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Mine Scheduling of Lateritic Nickel Ore in The Mawar Block of PT Ang and Fang Brother Site Lalampu, Central Sulawesi Province, Indonesia

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Abstract

PT Ang and Fang Brothers planned to open a new pit of lateritic nickel ore in Mawar Block. Mine scheduling of open-pit mines is an important thing in surface mine planning so the purpose of this research is to provide an overview of pit design and mining sequences, amount of production and number of equipment allocated in each sequence. The production targeted by the company was 50,000 tons by considering the mine recovery factor of 90%. Mine scheduling requires several data, namely cycle time, loss time, block model, equipment specifications and availability, slope and mine haul road geometry, and topography. The data used to design pit limits, mining sequences, and production scheduling. Based on the design of the mine pit, the total overburden that must be removed is 365,589 bcm and the total laterite nickel ore that must be stripped is 169,240 tons with a stripping ratio of 2.2:1 which is divided into three mining sequences. Total tonnage of lateritic nickel ore in the first to the third sequence is 55,677 tons, 55,518 tons, and 58,045 tons with overburden of 143,764 bcm, 136,055 bcm, and 85,770 bcm respectively. The equipment fleet of the first to the third sequence is 4 units' loader with 17 units' hauler, 4 units' loader with 17 units' hauler, and 3 units' loader with 13 units' hauler respectively.

Keywords: Mine scheduling; lateritic nickel; overburden; stripping ratio; mining sequence

1. Introduction

PT Ang and Fang Brother Site Lalampu is one of the nickel mining companies. The company's location is in Lalampu Village, Bahodopi District, Morowali Regency, Central Sulawesi Province. Site Lalampu is divided into Mining Permit 576 (576 hectares) and 199 (199 hectares). The research activity was carried out in the Mawar Block area. Mawar Block is one of four blocks in IUP 199 and the surface area is 4.8 hectares which has not been carried out with production activities. The planned nickel laterite production uses the open-pit mining method [1].

Nickel natural resources mainly occur as two types of sulfidic and lateritic (oxidic) ores. Despite the large share of the world lateritic nickel resources about 70%), nickel is mostly extracted from sulfides [2]. Lateritic nickel deposits classified in three main groups: oxidic or "limonitic" deposits, smectitic or "clay mineral" deposits, and hydrous Mg-Si-silicate deposits [3]. Classification of the laterite type does not follow a formal scheme but is conveniently made on the basis of the dominant Ni-host phase [4]–[6].

The formation of Ni laterites involves the interaction of numerous geological and environmental factors. Most lateritic nickel deposits consist of an oxide-style zone overlying a clay silicate or hydrous Ni-Mg-silicate zone [7]. The profile of lateritic nickel deposits in Mawar Block consists of overburden with main composition are Fe, Cr, Mn, and Co [8], limonite zone, saprolite zone, and blue zone (bedrock). The appearance of the overburden layer, limonite zone, and saprolite zone can be seen in Fig. 1.

The bedrock zone can be seen in Fig. 2. The Mawar Block will be mined by open pit mining method. Mine planning is one task to add considerable value to a mining business by using different strategy such as maximizing the NPV, extending the life of the mine, and minimizing risks [9].

Mine planning begins with designing a mining pit which is adjusted based on the shape of the lateritic nickel ore deposit in the mining area. Total volume of minerals based on the design of the mining pit becomes a reference in designing the mining sequence that show how a pit will be mined from the initial stage to the final stage of mine design (pit limit) [10].

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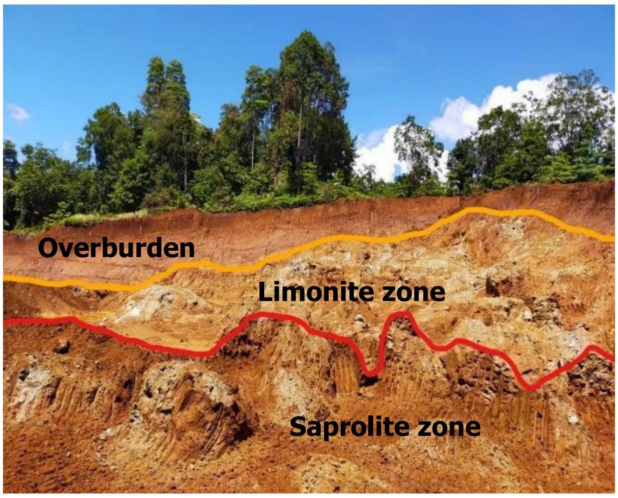

Figure 1. Overburden in lateritic nickel deposit at PT Ang and Fang Brother (February 17, 2021)

Figure 2. Bedrock in lateritic nickel deposit at PT Ang and Fang Brother (February 17, 2021)

The development stage translates mine planning studies into mine design by determining the mining method, which consists of the geometrical arrangements of structure, estimating production capacity and structure capital, and performing detailed engineering design [11].

Mine scheduling is an illustration of the amount of production and the number of equipment allocated in each mining sequence based on time and mining design. Its decisions are critical for a mining company to determine the periodical metal production and the financial returns [12]. Mine scheduling in open pit mining consists of long-term, medium-term, and short-term production scheduling. Long-term production scheduling is defined the yearly production schedules, meanwhile short-term scheduling is defined monthly, weekly, or even daily production schedules which are based on medium- and long-term scheduling [13].

Production scheduling is a very important part of the mining process therefore this research purpose is to set up mine scheduling of lateritic nickel ore at the Mawar Block of PT Ang and Fang Brother.

2. Research Methods

2.1. Data collection

Data collection in this study consisted of:

- Cycle time

This data consists of the cycle time of loader and hauler in the activity of overburden stripping and laterite nickel ore mining. The distance between the mining pit to the stockpile is ±1000 meters and the distance between the mining pit to the disposal is ±500 meters.

- Loss time

The data obtained from the Mine Plan Engineer Department included standby time, delay time, and repair time.

- Availability of equipment

Data on the availability of equipment were obtained from the Mine Plan Engineer Department. Data on equipment availability show the number of equipment owned and rented by the company.

- Equipment specification

Equipment specification data was obtained from the Cat 320, Komatsu 210, and Hitachi 350 type handbook of loader equipment specifications. The equipment specification data used was bucket capacity: Cat 320 was 1.19 m^3, Komatsu 210 was 1.2 m^3, and Hitachi 350 was 1.5 m^3 [14]–[16].

- Slope geometry and haul road geometry

Slope geometry data were bench height (5m), berm width (2m), and slope angle (60^o) used in pit design and mining sequences. Haul road geometry data were road width (10m) and grade (10%). The data were obtained from the Mine Plane Engineer Department.

- Block model

The data was obtained from the Exploration Department and it was the basic model that used in pit design. The block model can be seen in Fig. 3.

- Topography

The data is topographic of the research location in January 2021 and obtained from the Mine Plan Engineer Department (Fig. 4).

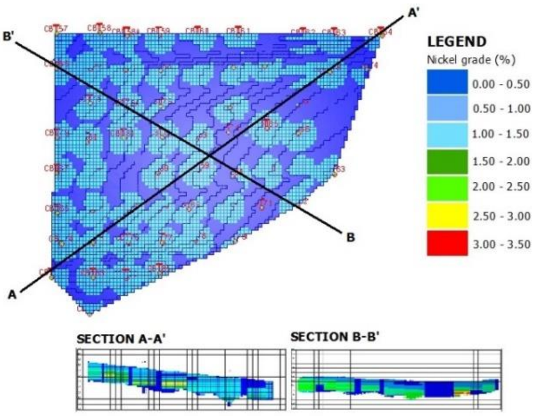

Figure 3. Block model of Mawar Block

Figure 4.The topography of Mining Permit 199

2.2. Data processing

The data processing with the following stages:

- Mine pit design

Mine pit design is the initial stage in designing a mining sequence that used block model and topographic data. Mine pit in this research designed by using Micromine 2018 where the width of mine haul road determined according to AASHTO using Eq. 1 [17]:

$$L_{min} = n \times Wt + (n+1)\,(0.5 \times Wt) \quad (1)$$

where,
L_{min} : minimum haul road width (m)
n : number of lanes
Wt : maximum hauler width (m)

- Mining sequences design

The data used in mining sequence design were block model and topographic data.

- Mine scheduling

Scheduling is carried out with the aim that production activities can be completed on time based on predetermined production targets and can maximize productivity. The data used for the calculation of equipment productivity were equipment availability, equipment specifications, equipment work efficiency, cycle time, working hours, and loss time. The steps taken in calculating equipment productivity were calculation of equipment efficiency the available working hours in one shift is nine hours in accordance with company regulations, while the loss time can be calculated based on several factors, namely standby time, delay time, and repair time.

The effective of working hours of the equipment was calculated by using Eq. 2 [18].

$$Ewh = Available\ hour - loss\ time \quad (2)$$

where Ewh is the effective of working hours.

After knowing the effective working hours, the next step was determining the working efficiency of the equipment (E) with Eq. 3 [18].

$$E = \frac{Effective\ working\ hours}{Working\ hours\ available} \times 100\% \quad (3)$$

Cycle time of loaders were calculated by using Eq. 4 [18].

$$CTL = W_g + W_{am} + W_b + W_{ak} \quad (4)$$

where,
CTL : cycle time of loader
W_g : digging time
W_{am} : swing load time
W_b : dumping time
W_{ak} : swing empty time

Cycle time of haulers were calculated with Eq. 5 [18].

$$CTH = W_q + W_{ml} + W_l + W_{md} + W_d + W_{tb} \quad (5)$$

where,
CTH : cycle time of hauler
W_q : queueing time
W_{ml} : maneuver loading time
W_l : loading time
W_{md} : maneuver dumping time
W_d : dumping time
W_{tb} : turn back time

The equation used in calculating the productivity of the loader is shown in Eq. 6 [18].

$$QL = \frac{Kb \times E \times Ff \times Sf \times 3600\ second/hour}{CTL} \quad (6)$$

where,
QL : productivity of loader
Kb : bucket capacity
E : efficiency of equipment
Ff : fill factor
Sf : swell factor

The equation used in calculating the productivity of hauler is shown in Eq. 7 [18].

$$QH = \frac{(Kb \times n) \times E \times Ff \times Sf \times 60\ minute/hour}{CTH} \quad (7)$$

where,
QH : productivity of hauler
Kb : bucket capacity
n : the number of bucket stuffing
E : efficiency of equipment
Ff : fill factor
Sf : swell factor

The number of equipment planned to operate in each sequence is calculated based on the tonnage of lateritic nickel ore and overburden to be removed in each mining sequence, the productivity of each equipment, and working days.

The number of equipment used in each mining sequence was calculated by using Eqs. 8 and 9 [19].

$$Number\ of\ loaders = \frac{Ton\ Ore\ /\ Vol\ OB}{(QL\ x\ Working\ days)} \quad (8)$$

$$Number\ of\ haulers = \frac{Ton\ Ore\ /\ Vol\ OB}{(QH\ x\ Working\ days)} \quad (9)$$

In an effort to improve the quality of the work system, it is necessary to pay attention to the match factor between each operating equipment [18]. The value of MF can be known by using Eq. 10.

$$E = \frac{NH \times (CTL \times Number\ of\ bucket\ filling)}{NL \times CTH} \quad (10)$$

where,
NL : number of loaders
NH : number of haulers
CTL : cycle time of loader
CTH : cycle time of hauler

3. Results and Discussion

3.1. Mining pit design

The mining method that will be apply in Mawar Block is an open pit mining. The cutoff grade (COG) value of 1.4% and density of 1.5 kg/m^3 used to determine total tonnage of lateritic nickel ore. Based on pit limit design (Fig. 5), obtained 169,240 tons of lateritic nickel ore (Table 1) and 365,589 bcm of overburden to be removed (Table 2), therefore the stripping ratio value is 2.2:1.

The highest grade of lateritic nickel is 3.2% and the largest tonnage of 37,304 tons which is found in the grade range of 1.4% to 1.5%. The grade values that were below cutoff grade (COG) then categorized as waste.

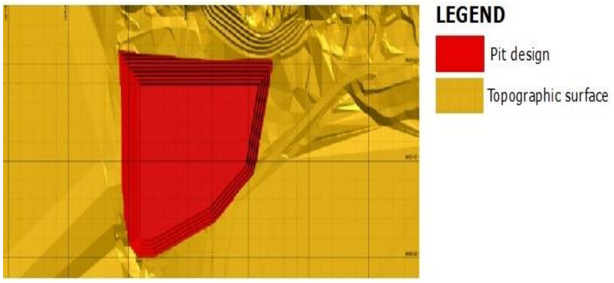

Figure 5. Pit limit design of Mawar Pit

Table 1. Total tonnage of lateritic nickel ore

Layer	Range of Ni Grade (%)	Volume (bcm)	Tonnage (tons)	Ni (%)	Fe (%)
	1.4 – 1.5	24,869	37,304	1.44	27.76
	1.5 – 1.6	22,269	33,404	1.54	21.81
	1.6 – 1.7	15,444	23,166	1.65	19.25
	1.7 – 1.8	13,950	20,925	1.75	18.07
	1.8 – 1.9	8,825	13,237	1.84	21.39
	1.9 – 2.0	7,207	10,810	1.95	17.96
Overburden	2.0 – 2.1	4,976	7,463	2.04	20.42
	2.1 – 2.2	2,819	4,228	2.14	19.47
	2.2 – 2.3	6,213	9,319	2.23	16.01
	2.3 – 2.4	1,900	2,850	2.33	13.85
	2.4 – 2.5	1,326	1,987	2.47	14.26
	2.5 – 2.6	50	75	2.54	16.99
	2.6 – 2.7	1,525	2,288	2.63	17.51
	2.7 – 2.8	956	1,434	2.76	15.41
	2.8 – 2.9	31	47	2.80	16.74
	3.1 – 3.2	469	703	3.12	13.31
Total			169,240		

Table 2. Total volume of overburden

Layer	Range of Ni Grade (%)	Volume (bcm)	Ni (%)	Fe (%)
	0.0 – 0.1	129,581	0.00	00.00
	0.3 – 0.4	5,869	0.38	37.74
	0.4 – 0.5	17,319	0.45	41.10
	0.5 – 0.6	31,662	0.54	43.22
	0.6 – 0.7	34,794	0.64	44.59
Limonite,	0.7 – 0.8	19,231	0.74	44.96
Saprolite	0.8 – 0.9	19,119	0.85	46.22
	0.9 – 1.0	16,237	0.94	45.31
	1.0 – 1.1	18,663	1.04	40.37
	1.1 – 1.2	22,619	1.14	44.41
	1.2 – 1.3	26,557	1.25	32.94
	1.3 – 1.4	23,938	1.34	31.38
Total Volume		365,589		

The largest volume of overburden is 129,581 bcm which is in the range of 0.0% to 0.1%.

3.2. Mining pit design

Mine sequence design process is strictly dependent on the economic variables of the orebody having an effect on the physical parameters of the intended mining system [20].

Mining sequence design based on production targets of 50,000 tons/month. Mine recovery factor in nickel mining could be 95% [21] or at least 90% based on Decision of The Minister of EMR Regarding 1827 K/30/MEM/2018 about Implementing Guidelines on Good Mining Practices.

PT Ang and Fang Brother used mine recovery of 90%; therefore, the production target increased to 55,000 tons.

The width of the largest hauler, Hino 500 type is 2.490 meters. The number of lanes taken into account in the haul road design is two lanes, so the results of the calculation of the minimum haul road width based on Equation 1 was 8,6 meters. The mining sequence of Mawar Pit is divided into three sequences, namely:

- Sequence I
  In the sequence I there are 55,677 tons of lateritic nickel ore and 143,764 bcm of overburden to be removed with stripping ratio value is 2.5:1. Sequence I design can be seen in Fig. 6.

- Sequence II
  Based on the sequence II design (Fig. 7) there are 55,518 tons of lateritic nickel ore and 136,055 bcm of overburden to be removed. The stripping ratio is 2.4:1.

- Sequence III
  There are 58,045 tons of lateritic nickel ore and 85,770 bcm of overburden to be removed in Sequence III. The value of stripping ratio is 1.4:1. The design can be seen in Fig. 8.

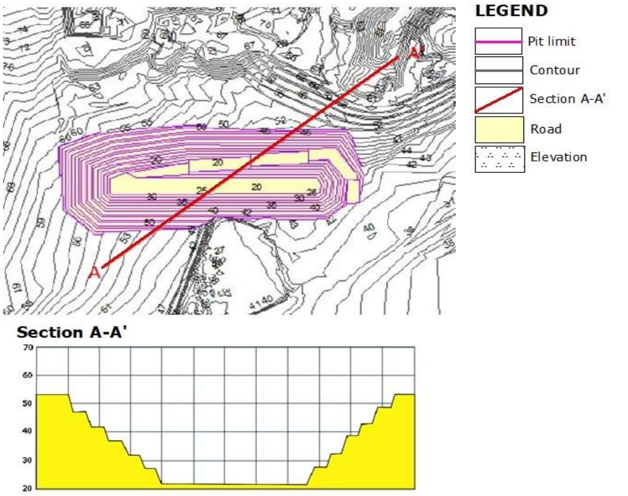

Figure 6. Design of Sequence I

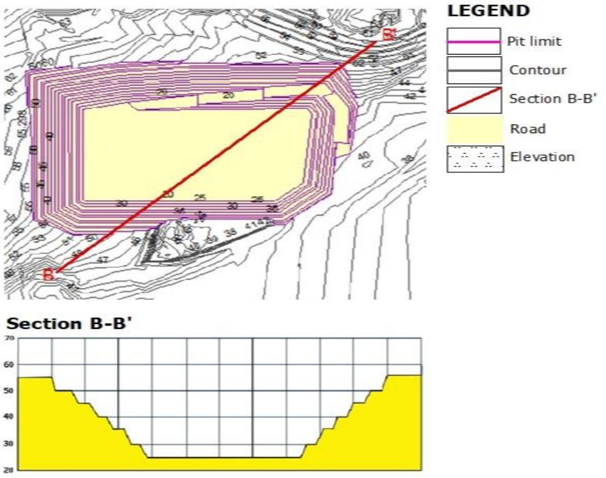

Figure 7. Design of Sequence II

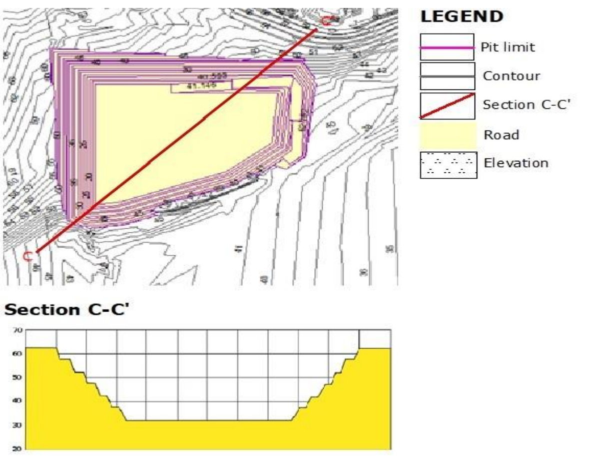

Figure 8. Design of Sequence III

3.3. *Mine scheduling*

Production planning in this research is to determine the amount of lateritic nickel ore and overburden that will be removed every month based on the capacity of the equipment fleet. Mine scheduling requires to select and schedule blocks in a sequence that maximizes or minimizes a specific goal, minimizes deviations from planned production targets [22].

Production scheduling of open-pit mines is an important problem that arises in surface mine planning. It can be summarized as follows the ore body is represented as a three-dimensional array of blocks [12]. The parameters used in mine scheduling are:

- Work Efficiency

The factors that affect the work efficiency of the equipment are loss time, effective working time, and available time. Loss time data can be seen in Table 3. The largest total loss time for loader was Cat 320 of 178.71 minutes/day and for hauler was Hino 500 of 124.94 minutes/day.

The effective working time calculated using Equation 1 based on total loss time (Table 5) and company working time of company of 9 hours or 540 minutes. The results can be seen in Table 4.

The results in Table 6 are used to calculate the work efficiency of the equipment by using Eq. 2, which can be seen in Table 5. The results show that the loader of Hitachi 350 and the hauler of Fuso 220 have the highest work efficiency.

- Cycle time

The calculation of the cycle time is carried out on the loader (Table 6) and hauler (Table 7) by using Eq. 3.

Table 3. Total loss time of equipment

Equipment Type	Delay Time (minutes)	Standby Time (minutes)	Repair Time (minutes)	Total Loss Time (minutes)
Cat PC 320	73.44	82.30	3.46	159.21
Komatsu 210	73.45	82.34	3.65	159.44
Hiitachi 350	73.32	82.37	1.54	157.23
Hino 500	57.68	83.34	1.69	141.71
Fuso 220	57.71	82.37	1.54	141.63

Table 4. Effective working hours of equipment

Equipment	Equipment Type	Effective Working Hour	
		Minutes	Hours
Loader	Cat PC 320	380.79	6.35
	Komatsu 210	380.56	6.34
	Hiitachi 350	382.77	6.38
Hauler	Hino 500	398.29	6.64
	Fuso 220	398.37	6.64

Table 5. Calculation of the equipment efficiency

Equipment	Equipment Type	Equipment Efficiency (%)
Loader	Cat PC 320	70.52
	Komatsu 210	70.47
	Hitachi 350	70.88
Hauler	Hino 500	73.76
	Fuso 220	73.77

Table 6. Cycle time of loader

Equipment Type	Cycle Time (Second)	Activity
Cat 320	17.30	Nickel ore loading
Komatsu 210	17.81	Overburden loading
Hitachi 350	22.04	Overburden loading

Table 7. Cycle time of hauler

Equipment Type	Cycle Time (minutes)	Activity
Hino 500	11.51	Nickel ore hauling
Fuso 220 pair with Komatsu 210	8.27	Overburden hauling
Fuso 220 pair with Hitachi 350	7.18	Overburden hauling

The Cat 320 has a bucket capacity of 1.19 bcm, the Komatsu 210 has a bucket capacity of 1.20 bcm, and the Hitachi 350 has a bucket capacity of 1.50 bcm. Based on the calculation results of the loader and hauler equipment cycle time in Table 8, it can be concluded that the smaller the bucket capacity of an equipment, the smaller the cycle time allocated to operate in one cycle.

The distance between the mining pit to the stockpile is ±1000 meters, while the distance between the mining pit to the disposal is ±500 meters so that the cycle time shows that the time taken by the hauler to the disposal is smaller than to the stockpile.

- Productivity of equipment

Equipment productivity is used to determine the amount of lateritic nickel tonnage and overburden production based on a certain unit of time. The loader's productivity was calculated using Eq. 5 (Table 8) and the hauler's Eq. 6 (Table 9).

Table 8. Productivity of loader

Description	Ore Production	Overburden Production	Overburden Production
	Cat 320	Komatsu 210	Hitachi 350
Kb (bcm)	1.19	1.2	1.5
E (%)	71%	71%	71%
Ff	1	1	1
Sf	0.9	0.9	0.9
CTL (Second)	17.30	17.81	22.04
Density (Ton/m3)	1.5	1	1
Q (bcm/hour)	158.23	154.99	156.56
Q (Ton/hour)	237.35	154.99	156.56
Q (Ton/day)	3,014.39	1,965.35	1,997.72

Table 9. Productivity of hauler

Description	Ore Production	Overburden Production	Overburden Production
	Hino 500 pair with Cat 320	Fuso 220 pair with Komatsu 210	Fuso 220 pair with Hitachi 350
Kv (bcm)	8.33	9.6	5.6
E (%)	74%	74%	74%
Ff	1	1	1
Sf	0.9	0.9	0.9
CTL (Second)	14.81	9.50	7.30
Density (Ton/m3)	1.5	1	1
Q (bcm/hour)	22.48	40.38	30.82
Q (Ton/hour)	33.71	40.38	30.82
Q (Ton/day)	576.08	616.01	443.46

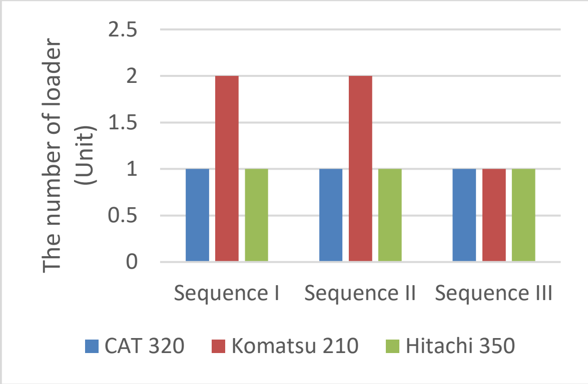

Figure 9. The number of loaders allocated

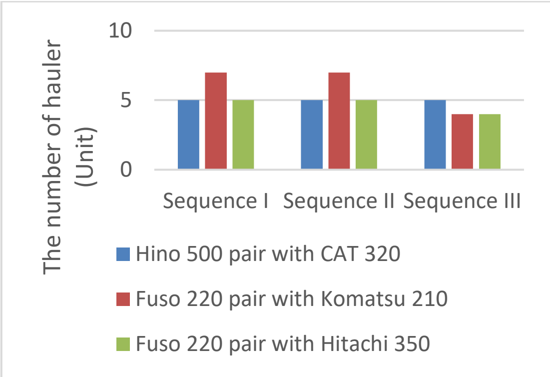

Figure 10. The number of haulers allocated

- The number of loader and hauler

The equations used in calculating the number of loader and hauler are Equation 7 and Equation 8.

The results of loader allocated in each sequence can be seen in Fig. 9.

Based on Fig. 9, it can be seen that the number of loaders in the first and second sequences is the same, while the third sequence has decreased. The decrease in the number of loaders was caused by the reduced volume of excavated material to be removed in sequence. The results of the hauler allocated in each sequence can be seen in Fig. 10.

Figure 10 shows the number of haulers in the first sequence and the second sequence is the same, while there is a decrease in the third sequence. This is due to the reduced volume of excavated material to be removed and the number of haulers served in the third sequence.

The number of loaders and haulers is used in calculating the match factor by using Eq. 10. The results of the match factor calculation for each mining sequence are:

- Sequence I

The result of match factor for loader and hauler that will be allocated for activities of lateritic nickel ore mining and overburden stripping in Sequence I can be seen in Table 10.

The match factor on fleet I and II is <1; therefore, the loaders work less than 100%, while the haulers work 100%, so there is a waiting time for the loaders. The match factor of fleet III = 1 means that the loaders and haulers work 100%, so there is no waiting time for the equipment.

Table 10. Match factor of equipment in Sequence I

Fleet	Loader Type	Number (Unit)	Hauler Type	Number (Unit)	Match Factor
I	Cat 320	1	Hino 500	5	0.7
II	Komatsu 210	2	Fuso 220	7	0.9
III	Hitachi 350	1	Fuso 220	1	1.0

Table 11. The equipment match factor of Sequence II

Fleet	Loader Type	Number (Unit)	Hauler Type	Number (Unit)	Match Factor
I	Cat 320	1	Hino 500	5	0.7
II	Komatsu 210	2	Fuso 220	7	0.9
III	Hitachi 350	1	Fuso 220	5	1.0

Table 12. Match factor of equipment in Sequence III

Fleet	Loader Type	Number (Unit)	Hauler Type	Number (Unit)	Match Factor
I	Cat 320	1	Hino 500	5	0.7
II	Komatsu 210	1	Fuso 220	4	1.0
III	Hitachi 350	1	Fuso 220	4	0.8

- Sequence II

The match factor of loader and hauler that on each fleet will be allocated for mining activities of lateritic nickel ore and overburden stripping in the Sequence II can be seen in Table 11.

The match factor on fleet I and II <1, therefore the loaders work less than 100%, while the haulers works 100%, so there is a waiting time for the loaders. The match factor of fleet III = 1 means that the loaders and haulers work 100%, so there is no waiting time for the equipment.

- Sequence III

The match factor of each fleet from pairing the loader and the hauler in Sequence III can be seen in Table 12. The match factor of fleet I and III <1 which is means that the loaders work less than 100%, while the haulers work 100%, so there is a waiting time for the loaders. The match factor of fleet II = 1 means that the loaders and haulers work 100%, so there is no waiting time for the equipment.

4. Conclusion

Mawar Block has 169,240 tons of lateritic nickel ore and 365,589 bcm of overburden which is divided into three sequences. The first sequence has a tonnage of lateritic nickel ore of 55,677 tons with an overburden volume of 143,764 bcm. The second sequence has a tonnage of lateritic nickel ore of 55,518 tons with an overburden volume of 136,055 bcm. The third sequence has a tonnage of lateritic nickel ore of 58,045 tons with a volume of overburden of 85,770 bcm.

To achieve the production target, equipment fleet will be allocated for the first mining sequence to the third mining sequence in a row is 4 units, 4 units, and 3 units. The number of haulers allocated in the first mining sequence to the third mining sequence in a row is 17 units, 17 units, and 13 units.

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