Analysis Match Factor Loader and Hauler for Activities Overburden Removal Using the Queue Method at PT Andalan Artha Primanusa Jobsite PT Budi Gema Gempita, South Sumatera Province

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Abstract. PT Andalan Artha Primanusa (AAP), a coal producer, set a production target of 817,343 bcm/month for overburden (OB) in November 2022, but only achieved 55.4% of the target with realized production of 453,000 bcm/month. The company identified fleet mismatch and high unit turnaround time as factors hindering production. XCMG's ADT turnaround time was found to be 13.5 minutes, which led to suboptimal work output. Another contributing factor was the poor condition of the haul road, which necessitated a reduction in speed and an increase in turnaround time. To solve this problem, the company conducted a study using queuing theory to analyze the unit's actual production, fleet fit factor, and production achievement in overburden removal activities. The analysis results showed that 7 ADT units were required for each fleet, and the achieved overburden production was 322,513.6 bcm/month, which was 39.4% of the target. To optimize production, the researchers used the best cycle time and work efficiency values of the units, resulting in hauler production of 955,839.6 bcm/month or 116.94% of the target.

Keywords: Match Factor, Production, Queuing Theory

1 Introduction

PT. Andalan Artha Primanusa (AAP) is a company engaged in coal production. Coal mining activities at PT. AAP starts from mapping survey activities, land clearing, stripping and transportation top soil, stripping and transporting overburden, coal cleaning, coal mining and transportation, coal processing (crusher), marketing, and post-mining land reclamation.

In activities overburden removal in Section 2 PT. AAP uses two fleet which consists of a unit loader of excavator Hitachi ZX870 with code EX-823 for fleet one and EX-822 for fleet two and 4 units of ADT XCMG XDA40 hauler each fleet. In November 2022 PT. AAP sets production targets overburden amounting to 817,343 bcm/month, with actual achievement being 453,000 bcm/month or around 55.4% of the planned production target. Based on observations in the field, one of the factors that can hamper production is incompatibility fleet (loader waiting) and quite high unit circulation time, circulation time excavator The Hitachi ZX870 is 25.64 seconds and the circulation time of the ADT hauling which is not good so the operator has to reduce the speed which is one of the causes of high circulation time. So companies must further optimize production activities by improving strategies and making improvements in the production process overburden.

Compatibility fleet The ideal in the field is very difficult to achieve, but this can be achieved by analyzing the effective number of units in production operations overburden removal [1]. In this research, to obtain the compatibility of loader and hauler, researchers used match factor and queuing theory to get composition fleet required to achieve optimal production. This encourages researchers to conduct research on the topic **"Analysis Match Factor Loader and Hauler for Activities Overburden Removal Using the Queue Method at PT. Andalan Artha Primanusa Jobsite PT. Budi Gema Gempita, South Sumatra Province".**

2 Research sites

2.1 Regional Achievement Locations

To reach the research location from Padang City, you can take the following travel route:

a. The land route, from Padang City to Lahat Regency takes ± 18 hours, then from Lahat to Muara Lawai Village takes ± 45 minutes, continue the road tosite PT. Budi Gema Gempita takes ± 10 minutes.
b. By air, from Minangkabau International Airport in Padang to Sultan Mahmud Baharudin II Airport in Palembang, South Sumatra by plane, it takes ± 1 hour.
c. The journey from Palembang continues with a road trip using four-wheeled vehicles via land with fairly good road conditions, as far as ± 200 km to the

Southwest to Lahat with a travel time of approximately 4 hours.

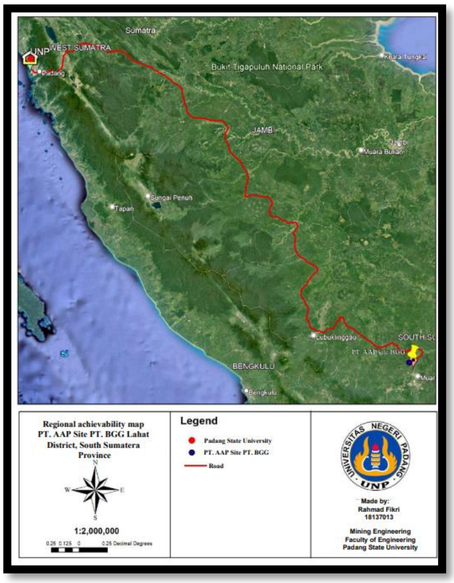

Figure 1. Regional Achievability Map PT. Budi Gema Gempita

2.2 Lithology and Geology Conditions

2.2.1. Lithological Condition

From the outcrop mapping and drilling activities that have been carried out, it is known that the overburden is dominated by clay rock and in some places is accompanied by fine sandstone and the thickness of this overburden is between 0.5-60 m. Meanwhile, it is also known that the thickness of the coal seam varies between 1-18 m with inserts of clay rock and coal clay. Based on drilling results in the Lawai I Block, it is known that there are 4 (four)seam coal with a thickness of between 4-12 m.

2.2.2. Geological Structure

In the IUP area PT. Budi Gema Gempita has three rock formations based on the regional geological map of the Lahat sheet as shown in the picture. The three rock formations are the Muara Enim Formation, Kasai Formation and Air Benakat Formation.

3 Theoretical Studies

3.1 Productivity of Loader and Hauler

3.1.1 Loader Productivity

To estimate the productivity of loader, you can use equation 1:

$$Q = \frac{3600}{CT} \times q \times E \times SF \text{ ....}(1)$$

Source: [2]

Information:
Q : Production per hour (bcm/hour)
q : Production of loader per cycle (m^3)
E : Work Efficiency (%)
SF : Swell factor (%)
CT : Cycle time (s)

Where the value of q can be found using the following equation 2:

$$q = q_1 \times k \text{ ....}(2)$$

Information:
q_1 : Capacity bucket (m^3)
k : Factor bucket (%)

3.1.2 Productivity of Hauler

To estimate the productivity of Hauler, you can use the following 3 equations [3]:

$$Q = \frac{60}{CT} \times C \times E \times SF \text{ ....}(3)$$

Information:
Q : Production per hour (bcm/hour)
C : Production per cycle (bcm/cycle)
E : Work efficiency (%)
CT : Cycle time (s)

Where the value of C can be found using the following equation 4:

$$C = n \times q_1 \times k \text{ ....}(4)$$

Information:
n : number of bucket
q_1 : Capacity bucket (m^3)
k : Factor bucket (%)

3.2 Match Factor of Loader and Hauler

Match factor is the work compatibility factor between the loader and the hauler [4]. Match factor analyzed using equation as 5 [5]:

$$MF = \frac{CTm \times n \times Na}{CTa \times Nm} \text{ ....}(5)$$

Information:
MF : Match factor
Na : Number of hauler
n : Number of filling bucket
CTm : Cycle time loader
Nm : Number of loader
CTa : Cycle time hauler

3.3 Queuing Theory

3.3.1 Characteristics of Round Queuing Systems

Queuing operations use a round queuing system consisting of a collection of stages in a closed circuit. This system uses 1 unit of loading and digging equipment as a service to serve transportation equipment as customers. Customers who complete stage i immediately queue to receive service at stage i + 1, i = 1,2,…,M, where M is the number of all stages. The output of i is the input at stage i + 1. After complete service at stage M, customers queue to get service at stage i, so the stage repeats itself. Because this operation is a closed circuit, there are only a limited number of customers (K) throughout the stages. For example, mining operations involve hauler (excavators) and several hauler (dump trucks) which consist of 4 stages, namely:

(μ_1) : Is a dump truck loading service

(μ_2) : Is a transportation service to disposal
(μ_3) : It is a service dump truck shed overburden
(μ_4) : This is a return to dump truck service front loading

3.3.2 Characteristics of the Service Balance System

To expand the round queue model, each stage can be considered the same, such as the situation for the entire round system which can be shown by (n_1, n_2,…, nM) where n_1 is for units in stage 1, there is n_2 for units in stage 2 and so on until stage M. For K units of rotation are obtained

$$\sum_{i=1}^{M} n1 = k \quad (6)$$

(Modified from Ariyantoro, 2003:28)

The steady state equation for the case of M stages and K dump trucks becomes:

$$\frac{(K+M-1)!}{(M-1)!(K)!} \quad (7)$$

Information:
K : Number of units of hauler used
M : Number of queue stages (there are 4 stages)

3.3.3 Characteristics of the Service Balance System

For service equilibrium, the state probabilities and system properties in the round queue can be simplified. If it is assumed that all stages have the same properties. So μi = μ where, I = 1, 2, …, M

$$P(n_1,n_2,n_3,n_4) = \frac{\mu 1^{(k-n1)}}{n_2\,!\,\mu 2^{n2}\,\mu 3^{n3}\,n_4\,!\,\mu M^{nm}}\ P(K,0,\dots,0) \quad (8)$$

(Modified from Ariyantoro, 2003: 29)

So dump truck in each level (Li) is:

$$Li = (L) = \frac{K}{M} \quad (9)$$

(Modified from Ariyantoro, 2003: 30)

Number of dump truck waiting queues in each stage are:

$$Lqi = \frac{K}{M} = \frac{(K(K-1)!}{M(K+M-1)!} = \frac{K+M-1}{\mu k} = \frac{(K-1)}{\mu M} \quad (10)$$

(Modified from Ariyantoro, 2003: 30)

Results (dump truck who have been served) for each stage (π), is:

$$\theta = \frac{\eta}{\mu} = \frac{\mu k}{K+M-1} \quad (11)$$

(Modified from Ariyantoro, 2003: 30)

Time dump truck in queue:

$$Wq = \frac{Lq}{\theta} = \frac{(K(K-1)!}{M(K+M-1)!} = \frac{K+M-1}{\mu k} = \frac{(K-1)}{\mu M} \quad (12)$$

(Modified from Ariyantoro, 2003: 30)

So the total average circulation time is 1 unit dump truck (CT) are:

$$CT = (K - 1)/\ \mu + M/\mu \quad (13)$$

4 Research methods

4.1 Types of research

This research uses a quantitative type of research. This research will use data in the form of numbers.

4.2 Data Collection Techniques

4.2.1 Study Literature

Literature study is part of research activities which aims to collect, study and read various library sources in the form of books, previous research, company data and other sources that refer to things that support research activities.

4.2.2 Data Preparation

In this research, the data that needs to be prepared is primary data and secondary data, including:

a. Primary data is data obtained directly from researchers' observations in the field. Data that researchers obtain in the data field cycle time loader and hauler during activities overburden removal.

b. Secondary data is data that can be obtained from PT. Andalan Artha Primanusa, the data that researchers obtained is as follows:

1) Production data overburden in November 2022
2) Specifications for loader and hauler
3) Planned working time and actual working time
4) Geological conditions and statigraphy

4.2.3 Data Processing and Analysis Techniques

The stages of data processing and analysis used in this research are mathematical techniques, namely regarding the results of data obtained from measurements in the field.

After the researcher obtained primary data and secondary data, the researcher used formulas through existing literature to analyze the data. Data analysis included the following:

a. Calculating the productivity of loader and hauler during activities overburden removal.

b. Calculating production achievements in activities overburden removal use match factor**.**

c. Calculating production achievements in activities overburden removal using queuing theory**.**

4.2.4 Conclusions and Suggestions

Conclusions were obtained from the results of data processing and analysis, namely the productivity of digging-loading equipment and transportation equipment, the compatibility factor of loader and hauler, as well as the productivity of loader and hauler using match factors and queuing theory. Furthermore, the results of this research can be recommended to the company as a reference and consideration in carrying out evaluations to improve the production plans that have been determined.

5 Results and Discussion

5.1 Results

5.1.1 Unit Productivity

5.1.1.1 Unit Availability

Based on actual conditions in the field of activity overburden removal consists of two fleet with MA, PA, UA and EU values for the Hitachi ZX870 excavator loading digging tool as in Table 1:

Table 1. Availability Value Excavator

Unit	MA	PA	UA	EU
EX-823	100%	100%	84,7%	84,7%
EX-822	100%	100%	81,7%	81,7%

Based on company data, it is known that the operating hours of fleet 1 hauler are as shown in Table 2.

Table 2. Hauler Availability Value Fleet I

Unit	MA	PA	UA	EU
ADT 914	95%	96%	81%	77,9%
ADT 925	58,9 %	66,6 %	71,7%	47,8%
ADT 926	100%	100%	83,7%	83,7%
ADT 922	100%	100%	83%	83%

Based on company data, it is known that the operating hours of fleet 2 hauler are as shown in Table 3.

Table 3. Hauler Availability Value Fleet II

Unit	MA	PA	UA	EU
ADT 916	100%	100%	78,4%	78,4%
ADT 917	70%	72,3%	83,6%	60,4%
ADT 918	97,6%	98%	79,2%	77,67%
ADT 921	100%	100%	80%	80%

5.1.1.2 Loader Productivity

Parameters to analyze the productivity value of the loader can be seen in the table 4.

Table 4. Productivity Parameters Loader

Parameter	EX-823		EX-822	
	Shift 1	Shift 2	Shift 1	Shift 2
q1	5	5	5	5
k	0.85	0.85	0.85	0.85
q	4.25	4.25	4.25	4.25
SF	0.85	0.85	0.83	0.85
E	0.847	0.847	0.817	0.817
CT	23,84	27,43	23,25	24,14

1) EX-823 Shift I

$$Q = \frac{3600}{CT} \times q \times E \times SF$$

$$= \frac{3600}{23,84} \times 4,25 \times 0,7 \times 0,85$$

= 381,86 bcm/jam

So the productivity of loader in shift I in November 2022 can be analyzed using the effective working hours of PT. AAP is 8.05 hours per shift for one working day.

= 381,86 bcm/jam × 8.05 hours/day

= 3,719.49 bcm/day× 30 days/month

= 111,584.7 bcm/month

2) EX-823 Shift II

$$Q = \frac{3600}{CT} \times q \times E \times SF$$

$$= \frac{3600}{27,43} \times 4,25 \times 0,7 \times 0,85$$

= 331,88 bcm/jam

So the productivity of loader will increase shift II in November 2022 can be analyzed using the effective working hours of PT. AAP is 8.05 hours per shift for one working day.

= 331,88 bcm/jam × 8.05 hours/day

= 3,232.69 bcm/day× 30 days/month

= 96,980.65 bcm/month

3) EX-822 Shift I

$$Q = \frac{3600}{CT} \times q \times E \times SF$$

$$= \frac{3600}{23,25} \times 4,25 \times 0,6 \times 0,85$$

= 335,67 bcm/jam

So the productivity of loader will increase shift I in November 2022 can be analyzed using the effective working hours of PT. AAP is 8.05 hours per shift for one working day.

= 335,67 bcm/jam × 8.05 hours/day
= 3,679.37 bcm/day× 30 days/month
= 110,381 bcm/month

4) EX-822 Shift II

$$Q = \frac{3600}{CT} \times q \times E \times SF$$

$= \frac{3600}{24,14} \times 4,25 \times 0,6 \times 0,85$

= 323,22 bcm/jam

So the productivity of loader will increase shift II in November 2022 can be analyzed using the effective working hours of PT. AAP is 8.05 hours per shift for one working day.

= 323,22 bcm/jam × 8.05 hours/day

= 3,542.92 bcm/day× 30 days/month

= 106,288 bcm/month

Based on the results of the analysis of the productivity of the loader, the total production was obtained excavator Hitachi ZX870 is 15,073 bcm/day or 425,234 bcm/month, as in Table 5.

Table 5. Productivity Analysis Results Excavator

Parameter	EX-823		EX-822		Total (bcm)
	Shift I (bcm)	*Shift II* (bcm)	*Shift I* (bcm)	*Shift II* (bcm)	
Daily production target	27.244				
Daily production	3.719,49	3.232,69	3.679,37	3.542,92	15.073
Monthly production target	817.343,63				
Monthly production	111.548,7	96.980,65	110.381	106.288	425.234

5.1.1.2 Productivity of Hauler

The parameters that will be used to analyze the productivity of fleet I hauler are as in Table 6.

Table 6. Hauler Productivity Parameters Fleet I

Parameter	Symbol	Value			
		ADT 914	ADT 922	ADT 925	ADT 926
Work efficiency	E	77,9%	83%	47,8%	83,7%
Bucket capacity	q1	5 m^3			
Fill factor	k	0,85			
Number of bucket	n	4 *bucket*			
Cycle production	C	17 m^3			
Swell factor	SF	0,85			
Cycle time Shift I	CTa	13,375	13,491	13,495	13,661
Cycle time Shift II	CTa	13,681	14,045	13,828	13,597
Density Insitu	ρ	1 bcm			

The parameters that will be used to analyze the productivity of fleet II hauler are as in Table 7.

Table 7. Hauler Productivity Parameters Fleet II

Parameter	Symbol	Value			
		ADT 916	ADT 917	ADT 918	ADT 921
Work efficiency	E	78,4%	60,4%	77,67%	80%
Bucket capacity	q1	5 m^3			
Fill factor	k	0,85			
Number of bucket	n	4 *bucket*			
Cycle production	C	17 m^3			
Swell factor	SF	0,85			
Cycle time Shift I	CTa	13,385	13,715	13,788	13,688
Cycle time Shift II	CTa	13,763	14,057	13,966	13,657
Density Insitu	ρ	1 bcm			

Based on the analysis of hauler productivity using the parameters in Tables 6 and 7, the results obtained are as in Table 8.

Table 8. Productivity Results of Hauler Fleet I and II

Parameter		*Shift* I (bcm)	*Shift* II (bcm)	Total (bcm)
Daily production target	27.244 bcm			
Daily production *fleet* I	ADT 914	406.50	397,41	804
	ADT 922	429,39	412,45	842
	ADT 925	247,21	241,26	488
	ADT 926	427,62	429,63	857
Daily production *fleet* II	ADT 916	408.80	397.59	806
	ADT 917	307.37	299.90	607
	ADT 918	393.16	388.16	781
	ADT 921	407.91	408.84	817
Total p				**6.003**
Montly production target	817.343 bcm			
Montly production *fleet* I	ADT 914	12.195	11,922	24.117
	ADT 922	12,882	12,374	25.255
	ADT 925	7,416	7,238	14.654
	ADT 926	12,829	12,889	25.718
Montly production *fleet* II	ADT 916	12,264	11,928	24.264
	ADT 917	9,221	8,997	18.218
	ADT 918	11,795	11,645	23.439
	ADT 921	12,237	12,265	24.502
Total		61.930	60.701	**180.096**

5.1.2 Fleet Match Factor

Based on analysis using actual data Section 2 PT.AAP data, the match factor value and production capability for each month are obtained as in Table 9.

Table 9. Match Factor and Unit Production Capability

Fleet	Number of *Loader*	Number of *Hauler*	MF	Monthly production	Production achievement
I	1	4	0,501	208.565	Not Yet Achieved
II	1	4	0,459	216.669	Not Yet Achieved

5.1.3 Productivity Analysis Using Queuing Theory

5.1.3.1 Actual Fleet Management

Fleet management is useful for optimizing fleet conditions in order to obtain ideal compatibility conditions and achievement of production targets, The number of ADTs used will be simulated based on queuing theory. The actual fleet management in Section 2 is as shown in Table 10.

Table 10. Actual Management Fleet

Fleet I		*Fleet* II	
Loader	*Hauler*	*Loader*	*Hauler*
Excavator Hitachi ZX870-823	XCMG-914	Excavator Hitachi ZX870-822	XCMG-916
	XCMG-926		XCMG-917
	XCMG-925		XCMG-918
	XCMG-922		XCMG-921

5.1.3.2 Determination of Service Levels

Based on the analysis obtained the determination of the level of service as in table 11.

Table 11. Determining of Unit Service Level

Fleet	Indikator	Stage I	Stage II	Stage III	Stage IV
I	Aktivity	*maneuver loading time* / *Loading time*	*Hauling time*	*manuver dumping time* / *Dumping time*	*Hauling time*
	Time duration	2,251 second/ADT	6,618 second/ADT	0,523 second/hour	4,248 second/hour
	Probabilitas of arrival	27 ADT/hour	9 ADT/ hour	115 ADT/ hours	14 ADT/ hour
II	Aktivity	*maneuver loading time* / *Loading time*	*Hauling time*	Waktu *manuver dumping* / Waktu *dumping*	*Hauling time*
	Time duration	2,296 second/ADT	6,665 second/ADT	0,522 second/hour	4,247 second/hour
	Probabilitas of arrival	26 ADT/hour	9 ADT/hour	115 ADT/hour	14 ADT/hour

5.1.3.3 Probability of Queue State

The number of transport equipment (K) served by the Hitachi ZX870 excavator is 4 units with 4 queue stages (M). So the number of possible queue states is:

$$\text{Round Queue} = \frac{(K+M-1)!}{(M-1)!(K)!}$$

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

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

= 35 conditions

5.1.3.4 Calculation of Lq1, Lq3, Wq1 and Wq3

Based on analysis using queuing theory, the values Lq1, Lq3, Wq1, Wq3, cycle time ADT, and ADT amount for fleet, as in Table 13.

Table 13. Results of Applying Queuing Theory

Parameter	EX-823	EX822
Lq1	1	0,36
Lq3	0,0162	0,0158
Wq1 (second)	1,327	1,358
Wq3 (second)	0,060	0,059
Cycle time	15,08	15,2
Number of ADT	7	7

5.1.3.5 Productivity Analysis After Implementing Queuing Theory

Based on the analysis that has been carried out, the productivity of the transportation equipment after repairs is obtained, as in Table 14.

Table 14. Production of Hauler After Repair

Unit	Number of ADT		Monthly production		*Match Factor*	
	Before repair	After repair	Before repair	After repair	Before repair	After repair
Fleet I	4	7	89,744 bcm	160.225,59 bcm	0,501	0,876
Fleet II	4	7	90,35 bcm	162.288 bcm	0,459	0,807

5.1.3.6 Unit Production Optimization After Application of Queuing Theory

Unit production optimization is carried out using cycle time the ideal value of the unit, and the maximum effective value of work to increase production from each unit.

$$Q = \frac{60}{CTa} \times E \times C \times SF$$

$$= \frac{60}{6{,}575} \times 0{,}837 \times 17 \times 0{,}85$$

= 110,369 bcm/jam

Based on the effective working hours of PT. AAP per day is 20.62 hours (obtained from effective hours without time slippery and rain) with a total of 14 ADT units, production will be obtained fleet I and fleet II in November 2022 as follows:

= 110,369 bcm/jam × 20.62 hours/day× 14 ADT

= 31,861.32 cm/day× 30 days

= 955,839.6 bcm/month

Based on this analysis it can be seen that total production overburden in one month, namely 955,839.6 bcm/month, around 116.94% of the production target overburden which has been set by PT. AAP.

5.2 Discussion

Based on the analysis results, it was found that the total production of Hitachi ZX870 823 excavator was 208,565 bcm/month, while the OB production of ADT namely 0.501 or MF < 1, which means that the excavator is waiting while the hauler is working fully, and the production of the Hitachi ZX870 822 excavator or fleet II is 216,669 bcm/month, with ADT XCMG production in fleet II being 90,352 bcm/month. Based on these details, the total OB production for Hitachi fleet I and fleet II excavators is 425,234 bcm/month or 52% of the OB production target set by PT AAP.

The application of queuing theory is carried out with the number of conditions in the queue for loader and hauler serving 4 ADT units with 35 conditions, which means there are 35 patterns or forms of conditions in the ADT queuing system. For details of the probability calculation of conditions, see Appendix 25 and 26. Based on Table 16, it is found that in fleet I EX-823, the number of hauler queuing at the front loading is 1 ADT with a waiting time for ADT at the front loading of 1,327 minutes and the number of ADTs queuing at the disposal area is 1 ADT with a waiting time of 0.06 minutes, while in fleet II EX-823 822, the number of ADTs queuing at the front loading is 1 ADT with a waiting time of 1.358 minutes and the number of ADTs queuing at the disposal area is 1 ADT with a waiting time of 0.059 minutes. The number of ADTs required is in accordance with the excavator service level, namely 7 ADTs for each fleet. The solution for adding 6 ADT units can be done by repairing ADTs that are currently breakdown at PT.AAP.

Based on the analysis carried out, it can be concluded that to obtain optimal production it cannot be done only by adding ADT units but also by reducing the waiting time that occurs in the field, so that OB production is obtained, namely 955,839.6 bcm/month or 116.94% of the target set.

6 Conclusions and Suggestions

6.1 Conclusion

Based on the analysis that has been carried out, the following conclusions are obtained:

1. Actual production excavator Hitachi ZX870 is 425,234 bcm/month or around 52% of the production target overburden, while the actual total achievement of ADT XCMG is 180,096 bcm/month or 22% of the production target overburden.
2. Based on compatibility analysis on fleet I obtained an MF value of 0.501, which means the loader is waiting and the ADT is working fully, while the MF value at fleet II is 0.459, which means the loader is waiting and the ADT is working fully.
3. The production achievement after applying the queuing theory was that ADT production increased from 180,096 bcm/month to 322,513.6 bcm/month or 54% of the production target overburden and production overburden increased to 955,839.6 bcm/month or 116.94% after production optimization.

6.2 Suggestion

1. Monitoring of equipment compatibility is required can loader and hauler so that there is no waiting time for loader and hauler.
2. Forget More optimal productivity is expected to review the need for tools used in picking activities overburden.
3. Required area widening front loading thus facilitating ADT to loading maneuver.

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