The Accuracy Of Ore Reserves Estimation
Case Study : Laterite Nickel Deposits

Eddy Winarno¹, Gunawan Nusanto², Peter Eka Rosadi²

¹Magister Teknik Pertambangan UPN “Veteran” Yogyakarta
²Prodi Teknik Pertambangan, UPN “Veteran” Yogyakarta
winarnoeddy@gmail.com

Abstract--- Determining the accuracy of the estimated ore reserves become one of the most important things in order to reach the effectiveness exploration and optimization of reserves utilization. Improved accuracy of the estimated value of the ore reserves is directly correlated with the stages of exploration, the higher of exploration the greater of the accuracy value. In this paper, the accuracy value is calculated base on of the data validation, treatment of data analysis, and ore resource estimation methods. The accuracy value so related to the scaling theory (schaling methods), the theory of weighting (weighting value), and theories of probability and accuracy. The case study conducted on lateritic nickel reserves is based on a cut-off grade (lowest average grade), nickel reserves statement with the estimated of accuracy value.

Keywords: ore reserves estimates, the accuracy, the statement reserves

I. INTRODUCTION

Stages of mining activities, especially ore body start from the determination of activities prospected area (prospecting), the quantity and quality (exploration), feasibility of mining operation (exploitation), processing metallurgically (processing), and marketing (marketing). The linkages of mining activities require a whole series of data accuracy, either at the time of data acquisition and processing, data analysis and interpretation.

The existence of ore body, known as the genesis of ore body, is unique and specific due to the specific parameter form (e.g levels of a precipitate), is strongly influenced by the presence of other minerals forming parameters (heat, temperature, and others). Therefore, the accuracy of determining the location of the sample, the amount of samples, and gathering sample and sample treatment procedure (sampling techniques) are a requirement that must be met.

A. Resources and Reserves

Classification of resources and the reserve has been published by the Australasian IMM / AMIC base on classification accuracy improvement and the results of geological investigations (Table 1).

TABLE 1. AIMM/AMIC CLASSIFICATION OF IDENTIFIED MINERALS RESOURCES

<table>
<thead>
<tr>
<th>Identified mineral resources (in situ)</th>
<th>Ore reserves (mineable)</th>
<th>Increasing level of geological knowledge and confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferred</td>
<td>Indicated</td>
<td>Probable</td>
</tr>
<tr>
<td>Consideration of economic, mining,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>metallurgical, marketing,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>enviromental, social and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>govermental factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured</td>
<td>Proved</td>
<td></td>
</tr>
</tbody>
</table>

Sources : Mineral Deposit Evaluation, A.E. Annel (1991)
Table 1 indicates that the increased resources into reserves to account for economic factors, mining, processing, market, environment, and government regulation.

Based on Table 1, Diehl and David in A.E. Annels (1991) develop a classification of ore deposits involves a degree of uncertainty (assurance) and degree of accuracy (error tolerance) for each of the different deposits. It was stated comprehensively in Table 2 below.

### TABLE 2. ORE RESERVE CLASSIFICATION

<table>
<thead>
<tr>
<th>Identified</th>
<th>Undiscovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrated</td>
<td></td>
</tr>
<tr>
<td>Measured</td>
<td></td>
</tr>
<tr>
<td>Proved</td>
<td>Probable</td>
</tr>
<tr>
<td>+10%</td>
<td>+20%</td>
</tr>
<tr>
<td>&gt;80%</td>
<td>60-80%</td>
</tr>
<tr>
<td>Indicated</td>
<td></td>
</tr>
<tr>
<td>(Possible)</td>
<td></td>
</tr>
<tr>
<td>+40%</td>
<td>40-60%</td>
</tr>
<tr>
<td>Inferred</td>
<td></td>
</tr>
<tr>
<td>Hypothetical</td>
<td></td>
</tr>
<tr>
<td>+60%</td>
<td>20-40%</td>
</tr>
<tr>
<td>Speculative</td>
<td></td>
</tr>
<tr>
<td>Economically significant</td>
<td>Resources base</td>
</tr>
<tr>
<td>resources</td>
<td></td>
</tr>
</tbody>
</table>

The concept of accuracy value in ore resource and reserves can be expressed with:

1. In the mining production actual stage:
   -Accuracy value = 100% - percentage error
   -Error = true quantity of reserve – true quantity of mining production

2. In the ore reserves estimation stage:
   -Accuracy value = 100% - percentage error
   -Error = convergence value can be reached in iterative methods

### B. Ore reserves estimation methods

One of ore reserves estimation methods is called as block model. If the block is divided into a mesh of small blocks, the calculation would be made for each block and the result summed. The tonnage of each block can be easily found from the block volume (the same for all block) and the tonnage factor.

\[
\text{Tonnage} = \text{block volume} \times \text{tonnage factor (grade)}
\]

Two techniques for tonnage factor:

1. If the block have tonnage factor (grade) from the log bor, the tonnage factor can be estimated with the formula:

\[
\frac{\sum_{i=1}^{n} g_i}{n} \geq \text{COG} \quad \text{COG} = \text{Cut Off Grade}
\]

2. If the block no have tonnage factor (blank block), the tonnage factor can be estimated same with grade of the nearest block from the blank block.

### II. SCALE OF THEORY

#### A. Error Formula

In general, error can be introduced as Error = True Value - Approximate value. The error may be divided into following different types: inherent error, round-off error, truncation error, absolute error, relative error, and percentage error.

\[
E_p = 100\% \left| \frac{x - x'}{x} \right| = \frac{E_a}{\text{True Value}}
\]

where: \( E_p \) = Percentage Error ; \( x \) = true value \( x' \) = approximate value
\( E_r \) = Relative Error ; \( x' \) = approximate value
\( E_a \) = Absolute Error

Let \( X = f(x_1, x_2, x_3, \ldots, x_n) \) be the function having \( n \) variables. To determined the error \( \delta X \) in \( X \) due to the error \( \delta x_1, \delta x_2, \ldots, \delta x_n \) in \( x_1, x_2, \ldots, x_n \) respectively.

\[
X + \delta X = f(x_1 + \delta x_1, x_2 + \delta x_2, \ldots, x_n + \delta x_n)
\]
using Taylor’s series for more than variables:

\[ X + \partial X = f(x_1, x_2, \ldots, x_n) + \left( \partial x_1 \frac{\partial X}{\partial x_1} + \partial x_2 \frac{\partial X}{\partial x_2} + \ldots + \partial x_n \frac{\partial X}{\partial x_n} \right) + \]

\[ + \frac{1}{2} \left( (\partial x_1)^2 \frac{\partial^2 X}{\partial x_1^2} + (\partial x_2)^2 \frac{\partial^2 X}{\partial x_2^2} + \ldots + (\partial x_n)^2 \frac{\partial^2 X}{\partial x_n^2} + 2 \partial x_1 \partial x_2 \frac{\partial^2 X}{\partial x_1 \partial x_2} + \ldots \right) + \ldots \]

error \( \partial x_1, \partial x_2, \ldots, \partial x_n \) all are small so that the term containing \((\partial x_1)^2, (\partial x_2)^2, \ldots, (\partial x_n)^2\) and higher power of \( \partial x_1, \partial x_2, \ldots, \partial x_n \) are being neglected.

Therefore \[ X + \partial X = f(x_1, x_2, \ldots, x_n) + \left( \partial x_1 \frac{\partial X}{\partial x_1} + \partial x_2 \frac{\partial X}{\partial x_2} + \ldots + \partial x_n \frac{\partial X}{\partial x_n} \right) \] \hspace{1cm} \( \text{(1)} \)

\[ \partial X = \partial x_1 \frac{\partial X}{\partial x_1} + \partial x_2 \frac{\partial X}{\partial x_2} + \ldots + \partial x_n \frac{\partial X}{\partial x_n} \] \hspace{1cm} \( \text{(2)} \)

Equation (2) represents the general formula for errors.

If equation (2) divided by \( X \), is called relative error, \[ E_r = \frac{\partial X}{X} = \frac{\partial x_1 \frac{\partial X}{\partial x_1} + \partial x_2 \frac{\partial X}{\partial x_2} + \ldots + \partial x_n \frac{\partial X}{\partial x_n}}{X} \]

Absolute value for equation (2), is called absolute error, \[ |\partial X| = \left| \partial x_1 \frac{\partial X}{\partial x_1} \right| + \left| \partial x_2 \frac{\partial X}{\partial x_2} \right| + \ldots + \left| \partial x_n \frac{\partial X}{\partial x_n} \right| \]

B. Convergence of Iterative Methods

Convergence of an iterative method is judged by the order at which the error between successive approximations to the root decreases. The order of convergence of an iterative method is said to be \( k \)th order convergence if \( k \) is the largest positive real number such that:

\[ \lim_{i \to \infty} \left| \frac{e_{i+1}}{e_i} \right| \leq A \]

where: \( A \) is non-zero finite number called asymptotic error constant \( e_{i+1} \) and \( e_i \) are the error in successive approximations

In the other word, the error in any step is proportional to the \( k \)th power of the error in the previous step. Physically, the \( 4 \)th order convergence means that in each iteration, the number of significant digits in each approximation increases \( 4 \) times.

C. Scale of Accuracy

From the scalling methods theory, the scale of accuracy applied on 5-scale methods with the criteria (see Table 3)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Value</th>
<th>Accuracy</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>81 – 100</td>
<td>Very Strong</td>
<td>The linkage between the components of the technical approach are in line (cohesive) with standard scientific concepts</td>
</tr>
<tr>
<td>4</td>
<td>61 – 80</td>
<td>Strong</td>
<td>Lower than 5 scale</td>
</tr>
<tr>
<td>3</td>
<td>41 – 60</td>
<td>Moderate</td>
<td>At most there are three technical components of the approach is scientifically</td>
</tr>
<tr>
<td>2</td>
<td>21 – 40</td>
<td>Less Accurate</td>
<td>Lower than 3 scale</td>
</tr>
<tr>
<td>1</td>
<td>0 – 20</td>
<td>Not Accurate</td>
<td>No procedure</td>
</tr>
</tbody>
</table>
III. CASE STUDY

The case study conducted on lateritic nickel reserves is based on a cut-off grade (lowest average grade).

1). Characteristics of Nickel Ore

Reserve estimation carried out simulations on the “X nickel deposits”. Exploration activity that has been done is taking samples with a regular distance of 25 m by using a rotary drilling tool. Topography of the hills with a slope of 30°-50° and 50-230 meters above sea level (mdpl).

Based on how the formation, geology of ore deposits is a nickel laterite ore, mineral deposit is the result of the weathering of ultra basic rock peridotite, in general, contain elements of iron, cobalt and klorium.

This ultramafic rock outcrops generally have undergone weathering, yellow-brown mottled gray, black or white with a greenish tint on the outer edge or rim. In this area there are also small cracks, fractures are commonly filled by secondary minerals (silica and magnesite).

In general profiles ore deposits in the study area, Figure (1), are as follows:

a. Top Soil, ground cover is reddish brown, there are the rest of the herbs.

b. Limonite, is the result of weathering of the soil soft yellowish brown color containing nickel and iron in the ratio is not necessarily.

c. Saprolite, is highly weathered soils have yellowish brown to greenish with many veins garnierit and onyx, has a relatively high nickel content.

d. Bed Rock, a peridotite host rock that has not weathered serpentinite.

![Figure 1. Nickel Ore Deposition Profile](image-url)
2) Simulation

Computing applications Cut-Off Grade (COG) lowest grade = 1.7 % Ni and reserve estimation applied to one drill hole samples 1559B along with the drill log results (Table 4), is a layer that can be mined ranging depth (level) 4 m to 14 m, with an average content value:

$$COG = \frac{1.93 + 2.10 + 2.32 + 1.77 + 1.39 + 1.47 + 2.13 + 1.75 + 1.21 + 1.18 + 2.20}{11} = 1.768\%$$

<table>
<thead>
<tr>
<th>NO</th>
<th>COG (%) Ni</th>
<th>Grade (%) Ni</th>
<th>Tonnage (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>100x100m</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>1.71</td>
<td>2,023</td>
</tr>
<tr>
<td></td>
<td>0.499</td>
<td>0.391</td>
<td>0.236</td>
</tr>
<tr>
<td>2</td>
<td>1.8</td>
<td>1.87</td>
<td>1,452</td>
</tr>
<tr>
<td></td>
<td>0.793</td>
<td>0.526</td>
<td>0.346</td>
</tr>
</tbody>
</table>

From Table 5 for the average level of 1.6 %Ni, error value obtained by 0.193 the value already has a relatively constant tendency (convergent); the accuracy of calculation of 0.807 or 80.7%. As for the average...
level of 1.8 %Ni obtained an accuracy of 76.5 %. The tendency of the error value is relatively constant (convergent) also can be seen in Figure 2 and 3 below.

**FIGURE 2.** VALUE OF ERROR IN AVERAGE GRADE 1.6 % Ni

**FIGURE 3.** VALUE OF ERROR IN AVERAGE GRADE 1.8%Ni
IV. DISCUSSION

From Table 5 and Figure 2, Figure 3 and Figure 4, shows that for the average grade of 1.6% Ni which is an average COG obtained tonnage reserves of 2,050,100 tons with an accuracy of ± 80.7% in blocks ranging in size less equal to 25 x 25 m. As for the COG average of 1.8% Ni obtained tonnage reserves of 1,480,520 tons with an accuracy of ± 76.5% in blocks ranging in size from less equal to 25 x 25 m.

Attributed to standardize accuracy values in Table 3 above, the tonnage of the area carefully situations in the category very accurate. If explored more deeply accuracy value is highly influenced by the accuracy of the drill data (exploration and treatment of samples) and the potential resources (clarity limit geological model, cross-section maps, and resource estimation methods).

V. CONCLUSION

Accuracy lateritic nickel resource tonnage statement is strongly influenced by the accuracy of the data, the geological model, and resource estimation methods. On the resource estimate block method, the estimation accuracy is strongly influenced by the size of the block estimation, accuracy will be obtained in the calculation error (error) which has a constant value (convergent).

REFERENCES


