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Mine Design of Laterite Nickel Ore Based on Pit Limit Optimization with Floating Cone Method at Meranti Pit of PT Ang and Fang Brother

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Abstract

PT Ang and Fang Brother Site Lalampu is a nickel laterite mines company located at Lalampu Village, Morowali Regency, Central Sulawesi Province. The purpose of research is to determine the ultimate pit limit using floating cone method and calculate the net present value (NPV), to design the ultimate pit limit at Front 8 of Meranti Pit (one of the company's fronts), to calculate the mined laterite nickel reserves and the overburden based on the pit design. The data used are block model data, topography, capital and operating costs, commodity price, density, geotechnical data, mine recovery 85%, cut-off grade 1.3%, and the company's production target of 50,000 tons/month. Data processing generates Pit Shell 9 as the ultimate pit limit with ore recovery of 264,375 tons from 284,063 tons of Front 8 resources. Based on the design using Micromine 2021 software with an area of 5.25 hectares, a total of 234,142 tons laterite nickel ore obtained by stripping 389,063 BCM of the overburden, and it still economical with stripping ratio value (1.66 BCM/ton), smaller than the BESR value (6.32 BCM/ton). The amount of nickel laterite reserves produced based on mine recovery of 85% is 199,021 tons so the life of mine lasted 3.98 months.

Keywords: Laterite nickel; pit optimization; pit design.

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Introduction

PT Ang and Fang Brother Site Lalampu is one of the companies engaged in mining, especially for laterite nickel ore mining. The company is located at Lalampu Village, Bahodopi District, Morowali Regency, Central Sulawesi Province. The Mining Business Permit obtained by PT Ang and Fang Brother at Lalampu is divided into two, which are IUP 576 and IUP 199. IUP 576, which is the research location, has a mining area of 576 hectares based on Morowali Regent Decree No.540.3/SK.002/DESDM/IV/ 2012 dated April 19, 2012 (PT Ang and Fang Brother, 2019). IUP 576 consists of several pits, one of them is the Meranti Pit. It is carried out the mining operation based on the consideration of a cut-off grade of 1.3%. It also has eight mining fronts; six fronts are in the mining process and two other fronts have not been mined yet including Front 8. Front 8 has an area of 5.68 hectares (Figure 1) and there are 21 drill points obtained from exploration activities and used in the mine planning stage.

PT Ang and Fang Brother applies an open-pit mining system (surface mining) with a selective mining method. Open pit mining is a common mining method which carried out above the surface by stripping the overburden. Open pit mine design and long-term production scheduling is a critically important part of mining business. The optimization of long-term planning deals with the maximization of Net Present Value (NPV). Life-of-mine planning determines the technical plan to be followed from mine development to mine closure and further rehabilitation. The work must associate all the different processes in the mining value chain to maximize Net Present Value (NPV) (Araya et al., 2020; Meagher et al., 2014).

Figure 1. The location of Front 8 of Meranti Pit that has an area of 5.68 hectares.

Pit optimization is an effort to determine the ultimate pit limit (UPL) that engenders the highest NPV compared the other potential pits (Esmaeil et al., 2018). The pit expansion that gives a profit equal to zero is called the break-even stripping ratio (BESR). The break-even approach of pit limit is often sought for through the economic limit stripping ratio, which is the maximum stripping ratio above which the pit cannot break-even. The limiting stripping ratio can only be used in a preliminary assessment of pit limits. However, the use of NPV in pit limit analysis optimizes the value of the deposit (Nwosu et al., 2022).

The methods that are often applied in pit optimization, especially in ore mining are the Learch-Grossman method and the floating/moving cone. The floating or moving cone algorithm is one of the easiest and fastest algorithms to determine the optimum solution of mining pit limit (Jodeiri et al., 2021; Zeyni et al., 2011). This algorithm first designed an upward cone for ore blocks based on the desired slope angle. Then the value of all the blocks in the cone is added together. If the result is a positive value, all the blocks inside the cone are removed. Otherwise, it is ignored (Azadi et al., 2023).

The floating cone method is not commonly used compared to the Lerch-Grossman method and still has disadvantage, that is the maximum net present value (NPV) produced by the pit shell is smaller than the Lerch-Grossman method. However, the floating cone method always provides a solution and can be easily programmed (Ares et al., 2022). In addition, restrictions of mining operations on various slopes can be perfectly applied to this method (Zeyni et al., 2012). The method contains errors in most cases but still used due to the simplicity (Jodeiri et al., 2021). Therefore, this study was conducted to design and determine the ultimate pit limit at Front 8 of Meranti Pit that has maximum NPV value using the floating cone method with considering the BESR value which provides the highest benefit.

Laterite Nickel

Laterite nickel is a material derived from regolith, a layer that is the result of weathering of rocks that surrounds a bedrock, from ultramafic igneous rocks containing Ni and Co elements, formed through intensive physical and chemical weathering processes in areas with tropical to subtropical climates. The process of forming laterite nickel deposits begins with the deposition of the parent rock, namely peridotite, which has a composition of laterite nickel ranged between 0.2% - 0.4%. Nickel is hosted in several minerals such as oxides, Mg silicates and clays. The mineralogy and ore grade depend on the lithology and climate during the formation of the deposit (König, 2021; Xiao, et al., 2020; Butt and Cluzel, 2014).

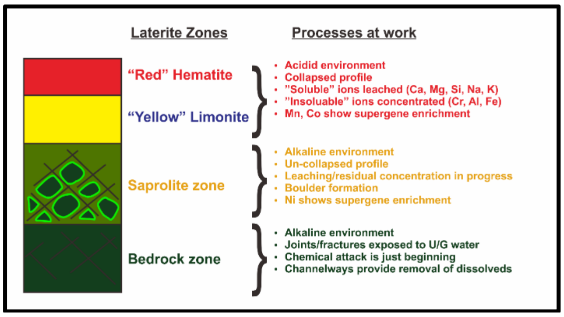

Figure 2. Lithology profile of laterite nickel deposits (Rahmi and Yulhendra, 2019).

The profile of laterite nickel deposits formed from weathering of ultramafic rocks generally consists of four layers, which are top soil, limonite, saprolite, and bedrock layers that are shown in Figure 2 (Rahmi and Yulhendra, 2019).

Floating Cone

Pit optimization determines the shape of the pit that is most likely to obtain the largest total recovery value (Whittle and Rozman, 1991). If optimization is a process, then the result of pit optimization is a pit that has become more effective and has advantages (Gusman and Octova, 2018). The floating or moving cone algorithm is one of the easiest and simplest algorithms to determine the optimal pit boundary (Ares et al., 2022).

The floating cone was first described by Carlson, Erickson, O'Brain and Pana in 1966, apply for each positive (ore) block. This method involves constructing a cone with oriented parallel sides to the slope angle of the pit, and then determining the value of the cone by summing value of the block enclosed in it. If the cone value is positive, all blocks inside the cone are mined. This process starts from the top level and moves downwards looking for positive blocks. It continues until there are no positive cones left in the block model (Zeyni et al., 2011).

The floating cone belongs in the automated method, means it's completely done by computer based on economic and physical parameters, and it is capable of designing mine boundaries based on existing economic and physical parameters without designer intervention. One of the computer programs that can perform these tasks is FOUR-D Whittle Open Pit Optimization Software program which is a product of Whittle Programming Proprietary Limited Australia, as well as other similar programs (Whittle and Rozman, 1991). The target that will be used in determining the pit limit in the floating cone method requires that the final limit calculated using basic return economics.

Pit Design

The design of a mining pit is the first step in evaluating the amount of minerals. One of the parameters that becomes a reference in the design of mining pit is the pit limit (Hustrulid et al., 2013). Parameters that affect mining boundaries to calculate mineable reserves include the strip ratio calculated by the BESR are mining slope geometry, topographical and geological conditions (Aswandi and Yulhendra., 2019).

Research Methods

Design and optimization pit aims to determine the most ultimate pit limit to obtain minerals that are constrained by mining and economic conditions. In general, this research discusses the ultimate pit limit design and requires detailed data related to technical and economic factors of mining.

1. Data Collections

a. Block model
   Block model is the basic model at the research site to make mining pit of Front 8.
b. Meranti Pit topographic

Topographic data is data related to the contour or elevation of the mining site in the Meranti Pit.

c. Density and cut-off grade
The ore density used in this study is 1.5 tons/BCM, the waste and overburden density are 1.6 tons/BCM, and the cutoff grade is 1.3%.

d. Mine recovery
Mine recovery is 85% based on historical data obtained from the Mine Plan Engineer Department.

e. Commodity price
Commodity price used is USD 38 per wet metric ton obtained from the Finance Department based on consideration of market conditions and economic analysis on the sale of low-grade nickel in 2021.

f. Capital cost
The capital cost in this study is historical data obtained from the Ministry of Finance which is shown in Table 1.

g. Operating costs
The operating costs calculated in this study are divided into two, which are the cost of mining and processing ore (ore) which is shown in Table 2 and the cost of stripping overburden (OB) which is shown in Table 3

Table 1. Capital cost parameters (PT Ang and Fang Brother, 2019).

Capital cost parameters	Cost (USD)
Licencing cost	477
Land acquisition cost	143,149
Exploration cost	84,327
AMDAL cost	1,193
Feasibility study cost	716
Construction cost	75,225
Total cost	305,086

Table 2. Ore cost parameters (PT Ang and Fang Brother, 2019).

Ore cost parameters	Cost (USD/ton)
Ore getting	1.55
Barging	1.92
Supporting	0.91
Man Power	0.53
Hauling	1.20
Blending	0.42
Total cost	6.53

Table 3. Overburden cost parameter (PT Ang and Fang Brother, 2019).

Overburden cost parameters	Cost (USD/ton)
OB removal	2.23
Supporting	0.91
Man Power	0.53
Hauling	1.19
Total cost	4.86

h. Operating costs
The operating costs calculated in this study are divided into two, which are the cost of mining and processing ore (ore) which is shown in Table 2 and the cost of stripping overburden (OB) which is shown in Table 3.

i. Bench geometry and haul roads
Bench geometry data includes a height of 3 meters, a width of 2 meters, and a slope angle of 60°. The width of the haul road (ramp) used by the company is 10 meters with a 10% grade.

j. Monthly production
Monthly production target is the planned number of tonnage of ore to be mined at the Front 8 of Meranti Pit every month. The production target used in making discounted cash flow is 50,000 tons/month.

2. Data Processing

a. Resource estimation using block model data.

b. Calculation of the break-even stripping ratio (BESR).
The BESR value can be obtained through the Equation 1 (Maritz and Uludag, 2019):

$$BESR = \frac{(1-x)s - c}{w} \quad (1)$$

where x = production fee / royalty (%), s = commodity price ($), c = variable cost of ore mining ($/ton), w = variable cost of stripping overburden ($/BCM). The data used commodity price (s) worth 38 USD/ton, ore mining cost (c) 6.53 USD/ton and overburden stripping cost (w) 4.86 USD/BCM obtained from the company and royalty value (x) 2%

based on Government Regulation no. 81 of 2019. The calculation of BESR is as follows:

$$\text{BESR} = \frac{(1\text{-}0{,}02)\ 38\ \text{USD/ton} - 6.52\ \text{USD/ton}}{4.86\ \text{USD/BCM}}$$

$$\text{BESR} = \frac{30.72}{4.86} = 6.32\ \text{BCM/ton}$$

c. Pit optimization using the floating cone method with the help of Whittle 4.5.1 and Surpac 6.6.2 software. The data used are block model data, capital costs, operating costs, and geotechnical data.
d. Calculation of NPV.
e. Mining pit design using Micromine 2021 based on a predetermined ultimate pit limit.
f. Calculation the amount of laterite nickel reserves and overburden based on the designed pit.

Results and Discussion

Cut-off grade is one of the most important parameters in metal ore mining because of its influence on the overall economic profit of mining production (Qing Hua et al., 2014). Laterite nickel deposits are limited by a cutoff grade (COG) as a criterion to identify waste of minerals in a mining reserve of 1.3% which was set by the company. Deposits that are limited by this COG value are further classified as a resource. Resource estimation is carried out to determine the volume, tonnage, and grade of laterite nickel ore deposits.

The total number of nickel resources in the Front 8 of Meranti Pit block model is known by reporting the block model obtained from the company and has been estimated using the Inverse Distance Weighting (IDW) method. The density of nickel ore was set by the company that used in this research is 1.5 tons/BCM. This density is used to determine the tonnage of laterite nickel ore deposits by multiplying the density and volume of laterite nickel ore deposits.

Resource reporting using Surpac 6.6.2 software by dividing reporting categories into four, that are high grade ore (HGO) with a grade range of 1.7%, medium grade ore (MGO) with a grade range of 1.5%-1.7%, and low-grade ore (LGO) with a grade range of 1.3%-1.5%, and the overall grade of ore is 1.3%. In addition to the nickel element, resource reporting is also carried out to display the grade of other elements, that are iron and cobalt contained in laterite nickel ore deposits. The results of reporting resources obtained can be seen in Table 4.

Table 4. Resources reporting results based on the Front 8 of Meranti Pit block model.

Category	Volume (BCM)	Tonnage (Ton)	Ni Grade Average	Fe Grade Average	Co Grade Average
LGO	67,188	100,781	1.39%	32.56%	0.10%
MGO	45,313	67,969	1.60%	23.92%	0.07%
HGO	76,875	115,313	1.91%	20.63%	0.05%
Total	189,375	284,063	1.65%	25.65%	0.08%

The total nickel laterite resource in Front 8 of Pit Meranti is 284,063 tons with an average nickel grade of 1.65%, an average iron grade of 25.65%, and an average cobalt grade of 0.08%. The grade of nickel ore in each class has a different tonnage amount, which are LGO with an average nickel grade of 1.39% at 100,781 tons, MGO with an average nickel grade of 1.60% at 67,969 tons, and HGO with an average of 1.91% of 115,313 tons. These resources are used as the basis for carrying out the mine planning stages, which are the optimization of pit limits, and additional attributes were added to the Front 8 of Meranti Pit block model using Surpac 6.6.2 software to overview the shape of the laterite nickel ore deposits. These additional attributes are grade attribute which reads ore with a value of 1, flag attribute which reads ore with ore character, and overburden density attribute to obtain stripping ratio value when optimizing pit limit.

Pit limit optimization on the Front 8 of Meranti Pit with the floating cone method is carried out using two different software that implements the floating cone algorithm.

a. Pit limit optimization using Whittle

Geovia Whittle 4.5.1 software able to design mine boundaries based on existing economic and physical parameters (Whittle and Rozman, 1991). Whittle produced a nested pit shell consisting of 17 pit shells with different Revenue Adjustment Factors (RAF) so that they have different ore and overburden tonnage gains. The obtained ore tonnage and overburden for each pit shell produced are shown in Table 5 and Figure 3.

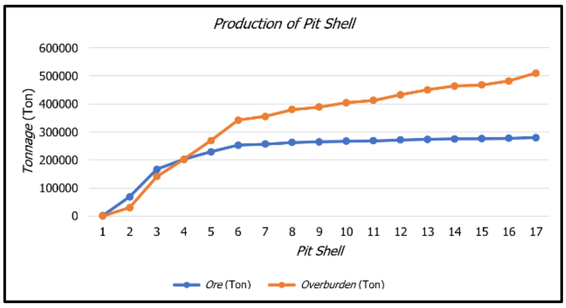

Figure 3. Tonnage graphic of nested pit shell.

The volume of overburden is obtained by dividing the tonnage by the density of the overburden, which is 1.6 tons/BCM. In Pit Shell 9 with RAF 1 obtained 264,375 tons of ore by stripping 243,017.50 BCM of overburden so that the stripping ratio is 0.92 BCM/ton. The average nickel ore grade obtained from Pit Shell 9 is 1.66%, this value is almost close to the average nickel grade obtained from other pit shells. This means that there is no significant difference in the average nickel content gain in each pit shell.

The larger the number and the RAF pit shell, the greater the ore and overburden tonnage obtained. Pit Shell 1 with RAF 0.2 had the smallest gain due to the small pit shell opening area, while Pit Shell 17 with RAF 2 had the largest ore and overburden tonnage gain due to the large pit shell opening area.

Determination of the ultimate pit limit at Whittle using the floating cone method based on the value of the BESR and the calculation of discounted cash flow (DCF) for each pit shell so that it is known which pit shell has the largest NPV. BESR is the maximum stripping ratio (SR) of a pit shell that will be selected in the mining design process. Based on the calculated BESR value of 6.32 BCM/ton, it is known that economically 6.32 BCM overburden stripping to obtain one tons of nickel ore is still considered economical. All the pit shells produced have an SR value (Table 5) below the BESR value, so overall they are feasible to mine.

Pit shells that have a maximum NPV can be seen in pit shells that have an incremental SR value equal to the BESR value, so that an incremental SR calculation is carried out for each pit shell. The incremental SR value is obtained from the division of overburden and ore increments from each pit shell. Variable increase in ore per pit shell is obtained from reducing the amount of nickel ore in a pit shell with the amount of nickel ore in the previous pit shell, as well as the variable increase in overburden. The results of the incremental SR calculation for each pit shell are shown in Table 6.

The larger the pit shell opening, the greater the incremental SR produced. Pit Shell 16 with an RAF of 1.9 has an incremental SR value that is close to the BESR value, so it is assumed to have the largest NPV. Data processing is continued by calculating the discounted cash flow for each pit shell to determine the NPV of each pit shell based on the principle of sequence and scheduling on Whittle. The results of the discounted cash flow calculation can be seen in Table 7 and Figure 4.

Table 5. Tonnage gains of ore and overburden nested pit shell.

Pit Shell	RAF	Ore (Ton)	Overburden (Ton)	Overburden (BCM)	SR (BCM/ton)	Ni Ore Grade (%)
1	0.2	938	0	0,00	0.00	1.83
2	0.3	68,438	29,531	18,456.88	0.27	1.75
3	0.4	166,875	140,859	88,036.88	0.53	1.70
4	0.5	202,266	202,265	126,415.63	0.62	1.68
5	0.6	229,453	269,531	168,456.88	0.73	1.67
6	0.7	252,891	341,953	213,720.63	0.85	1.67
7	0.8	256,641	355,547	222,216.88	0.87	1.66
8	0.9	262,500	379,922	237,451.25	0.90	1.66
9	1.0	264,375	388,828	243,017.50	0.92	1.66
10	1.1	267,188	404,296	252,685.00	0.95	1.66
11	1.2	268,594	412,734	257,958.75	0.96	1.66
12	1.3	271,641	432,890	270,556.25	1.00	1.65
13	1.4	273,984	450,469	281,543.13	1.03	1.65
14	1.5	275,625	463,594	289,746.25	1.05	1.65
15	1.6-1.7	276,094	467,812	292,382.50	1.06	1.65
16	1.8-1.9	277,500	481,875	301,171.88	1.09	1.65
17	2.0	280,078	510,235	318,896.88	1.14	1.65

Table 6. Calculation results of incremental SR nested pit shell.

Pit Shell	RAF	Ore Changes (Tons)	Overburden Changes (BCM)	SR Incremental (Tons/BCM)
1	0.2	-	-	-
2	0.3	67,500	18,456.88	0.273
3	0.4	98,437	69,580.00	0.707
4	0.5	35,391	38,378.75	1.084
5	0.6	27,187	42,041.25	1.546
6	0.7	23,438	45,263.75	1.931
7	0.8	3,750	8,496.25	2.266
8	0.9	5,859	15,234.38	2.600
9	1.0	1,875	5,566.25	2.969
10	1.1	2,813	9,667.50	3.437
11	1.2	1,406	5,273.75	3.751
12	1.3	3,047	12,597.50	4.134
13	1.4	2,343	10,986.88	4.689
14	1.5	1,641	8,203.13	4.999
15	1.6-1.7	469	2,636.25	5.621
16	1.8-1.9	1,406	8,789.38	6.251
17	2.0	2,578	17,725.00	6.875

Whittle produces two kinds of scheduling scenarios, best case, and worst case. The best-case scenario has a mining pattern starting from a pit shell with a small SR so it is possible to get ore faster, while the worst-case scenario has a mining pattern starting from the highest elevation to the lowest elevation without considering the pit shell SR so that the actual implementation is easier.

RAF affects the discounted cash flow calculation for each pit shell. RAF varies the price of ore differently, resulting in different scheduling and NPV scenarios for each pit shell. Each pit shell has a different NPV value in each scenario, besides the mine life in the worst-case scenario is longer than the best-case scenario. Overall, in both scenarios, it is known that the larger the pit shell opening, the longer the life of the mine.

Figure 4 shows the results of discounted cash flow calculations and analysis of each pit shell. The x-axis being the pit shell and the y-axis being the NPV. The increase in the size of the pit shell does not determine the magnitude of the increase in profits. Profits are affected by the difference between the total profit from nickel ore mining and the cost of overburden removal. Pit Shell 9 is the most profitable pit shell or has the largest NPV in both scenarios, worth USD 5,557,414 in the best-case scenario and USD 5,512,302 in the worst-case scenario.

Table 7. Calculation result of discounted cash flow nested pit shell.

Pit Shell	NPV of Best Case (USD)	NPV of Worst Case (USD)	Life of Mine of Best Case (Month)	Life of Mine of Worst Case (Month)
1	-275,503	-275,503	0.02	0.02
2	1,658,924	1,658,924	1.37	1.37
3	4,034,807	4,030,936	3.33	3.33
4	4,755,217	4,746,147	4.04	4.04
5	5,191,137	5,175,106	4.58	4.58
6	5,480,747	5,446,448	5.05	5.23
7	5,515,702	5,477,699	5.12	5.33
8	5,552,153	5,508,912	5.25	5.49
9	5,557,414	5,512,302	5.30	5.54
10	5,553,142	5,507,491	5.39	5.60
11	5,546,958	5,500,977	5.43	5.63
12	5,522,786	5,475,611	5.55	5.69
13	5,492,305	5,442,120	5.64	5.75
14	5,466,284	5,414,256	5.71	5.79
15	5,456,164	5,403,358	5.73	5.81
16	5,417,756	5,362,238	5.81	5.85
17	5,332,697	5,271,807	5.95	5.94

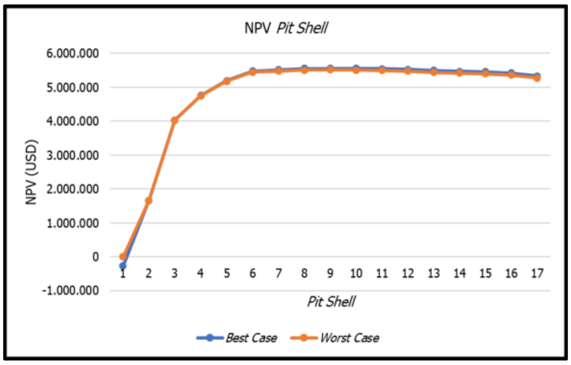

Figure 4. NPV Graphic of nested pit shell.

The optimal Pit Shell 16 based on BESR has a smaller NPV value than Pit Shell 9 after the scheduling scenario is carried out. This can be happened due to the addition of the discount rate and capital cost parameters which resulted in the optimal pit shell opening being smaller in the Whittle analysis. Pit Shell 9 is considered the most profitable to mine and is used as a reference in designing the ultimate pit limit as shown in Figure 5. The three-dimensional view of Pit Shell 9 is shown in Figure 6.

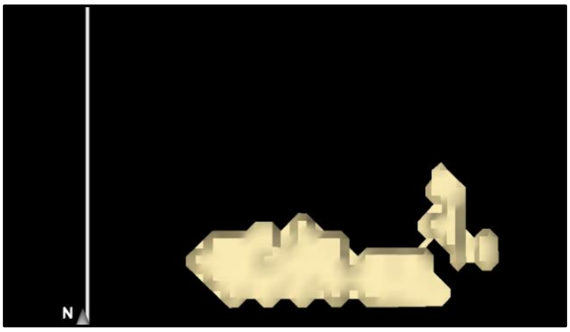

Figure 5. Pit Shell 9 display using Whittle. The pit shell is cream with plan view.

Pit Shell 9 is the ultimate pit limit at RAF 1 or when the normal ore selling price is USD 38/ton. The stripping ratio produced from this pit shell is 0.92 BCM/ton. The mining sequence in this pit shell starts from Pit Shell 1,2,3,4,5,6,7,8 to Pit Shell 9.

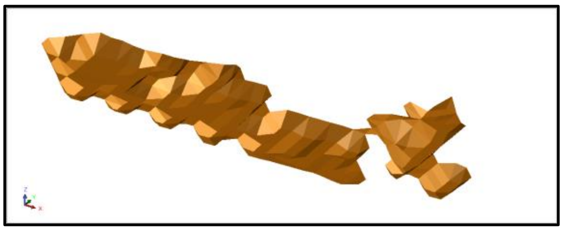

Figure 6. Pit Shell 9 display using Surpac. The pit shell is brown with 3d view.

b. Pit limit optimization using Surpac

Surpac is a mine planning and designing software that has been developed by Gemcom International. It uses in application for the process of geological modelling and opencast mine to quantify and evaluate mineral deposits and to plan the efficient extraction of reserves. Geovia Surpac is the most widely used software system of its kind in the world, supporting open pit and underground mining operations (Agrawal, 2012).

After optimization of pit limits, Surpac produces only one ultimate pit limit because it does not have RAF input parameters that can produce pit shell variations. Surpac's ultimate pit limit has an NPV of USD 9,840,855. This higher NPV is due to Surpac does not have an input of production parameters per month so that the mine life may be shorter, besides that capital costs are not included in the optimization process. The ultimate pit limit resulting from the optimization of the pit limit using Surpac is shown in Figure 7.

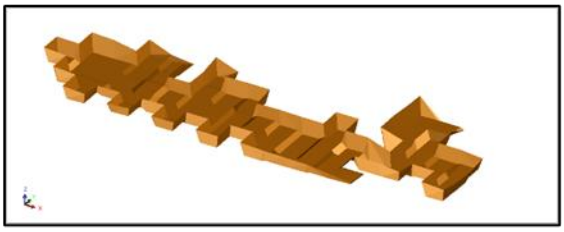

Figure 7. Ultimate pit limit by using Surpac. The pit limit is brown with 3D view.

The appearance and area of the ultimate pit limit produced by Surpac is identical to the Pit Shell 16 produced by Whittle which is the ultimate pit limit based on the BESR value. For this reason, the calculation of the amount of nickel ore obtained from the ultimate pit limit generated is carried out.

The results of the calculation of Surpac ultimate pit limit ore recovery are 277,266 tons (Table 8). The ore recovery is close to the ore recovery at Pit Shell 16 produced by Whittle, which is 277,500 tons. This shows that the ultimate pit limit produced by Surpac is the same as the optimal pit shell produced by Whittle based on the BESR value, but Pit Shell 16 has a less than optimal NPV value in the Whittle scheduling scenario. The pit shell that is used as a reference in designing the ultimate pit limit is Pit Shell 9 produced by Whittle which has a maximum NPV value.

Table 8. Calculation results of ore recovery on Surpac ultimate pit limit.

Category	Volume (BCM)	Tonnage (Ton)	Ni Grade Average
LGO	63,281	94,922	1.39%
MGO	44,688	67,031	1.60%
HGO	76,875	115,313	1.91%
Total	184,844	277,266	1.65%

The pit design is based on the mining method applied by the company, namely the open pit mining method. The open pit mining method is an open pit mining technique to extract nickel ore from pits. This mining method is effectively applied to the Front 8 of Meranti Pit area which is relatively flat.

The pit design is based on topographical forms and the ultimate pit limit results from the Whittle 4.5.1 software that have been previously determined. The ultimate pit limit design uses geometric parameters set by the company. The width of the haul road used in designing the ultimate pit limit based on company standards is 10 meters with a minimum slope of 10%. The ultimate pit limit on the Front 8 of Meranti Pit is designed using Micromine 2021 software because the process is easy and fast and can produce many types of output. The use of Micromine software is advised for all mining projects from exploration to exploitation and later operation (Shehu and Lipo, 2016).

The ultimate pit limit designed by using Micromine 2021 has a difference with the pit limit optimization results from Whittle. This is due to technical factors and several adjustments made, such as the construction of berms and ramps at each mining level which resulted in widening of the ultimate pit limit design. This widening causes the ore recovery to decrease, the overburden increases, to increase the stripping ratio. The resulting outputs include the pit limit design is shown in Figure 8.

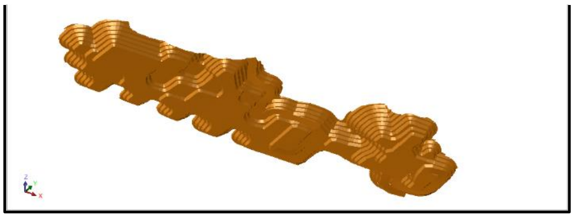

Figure 8. Front 8 ultimate pit limit design which 15 mining levels. The lowest elevation of 82 masl and the highest is 127 masl.

Surpac 6.6.2 produce several functions to modeling resources and reserves (ore bodies) (Tivig et al., 2015). Reserves are resources that have met the technical and economic factors to be mined, namely block models that have a nickel grade of more than or equal to the cut-off grade and are within the design pit limit. Overburden is a model block that is above the reserves that must be removed to obtain ore and have a nickel grade below the cut-off grade.

The density used to obtain the total tonnage is 1.5 tons/BCM for laterite nickel ore and 1.6 tons/BCM for overburden. The amount of nickel reserves in Front 8 of Meranti Pit based on the design pit limit is 234,142 tons with an average nickel grade of 1.66%, an average iron grade of 26.44%, and an average cobalt grade of 0.08%. The results of the calculation of reserves are shown in Table 9.

Table 9. Reserve calculation results at Front 8 of Meranti Pit.

Category	Volume (BCM)	Tonnage (Ton)	Ni Grade Average	Fe Grade Average	Co Grade Average
LGO	55,313	82,969	1.39%	33.91%	0.11%
MGO	32,188	48,282	1.60%	25.75%	0.08%
HGO	68,594	102,891	1.92%	20.74%	0.05%
Total	156,094	234,142	1.66%	26.44%	0.08%

Each grade of nickel ore has a different tonnage, which are LGO with an average nickel grade of 1.39% at 82,969 tons, MGO with an average nickel grade of 1.60% at 48,282 tons, and HGO with an average nickel grade of 1.92% of 102,891 tons. The amount of production obtained based on mine recovery of 85% is 199,021 tons. Based on the production target applied by the company of 50,000 tons/month, the life of the Front 8 of Meranti Pit mine is 3.98 months. The results of the calculation of overburden are shown in Table 10.

Table 10. Overburden calculation results at Front 8 of Meranti Pit.

Variable	Value
Volume (BCM)	389,063
Tonnage (Ton)	622,500
Ni average (%)	0.68
Fe average (%)	35.20
Co average (%)	0.12

The amount of overburden that must be removed at the Front 8 of Meranti Pit based on the pit limit design is 389,063 BCM with an uneconomical average nickel grade of 0.68%, an average iron grade of 35.20%, and an average cobalt grade of 0.12%. The Stripping Ratio (SR) resulting from this pit limit design is 1.66 BCM/ton. It is known that there is an increase in the stripping ratio by 5% after designing the ultimate pit limit from 0.92 BCM/ton to 1.66 BCM/ton which is influenced by technical factors such as widening of the berm and making ramps when designing the pit limit. Nevertheless, the pit limit design is still feasible and still profitable because the SR value obtained (1.66 BCM/ton) is still smaller than the BESR value (6.32 BCM/ton).

Conclusions

The ultimate pit limit based on the maximum NPV value after the Whittle scheduling scenario is Pit Shell 9 with ore recovery of 264,375 tons and the resulting NPV of USD 5,557,414 in the best case and USD 5,512,302 in the worst case. Surpac's ultimate pit limit has an NPV of USD 9,840,855. This higher NPV is due to Surpac does not have an input of production parameters per month so that the mine life may be shorter, besides that capital costs are not included in the optimization process. The pit limit design is still economical because it has a stripping ratio value (1.66 BCM/ton) smaller than BESR value (6.32 BCM/ton). Based on the pit limit design that has been made, the total tonnage of laterite nickel ore is 234,142 tons and the overburden volume is 389.063 BCM. The amount of laterite nickel ore production obtained based on mine recovery of 85% is 199,021 tons with a mine life of 3.98 months.

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Author Contribution

Rifyan Sabaruddin conducted all stages of the research and wrote the paper. Aryanti Virtanti Anas corrected the mine design, the results of pit limit optimization, and revised the paper. Rizki Amalia corrected the calculation of reserves, overburden, and NPV value. Rini Novrianti Sutardjo Tui corrected the resources estimation and BESR value.

Conflict of Interest

The authors declare no conflict of interest.

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