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Optimum Haul Road Track Selection on Open Pit Coal Mine By Fuzzy Analytical Hierarchy Process (FAHP) Implementation

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Abstract: The optimal design of roads in mines is very crucial to the success of the mining operation. However, the transportation roads of mines are often inadequately designed and rarely properly maintained in order to save cost. In order to acquire the optimum track of road for the open pit coal mine, analysis of the topography factor, land usage, environment, and geology are needed on the basic engineering design phase. Considering the amount of overlapping and influencing criteria, the method of Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is used. FAHP is the combination of AHP with the mathematical method of fuzzy. The difference between FAHP and AHP is the implementation of the level of importance in the paired comparison of the comparison matrices, which uses Triangular Fuzzy Numbers (TFN). Following the geometric planning of the open pit coal mine haul road, several track alternatives are considered. Fuzzy AHP was used to select the final alternative that should be implemented. The criteria for the fuzzy AHP operation were acquired through expert opinions. The resulting criteria and scores were processed, with the final result of a feasibility ranking of each track alternative. Fuzzy AHP were proven to be very effective to be used in determining the optimum haul road track alternative for an open pit coal mine.

Index Terms: coal mine, fuzzy Analytic Hierarchy Process (Fuzzy AHP), haul road

I. INTRODUCTION

The optimal design of roads in mines is very crucial to the success of the mining operation. However, the transportation roads of mines are often inadequately designed and rarely properly maintained in order to save cost [1]. On the international level, the transportation cost of open pit coal mines is 40% more expensive than what was anticipated in the planning stage which makes the operation less viable economically. The correction to this problem is very important and urgent [2], because a properly designed and maintained road is the key to minimize the coal transport cost. The transportation cost itself could cover up to 50% of the cost of open pit coal mine [3].

In order to acquire the optimum track of road for the open pit coal mine, analysis of the topography factor, land usage, environment, and geology are needed on the basic engineering design phase for the purpose of obtaining the road track with feasible construction, operation, and maintenance cost [4]. Considering the amount of overlapping and influencing criteria, the method of Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is used [5]. The purpose of this research is to get the plan of a transportation road track for the open pit coal mine with the decision making process that involved expert opinions and criteria based on the implementation of Fuzzy AHP. This process is expected to be a model in future planning of transportation roads in mines that could provide properly designed and cost effective solution.

II. FUZZY ANALYTIC HIERARCHY PROCESS

A. Concept of Fuzzy AHP

Fuzzy analytic hierarchy process is considered to be an analytical tool that is a result from the development of AHP. FAHP is the combination of AHP with the mathematical method of fuzzy [6]. The difference between FAHP and AHP is the implementation of the level of importance in the paired comparison of the comparison matrices, which uses Triangular Fuzzy Numbers (TFN) [7]. This means the amount of the paired comparison is not one, but three [8]. According to the concept of fuzzy, the membership function of the criteria's level of importance could be observed in figure 1.

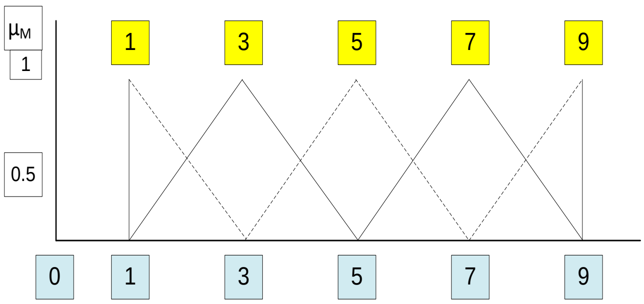

Figure 1. Linguistic Variables for the Importance Weight of Each Criterion

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[9]The logic of fuzzy has a suitable potential for a process of decision making that involves the trend of denying the more precise numerical specification due to the nature of the problem itself or the linkages of the involved parties [10]. The fundamental concept of the fuzzy logic could be observed in figure 2.

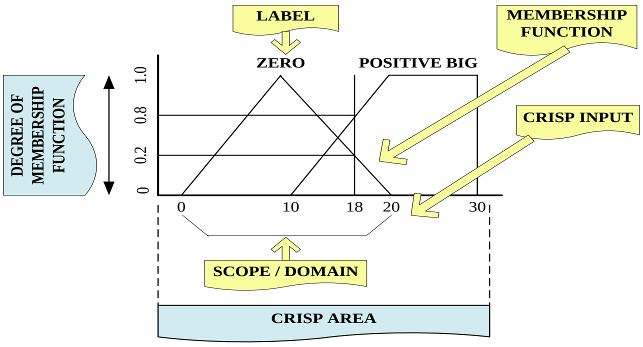

Figure 2. Basic Concept Of Fuzzy Logic
[11]

B. Calculation phases

The extent analysis method was introduced by Chang (1996) to calculate the synthetic value of fuzzy paired comparisons. The process of extent analysis begins with the calculation of fuzzy synthetic extent value [12].

$$Si = \sum_{j=1}^{m} M_{gi}^{j} \, x \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad \text{.......................... (1)}$$

$\sum_{j=1}^{m} M_{gi}^{j}$: is the addition operation of TFN from every row [13], which could be defined as:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left[\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j}^{m} uj\right] \quad \text{........................ (2)}$$

$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}$, is the result of the whole TFN in the paired comparison matrices [14], as explained in the following equation :

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left[\sum_{j=1}^{n} li, \sum_{j=1}^{n} mi \sum_{j=1}^{m} ui\right] \quad \text{.................. (3)}$$

The next step of the process is to calculate the inverse value [12] with the following equation :

$$\left[\sum_{i=1}^{n} li, \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{n} ui}, \frac{1}{\sum_{j=1}^{n} mi}, \frac{1}{\sum_{j}^{n} li}\right) \quad \text{........... (4)}$$

Two TFN values, $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, with the possibility level of $(M_2 \geq M_1)$[15]are defined as

$$V(M_2 \geq M_1) \begin{cases} 1, if \ m_2 \geq m_1 \\ 0, if \ l_1 \geq u_2 \\ \dfrac{l1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \end{cases} \quad \text{..................... (5)}$$

The preferable value for the M convex fuzzy compared to the Mi convex value could be determined with the max and min operation [16] in the following equation:

$$V(M \geq M_1, M_2, \ldots, M_k)$$

$$= V(M \geq M_1) \text{ dan } (M \geq M_2) \text{ and } \ldots \text{ and} (M \geq M_k)$$

$$= \min V(M \geq M_1) \quad \text{.. (6)}$$

With I = 1,2,3, …, k.

Assume that $d(A_1) = \min V(Si \geq Sk)$ for k=1,2,...n; $k \neq i$, so that the weight og the vector [17] could be defined as:

$$W' = (d'(A_1), d'(A_2, \ldots, d'(An))^T \quad \text{........................ (7)}$$

with $A_1 = (i = 1,2, \ldots, n)$ as n element.

The final step of this process is to normalize the acquired weight of the vector [15] with the following operation :

$$W' = (d(A_1), d(A_2, \ldots, d(An))^T \quad \text{........................ (8)}$$

$$d(An) = \frac{d'(An)}{\sum_{1}^{n} ld'(An)} \quad \text{.................................... (9)}$$

with W as non-fuzzy number.

III. FUZZY AHPIMPLEMENTATION AND RESULT

This research utilized Fuzzy AHP to select the correct haul road track alternative for the open pit coal mine. The selection of the track involves many criteria that should be considered [18], which includes the length of the track, the volume of road works, river crossing, geology, and lithology structures.

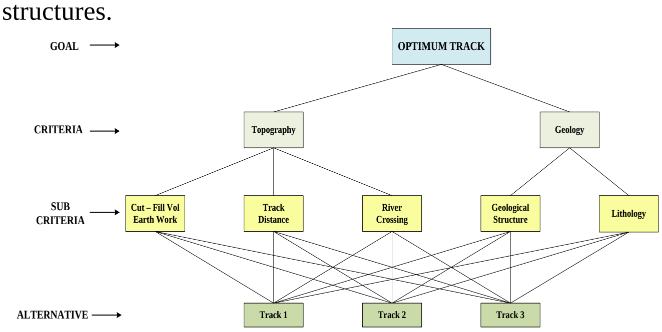

Figure 3. Hierarchy Structure and Criteria

Following the geometric planning of the open pit coal mine haul road [19], several track alternatives are considered. Fuzzy AHP was used to select the final alternative that should be implemented. The flow chart of fuzzy AHP implementation to select the open pit coal mine haul road track alternative could observed in figure 4.

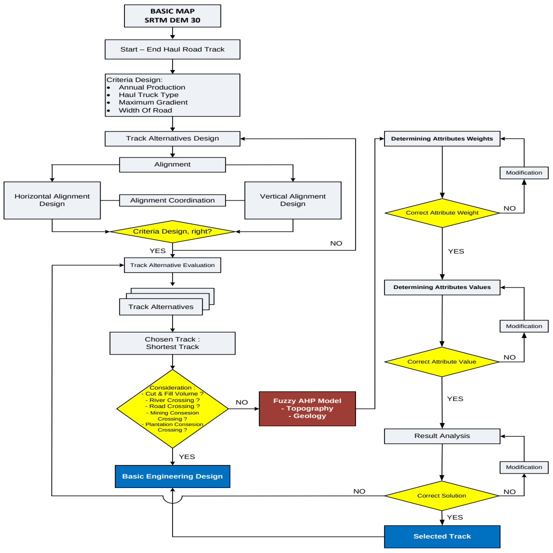

Figure 4. Fuzzy AHP Method for Coal Mine Haul Road Track SelctionFlow Chart

A. Research instrument and adviser

The research instrument used in this research is a questionnaire. The preparation of the questionnaire involved variable identification including its main factors and sub factors, followed by finding the most important factor [20].

The experts interviewed for their opinions are practitioners that have been involved in the mining sector for at least 10 years. The criteria to be scored by the adviser includes track distance, cut-fill volume, river crossing, geological structure, and lithology. Considering the limited amount of experts in coal mine haul road, 7 people were considered enough to satisfy the minimum requirement of fuzzy AHP.

B. Track alternatives

This research utilized Civil 3D software for the geometric planning and the calculation of the cut-fill volume. The result of the cut-fill calculation could be observed on 3 track alternatives listed in table 1.

Table 1.Track Distance and Earth Works Volume

	Track Alternative		
	Alternative 1	**Alternative 2**	**Alternative 3**
Distance (km)	38.775	36.002	42.203
Cut Volume (m3)	6,759,318.79	7,113,799.36	4,733,953.01
Fill Volume (m3)	3,122,984.56	1,814,697.99	2,711,301.94

C. FAHP criteria calculation

After the result of the 7 questionnaires have been processed until the value of the criteria vector are acquired, then with the equation 8 and 9 the value of the normalized weight of vectors from the 7 experts could be acquired as could be observed in table 2-8.

Table 2.Normalization Vector Weight for Comparison Expert #1

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,311342279	
C2	0,894		0,278436355	
C3	0,841	3,212	0,261826186	1
C4	0,213		0,066262427	
C5	0,264		0,082132753	

Table 3.Normalization Vector Weight for Comparison Expert #2

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,873128698	
C2	0,145		0,126871302	
C3	0,000	1,145	0	1
C4	0,000		0	
C5	0,000		0	

Table 4.Normalization Vector Weight for Comparison Expert #3

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,985967499	
C2	0,014		0,014032501	
C3	0,000	1,014	0	1
C4	0,000		0	
C5	0,000		0	

Table 5.Normalization Vector Weight for Comparison Expert #4

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,88327431	
C2	0,132		0,11672569	
C3	0,000	1,132	0	1
C4	0,000		0	
C5	0,000		0	

Table 6.Normalization Vector Weight for Comparison Expert #5

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,906353519	
C2	0,103		0,093646481	
C3	0,000	1,103	0	1
C4	0,000		0	
C5	0,000		0	

Table 7.Normalization Vector Weight for Comparison Expert #6

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,985967499	
C2	0,014		0,014032501	
C3	0,000	1,014	0	1
C4	0,000		0	
C5	0,000		0	

Table 8.Normalization Vector Weight for Comparison Expert #7

Criteria	Min	Total	W	$\sum W$
C1	1,000		0,88327431	
C2	0,132		0,11672569	
C3	0,000	1,132	0	1
C4	0,000		0	
C5	0,000		0	

D. Composite weight for alternative track

The criteria used on the support system of the weighted decision making process for the haul road track alternative is based on the cost incurred. The criteria used are capital expenditures, operating expenses, and maintenance cost.
The result of the composite weight calculation for every track alternatives as the next step of the priority vector weight calculation of each criteria from the 3 experts utilizing the Fuzzy Analytical Hierarchy Process (AHP) are shown in table 9 – 12.

Table 9. Alternative Track Composite Weight - Expert #1

Overall Composite Weight	Weight	Alternative 1	Alternative 2	Alternative 3
Opex	0.589	0.589	0.252	0.159
Capex	0.252	0.608	0.272	0.12
Maintenance	0.159	0.539	0.297	0.164
Composite Weight		**0.586**	**0.264**	**0.15**

Table 10.Alternative Track Composite Weight - Expert #1

Overall Composite Weight	Weight	Alternative 1	Alternative 2	Alternative 3
Opex	0.539	0.49	0.312	0.198
Capex	0.297	0.525	0.334	0.141
Maintenance	0.164	0.595	0.277	0.129
Composite Weight		**0.518**	**0.313**	**0.17**

Table 11. Alternative Track Composite Weight - Expert #1

Overall Composite Weight	Weight	Alternative 1	Alternative 2	Alternative 3
Opex	0.722	0.655	0.211	0.133
Capex	0.174	0.7	0.193	0.107
Maintenance	0.103	0.722	0.174	0.103
Composite Weight		**0.67**	**0.204**	**0.126**

Table 12. Average Alternative Track Composite Weight

Composite Weight	Alternative 1	Alternative 2	Alternative 3
Expert #1	0.5858	0.2641	0.15
Expert #2	0.5178	0.3126	0.1696
Expert #3	0.6699	0.2044	0.1257
Average Comp. Weight	**0.5911**	**0.2604**	**0.1484**

E. Ranking of result

The result of the ranking system were acquired by multiplying the value of the normalized weight vectors with the alternative values of each criteria. The result of the multiplication operation could be observed in table 13.

Table 13.Multiplication Result of Composite Weight Alternativeand Vector Weight

	C1	C2	C3	C4	C5	Total
Weight Vector Normalization	0.311	0.278	0.262	0.067	0.082	1.000
Alternatif 1	0.184	0.165	0.154	0.039	0.049	**0.591**
Alternatif 2	0.081	0.073	0.068	0.017	0.021	**0.260**
Alternatif 3	0.046	0.041	0.039	0.010	0.012	**0.148**

Finally, the results were ranked to select the best alternative. The final rank of the alternatives is shown in table 14.

Table 14.Rank Result F-AHP Method

Track Alternative	Result	Priority Rank
Alternative 1	0.591	1
Alternative 2	0.26	2
Alternative 3	0.148	3

IV. CONCLUSION

1. Geological factors should also be the consideration in addition to the topographical factors in selecting the right track alternative for the haul road in mines.
2. By considering all of the criteria, the track alternative 1 was selected as the optimum alternative, regarding its capital expenditures, operating expensesand maintenance cost.
3. Fuzzy AHP method is very effective in selecting the optimum haul road track alternative in mines.

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