Sensitivity Analysis of Net Present Value due to Optimal Pit Limit in PT Ceria Nugraha Indotama, Kolaka Regency, Southeast Sulawesi Province

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Abstract. PT Ceria Nugraha Indotama is planning to open a new mining site in Lapaopao Block area. In order to determine the most profitable pit design on this new area, pit limit optimization is required. Pit limit is optimized by considering economic parameters, geotechnical parameters, and production target. The optimal pit limit generates the highest Net Present Value (NPV) which is affected by economic parameters. The objective of this research is to analyse the NPV sensitivity of pit due to the changes of economic parameters namely mining cost, processing cost, and selling cost by using sensitivity analysis. Data used in this research were drill hole, ore and waste density, slope geometry, production target. The planned production target, ore price, recovery factor, dilution factor, mining cost, processing cost, and selling cost. The analysis results showed when mining costs increased by 20%, NPV decreased from $2,407,032 to $1,683,430 and when mining costs decreased by 20%, NPV increased from $2,407,032 to $3,130,635. When processing cost increased by 20%, NPV decreased from $2,407,032 to $2,133,523 and when processing cost decreased by 20%, NPV increased from $2,407,032 to $2,680,542. When selling cost increased by 20%, NPV decreased from $2,407,032 to $1,995,755 and when selling cost decreased by 20%, NPV increased from $2,407,032 to $2,818,310. It indicated that the economic parameters significantly affect the NPV and most sensitive to the mining cost parameter changes.

1. Introduction

PT Ceria Nugraha Indotama operates a laterite nickel mine on an area of 6,785 hectares called Lapaopao Block in Wolo District, Kolaka Regency, Southeast Sulawesi Province. One of the area in Lapaopao Block will be used as a new mining site. In order to obtain the best possible economic benefit from the resources available at this project, pit limit optimization is required. Pit limit optimization is conducted to determine the best pit design that obtain the largest profit [1]. The size and shape of pit depends on economic factors and design or production constraints. Understandably, pit optimization is the maximization of Net Present Value (NPV) for a given ore deposit subject to numerous of mining and economic constraints [2]. Pit limit is optimized by considering some parameters such as economic parameters, geotechnical parameters, and production target. The optimal pit limit generate the highest Net Present Value (NPV) which is highly affected by economic parameter such as mining cost, processing cost, and selling cost.

The purpose of this study is to find out how the changes of economic parameters affect the Net Present Value NPV, therefore sensitivity analysis is performed. Sensitivity analysis is necessary to...
evaluate probable effects of project parameters on economic outputs that can be used for recognizing the most critical factors and in this way, prediction of extreme optimistic and pessimistic conditions would be possible. In this process, range of variation of variables is determined [3]. Sensitivity analysis is performed to determine the impact of changes in the value of mining costs, processing costs, and selling costs on the Net Present Value (NPV). The sensitivity analysis of Net Present Value (NPV) based on economic parameters could be a key consideration for companies to anticipate future events due to changes in economic parameters.

2. Research Method
Sensitivity analysis is an analytical method for risky projects using an estimation of Net Present Value (NPV) for each situation where the intended parameters taken as the values of optimistic, pessimistic, or most likely [4]. Sensitivity analysis allows to evaluate the project performance at different values of parameters and to determine the most critical variables that have the greatest affect on the feasibility of the project [5]. In this research, sensitivity analysis was conducted to determine the sensitivity of Net Present Value (NPV) due to changes of economic parameters.

Data in this research consisted of:
- Drill hole data: collars, surveys, assays, and geology.
- Density of ore and waste: 1.6 tonnes/m3.
- Slope geometry: single slope of 60°, overall slope of 40°, bench high of 5 meters, and bench width of 2 meters.
- Production target: 5,000 tonnes per day.
- Ore price: $10/tonnes.
- Recovery factor: 95%.
- Dilution factor: 5%.
- Capital cost $174.503.
- Mining cost: $0.51/tonne.
- Mining CAF of 2.77.
- Processing cost: $1.35/tonne.
- Selling cost: $2.02/tonne.

Data were processed using Surpac 6.5.1 to reconstruct block model and to design pit limit, Whittle 4.5.1. for pit optimization, and Microsoft Excel for sensitivity analysis with following steps:
- Created a block model by adding density and drillhole data.
- Optimized pit limit by adding the block model, overall slope, production target, recovery factor, dilution factor, and economic parameter where 13 pit shell generated through this process.
- Determined optimal pit shell. The fifth pit shell selected as the optimal pit shell due to the number of revenue factor = 1.
- Designed pit limit based on the pit shell.
- Calculated the ore reserves using pit limit design and topographic map of the research area.
- Composed a cash flow statement based on amount of reserves and economic parameters.
- Calculated the Net Present Value (NPV) based on the cash flow statement.
- Analyzed the sensitivity of Net Present Value (NPV) due to the changes of mining cost, processing cost, and selling cost.

3. Results
3.1 Bock Model Reconstruction and Nickel Resources Estimation
The reconstruction of nickel resources block model is performed to get a visualisation of ore deposit geometry as shown in Figure 1. Resources estimation is performed to determine volume, tonnage, and grade of the resources. In this research, nickel resources estimation using a cut-off grade of 1.4% with Inverse Distance Weighting (IDW) method (Table 1).
Figure 1. Block model reconstruction of nickel resources

Table 1. Nickel resources estimation

| Ni Range (%) | Volume (m$^3$) | Tonnage (ton) | Ni Average (%) |
|--------------|---------------|---------------|----------------|
| 0.0 – 1.4    | 17,207        | 27,531        | 1.40           |
| 1.4 – 1.5    | 310,605       | 496,969       | 1.45           |
| 1.5 – 1.7    | 286,875       | 459,000       | 1.58           |
| 1.7 – 2.0    | 74,277        | 118,844       | 1.80           |
| >2.0         | 55,508        | 88,813        | 2.40           |
| **Total**    | **744,473**   | **1,191,157** | **1.61**       |

3.2. Pit Limit Optimization

Pit limit optimization is conducted to produce a pit shell with the highest Net Present Value (NPV) by used data were block model, overall slope 40o, mining cost $0.51/tonne, mining CAF 2.77, processing cost $1.35/tonne, selling cost $3.02/tonne, ore price $10/tonne, capital cost $174.503, mining recovery fraction 0.95, mining dilution fraction 0.05, annual discounting 10%, annual production target 7,500,000 tonne/year (360 work days), and revenue factor range 0.3 to 2 using 0.1 steps. The results of pit limit optimization are shown in Table 2.

Table 2. Results of pit limit optimization

| Pit Shell | Revenue Factor | NPV ($) | Ore (Tonnes) | Waste (Tonnes) | Life Years |
|-----------|----------------|---------|--------------|----------------|------------|
| 1         | 0.6            | 10,599  | 51,331       | 51,414         | 0.0137     |
| 2         | 0.7            | 2,014,394 | 721,275     | 1,418,600      | 0.28532    |
| 3         | 0.8            | 2,683,426 | 1,050,450   | 2,612,779      | 0.48483    |
| 4         | 0.9            | 2,733,559 | 1,094,259   | 2,842,322      | 0.52488    |
| 5         | 1              | 2,738,475 | 1,118,136   | 3,010,422      | 0.55047    |
| 6         | 1.1            | 2,734,936 | 1,122,990   | 3,053,320      | 0.55684    |
| 7         | 1.2            | 2,727,692 | 1,127,474   | 3,100,587      | 0.56374    |
| 8         | 1.3            | 2,725,062 | 1,128,556   | 3,113,693      | 0.56563    |
| 9         | 1.4            | 2,715,221 | 1,131,374   | 3,153,533      | 0.57132    |
| 10        | 1.5            | 2,704,607 | 1,133,848   | 3,192,372      | 0.57683    |
| 11        | 1.6            | 2,702,005 | 1,134,343   | 3,201,065      | 0.57805    |
| 12        | 1.7-1.8        | 2,690,215 | 1,136,299   | 3,238,240      | 0.58327    |
| 13        | 1.9-2          | 2,688,439 | 1,136,516   | 3,243,273      | 0.58397    |
From Table 2, optimal pit shell with revenue factor (RF) 1 is Pit Shell 5 with NPV of $2,738,475. Pit shell 5 is shown in Figure 2.

3.3. Sensitivity Analysis of Net Present Value (NPV) of Pit Shell 5
Sensitivity analysis is used to determine how different values of independent variable impact a particular dependent variable. The dependent variable in this research is Net Present Value (NPV), while the dependent variables are economic parameters namely mining costs, processing costs, and selling costs.

3.3.1. Sensitivity Analysis of Net Present Value (NPV) due to Mining Cost. In this sensitivity analysis, NPV is determined from different values of mining cost changes as shown in Table 3 and Figure 3.

Table 3. The sensitivity of NPV due to mining cost

| Changes of Mining Cost (%) | NPV ($)   |
|---------------------------|-----------|
| -20                       | 3,330,093 |
| -15                       | 3,182,189 |
| -10                       | 3,034,284 |
| -5                        | 2,886,380 |
| 0                         | 2,738,475 |
| 5                         | 2,590,570 |
| 10                        | 2,442,666 |
| 15                        | 2,294,761 |
| 20                        | 2,146,856 |

Figure 3. Graph of sensitivity of NPV due to mining cost
Table 3 and Figure 3 shows that the rate of mining cost is inversely to the NPV. The NPV decrease from $2,738,475 to $2,146,856 when mining cost increase by 20% and increase from $2,738,475 to $3,330,093 when mining cost decrease by 20%.

3.3.2. Sensitivity Analysis of Net Present Value (NPV) due to Processing Cost. In this sensitivity analysis, the sensitivity of NPV is determined from the processing cost changes. The results of this analysis are shown in Table 4 and Figure 4.

| Changes of Processing Cost (%) | NPV ($)   |
|-------------------------------|-----------|
| -20                           | 3,024,941 |
| -15                           | 2,953,324 |
| -10                           | 2,881,708 |
| -5                            | 2,810,091 |
| 0                             | 2,738,475 |
| 5                             | 2,666,858 |
| 10                            | 2,595,242 |
| 15                            | 2,523,626 |
| 20                            | 2,452,009 |

Figure 4. Graph of sensitivity of NPV due to processing cost

Table 3 shows that the NPV decrease from $2,738,475 to $2,452,009 when processing cost increase by 20% meanwhile the NPV increase from $2,738,475 to $ 3,024,941 when the processing cost decrease by 20%. Figure 4 shows that the rate of processing cost changes is inversely proportional to the NPV.

3.3.3. Sensitivity Analysis of Net Present Value (NPV) due to Selling Cost. In this sensitivity analysis, the NPV is determined from changes in selling cost as shown in Table 5 and Figure 5.
Table 5. The sensitivity of NPV due to processing cost

| Changes of Selling Cost (%) | NPV ($) |
|-----------------------------|---------|
| -20                         | 3,110,518 |
| -15                         | 3,017,507 |
| -10                         | 2,924,496 |
| -5                          | 2,831,486 |
| -                           | 2,738,475 |
| 5                           | 2,645,464 |
| 10                          | 2,552,454 |
| 15                          | 2,459,443 |
| 20                          | 2,366,432 |

Figure 5 shows that the rate of changes in selling cost is inversely to the rate of NPV. Table 5 shows that the NPV value decrease from $2,738,475 to $2,366,432 when selling cost increase by 20%, and the NPV increase from $2,738,475 to $3,110,518 when selling costs decrease by 20%. Sensitivity analysis of Net Present Value (NPV) of Pit Shell 5 based on mining cost, processing cost, and selling cost is shown in Figure 6.
Figure 6 shows that the Net Present Value (NPV) is most sensitive to mining cost changes than to selling cost changes and processing cost changes.

3.4. Design of Pit
The pit is designed based on pit shell 5 which requires several important parameters namely height of bench 5 m, width of bench 2 m, and single slope 60°. Design of the pit is shown in Figure 7.

![Figure 7. Design of Pit](image)

3.5. Reserves Estimation
Reserves estimate from material between topography and pit based on the block model. Total reserves estimation is shown in Table 6.

| Waste/Ore | Ni Range (%) | Volume (m$^3$) | Tonnage (tonnes) | Ni Average (%) |
|-----------|--------------|----------------|------------------|----------------|
| Waste     | 0.0 - 0.5    | 478,242        | 765,188          | 0.00           |
|           | 0.5 - 0.9    | 762,168        | 1,219,469        | 0.81           |
|           | 0.9 - 1.4    | 1,005,723      | 1,609,156        | 1.09           |
| Sub-Total |              | 2,246,133      | 3,593,813        | 0.76           |
| Ore       | 1.4 - 1.5    | 287,715        | 460,344          | 1.45           |
|           | 1.5 - 1.7    | 278,262        | 445,219          | 1.58           |
|           | 1.7 -> 2.0   | 73,340         | 117,344          | 1.80           |
|           | > 2.0        | 55,410         | 88,656           | 2.40           |
| Sub-Total |              | 694,727        | 1,111,563        | 1.62           |
| Total     |              | 2,940,860      | 4,705,376        | 0.96           |

3.6. Net Present Value of Pit Design
The Net Present Value (NPV) from pit design is calculate using cash flow analysis with discount rate 9.73% as shown in Table 7. Based on the cash flow in Table 7, the result of Net Present Value (NPV) from pit design is $2,407,032.
Table 7. Cash flow analysis

| Year | 0              | 1              |
|------|----------------|----------------|
| Revenue ($) | 10,559,849    |                |
| Operational Cost ($) | (7,727,130)   |                |
| Capital Cost ($) | (174,503)     | 2,832,719      |
| Cash Flow ($) | (174,503)     |                |
| Discount Rate (%) | 9.73         |                |
| Discounted Cash Flow ($) | (174,503)     | 2,581,535      |
| Cumulative Discounted Cash Flow (NPV) ($) | 2,407,032    |                |

3.7. Sensitivity Analysis of Net Present Value of Pit Design
The sensitivity of Net Present Value (NPV) of pit design as shown in Table 7 is analyzed by using three parameters namely mining cost, processing cost, and selling cost.

3.7.1. Sensitivity Analysis of Net Present Value (NPV) due to Mining Cost. In this sensitivity analysis, NPV is determined from changes in mining cost. The results are shown in Table 8 and Figure 8.

Table 8. The sensitivity of NPV due to mining cost

| Changes of Mining Cost (%) | NPV ($)     |
|----------------------------|-------------|
| -20                        | 3,130,635   |
| -15                        | 2,949,734   |
| -10                        | 2,768,834   |
| -5                         | 2,587,933   |
| 0                          | 2,407,032   |
| 5                          | 2,226,132   |
| 10                         | 2,045,231   |
| 15                         | 1,864,330   |
| 20                         | 1,683,430   |

Figure 8. Graph of NPV sensitivity due to mining cost
Figure 8 shows that the mining cost changes is inversely to the rate of NPV. Table 8 shows that the NPV decrease from $2,407,032 to $1,683,430 when mining costs increase by 20% and NPV increase from $2,407,032 to $3,130,635 when mining costs decrease by 20%.

3.7.2. Sensitivity Analysis of Net Present Value (NPV) due to Processing Cost. In this analysis, the NPV is determined from the changes of processing cost. The results of this analysis are shown in Table 9 and Figure 9.

Table 9. The sensitivity of NPV due to processing cost

| Changes of Processing Cost (%) | NPV ($)    |
|--------------------------------|------------|
| -20                            | 2,680,542  |
| -15                            | 2,612,165  |
| -10                            | 2,543,787  |
| -5                             | 2,475,410  |
| 0                              | 2,407,032  |
| 5                              | 2,338,655  |
| 10                             | 2,270,278  |
| 15                             | 2,201,900  |
| 20                             | 2,133,523  |

Figure 9. Graph of NPV sensitivity due to processing cost

Table 9 shows that the NPV decrease from $2,407,032 to $2,133,523 when processing cost increase by 20%, and NPV increase from $2,407,032 to $2,680,542 when the processing cost decreases by 20%.

3.7.3. Sensitivity Analysis of Net Present Value (NPV) due to Selling Cost. The sensitivity of NPV is determined from the selling cost changes which is shown in Table 10 and Figure 10.
Table 10. The sensitivity of NPV due to selling cost

| Changes of Selling Cost (%) | NPV       |
|-----------------------------|-----------|
| -20                         | 2,818,310 |
| -15                         | 2,715,490 |
| -10                         | 2,612,671 |
| -5                          | 2,509,852 |
| 0                           | 2,407,032 |
| 5                           | 2,304,213 |
| 10                          | 2,201,394 |
| 15                          | 2,098,574 |
| 20                          | 1,995,755 |

Figure 10 shows that the rate of changes in selling cost is inversely to the rate of NPV changes. Table 10 shows that the NPV value decrease from $2,407,032 to $1,995,755 when selling costs increase by 20%, and NPV increase from $2,407,032 to $2,818,310 when selling cost decrease by 20%.

Sensitivity analysis of Net Present Value (NPV) of pit design based on mining cost, processing cost, and selling cost are shown in Figure 11.
Figure 11 shows that the Net Present Value (NPV) of pit design is most sensitive to mining cost changes than to selling cost changes and processing cost changes.

4. Conclusion
It is recognized that economic parameters namely mining cost, processing cost, and selling cost affect the value of Net Present Value (NPV). The results of sensitivity analysis show that when mining cost increase by 20%, NPV decrease from $2,407,032 to $1,683,430 and when mining cost decrease by 20%, NPV increase from $2,407,032 to $3,130,635. When processing cost increase by 20%, NPV decrease from $2,407,032 to $2,133,523 and when processing cost decrease by 20%, NPV increase from $2,407,032 to $2,680,542. When selling costs increase by 20%, NPV decrease from $2,407,032 to $1,995,755 and when selling cost decrease by 20%, NPV increase from $2,407,032 to $2,818,310. The Net Present Value (NPV) of pit design is most sensitive to mining cost changes than to selling cost changes and processing cost changes.

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