The Effect of Overburden Loader and Hauler Match Factor on Fuel Consumption and Cost Using Queueing Theory (Case Study: Coal Mining PT. Perkasa Inakakerta East Kalimantan Province)

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Abstract

Overburden removal activity in PT. Perkasa Inakakerta was conducted in a close circuit service system. Each service system consisted of 1 unit of PC 850-8 and 4 units of HD 465-7. Production of the loader and the hauler respectively was 556.30 bcm/hour and 480.96 bcm/hour. These amounts had not achieved overburden production target which was 1,138.05 bcm/hour, because match factor value of the equipment was less than 1 (MF < 1), which 0,79. Disproportion of the loader and the hauler affected fuel consumption and fuel cost due to alteration of queueing time. Therefore, match factor test was conducted to increase the match factor of the equipment from 0.79 to 0.99 by adding 1 unit of hauler HD 465-7. Data used in this research were cycle time, fuel consumption, fuel cost, and fuel price data. After the additional hauler unit, the queueing time was analyzed using queueing theory to calculate change of the fuel consumption and cost. The addition of 1 unit of HD 465-7 increased the production 167.22 bcm/hour or 34.77% to 648.18 bcm/hour. The fuel cost spent after the addition as many as 167.22 bcm/hour was Rp1,318,434.1 per hour, so that the total fuel cost spent for 1 unit of PC 850-8 and 5 units of HD 465-7 was Rp1,700,151.28 per hour.

Keywords: Overburden; production; queueing time; match factor; fuel cost

1. Introduction

PT. Perkasa Inakakerta is a coal mining company located in Bengalon District, East Kutai Regency, East Kalimantan Province. PT. Perkasa Inakakerta is a subcompany of PT. Bayan Resources, Tbk, located in East Kalimantan. Bayan Group operates various coal mining companies ranging from environmentally friendly cokes coal with low sulfur to sub-bituminous coal [1]. At present, mining was carried out in one active pit, Pit 71N. Coal mining activities at PT. Perkasa Inakakerta use open cut or open mining methods that utilized mechanical equipment such as power crawlers or excavators to extract and load and heavy-duty dump trucks for transportation.

PT. Perkasa Inakakerta works with PT. Karunia Wahana Nusa as a contractor in carrying out mining activities, including stripping of overburden. The activity of stripping overburden material is one of the stages of mining activities that need to be carried out so that the coal extraction process can be done. The activity of stripping overburden material generally involves two types of mechanical equipment, namely loading and hauling equipment. PT. Perkasa Inakakerta uses 4 units of PC 850-8 as loaders and 18 units of HD 465-7 as haulers. In companies, these two types of equipment are classified as overburden units.

Based on data plan in November 2017, target of overburden production is 22,601.62 bcm/day or 1,138.05 bcm/hour, but production by mechanical devices was unable to meet production target of the overburden. It was caused by unbalanced match factor of the devices. Capacity of loading and transport equipment was considered balanced when its value was almost or equal to one [2]. Based on match factor test, value of the match factor of 1 unit PC 850-8 and 4 (four) units of HD 465-7 was 0.79. This indicated that there was lack of haulers used, so it was necessary to increase the number of haulers [2]. How the number of loading and hauling equipment matched affected queueing time of the equipment because operation of the activity was carried out in a closed circuit (round queue), where there were only a limited number of customers in all stages [3]. Long queueing time would have resulted in big fuel consumption. Low production of mechanical equipments and the unbalanced match factor of the equipments required the match factor correction. Improvement of the match factor was done by increasing number of haulers used because the value of the match factor is less than 1 (MF <1) [2]. The applied closed-circuit service system meant increasing the number of haulers would increase the queuing time of the system. Therefore, this study was conducted to determine effect of the match factor on the fuel consumption and costs of loading equipment and overburden haulers using queuing theory.

2. Methodology

Method in this study consists of several stages related to problem solving. The first stage was field studies, which also included data collection. After collecting, the next stage was data processing by using the match factor test to increase the value to be equal to 1 (MF = 1). The increasing in the value of the match factor would affect the productivity of equipment as well as changes in the fuel consumption and costs of the equipment caused by the queueing time. The next stage was doing, a queueing time analysis using queueing theory to determine the fuel consumption and costs incurred based on the results of an increase in the match factor in the number of loading equipment and hauling equipment.

A. Data Collection

Data collection was carried out at the Pit 71N area of PT. Perkasa Inakakerta. Data collected, consists of:

a. Primary Data, field data sourced directly from observations and surveys in the field. Primary data are:
   - Cycle time or loading time for loading and hauling equipment. Data on circulation of loading equipment and hauling equipment was taken using a digital stopwatch. The amount of data for the distribution of loading equipment was 50 data and circulating time data for the hauling

equipment was 20 data. Data of loading equipment was collected on the mining front area and of hauling equipment was on the mining front and disposal area.

- Number of loading equipment and hauling equipment operating in the field (Table 1).

b. Secondary data, collection of data and information from companies, including:

- Schedule of loading and hauling equipment.
- Loading and hauling equipment productivity (Table 1).
- Fuel consumption of loader and hauler (Table 1).
- Fuel prices (Table 1).

Table 1. Data Tabulation

Entry	Loader	Hauler
Number of Fleet Operated (Unit)	4	18
Productivity (bcm/hour)	556.30	480.96
Fuel Consumption (Litre/Hour/Unit)	52.96	36.59
Fuel Price per January 2018 (Rupiah/Litre)	7,207.037	

B. Data Processing

Data obtained in the field and data obtained from companies was processed in the Mine Planning and Valuation Laboratory with the following stages:

a. Calculate the working efficiency of loading equipment and hauling equipment. The work efficiency of loading equipment and hauling equipment was obtained from a comparison between the time used to work with the available time in the form of percent (%), where the time spent has been reduced by the constrain time.

b. Calculate the cycle time or circulation time of the loading equipment and hauler. The cycle time or loading time was obtained from the results of observations directly starting from the time of digging, filling a bucket, rotating with a filled bucket, spilling material and rotating with an empty bucket. Release time of hauling equipment was obtained from observations ranging from the time it was filled to full by loading equipment, travelling to disposal, taking positions for dumping, dumping material, returning to the front with empty cargo, lining up, and taking positions to be refilled. Data processing was done using Microsoft Excel.

c. Calculate the service time or service time of the hauler. The time of service was obtained based on data on circulating hauler mean by dividing the service into four stages, namely:

- The first stage was when the hauler was on the mining front and in the material filling position.
- The second stage was in the position of the hauler carrying material to the disposal (travelling).
- The third stage was in the position of the hauler taking the position of dumping the material.
- The fourth stage was in the position of the hauler back to the mining front.

The four stages showed how many haulers operate each hour. These data was calculated using Microsoft Excel.

d. Calculating the production of loading equipment and hauling equipment. Data on the production of loading equipment and hauling equipment was obtained from the results of a comparison between the number of tools used and the work efficiency of the tool and the real capacity of the hauler with the cycle time of the equipment, in seconds.

e. Calculate the matching number of loading and hauling equipment. The matching number was calculated using the match factor test. The match factor value of the number of loading equipment was considered balanced when its value was almost or equal to 1 (MF = 1), so that the number of hauler was carried out so that the value of the match factor of the tool increases. The calculation of the matching of the number of loading equipment and hauler was calculated using Microsoft Excel.

f. Calculate changes in queueing time based on the increase in the number of hauling equipments. The changes of the queueing time were calculated using queueing theory. The queueing time was analyzed based on the number of additions of the hauler used to increase the value of the match factor of the loading and hauling equipment. Changing of the queueing time was calculated using Microsoft Excel.

g. Calculate the fuel consumption and costs of loading and hauling equipment. The cost of fuel consumption for loading equipment and hauling equipment is obtained by multiplying price of fuel per liter with total amount of fuel consumed by the loaders and hauling equipment.

3. Result & Discussion

A. *Match Factor 0.79 (MF = 0.79)*

Basically, the combination of the highest efficiency of loading equipment and hauling equipment chosen for use. The right combination of work between loading equipment and hauling equipment was determined by calculating the match factor. The match factor value of 1unit PC 850-8 and 4 units HD 465-7 obtained from match factor test was 0.79. The following was calculation of production and queueing time analysis on 1unit of the PC 850-8 and 4 (four) units of HD 465-7 based on the match factor value of 0.79.

Based on the current work time scheduling, the number of working hours can be determined, so that the normal working time:

Working time available (Wkt):

$$= \frac{139\ hour/week}{7days}$$

$$= 19.86\ hours/day$$

Effective working time was work time after being calculated with the time the constrain occur.

Effective working time (Wke) = Wkt - (Whd + Whtd) (1)

- Loader PC 850-8

  Wke = 19.86- (1.75 + 1.75)

  = 16.36 hours/day

- Hauler HD 465-7

  Wke = 19.86- (1.67 + 1.67)

  = 16.52 hours/day

Work efficiency was an assessment of the implementation of a job or was a comparison between the time used to work with the available time.

Work Efficiency = Wke/ Wkt x 100% (2)

- Loader PC 850-8

  Work Efficiency = 16.36/19.86 x 100%

  = 82.38%

- Hauler HD 465-7

  Work efficiency = 16.52/19.86x 100%

  = 83.18%

A.1 Loading

From the data of cycle time calculation, it was calculated the average cycle time using statistical calculations with frequency distribution [4], the equation is:

K = 1 + 3.3 log M (3)

R = X_maks - X_min (4)

IK = R / K (5)

x = (fi.xi) / fi (6)

Where, K (number of interval classes), M (amount of observation data), R (range), X_maks (the biggest observation data), X_min (the smallest observation data), IK (interval class length), x (average value), fi (frequency), xi (middle value).

After calculating 50 numbers of data, it was known that the average time to move back empty was equal to 4.0756 seconds. From the data above, the average circulation time of the loading equipment PC850-8 was obtained:

T1 = 10.754 seconds

T2 = 5.8596 seconds

T3 = 3.3006 seconds

T4 = 4.0756 seconds

The loading time for loader PC 850-8 was:

CTm = (T1 + T2 + T3 + T4)

= (10.754+5.8596+ 3,3006 + 4,0756)

= 23.99 seconds

= 0.40 minutes

A.2 Hauling

In the round queueing method, it was assumed that in one cycle it was divided into 4 stages and at each stage has a service level which, if specified, was:

- Backhoe (overburden loading service), μ1
- Dump trucks carry out their own service (self-service), hauling services to the disposal unit, μ2
- The disposal unit (dump truck service dumping overburden), μ3
- Empty dump truck (self-service, dump truck service back to the mining front), μ4

The amount of time spent on the hauler HD 465-7 served by the loader PC 850-8 was:

Cta = (T1 + T2 + T3 + T4 + T5 + T6)
= (243.21 + 150.14 + 200,925 + 22,52 + 34.01 + 200,925)
= 851.73 seconds
= 14.20 minutes

The average service level of a backhoe for a dump truck at each stage was:

- Stage 1: Time for backhoe service to service dump trucks.

WPm = T1 + T2
or,
WPm = T1 + (n x CTm)
Where:
T1 = 243.21 seconds
T2 = 150.14 seconds
so that,
Time of backhoe service for 1unit dump truck service:
WPm = (243.21 + 150.14) seconds
= 393.35 seconds
= 6.56 minutes

then the backhoe service level every 1 hour to service each dump truck was:

μ1 = (1 /WPm) x 60 trucks/hour
= (1/6,56) x 60 trucks/hour
= 9.15 trucks/hour
≈ 9 trucks/hour

- Stage 2: Time for dump truck service to transport material to disposal.

WPa = T3 = 200.925 seconds
= 3.35 minutes

then the dump truck service level every 1 hour in transporting material to disposal was:

μ2 = (1 /WPa) x 60 trucks/hour
= (1/3, 35) x 60 trucks/hour
= 17.92 trucks/hour
≈ 18 trucks/hour

- Stage 3: Time for dump truck service to dump material into the disposal.

WPa = T4 + T5
Where:
T4 = 22.52 seconds
T5 = 34.01 seconds
so that,
The time for dump truck service to dump material at disposal was:
WPa = (22.52 +34.01) seconds
= 56.53 seconds
= 0.94 minutes

then the level of dump truck service in 1 (one) hour to dump material was:

μ3 = (1 /WPa) x 60 truck /hour

= (1 / 0.94) x 60 trucks/hour

= 63.68 trucks/hour

≈ 64 trucks/hour

- Stage 4: Time for dump truck service to return to the mining front

  WPa = T6 = 200.925 seconds

  = 3.35 minutes

  then the dump truck service level every 1 hour to return to the mining front was:

  μ4 = (1 / WPa) x 60 trucks/hour

  = (1/3, 35) x 60 trucks/hour

  = 17.92 trucks/hour

  ≈ 18 trucks/hour

A.3 Probability of the Queueing Situation

In actual situation there were 4 units of hauler HD 465-7 which served by 1 unit PC 850-8 loading equipment in a service system. The number of queueing round conditions for (n1, n2, n3, n4) were n1+ n2 + n3 + n4 = 4.

Where ni was number of stage i dump trucks. The average number of hauling equipment operating on the mining front is 4 trucks (K = 4). The number of possibilities that can occur in the queue of rotation of the distribution of 4 trucks in the case of 4 stages (M = 4) were:

$$= \begin{bmatrix} K+M-1 \\ K \end{bmatrix} = \frac{(K+M-1)!}{(M-1)!K!}$$

$$= \frac{(4+4-1)!}{(4-1)!4!}$$

$$= \frac{7!}{(3)!4!}$$

$$= \frac{1x2x3x4x5x6x7}{(1x2x3)(1x2x3x4)}$$

= 35 probabilities

So, there are 35 possible queues from the distribution of 4 trucks between the 4 stages. Calculation Lq1 (number of trucks waiting in stage 1), Lq3 (number of trucks waiting in stage 3), Wq1 (truck waiting time in line 1), and Wq3 (time waiting for the truck in line 3):

a. Average number of dump trucks waiting in line

- Stage 1 was when the dump truck waits to be loaded with a backhoe with the condition that it is n1> 1 so that the average dump truck is waiting on the backhoe.

  Lq1 = 1 x Σ (State Probability 20,21,22,27,28,29) + 2 x Σ (State Probability 14,15,16) + 3 x Σ (State Probability 4)

  = 1.89 trucks ≈ 2 trucks

- Stage 3 was when the dump truck waits to dump the load at disposal, with the provisions of n3> 1, so that the average dump truck waiting to dump the load is:

  Lq3 = 1 x Σ (State Probability 17,19,22,23,26,32) + 2x Σ (Situation Probability 6,8,12) +3 x Σ (State Probability 2)

  = 0.02 trucks ≈ 0 trucks

b. Average waiting time for a dump truck in line

The level of activity of a backhoe can be calculated using the following equation:

$$\eta 1 = 1 - \Sigma P (0, n2, n3, n4) \qquad (7)$$

The equation was obtained from the condition n1 = 0, which was a situation where there are no dump trucks coming to the mining front (the backhoe was idle).

then,

$\eta 1$ = {1-Σ (probability of condition 1,2,3,5,6,7,8,9,10,17,18,19,23,24,25)} x 100%

= 97.507%

≈ 97.5%

So the level of backhoe PC 850-8 in mining operations was 97.5%.

Because loading operations were in stage 1, the number of trucks that can be served at this stage was:

$\Theta 1$ = $\eta 1$ x $\mu 1$

= (97.5% x 9 trucks / hour)

= 8.775 trucks / hour

≈ 9 trucks / hour

For stages 2, 3 and 4, the price of Θ was assumed to be the same, so:

$\Theta 1 = \Theta 2 = \Theta 3 = \Theta 4 = \Theta$

so that,

- The average waiting time for a dump truck in line at a backhoe was:

  Wq1 = Lq1 / Θ

  = (1.89 trucks)/(9 trucks/ hour)

  = 0.2103 hours

  = 12.62 minutes

- The average waiting time for dump trucks at disposal was:

  Wq3 = Lq3 / Θ

  = (0,02 trucks) / (9 trucks / hour)

  = 0.0022 hours

  = 0.126 minutes

Calculation of distribution time of hauling equipment without waiting time (waiting) was obtained as follows:

CTt = (1 / μ1 + 1 / μ2 + 1 / μ3 + 1 / μ4)

= (1/9 + 1/18 + 1/64 + 1/18) hours/truck

= 0.2378 hours/truck

= 14.27 minutes

Based on the application of queueing theory, the total cycle time of the hauler each time becomes:

Total CTt = (1 / μ1 + 1 / μ2 + 1 / μ3 + 1 / μ4 + Wq1 + Wq3) hours / truck

= (0.2378 + 0.2103 + 0.0021) hours/truck

= 0.4504 hours/truck

= 27.02 minutes/truck

so that the arrival rate of each dump truck unit in one hour both on the mining front and at the disposal was:

λ = λ1 = λ3 = 1 / 27.02 x 60 trucks/hour

= 2.22 trucks/hour

≈ 2 trucks/hour

In determining the number of dump trucks needed in accordance with the service level of loading equipment without waiting time were:

N = μ1 / λ1 x 1 truck

= (9 trucks/hour) / (2.22 trucks/hour) x 1 truck

= 4.05 trucks ≈ 4 trucks

A.4 Production of Mechanical Tools

Production of mechanical devices can be calculated using Equation 8:

$$P = n \times (60 \times Eff \times Kn) / CT \quad (8)$$

Where n (number of tools (units)), Eff (tool work efficiency based on waiting time (%)), Kn (real capacity of mechanical devices (tons)), CT (release time (minutes)).

Calculating based on Equation 8 was obtained by the production of a mechanical device of:

- Loader PC 850-8

  n = 1 unit

  Eff = 82.38%

  Kn = 4.5 m³

  CT = 0.39983 minutes

  then,

  P = n x (60 x Eff x Kn) / CT

  = 1 x (60 x 0.8238 x 4.5) / 0,39983

  = 556,30 BCM/hour

- Hauler HD 465-7

  n = 4 units

  Eff = 83.18%

  Kn = 34.3 m³

  CT = 14,1955 minutes

  then,

  P = n x (60 x Eff x Kn) / CT

  = 4 x (60 x 0.8318 x 34.2) / 14,1955

  = 480.96 BCM/hour

Based on the calculation of the production of loading and hauling equipment, it was known that the production of hauling equipment is 480.96 BCM/hour smaller than the loader production capability of 556.30 BCM/hour.

The current production capability of mechanical devices refers to the smallest production capability of mechanical devices, namely the production of hauler of 480.96 BCM/hour. Therefore, the current production capability of mechanical devices has not reached the planned production target which was equal to 1,138.05 BCM/hour due to a shortfall of 581.75 BCM/hour.

B. Improvement of the Match Factor Value

Increasing the production of loading equipment and hauling equipment was done by improving the match factor of the number of loading equipment and hauling equipment.

Based on the match factor test of 1 unit PC 850-8 and 4 units HD 465-7, the match factor value was 0.79. The value of the match factor which was less than 1 (MF <1), indicates that the number of hauler is lacking, consequently the loaders were waiting a lot, while the hauler was busy, so the need for additional hauling equipment was needed to obtain matching between HD 465-7 and backhoe PC 850-8 where the match factor value (match factor) must be close to or equal to 1. The result of match factor with the addition of 1 unit of hauler:

MF = (7.039983 x 5) / (14,1955 x 1)

= 0.99

So, the match factor between the HD 465-7 and the backhoe PC 850-8 is reached if the HD 465-7 transport was added to 5 units.

C. Match Factor 0.99 (MF = 0.99)

In the situation after correction there are 5 hauling units of HD 465-7 which are served by 1 unit PC 850-8 loading equipment in a service system. The number of queues round conditions for (n1, n2, n3, n4) were: n1 + n2 + n3 + n4 = 4

Where n_i was number of stages i dump trucks. The average number of hauling equipments operating on the mining front after repairs was 5 units' dump trucks (K = 5). The number of possibilities that can occur in the queue of rotation of the distribution of 5 units' dump trucks in the case of 4 stages (M = 4) are:

$$=\begin{bmatrix} K+M-1 \\ K \end{bmatrix} = \frac{(K+M-1)!}{(M-1)!K!}$$

$$= \frac{(5+4-1)!}{(4-1)!5!}$$

$$= \frac{8!}{3!5!}$$

$$= \frac{1x2x3x4x5x6x7x8}{(1x2x3)(1x2x3x4x5)}$$

= 56 probabilities

So there are 56 possible queues from the distribution of 5 units' dump trucks between the 4 stages.

Calculation Lq1 (number of trucks waiting in stage 1), Lq3 (number of trucks waiting in stage 3), Wq1 (truck waiting time in line 1), and Wq3 (time waiting for the truck in line 3):

a. Average number of dump trucks waiting in line

- Stage 1

  Stage 1 was when the dump truck waits to be loaded with a backhoe with the condition that it is $n_1 > 1$ so that the average dump truck was waiting on the backhoe.

  Lq_1 = 1 x Σ (circumstances probability 19,22,25,35,36,37,38,39,40,56) +2 x Σ (probability of condition 26,27,28,41,42,43) + 3x Σ (state probability 14,15,16) + 4xΣ (state probability 4)

  = 2.85 trucks ≈ 3 trucks

- Stage 3

  Stage 3 was when the dump truck waits to dump the load at disposal, with the provisions of $n_3 > 1$, so that the average dump truck waiting to dump the load is:

  Lq_3 = 1 x Σ (state probability 17,24,27,29,31,32,34,35,38,54) +2 x Σ (probability of the condition 20,21,22,45,47,52) + 3x Σ (state probability 8,9,10) +4 x Σ (state probability 2)

  = 0.022 trucks ≈ 0 trucks

b. Average waiting time for a dump truck in line

The level of activity of a backhoe can be calculated using the following equation:

η1 = 1 - Σ P (0, n2, n3, n4)

The equation was obtained from the condition n1 = 0, which was a situation where there are no dump trucks coming to the mining front (the backhoe was idle).

then,

η1 = {1 - Σ (state probability 1,2,3,5,6,7,8,9,10,17,18,19,23,24,25)} x 100%

= 98.311%

≈ 98.3%

So the level of backhoe PC 850-8 in mining operations was 98.3%.

Because the loading operation was in stage 1, the number of trucks that can be served at this stage was:

ϴ1 = η1 x μ1

= (98.3% x 9 trucks / hour)

= 8.847 trucks / hour

≈ 9 trucks / hour

For stages 2, 3 and 4, the price of ϴ is assumed to be the same, so:

ϴ1 = ϴ2 = ϴ3 = ϴ4 = ϴ

so that,

- The average waiting time for a dump truck in line at a backhoe was:

  Wq1= Lq1 / ϴ

  = (2.85 trucks) / (9 trucks/hour)

  = 0.3167 hours

  = 19.002 minutes

- The average waiting time for dump trucks at disposal was:

  Wq3= Lq3 / ϴ

  = (0,022 trucks) / (9 trucks/hour)

  = 0.0024 hours

  = 0.144 minutes

Calculation of cycle time of hauling equipment without waiting time (waiting) was obtained as follows:

CTt = (1 / μ1 + 1 / μ2 + 1 / μ3 + 1 / μ4)

= (1/9 + 1/18 + 1/64 + 1/18) hours / truck

= 0.2378 hours / truck

= 14.27 minutes

Based on the application of queueing theory, the total cycle time of the hauler each time becomes:

Total CTt = (1 / μ1 + 1 / μ2 + 1 / μ3 + 1 / μ4

+ 〖Wq1 + Wq3) hours / truck

= (0.2378 + 0.3167 + 0.0024) hours/truck

= 0.557 hours/truck

= 33.42 minute/truck

so that the arrival rate of each dump truck unit in one hour both on the mining front and at the disposal was:

λ = λ1 = λ3 = 1 / 33.42 x 60 trucks/hour

= 1.795 trucks/hour

≈ 2 trucks/hour

In determining the number of dump trucks needed in accordance with the service level of loading equipment without waiting time were:

N = μ1 / λ1 x 1 truck

= (9 trucks/hour) / (1,795 trucks/hour) x 1 truck

= 5.013 trucks ≈ 5 trucks

D. Production and Fuel Costs Based on Improved Match Factor of Loading and Hauling Equipments

Production of mechanical devices after the addition of 1 (one) unit of HD 465-7 conveyance was calculated using Equation 8:

- Loader PC 850-8

  n = 1 unit

  Eff = 82.38%

  Kn = 4.5 m^3

  CT = 0.39983 minutes

  then,

  P = n x (60 x Eff x Kn) / CT

  = 1 x (60 x 0.8238 x 4.5) / 0.39983

  = 556.30 BCM/hour

- Hauler HD 465-7

  n = 5 units

  Eff = 89.68%

  Kn = 34.2 m^3

  CT = 14.1955 minutes

then,

P = n x (60 x Eff x Kn) / CT

= 5 x (60 x 0.8968 x 34.2) / 14.196

= 648,175 BCM/hour

Production of mechanical devices after adding 1 unit of hauler HD 465-7 to 5 units was 556.30 bcm/hour for loading equipment and 648,175 bcm/hour for hauling equipment.

Based on the results of match factor improvement of loading and overburden hauling equipment, and queue time analysis using queuing theory, it was obtained an increasing of loader production of PC 850-8 and hauler HD 465-7 and changes in fuel consumption and costs as shown in Table 2.

Table 2. Production, Consumption, and Fuel Cost Comparison

Entry	MF = 0,79		MF = 0,99	
	PC 850-8 (1 Unit)	HD 465-7 (4 Unit)	PC 850-8 (1 Unit)	HD 465-7 (5 Unit)
Productivity (bcm/hour)	556.30	480.96	556.30	648.18
Fuel Consumption (liter/hour)	52.96	146.350	52.96	182.937
Fuel Cost (Rupiah per hour)	381,717.12	1,054,747.3	381,717.12	1,318,434.2
Total Fuel Cost (Rupiah per hour)	1,436,464.45		1,700,151.28	

Based on Table 2, it was known that after the addition of 1 unit of hauler, the match factor of the loading and hauling equipment which was originally 0.79 increased to 0.99. The addition of 1 unit of hauler makes the fuel consumption of hauling equipment increase by 36.587 liters/hour, from 146.350 liters/hour to 182.937 liters/hour. Similarly, the fuel costs incurred increased by 25% from the original Rp1,054,747.3 per hour to Rp1,318,434.2 per hour. But with the addition of 1 unit of hauling equipment to 5 units made the production of hauling equipment increased by 167.22 BCM/hour or 34.77% from 480.96 bcm/hour to 648.18 BCM/hour.

4. Conclusion

Based on the results, there are two conclusions:

1. The number of hauling equipment is added by 1 unit from 4 units of HD 465-7 to 5 units of HD 465-7. It is to increase the match factor value of the number of loading and hauling equipment to 0.99 so that the production of equipment would increase by 167.22 BCM/hour or 34.77% from 480.96 BCM/ hour to 648.18 BCM/hour.
2. Fuel costs based on the results of the queueing time analysis and the addition of 1 unit of the hauler HD 465-7 is Rp1,318,434.2 per hour. The total fuel costs

incurred for 1 unit of loader PC 850-8 and 5 units HD 465-7 is Rp1,700,151.28 per hour.

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