Determining 150kv transmission tower route using FAHP method

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Abstract. PT. Vale Indonesia Tbk (PTVI) is a mineral mining company that produces nickel as its main product. PTVI requires high reliability of power supply so that it can produce nickel to the specified target. One of the important equipment to maintain the availability of electricity is the transmission tower. Failure of the transmission tower will have a disastrous effect on nickel production operations. PTVI will lose 165 MW in case of failure on the Larona transmission tower line to plant site and 200 MW on the Balambano transmission tower line to the plant site. Therefore, PTVI will build a new 150kV transmission tower line from Larona switchyard to Balambano switchyard to support the availability of sustainable electricity. The method to be used to determine the best alternative transmission tower route by considering multiple criteria is Fuzzy Analytical Hierarchy Process (FAHP). The results of each alternative are 0.477 for the North route, 0.364 for the Middle route, and 0.159 for the South route. The authors recommend the management of PT. Vale Indonesia, as the owner and operator of the hydroelectric power station, choses the north route for the planned construction of the 150kV transmission tower.

1. Introduction

PT. Vale Indonesia Indonesia, Tbk (PTVI), formerly known as PT INCO, is a mineral mining company that produces nickel as its main product. PT. Vale Indonesia operates in East Luwu Regency, South Sulawesi. In the area around PT. Vale Indonesia, three interconnected lakes that flow downstream of the Larona river which empties into the Ussu bay. With a total area of around 2,800 km\textsuperscript{2} which is a very large area of rainwater catchment. The Larona river has water in lake Towuti and empties into the gulf of Bone. Lake Towuti (El. +320 m) is a lake system in its upstream, namely lake Mahalona (El. +325 m) and lake Matano (El. +390 m). The three lakes are natural lakes that support the availability of water that functions as a Larona Hydroelectric Power Plant (PLTA) as a supplier for electricity needs at PT. Vale Indonesia's nickel smelting plant.

![Figure 1. Cascade PLTA PT Vale Indonesia.](image-url)
The utilization of reservoirs in the Larona river that has stratified characteristics is depicted as shown in Figure 1. Starting from the Matano lake as upstream to the Karebbe dam as downstream. With an average capacity for the Larona hydropower plant at 165 MW, the 110 MW Balambano hydropower plant, and finally the Karebbe hydropower plant at 90 MW. So that the total average supplied reached 365 MW.

PT. Vale Indonesia (PTVI) requires high power supply reliability from hydroelectric power plants (PLTA) to thermal power plants to be distributed to all production facilities so that it can produce nickel as expected. For this reason, the Utilities Department, as the unit responsible for the availability of electricity, must try to ensure that the electricity supply for nickel production must be met continuously. One of the important equipment to maintain electricity availability can be met is the transmission line tower. Currently, PTVI has 153 towers consisting of 57 Larona transmission line towers which are commonly referred to as Line 1 and 2, 76 Balambano transmission line towers and 20 Karebbe transmission line towers. Balambano and Karebbe transmission lines are commonly referred to as Lines 3 and 4. Failure of the transmission line tower will have a disastrous effect on nickel production operations. PT. Vale Indonesia will lose 165 MW if one of the tower lines of the Larona transmission line fails and the other side will lose 200 MW if one of the Balambano tower transmission lines fails. To support the continued availability of electricity, the construction of a 150kV transmission line 5 (Line 5) tower from the Balambano substation to the Larona substation.

To determine the construction of the transmission tower line from Larona switchyard to the Balambano switchyard has many considerations that must be considered because each alternative route has advantages and disadvantages of various aspects. Thus, one of the approaches that correspond to this problem is by the method of Analytical Hierarchy Process (AHP). AHP is a multi-criterion decision making tool with experts' opinions as a defining criterion. However, the preference assessment of the experts is often experienced ambiguity, the confusion in describing a proportion in the form of linguistic information (Dozic et al, 2017). So it is necessary to use Fuzzy to solve this problem. A Fuzzy AHP is a refinement of the classic Multiple Criteria Decision Making (MCDM) problem that overcomes uncertainty because it is caused by uncountable information, incomplete information and unclear information.

2. Methodology

Decision-making models need to tolerate ambiguity because uncertainty is a common feature in many decision-making issues (Yu, 2002). Because decision-makers often provide uncertain answers rather than exact values, the transformation of a qualitative preference to an approximate point may not make sense.

This decision-making is obtained in several stages. By using the hierarchical structure then obtained goals to be achieved, the criteria used and alternatives. The hierarchical structure can be seen in figure 2.

Figure 2. The hierarchical structure.
Pairwise comparisons on the Fuzzy AHP method are illustrated by a ratio scale that is related to the fuzzy scale value. Fuzzy numbers are complete on all scales described in Table 1.

Table 1. Triangular fuzzy numbers.

| Variables         | Likert Scale | Positive TFN  | Positive reciprocal TFN |
|-------------------|--------------|---------------|-------------------------|
| Extremely Strong  | 1            | (1,1,3)       | (1/1,1/1,1/3)           |
| Intermediate      | 2            | (1,2,4)       | (1/4,1/2,1/1)           |
| Very Strong       | 3            | (1,3,5)       | (1/5,1/3,1/1)           |
| Intermediate      | 4            | (2,4,6)       | (1/6,1/4,1/2)           |
| Strong            | 5            | (3,5,7)       | (1/7,1/5,1/3)           |
| Intermediate      | 6            | (4,6,8)       | (1/8,1/6,1/4)           |
| Moderately Strong | 7            | (5,7,9)       | (1/9,1/7,1/5)           |
| Intermediate      | 8            | (6,8,9)       | (1/9,1/8,1/6)           |
| Equally Strong    | 9            | (7,9,9)       | (1/9,1/9,1/7)           |

Fuzzy AHP procedure follows the steps of the rule by:

1. Create a hierarchical structure of the problem to be solved and determine the pairwise matrix comparison between the criteria and the triangle fuzzy number (TFN) scale.
2. Determine the fuzzy geometric mean value (r̂) of each criterion, sub-criteria, and alternative using the Buckley Method.
3. Determine fuzzy weights (ŵ) for each criterion, sub-criteria, and alternatives.
4. Defuzzify using the Center of Area (COA) method.
5. Normalization of vector weight or priority value criteria that have been obtained.

3. Results

3.1 Alternative Route

The following are 3 alternatives transmission tower lines from the Larona Hydroelectric Power Plant to the Balambano Hydroelectric Power Plant which are planned to be built are shown in Figure 3. The three alternative routes are:

1. North route, this route is the longest route, which is 7.505 km. This route follows the existing transmission line route.
2. Middle route, this route has a length of 5.931 km. This route is a new route that has never been cleared before. This route is the shortest route among other alternative routes.
3. South route, this route has a length of 6.292 km. This route is also a new route that has never been cleared before.

![Figure 3. Alternative transmission tower routes.](image-url)
3.2 Expert Selection
Experts in this study are competent expert respondents and can inherit in the decision-making process to evaluate the selection of alternative route 150kV transmission tower lines at PT. Vale Indonesia. In Table 2 below is a data of highly experienced expert respondents selected by the author to assist in this research.

Table 2. Identity of experts.

| Expert | Position                                | Experience |
|--------|-----------------------------------------|------------|
| 1      | Project Manager                         | 12 years   |
| 2      | Manager of Civil and Hydro Surveillance | 12 years   |
| 3      | Manager of Energy                       | 16 years   |
| 4      | Senior Energy Engineer                  | 15 years   |
| 5      | Manager of Utilities Engineering        | 16 years   |

3.3 Criteria Selection
Selection criteria are obtained from a combination of the journal references [4] and interviews from expert respondents. All of the results of interview criteria and journal reference selected. There are only a few criteria that are almost the same as one criterion. The summary of the criteria selection can be seen in Table 3 below.

Table 3. Criteria selection.

| No. | Alternative                                      | Code   |
|-----|--------------------------------------------------|--------|
| 1   | Construction costs                              | T-01   |
| 2   | Maintenance Access                              | T-02   |
| 3   | Soil Condition/Type                             | T-03   |
| 4   | Topography                                       | T-04   |
| 5   | Permit                                           | T-05   |
| 6   | Land acquisition                                | T-06   |
| 7   | Ease of installation                            | T-07   |
| 8   | Community Activities around the location        | T-08   |
| 9   | Proximity to other buildings                    | T-09   |
| 10  | Proximity to the river                          | T-10   |
| 11  | Habitat of Flora and fauna                      | T-11   |

3.4 Comparison Matrix
In this phase, all 5 experts were given questionnaires in the form of a comparison matrix of each criterion. Table 4 describes the results of the comparison of expert-1 as shown below.

3.5 Consistency Ratio (CR)
A summary of the results of calculating the consistency ratio (CR) is shown in Table 5. The consistency ratio matrix of the criterion value of each expert indicates good or acceptable consistency because all values are smaller than 0.1 (10%).
### Table 4. Comparison matrix expert-1.

| Criteria    | T-01 | T-02 | T-03 | T-04 | T-05 | T-06 | T-07 | T-08 | T-09 | T-10 | T-11 |
|-------------|------|------|------|------|------|------|------|------|------|------|------|
| T-01        | 1    | 7    | 3    | 1/3  | 1/5  | 7    | 2    | 1/3  | 3    | 4    | 5    |
| T-02        | 1/7  | 1    | 1/5  | 1/7  | 1/9  | 2    | 1/4  | 1/7  | 1/4  | 1/4  | 1/3  |
| T-03        | 1/3  | 5    | 1    | 1/3  | 1/5  | 5    | 2    | 1/5  | 3    | 3    | 3    |
| T-04        | 3    | 8    | 3    | 1    | 1/2  | 8    | 5    | 1    | 4    | 5    | 6    |
| T-05        | 5    | 9    | 5    | 2    | 1    | 9    | 5    | 3    | 6    | 7    | 7    |
| T-06        | 1/7  | 1/2  | 1/5  | 1/8  | 1/9  | 1    | 1/6  | 1/4  | 1/5  | 1/5  | 1/3  |
| T-07        | 1/2  | 4    | 1/2  | 1/5  | 1/5  | 6    | 1    | 3    | 3    | 3    | 4    |
| T-08        | 3    | 7    | 5    | 1    | 1/3  | 4    | 1/3  | 1    | 5    | 5    | 5    |
| T-09        | 1/3  | 4    | 1/3  | 1/4  | 1/6  | 5    | 1/3  | 1/5  | 1    | 1    | 1/2  |
| T-10        | 1/4  | 4    | 1/3  | 1/5  | 1/7  | 5    | 1/3  | 1/5  | 1    | 1    | 1    |
| T-11        | 1/5  | 3    | 1/3  | 1/6  | 1/7  | 3    | 1/4  | 1/5  | 2    | 1    | 1    |

### Table 5. Summary of consistency ratio.

| Expert    | CR  |
|-----------|-----|
| Expert-1  | 0.0938 |
| Expert-2  | 0.0989 |
| Expert-3  | 0.0957 |
| Expert-4  | 0.0910 |
| Expert-5  | 0.0899 |

### 3.6 Weighting of Criteria with Fuzzy AHP Method

At this stage, the conversion from the comparison matrix to the TFN scale. Because there are 5 experts who do the matrix assessment in pairs, then the geometric mean is used to represent the assessment results of all experts. Then by following steps of the Fuzzy AHP method as mentioned in the subchapter of the methodology, obtained the weights of each criterion as shown in Table 6.

### Table 6. Summary of weighting criteria using fuzzy AHP method.

| Criteria                                      | Weighting | Norm Weighting |
|-----------------------------------------------|-----------|----------------|
| T-01 Construction Costs                       | 0.130     | 0.104          |
| T-02 Maintenance Access                       | 0.046     | 0.037          |
| T-03 Soil Condition/Type                      | 0.100     | 0.080          |
| T-04 Topography                               | 0.127     | 0.101          |
| T-05 Permit                                   | 0.370     | 0.296          |
| T-06 Land acquisition                         | 0.174     | 0.139          |
| T-07 Ease of installation                     | 0.080     | 0.064          |
| T-08 Community Activities around the location| 0.098     | 0.078          |
| T-09 Proximity to other buildings             | 0.045     | 0.036          |
| T-10 Proximity to the river                   | 0.047     | 0.038          |
| T-11 Habitat of Flora and fauna               | 0.034     | 0.027          |
| Total                                         | 1.251     | 1              |
3.7 Weighting of Alternative Route with Fuzzy AHP Method

At this phase, the questionnaire was distributed back to each expert to provide an assessment of the comparison between alternatives of the selected criteria. A summary of the total value of each alternative is shown in Table 7.

Table 7. Summary of total value alternative route.

| Criteria                        | Weighting | North Route |      | Midlle Route |      | Soute Route |      |
|---------------------------------|-----------|-------------|------|--------------|------|-------------|------|
|                                 | Weighting | Total       | Weighting | Total       | Weighting | Total       |      |
| Construction Costs              | 0.104     | 0.080       | 0.008 | 0.681        | 0.071 | 0.239       | 0.025|
| Maintenance                     | 0.037     | 0.553       | 0.020 | 0.312        | 0.012 | 0.135       | 0.005|
| Access                           | 0.080     | 0.625       | 0.050 | 0.114        | 0.009 | 0.260       | 0.021|
| Soil                             |           |             |       |              |       |             |      |
| Condition/Type                  | 0.101     | 0.237       | 0.024 | 0.650        | 0.066 | 0.113       | 0.011|
| Topography                       | 0.296     | 0.594       | 0.176 | 0.372        | 0.110 | 0.034       | 0.010|
| Permit                           | 0.139     | 0.657       | 0.092 | 0.189        | 0.026 | 0.154       | 0.021|
| Land acquisition                 | 0.064     | 0.429       | 0.027 | 0.480        | 0.031 | 0.091       | 0.006|
| Ease of installation            | 0.078     | 0.682       | 0.053 | 0.153        | 0.012 | 0.165       | 0.013|
| Community                        |           |             |       |              |       |             |      |
| Activities around the location   | 0.036     | 0.020       | 0.001 | 0.335        | 0.012 | 0.645       | 0.023|
| Proximity to other buildings     | 0.038     | 0.236       | 0.009 | 0.138        | 0.005 | 0.627       | 0.024|
| Proximity to the river           |           |             |       |              |       |             |      |
| Habitat of Flora and fauna       | 0.027     | 0.612       | 0.017 | 0.381        | 0.010 | 0.007       | 0.000|
| Total                           |           |             |       |              |       |             |      |
|                                 | 0.477     | 0.364       | 0.159 |             |      |             |      |

3.8 Sensitivity Analysis

One method used to test the vulnerability of results to ranking changes is the weight adjustment method. In the sensitivity analysis phase is carried out by adding criteria weights from 5% to 50% to each criterion. This is done to see the level of sensitivity of the criteria that have been determined. The results of the sensitivity analysis of expert assessment results is shown in Table 8.

Based on the results of the sensitivity analysis of the model based on expert judgment it can be concluded that all of those criteria are robust criteria because the alternative ranking does not change after the simulation is done from 5% to 50%.
Table 8. Sensitivity analysis results.

| Alternative                        | North Route (N) | Middle Route (M) | South Route (S) | Alternative Ranking |
|-----------------------------------|----------------|-----------------|----------------|-------------------|
| **Existing**                      | 0.477          | 0.364           | 0.159          | N>M>S             |
| **Construction Costs**            |                |                 |                |                   |
| +5%                               | 0.47728        | 0.36728         | 0.16062        | N>M>S             |
| +20%                              | 0.47852        | 0.37790         | 0.16434        | N>M>S             |
| +50%                              | 0.48100        | 0.39912         | 0.17178        | N>M>S             |
| **Maintenance Access**            |                |                 |                |                   |
| +5%                               | 0.47789        | 0.36432         | 0.15963        | N>M>S             |
| +20%                              | 0.48095        | 0.36605         | 0.16038        | N>M>S             |
| +50%                              | 0.48708        | 0.36951         | 0.16188        | N>M>S             |
| **Soil Condition/Type**           |                |                 |                |                   |
| +5%                               | 0.47936        | 0.36420         | 0.16042        | N>M>S             |
| +20%                              | 0.47936        | 0.36557         | 0.16354        | N>M>S             |
| +50%                              | 0.47936        | 0.36831         | 0.16977        | N>M>S             |
| **Topography**                    |                |                 |                |                   |
| +5%                               | 0.47807        | 0.36704         | 0.15996        | N>M>S             |
| +20%                              | 0.48166        | 0.37690         | 0.16167        | N>M>S             |
| +50%                              | 0.48885        | 0.39664         | 0.16510        | N>M>S             |
| **Permit**                        |                |                 |                |                   |
| +5%                               | 0.48565        | 0.36924         | 0.15989        | N>M>S             |
| +20%                              | 0.51200        | 0.38574         | 0.16141        | N>M>S             |
| +50%                              | 0.56469        | 0.41872         | 0.16444        | N>M>S             |
| **Land acquisition**              |                |                 |                |                   |
| +5%                               | 0.48145        | 0.36506         | 0.16046        | N>M>S             |
| +20%                              | 0.49520        | 0.36901         | 0.16368        | N>M>S             |
| +50%                              | 0.52269        | 0.37692         | 0.17013        | N>M>S             |
| **Ease of installation**          |                |                 |                |                   |
| +5%                               | 0.47824        | 0.36528         | 0.15968        | N>M>S             |
| +20%                              | 0.48235        | 0.36989         | 0.16055        | N>M>S             |
| +50%                              | 0.49058        | 0.37910         | 0.16231        | N>M>S             |
| **Community Activities around the location** | | | | |
| +5%                               | 0.47954        | 0.36434         | 0.16003        | N>M>S             |
| +20%                              | 0.48754        | 0.36614         | 0.16197        | N>M>S             |
| +50%                              | 0.50354        | 0.36972         | 0.16585        | N>M>S             |
| **Proximity to other buildings**  |                |                 |                |                   |
| +5%                               | 0.47690        | 0.36435         | 0.16054        | N>M>S             |
| +20%                              | 0.47701        | 0.36615         | 0.16401        | N>M>S             |
| +50%                              | 0.47722        | 0.36976         | 0.17096        | N>M>S             |
| **Proximity to the river**        |                |                 |                |                   |
| +5%                               | 0.47731        | 0.36401         | 0.16057        | N>M>S             |
| +20%                              | 0.47865        | 0.36479         | 0.16412        | N>M>S             |
| +50%                              | 0.48132        | 0.36635         | 0.17121        | N>M>S             |
| **Habitat of Flora and fauna**    |                |                 |                |                   |
| +5%                               | 0.47770        | 0.36427         | 0.15939        | N>M>S             |
| +20%                              | 0.48020        | 0.36582         | 0.15942        | N>M>S             |
| +50%                              | 0.48520        | 0.36894         | 0.15948        | N>M>S             |

4. Conclusion
There are some conclusions obtained in the study of determining the 150kV transmission tower route in PT. Vale Indonesia is based on the Fuzzy AHP method. There are eleven criteria selected to make
decision in determining the transmission tower route. The eleven criteria are construction costs, maintenance access, soil condition or type, topography, permit, land acquisition, ease of installation, community activities around the location, proximity to other buildings, proximity to the river, and habitat of flora/fauna. These criteria are then used to weight the comparison matrices of each alternative of the 150kV transmission tower route. The results of value each alternative is 0.477 for the North route, 0.364 for the Middle route, and 0.159 for the South route. From this result, it can also be concluded that the transmission tower route length does not guarantee the best route choice because many other criteria considerations influence the implementation of the transmission tower construction. Therefore, the authors recommend the management of PT. Vale Indonesia, as the owner and operator of the hydroelectric power station, chose the north route for the planned construction of the 150kV transmission tower.

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