x\ K\ x\ 3600\ x\ E}{Cm} \quad (2)$$

Where Q is the productivity (BCM/hour), n is the dump truck filling frequency, q1 is the bucket capacity (BCM), K is the bucket factor, E is the job efficiency, and Cm is the cycle time (seconds).

Table 1. Job Efficiency

Operating Conditions	Job Efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

In the calculation of the production, there are factors that are very influential, namely the bucket factor and work efficiency. The bucket factor depends on the type of material to be excavated [16]. While work efficiency is very difficult to estimate because there are many other factors involved [17]. Job efficiency values can be given in accordance with Table 1 as a general guide [18].

1.2 Production Cost

Mine production costs are costs that will be incurred from mining operations which can be divided according to be fixed costs and variable costs. Fixed costs consist of depreciation, interest and taxation. Meanwhile, variable costs consist of fuel costs, repair costs, tire costs, lubricant costs, and operator salaries. In general, the production cost can be measured by the total cost divided by the resulting production so that the unit used is USD/BCM or Rp/m^3 [15], [19].

1.3 Match Factor

The equipment compatibility factor is the ratio of the truck arrival rate to the loading service time (the level of work suitability between dump truck and excavator equipment). The purpose of using the match factor is to determine the number of matched dump trucks to serve one excavator unit [10]. The tool compatibility factor ratio is an important productivity index in the mining industry [7]. The tool compatibility factor can be formulated as follows [20]:

$$MF = \frac{nH \ x \ n \ x \ CtL}{nL \ x \ CtH} \quad (3)$$

Where nH is the number of dump trucks (unit), nL is the number of excavators (unit), CtH is the cycle time dump truck (second), CtLis the cycle time excavator (second), and n is the dump truck filling frequency. The amount of the match factor can show the efficiency of the excavator and dump truck as shown in Figure 1. In addition, it can be concluded that:

a. If MF < 1, the excavator will often be idle.
b. If MF = 1, then there are no excavators and dump trucks idle.
c. If MF > 1, then the dump truck will often be idle.

In addition, it can also be concluded that to find out the number of dump trucks needed to achieve a match factor equal to one, it can be calculated using the following equation:

$$nH = \frac{nL \ x \ CtH}{n \ x \ CtL} \quad (4)$$

1.4 Linear Programming

Linear programming is a widely used mathematical technique designed to plan and make decisions regarding resource allocation to help operations managers make study decisions[11]. In line with this, linear programming is related to problems in the real world, which are then formulated into a mathematical model consisting of an objective function and a linear constraint system [21]. In linear programming, the objective is always to maximize or to minimize some linear function of these decision variables, but It often seems that real world problems are most naturally formulated as minimizations [22]. There are two models in linear programming [23], namely:

1. Graphics Model
   The graphic model is used to solve the problem of determining the optimum combination (maximum two variables) to maximize profit or minimize costs with certain constraints.
2. Simplex Model
   The simplex model is used to solve linear programming problems through iterations where the computational steps are repeated continuously before obtaining the optimal level. The goal is the same as the Linear Programming Graph Model, but in the simplex model, there are two or more variables.

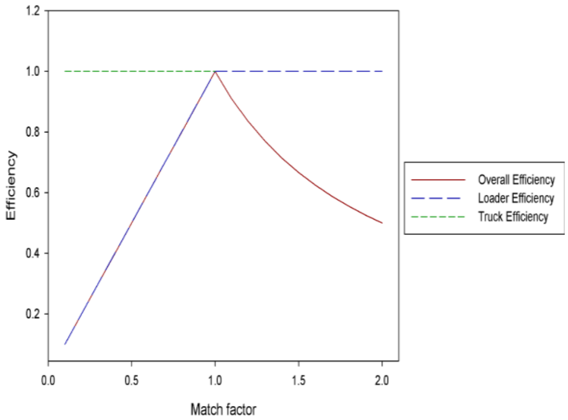

Figure 1 Combination of Match Factor for Dump Truck and Excavator Efficiency

2. METHODS

2.1. *Types of Research*

This type of research is a case study related to the optimization of heavy equipment costs which is expected to provide the best solution to the problem of PT XYZ, which aims to find the maximum or minimum point of an objective function with limited production factors to be as efficient as possible. Processed data includes cycle time, bucket capacity, bucket factor, operating hours, loss time, actual number of excavators and dump trucks, and cost realization. Data processing is done with the help of Microsoft Excel software and solver. The final output of this research is the design of the optimal number of dump trucks with optimal production and optimal production costs.

2.2. *Research Approach*

The approach of this research model is an optimization approach with the help of match factor and linear programming methods. In addition, data testing is also carried out on secondary data that will be used with the help of the Minitab19 software. The data test carried out is the normality and uniformity test of the data which in this study the secondary data used has been tested to have a normal and uniform distribution.

2.3. *Systematic Research*

The research methodology in this research uses systematic problem solving, so the problems that occur can be solved appropriately [24]. It can be seen in Figure 2 that there are six stages in solving the problem of this research. The first stage begins by conducting online sharing sessions with PT XYZ regarding information on existing conditions as a substitute for field studies. Based on the existing conditions associated with the study of literature and various other sources such as books, journals, and previous research as well as the formulation of the problems that occurred, the objectives and benefits of the research were obtained. The second stage is collecting data and information that can support the research objectives. At the data collection stage, data is collected in two ways, namely retrieval of data via online to the company and quoting data based on related references. In the data testing phase, the data obtained from citations based on related references will go through the testing phase. The testing phase consists of two tests, namely the normality test and the uniformity test. The testing phase is carried out with the help of the minitab19 software. The data to be tested is cycle time data for both excavators and dump trucks.

At this stage of data processing, processing is carried out with the help of Microsoft Excel software and solver. In addition, the data will be processed using match factor and linear programming methods. Before entering the method, the data that needs to be calculated is the productivity of dump trucks and excavators, then the actual match factor value for comparison later. Then after the productivity is known, then the estimated actual production that can be produced is calculated, followed by the estimated actual production costs. After that, enter into the calculation of the optimal number of dump trucks with the match factor method as well as the compatibility value. Then it will be continued with the calculation of the amount of production and optimal production costs that have been adjusted to the number of dump trucks with the match factor method. With the same flow, the optimal number of dump trucks is calculated using the linear programming method.

In the analysis stage, a review is carried out to compare the actual estimation results with the match factor and linear programming methods. The results compared include the number of dump trucks, the amount of production, and production costs. At the end of this stage, the best method can be determined that can be used as an alternative to determine the optimal number of dump trucks, so that in terms of production quantities and costs can also be more optimal. And at the last stage, conclusions are drawn from the predetermined problem formulation and constructive suggestions are given to PT XYZ.

Figure 2 Systematic Research

3. RESULTS AND DISCUSSION

3.1. Determining the Optimal Number of Dump Trucks

3.1.1. Determining the Optimal Number of Dump Trucks with Match Factor Method.

The match factor is the compatibility between the excavator and the dump truck so that in the process of stripping the overburden there is no undertruck or overtruck. Based on secondary data are taken from Dani, 2020 and sharing sessions with the company regarding the number of excavators, the number of dump trucks, cycle time excavators, and cycle time dump trucks, the match factor results are obtained as calculated in Table 2. By calculating the match factor equal to one, the total number of dump trucks needed is 26 units. This shows that it is necessary to add 5 units of dump trucks from the existing conditions in pit 2 of West Banko so that the productivity of the dump truck can match the productivity of the excavator.

Table 2. Simulation of Number of Dump Trucks with MF=1

No. Excavator	Actual DT Amount (Unit)	Number of MF=1 Simulation Units	Number of MF=1 Simulation Units (Rounding)	Simulation Match Factor
PC 3001	6	7.19	7	0.97
PC 3002	7	9.33	9	0.96
PC 3003	8	9.97	10	1.00
Total	21	26.49	26	

Table 3. Data Input for Solver

Minimize	X_1	X_2	X_3	RHS	Eq. Form
	Rp. 1.556	Rp. 1.696	Rp. 1.764		Min. $1556X_1+1696X_2+1764X_3$
Constrain 1	1	1	1	≥21	$X_1+X_2+X_3\geq 21$
Constrain 2	115.9	0	0	≥950	115.9≥950
Constrain 3	0	106.4	0	≥950	106.4≥950
Constrain 4	0	0	102.3	≥ 950	102.2≥950

3.1.2. Determining the Optimal Number of Dump Trucks with Linear Programming Method.

Determining the optimal number of dump trucks to optimize production and costs can also be done using the linear programming method. In this calculation, Microsoft Excel will be used with the help of a solver. Before calculating the optimal number of dump trucks, it is necessary to have goals and limitations that are translated into mathematical form first. The mathematical formulation that is made is then inputted into microsoft excel (Table 3), which will then be calculated using the solver.

3.1.3. Comparison of the Number of Dump Trucks.

Each method produces the same number of dump trucks, namely 26 units, but with different distributions. For the deployment of dump trucks using the match factor method, there are 7 units on fleet 1, 9 units on fleet 2, and 10 units on fleet 3. While deployment using linear programming method, 8 units on fleet 1, and 9 units on each fleet 2 and fleet 3. Thus, based on simulation calculations, it can be concluded that there needs to be an additional 5 units of dump trucks from the existing conditions that only 21 units. The comparison of the number of dump trucks for each method can be seen in Table 4 below. It should be underlined that the proposed number of dump trucks refers to the ability of excavators and dump trucks to work at their maximum capacity which is influenced by the cycle time and frequency of dump truck filling.

Table 4. Comparison of Number of Dump Trucks

No. Excavator	Actual	Match Factor Method	Linear Programming Method
PC 3001	6	7	8
PC 3002	7	9	9
PC 3003	8	10	9
Total	21	26	26

3.2. Determination of Optimal Production Amount

3.2.1. Determining the Optimal Production Amount with Match Factor Method.

Based on the calculation of the optimal number of dump trucks using the Match Factor method above, it can be calculated the amount of production per hour or even the amount of production in the 4th quarter of 2020 produced. The results of the production calculation can be

Table 5. Production Quantity based on Match Factor Method

NO. Excavator	DT Productivity per Unit No Queue (BCM/Hour)	Number of MF=1 Similation Units (Rounding)	Total DT Production per Hour (BCM/Hour)	Effective working time (Hour/Quarter 4)	Total DT production per quarter 4 (BCM)
PC 3001	115,96	7	811,73	1502,31	1.219.466
PC 3002	106,39	9	957,52	1502,31	1.438.490
PC 3003	102,26	10	1022,63	1502,31	1.536.300
Total	324,61	26	2991,87	4506,93	4.194.256

Table 6. Production Quantity based on Linear Programming Method

NO. Excavator	DT Productivity per Unit No Queue (BCM/Hour)	Number of MF=1 Similation Units (Rounding)	Total DT Production per Hour (BCM/Hour)	Effective working time (Hour/Quarter 4)	Total DT production per quarter 4 (BCM)
PC 3001	115,96	8	927,69	1502,31	1.393.676
PC 3002	106,39	9	957,52	1502,31	1.438.490
PC 3003	102,26	9	920,36	1502,31	1.382.670
Total	324,61	26	2805,57	4506,93	4.214.836

seen in Table 6. The optimal amount of production resulting from the match factor method in the 4th quarter of 2020 is 2,791.87 BCM/hour or 4,194,256 BCM with 26 dump trucks spread over 3 fleets which this value definitely exceeds the number of actual production (realization of production in pit 2 west banko) because there is an increase in the number of dump trucks carried out. What needs to be considered at this stage is that this value has reached the production target that has been set.

3.2.2. Determining the Optimal Production Amount with Linear Programming Method.

Based on the calculation of the optimal number of dump trucks using the Linear Programming method above, then in the same way as before, the number of products per hour or even the amount of production in the 4th quarter of 2020 produced can be calculated. The results of the production calculation can be seen in Table 6. The optimal production produced by the linear programming method in the 4th quarter of 2020 is 2,805.57 BCM/Hour or 4,214,836 BCM with 26 dump trucks spread over 3 fleets. With the same conclusion as in the results of calculations based on the match factor method, the amount of production produced based on this linear programming method must also exceed the number of actual production (realization of production in pit 2 west banko), and has reached the production target that has been set.

3.2.3. Comparison of Production Quantity.

The calculation of the production of each method produces a different total production depending on the number of dump trucks specified. Total production can be generated by multiplying the productivity of several dump trucks with their effective working time. The comparison of the total production of each method can be seen in Table 8. Based on the table it can be seen that the total production produced by both the match factor method with 4,194,256 BCM and linear programming with 4,214,836 BCM, has exceeded the realized production in pit 2 west banko in the 4th quarter of 2020 which amounted to 2,859,794. BCM and even reached the targeted production of 3,480,000 BCM.

Table 7. Comparison of Total Dump Truck Production in the 4th Quarter of 2020

No. Excavator	Actual	Match Factor Method	Linear Programming
PC 3001	1.006.103	1.219.466	1.393.676
PC 3002	1.025.197	1.438.490	1.438.490
PC 3003	1.173.663	1.536.300	1.382.670
Total	3.204.963	4.194.256	4.214.836

Table 8. Production Cost based on Match Factor Method

No. Ex-cavator	Loading cost per unit (Rp/hour)	Hauling cost per unit (Rp/hour)	Number of simulation units MF=1 (rounding)	Total DT production (BCM/Hr)	Hauling cost per unit (Rp/BCM)	Loading cost (Rp/BCM)	Total cost (Rp/BCM)
PC 3001	Rp450.723	Rp180.413	7	811,73	Rp1.556	Rp555	Rp2.111
PC 3002	Rp450.723	Rp180.413	9	957,52	Rp1.696	Rp471	Rp2.166
PC 3003	Rp450.723	Rp180.413	10	1022,63	Rp1.764	Rp441	Rp2.205
Total			26	271,87	Rp5.016	Rp1.467	Rp6.483

Table 9. Production Cost Based on Linear Programming Method

No. Exca-vator	Loading cost per unit (Rp/hour)	Hauling cost per unit (Rp/hour)	Number of LP solver simula-tion units (rounding)	Total DT production (BCM/hour)	Houling cost (Rp/BCM)	Loading cost (Rp/BCM)	Total cost (Rp/BCM)
PC 3001	Rp450.723	Rp180.413	8	927,69	Rp1.556	Rp486	Rp2.042
PC 3002	Rp450.723	Rp180.413	9	957,52	Rp1.696	Rp471	Rp2.166
PC 3003	Rp450.723	Rp180.413	9	920,36	Rp1.764	Rp490	Rp2.254
Total			26	2805,57	Rp5.016	Rp1.446	Rp6.462

3.3. Determination of Optimal Production Costs

3.3.1. Determination of Optimal Production Costs with Match Factor Method.

Based on the calculation of the number of dump trucks and the amount of production using the match factor method, it can be calculated production costs according to the hourly equipment costs which can be seen in Table 8. From this calculation, the optimal production costs can be obtained according to the optimal production and number of dump trucks. It can be seen that the total production costs for hauling and loading activities based on the match factor method are Rp 6,483 per BCM, where the total cost for 1 unit per BCM is cheaper than the actual production costs which amount to Rp7,225 per BCM.

4.3.2. Determination of Optimal Production Costs with Linear Programming Method.

Based on the calculation of the number and production of dump trucks using the linear programming method, it is possible to calculate production costs according to the hourly equipment costs which can be seen in Table 9. From this calculation, the optimal production costs can be obtained according to the optimal production and number of dump trucks. It can be seen that the total production cost for transportation and loading activities based on the linear programming method is Rp. 6,462/BCM, where the total cost is cheaper than the actual production cost as calculated based on the match factor method as well.

4.3.3. Comparison of Optimal Production Costs.

Production costs are the main factors that need to be considered in choosing alternatives based on each calculation method. Based on the number of dump trucks and the products produced by each method, the optimal production costs for hauling and loading activities can be determined. The comparison of total production costs for each method can be seen in Table 10. Based on the comparison results, it can be seen that the linear programming method produces a much more efficient cost than the match factor method. This can be seen from the total production cost based on the linear programming method of Rp. 6,462 per BCM, while the match factor method is Rp. 6,483 per BCM. Although indeed, both methods still make production costs more efficient than the actual production costs. This is because there has been an increase in the number of dump trucks in existing conditions which causes the excavator to no longer experience large idle time

Table 10. Comparison of Total Production Cost per BCM

No. Excavator	Actual	Match Factor Method	Linear Programming Method
PC 3001	Rp2.289	Rp2.111	Rp2.042
PC 3002	Rp2.511	Rp2.166	Rp2.166
PC 3003	Rp2.424	Rp2.205	Rp2.254
Total	Rp7.225	Rp6.483	Rp6.462

4. CONCLUSION

The actual number of dump trucks in Pit 2 West Banko is 21 units with the deployment of 6 units on fleet 1, 7 units on fleet 2, and 8 units on fleet 3. The total estimated actual production (theoretically) in Pit 2 West Banko in the 4th quarter of 2020 is 3,204,963 BCM with a production cost of Rp 7,225 per BCM. The optimal number of dump trucks for overburden material transfer in the 4th quarter of 2020 based on the match factor and linear programming methods is 26 units with distribution for the match factor method, 7 units on fleet 1, 9 units on fleet 2, and 10 units on fleet 3. Based on linear programming method, there are 8 units in fleet 1, 9 units in each fleet 2 and fleet 3.

The optimal amount of production based on the match factor method is 2,791.87 BCM/hour or 4,194,256 BCM, while based on the linear programming method is 2,805.57 BCM/hour or 4,214,836 BCM. The optimal production cost based on the match factor method is Rp 6,483 per BCM, while based on the linear programming method is Rp6,462 per BCM. Thus the optimal production cost is the production cost based on the linear programming method with Rp6,462 per BCM, where this figure is below the estimated actual production cost (Rp7,225 per BCM) and the production cost using the match factor method (Rp6,483 per BCM). So that the linear programming method can be used as an alternative to determine the most optimal number of dump trucks to achieve production targets with optimal costs.

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