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First Author:	Muhammad Asad Abdurrahman, MEng
Order of Authors:	Muhammad Asad Abdurrahman, MEng
	Lawalenna Samang
	Sakti Adji Adisasmita
	M. Isran Ramli
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A Comprehensive Framework for Evaluating the Feasibility of Upgrading Road Category Based On Analytic Hierarchy Process - Case Study in South Sulawesi Province, Indonesia

M. Asad ABDURRAHMAN [a], Lawalenna SAMANG [b], Sakti Adji ADISASMITA [c], M. Isran RAMLI [d]

[a,b,c,d] *Civil Engineering, Hasanuddin University, Makassar, 90245, Indonesia*
[a] *E-mail: muh.asad@yahoo.co.id*
[b] *E-mail: samang_l@yahoo.com*
[c] *E-mail: adjiadisasmita@yahoo.com*
[d] *E-mail: muhisran@yahoo.com*

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Keywords: Analytical Hierarchy Process, Multi-Criteria Decision-Making, Road Category.

1. INTRODUCTION

Road infrastructure has a significant role in economic growth, where the road infrastructure can reduce the transportation costs so that it can improve the efficiency of the institution (Tamin, 2004). Moreover, it also can reduce the inequality growth between regions within a country or between countries. Canning and Fay (1993, in Tamin 2004) add that the rate of return from transportation can exceed 200% in poor countries and developing countries, and about 50% for the newly industrialized countries. In Indonesia, the road transport infrastructure contributes to the total GDP of 6% (Antemang, 2001 in Tamin, 2004).

Considering that the role of road transport infrastructure is essential; therefore, the road infrastructure management should obtain serious attention. Figure from Public Works Department shows that the development of roads length in Indonesia is increasing. In 2005, the length of the existing road is 291.714 km. The condition of the existing road is 87,903 km in moderate condition and 159,681 km in poor condition and heavily damaged. The conditions of roads in South Sulawesi are 17.21%, 31.97%, and 50.83% in good, moderate and damaged condition respectively. Where the district/municipally roads are the most recorded for moderate conditions and damaged.

The management of road infrastructure should be supported by adequate funding. Currently, in Indonesia, roadwork funding is allocated from the government budget, while that budget comes from general taxation including road use tax. It can be concluded that the method of allocating funds for road management shows that there is no correlation between the basic needs of adequate financing to the allocated fund. In other words, there is a lack of funding for effective road management. In this condition, empirical evidence shows that the government's ability to providing necessary fund is inadequate over the years. The budget for the management of state roads, provincially roads and municipally roads continues to decline (Tamin, 2002) even though the price of construction materials is constantly increasing.

The gap between the financing needs to the funding allocated by the state resulted in local government is hard to manage the road infrastructure. Solution offered is to change the category from district/municipally roads into provincial funded road and/or provincially roads into state funded roads. Since, there is no actual reference to these changes; this paper suggests a comprehensive assessment framework that enables to take a number of major quantitative and qualitative factors into consideration. The Analytic Hierarchy Process (AHP) (Saaty, 1980) is used to evaluate and rank these roads with respect to prescribed criterions. The AHP seems to be a flexible decision making tool for multiple-criterion problems. It enables decomposition of a problem into hierarchy and ensures that both quantitative and qualitative aspects of a problem are included in evaluation process.

2. RESEARCH METHODOLOGY

The assessment for changing road category is a very complex process. Many factors, such as cost, performance, and level of service should be taking into consideration. The proper solution to this complex and multi-criteria problem is to segregate the problem into a number of smaller sub-problems and solve them individually.

The Simple Multi-attribute Rating Technique (SMART) is one of the methods in dealing with the multi-objectives problems. Its main strength is its relative simplicity; however, the cost of its simplicity is that the method may not capture all the detail and complexities of the real problem (Goodwin and Wright, 2004). Decision tree is a valuable tool for people to obtain a deeper understanding of complex problems, but it deals with decision problems that consist of multi-stages. In addition, it involves continuous probability distribution that makes it difficult to use in practice. ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality) (ELECTRE) is another way of evaluating decision options which widely used and applied for many practical problems. However, since the method does not provided a way of obtaining weights and score, the numbers are accepted unchallenged as inputs to a complicated algorithm. Moreover, it compares alternatives but does not produce a single index of performance (Watson and Buede, 1987)

In our evaluating framework, we proposed to utilize analytic hierarchy process (AHP). It offers a number of strength over methods pointed out previously. Its widespread use has verified its popularity among decision-makers. The relative strengths of AHP include: (a) formal structuring of problem; (b) simplicity of pair-wise comparisons; (c) redundancy allows consistency to be checked; and (d) having great diversity or variety. AHP offers an alternative approach when a decision-maker is dealing with a problem that involving multiple criteria. The method that was originally developed by Thomas Saaty (1980) has been commonly used in decision problems in areas such as project selection, economics and planning, material purchasing and handling, and transportation. The process consists of the following steps: (1) Set up the decision hierarchy, (2) Conduct pair-wise comparisons of criteria and alternatives, (3) Convert the comparisons into weightings and check the consistency of the comparisons, and (4) Use the weightings to gain scores for the different options and make a decision.

The study conducted in four road segments as shown in table 1. The road segments located in city of Makassar, Takalar, and Pare-pare within the province of South Sulawesi.

Table 1. Road segment as the alternatives

Road Code	Road Name	Location
A	Tanggul Cempae Rd.	S4.003 E119.622 – S3.991 E119.637
B	Barombong – Buludoang Rd.	S5.210 E119.395 – S5.451 E119.421
C	Makassar – Samata Rd.	S5.191 E119.493 – S5.198 E119.491
D	Pettarani Rd.	S5.174 E119.431 – S5.137 E119.440

This decision hierarchy takes into account a number of tangible and intangible factors in the assessment. These factors and the hierarchy were identified by repetitively interviewing, discussing, and consulting with a number of professional and government staffs. They included officials from the Public Works Department, and Regional Planning Development Agency. Seven criterions with their sub-systems have been identified for the model as listed below:

- A.1. Flow function which describes the performance of road to accommodate the traffic movement.
  - A.1.1. Traffic volume (passenger car unit/hour)
  - A.1.2. Road capacity (passenger car unit/hour)
  - A.1.3. Traffic velocity (km/hour)
- A.2. Hierarchical integration which regards to the alignment with the hierarchy of road network
  - A.2.1. Road function (artery, collector, local)
  - A.2.2. Road class (I, II, IIIA, IIIB, IIIC)
  - A.2.3. Road status (state, provincial, municipality)
- A.3. Multi-modal aspect describes the integration between transportation modal
  - A.3.1. Ratio of intra-province public transport route
  - A.3.2. Connection to airport, sea port, and bus terminal
- A.4. Accessibility and connectivity to inter region
  - A.4.1. Contribution to accessibility index (%)
  - A.4.2. Contribution to mobility index (%)
- A.5. Operational cost to maintain and operate the road
- A.6. Regional development expresses road contribution in supporting the economic zone
  - A.6.1. Connection to city level of I, II, and III
  - A.6.2. Connection to strategic region within province
- A.7. Support system describes the existence of development plan that adjoining the road path

3. AHP AS THE FRAMEWORK FOR EVALUATING THE FEASIBILITY OF UPGRADING ROAD CATEGORY

AHP assists capture both objective and subjective evaluation measures, providing a useful mechanism for inspecting the consistency of the evaluations therefore reducing bias in decision making. When making complex decisions involving multiple objectives, the first step is to decompose the main goal into its constituent sub-goals or sometimes called objectives or criteria, progressing from the general to the specific. This structure contains a goal, criteria or objective and alternative level. Each set of criteria would then be further divided into an appropriate level of detail as illustrated Figure 1.

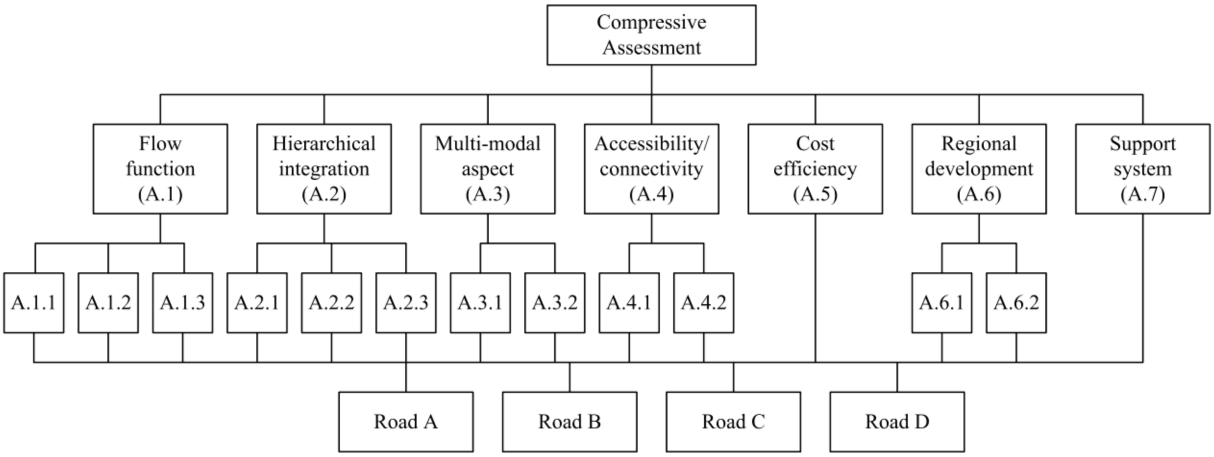

Figure 1. AHP hierarchy of goals, criterions, and alternatives

Generally, the main goal is placed on the top hierarchy while the decision alternatives are at the bottom. The relevant attributes of the decision problem such as the selection criteria and objectives lay between the top and bottom levels reside. Relative weights to each item in the corresponding level are assigned. Each criterion has a local and global priority. The sum of all the criteria beneath a given parent criterion in each layer of the model must equal one. The global priority shows alternatives relative importance within the overall model.

After the criteria factors are identified, scoring of each level with respect to its parent is conducted using a relative relational basis by comparing one option to another. Relative scores for each option are computed within each leaf of the hierarchy. Scores are then synthesized through the model, yielding a composite score for each option at every layer, as well as an overall score.

This relative scoring within each level will result in a matrix of scores, say a(i, j). The matrix holds the expert judgment of the pair-wise comparisons. Nevertheless, the judgment should be consistent. Therefore, inconsistency test is necessary to validate it. The inconsistency measure is useful for identifying possible errors in judgments data entry as well as actual inconsistencies in the judgments themselves. Inconsistency measures the logical inconsistency of the judgments. For instance, if we say that “A” is more important than “B” and “B” is more important than “C” and then say that “C’ is more important than “A”, we are not being consistent. A somewhat less inconsistent situation would occur if we would say that “A” is 4 times more important than “B”, “B” is 3 times more important than “C”, and that “C” is 7 times more important than “A”. In broad-spectrum, the inconsistency ratio should be less than 0.1 be considered as reasonably consistent. Particularly, a matrix a(i, j) is said to be consistent if all its elements follow the transitivity and reciprocity rules below:

$$a_{i,j} = a_{i,k} \cdot a_{k,j} \tag{1}$$

$$a_{i,j} = \frac{1}{a_{j,i}} \tag{2}$$

Where i, j and k are any alternatives of the matrix. For instance if “A” is considered 3 times more important than “B”, then “B” should be 1/3 times more important than “A”. The relational scale used in ranking is presented in Table 2.

Table 2. AHP importance scale

For any pair of objectives i, j:	
Score	Relative importance
1	Objectives i and j are of equal importance.
3	Objective i is weakly more important than j.
5	Objective i is strongly more important than j.
7	Objective i is very strongly more important than j.
9	Objective i is absolutely more important than j.
Note: 2, 4, 6, 8 are intermediate values.	

The pair-wise comparison matrices are able to be represented as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \quad (3)$$

For a consistent matrix, it can be demonstrated that:

$$A = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \quad (4)$$

where A is the comparison matrix , w is the eigenvector and n is the dimension of the matrix. The equation above can be treated as an eigenvalue problem. For a slightly inconsistent matrix, the eigenvalue and the eigenvector are only slightly modified. Saaty (1980) demonstrated that for consistent reciprocal matrix, the largest eigenvalue is equal to the number of comparisons, or $\lambda_{max} = n$. Then he gave a measure of consistency, called Consistency Index as a deviation or a degree of consistency using the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

The average random Consistency Index of a sample size of 500 matrices is shown in the table 3 (Saaty, 1980). Other researchers have conducted simulations with different numbers of matrices (Tummala, 1994; Alonso, 2006). Their indices are different but similar to Saaty's.

Table 3: Random index (RI) for the factors used in the decision making process

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

A Consistency Ratio is a comparison between Consistency Index and Random Consistency Index, or in formula:

$$CR = \frac{CI}{RI} \quad (6)$$

If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. Alternately, if the Consistency Ratio is greater than 10%, the judgment should be revised.

4. ANALYTIC HIERARCHY PROCESS AT WORK

According to the above assessment framework, a weighting was assigned to each of the factors, and scores were given with respect to each of these factors. The weightings were obtained through a purpose-designed questionnaire completed by 21 experts. In addition, a survey was conducted to acquire traffic data and literature review was carried out to obtain additional information. These data are listed in table 4.

Table 4: Recapitulation data collected from the questionnaire, consulting, and survey

Criteria	Sub Criteria	Weight	Road A	Road B	Road C	Road D
Flow function	Traffic volume (pcu/hour)	40%	0.00	28.12	50.17	81.02
	Road capacity (pcu/hour)	30%	0.00	79.29	81.82	94.76
	Traffic velocity (km/h)	30%	0.00	96.11	98.86	86.41
Hierarchical integration	Road function (artery, collector, local)	40%	80.00	95.00	60.00	100.00
	Road class (I, II, IIIA, IIIB, IIIC)	30%	75.00	30.00	60.00	100.00
	Road status (state, provincial, municipality)	30%	60.00	60.00	60.00	60.00
Multi-modal aspect	Ratio of intra-province public transport route	75%	30.00	50.00	35.00	40.00
	Connection to airport, sea port, and bus station	25%	75.00	80.00	60.00	95.00
Accessibility/ connectivity	Contribution to accessibility index (%)	50%	60.00	70.00	80.00	100.00
	Contribution to mobility index (%)	50%	60.00	60.00	50.00	90.00
Operational cost	-	-	45.00	70.00	20.00	25.00
Regional development	Connection to city level of I, II, and III	50%	50.00	100.00	85.00	100.00
	Connection to strategic region within province	50%	100.00	100.00	85.00	100.00
Support system	-	-	100.00	80.00	75.00	100.00

A scale of verbal assessments is used in the questionnaire, namely: Extreme, Very strong, Strong, Moderate and Equal importance along with their corresponding scale of importance (Finan, 1999). Table 5 shows pairwise comparison between main criteria which obtained by expert judgment.

Table 5. Pairwise comparison of main criteria

Criteria	A1	A2	A3	A4	A5	A6	A7
A1	1	1	1	1	3	3	3
A2	1	1	1	2	3	2	2
A3	1	1	1	5	3	3	2
A4	1	1/2	1/5	1	3	2	2
A5	1/3	1/3	1/3	1/3	1	2	2
A6	1/3	1/2	1/3	1/2	1/2	1	1
A7	1/3	1/2	1/2	1/2	1/2	1	1

Then if the columns of the above table are normalized and the resulting rows are averaged we acquire the corresponding weights of each criterion as demonstrated below:

$$\begin{bmatrix} 0.2 & 0.21 & 0.23 & 0.1 & 0.21 & 0.21 & 0.23 \\ 0.2 & 0.21 & 0.23 & 0.19 & 0.21 & 0.14 & 0.15 \\ 0.2 & 0.21 & 0.23 & 0.48 & 0.21 & 0.21 & 0.15 \\ 0.2 & 0.1 & 0.05 & 0.1 & 0.21 & 0.14 & 0.15 \\ 0.07 & 0.07 & 0.08 & 0.03 & 0.07 & 0.14 & 0.15 \\ 0.07 & 0.1 & 0.08 & 0.05 & 0.04 & 0.07 & 0.08 \\ 0.07 & 0.1 & 0.11 & 0.05 & 0.04 & 0.07 & 0.08 \end{bmatrix}$$

Therefore, the row averages are $(0.199\ 0.191\ 0.243\ 0.137\ 0.087\ 0.068\ 0.074)^T$ which explains the priority weight of main criteria. The largest eigenvalue (λ_{max}) of the matrix in Table 5 is 7.448. The random consistency index of a 7 criterion matrix = 1.32 as listed in Table 3; hence, the calculated CI is equal to 0.057 ≈ 0.06. The similar result is found using software package Expert Choice® as shown for this particular criterion in Figure 2. As stated above, a CI ratio that is less than 10% is acceptable and the judgments are considered to be consistent.

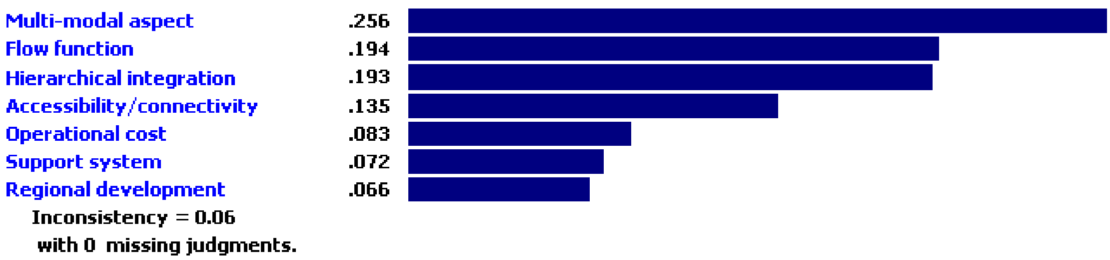

Figure 2. Priority weights of main criteria

For quantitative data, it is allowed to directly assign priorities without having to make paired comparisons. The values of the factors are normalized into dimensionless relative values with a range between 0 and 1. Figure 3 presents the normalized of alternative values in table 4 as the result of direct assessment in Expert Choice®.

Synthesis which is the process of weighting and combining priorities throughout the model after judgments are made to yield the final result. Global priorities are obtained for nodes throughout the model by applying each node's local priority and its parent's global priority. The global priorities for each alternative are then summed to yield overall or synthesized priorities. The most preferred alternative is the one with the highest priority. Figure 4 presents the synthesis with respect to main goal. It shows that road D has the highest priority which expresses the most feasible of changing its category, followed by Road B, Road C, and Road A respectively.

Based on discussion and consulting with the government official as well as with the transportation experts, it already established that the road will be proposed to upgrade its status if its weight is more than 0.25. Regarding this limit value, the Road B (Pettarani Rd) and Road C (Barombong – Buludoang Rd) are selected to be proposed for upgrading their status.

A complete hierarchy of goals and objectives with the corresponding aggregate weights is shown in Figure 5. It shows that multi-modal aspect factor contributes for the most weight in the hierarchy.

Alternative	Pairwise Flow function Traffic volume (L: .400)	Pairwise Flow function Road capacity (L: .300)	Pairwise Flow function Traffic velocity (L: .300)	Pairwise Hierarchical integration Road function (L: .400)	Pairwise Hierarchical integration Road class (L: .300)
Road A	.000	.000	.000	.800	.750
Road B	.347	.837	.972	.950	.300
Road C	.619	.863	1.000	.600	.600
Road D	1.000	1.000	.904	1.000	1.000

Alternative	Pairwise Hierarchical integration Road status (L: .300)	Pairwise Multi-modal aspect Number of intra-province public transport route (L: .750)
Road A	1.000	.600
Road B	1.000	1.000
Road C	1.000	.700
Road D	1.000	.800

Alternative	Pairwise Multi-modal aspect Connection to airport, sea port, and bus station (L: .250)	Pairwise Accessibility/connectivity Contribution to accessibility index (L: .500)
Road A	.790	.600
Road B	.842	.700
Road C	.632	.800
Road D	1.000	1.000

Alternative	Pairwise Accessibility/connectivity Contribution to mobility index (L: .500)	Pairwise Operational cost (L: .083)	Pairwise Regional development Connection to city level of I, II, and III (L: .500)
Road A	.667	.643	.500
Road B	.667	1.000	1.000
Road C	.556	.286	.850
Road D	1.000	.357	1.000

Alternative	Pairwise Regional development Connection to strategic region within province (L: .500)	Pairwise Support system (L: .072)
Road A	1.000	1.000
Road B	1.000	.800
Road C	.850	.750
Road D	1.000	1.000

Figure 3. Normalized of alternative values

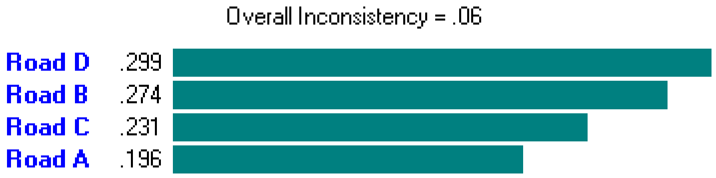

Figure 4. Synthesis with respect to main goal.

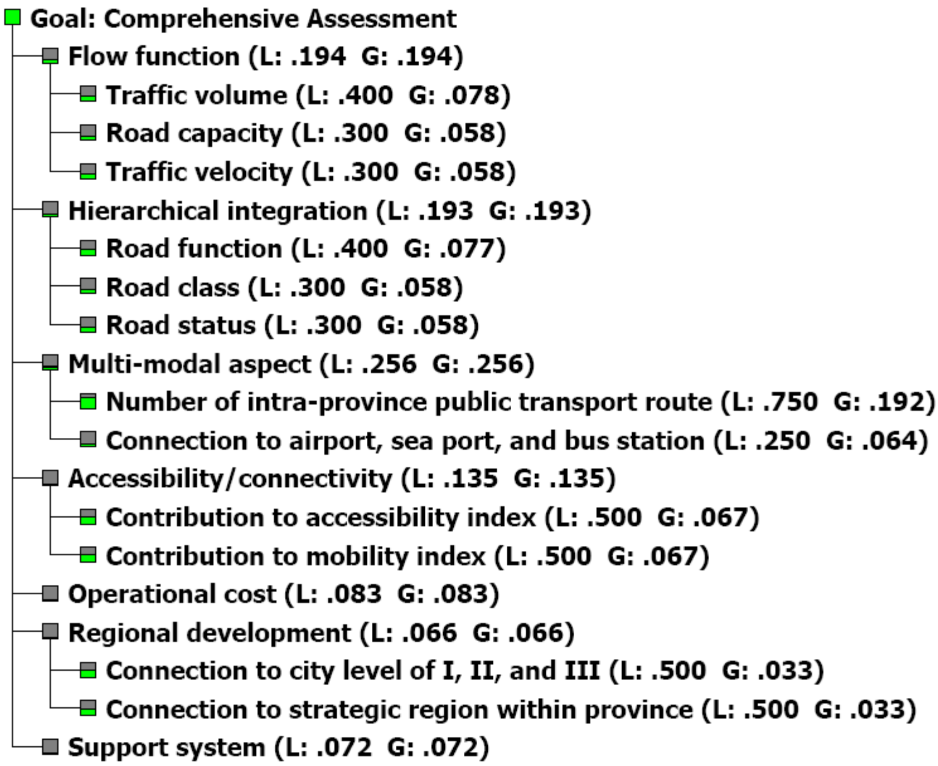

Figure 5. Importance of each factor with respect to the main goal and parent criterion

Lastly, sensitivity analysis is used to investigate the sensitivity of the alternatives to changes in the priorities of the objectives. What-if analysis can be performed with the sensitivity analyses graphs to determine how the overall result would change if the priorities of the objectives were changed. Figure 6 shows the current weights of each main criterion and alternatives with respect to the main goal. Noticeably, the results are in favor of the Road D. Now that the optimum option has been identified, how would the model respond to any changes in the weights of the listed criterions?

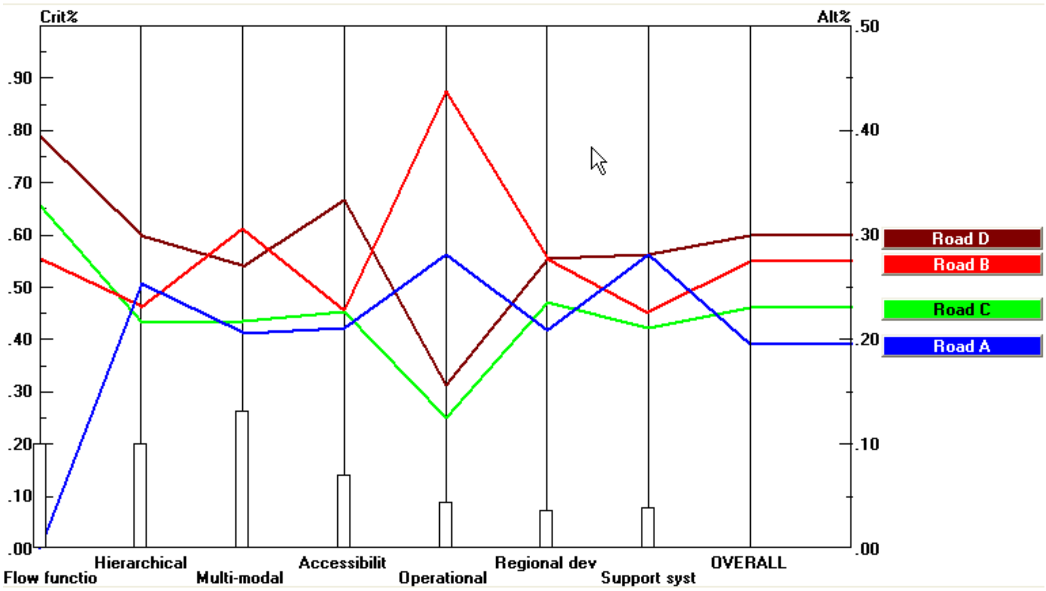

Figure 6. Sensitivity graph of the main factors and alternatives with respect to the main goal.

First, consider the flow function, by increasing the share of this criterion to an extreme of 75% of the main goal, leaving 25% for the others while keeping the proportionality between each, it has been noticed that the model is still in favor of Road D with a score of 36.7% (Figure 6), followed by Road C, Road B and Road A. The same conclusion can be drawn for the hierarchical integration, where the Road D stays as the optimum alternative with a score of 31.7% (Figure 7).

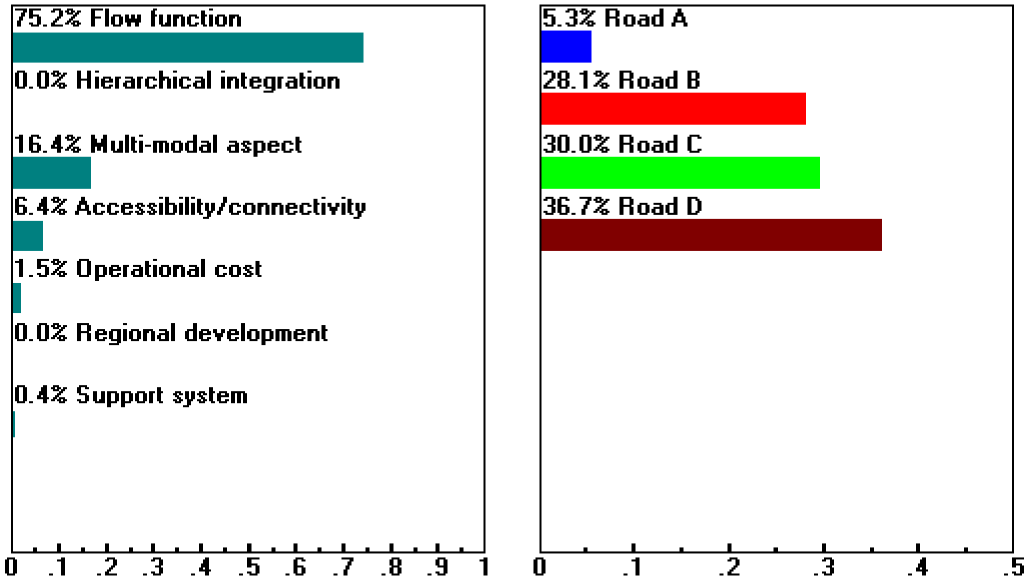

Figure 7. Sensitivity analysis of flow function, the new assigned weights (left) and the resulting scores of the alternatives (right).

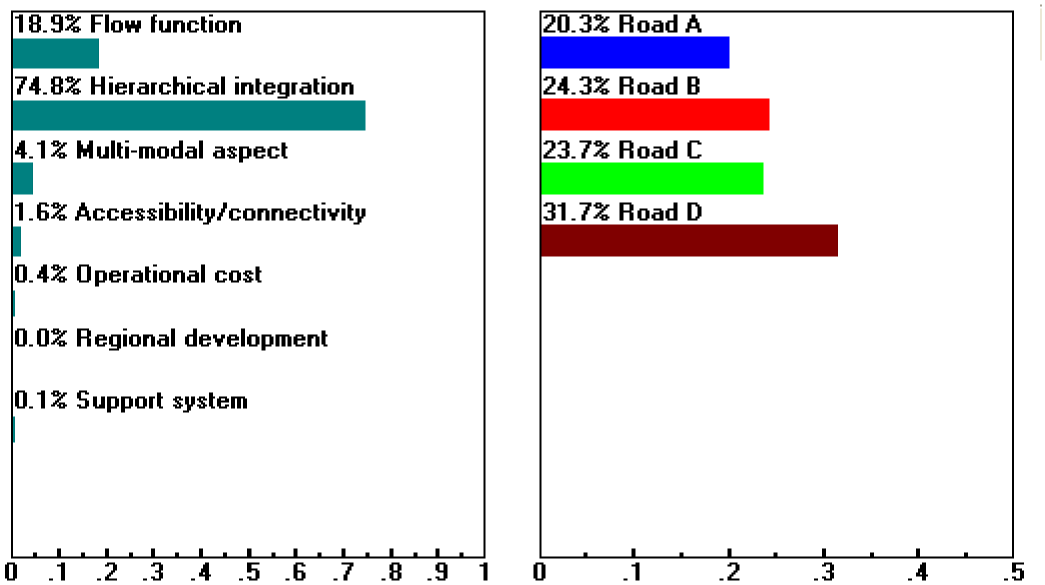

Figure 8. Sensitivity analysis of hierarchical integration, the new assigned weights (left) and the resulting scores of the alternatives (right).

However, if the priority of operational cost is increased to an extreme of 75% of the main goal, the model shows different result where model in favor of Road B with a score of 38.7% (Figure 9). The result is fairly reasonable since the Road B has the longest length; thus, it requires more operational cost.

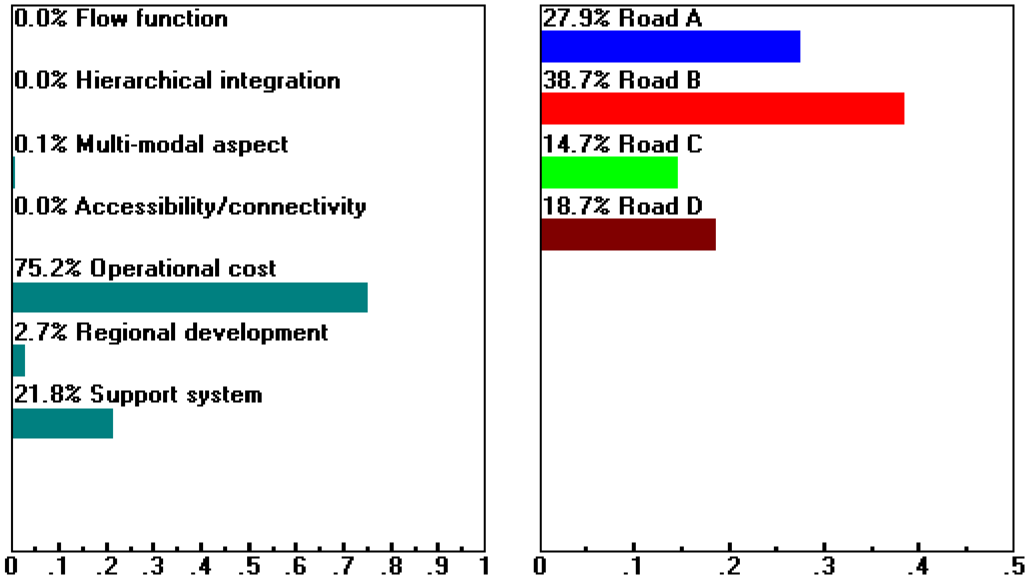

Figure 9. Sensitivity analysis of operational cost, the new assigned weights (left) and the resulting scores of the alternatives (right).

Similar result shown in Figure 10, where the increasing of regional development factor up to 75% resulting the weight priority of Road B to 30.6%. A reasonable explanation is that the Road B located on the south coast so that the road path adjoining to the planned container port.

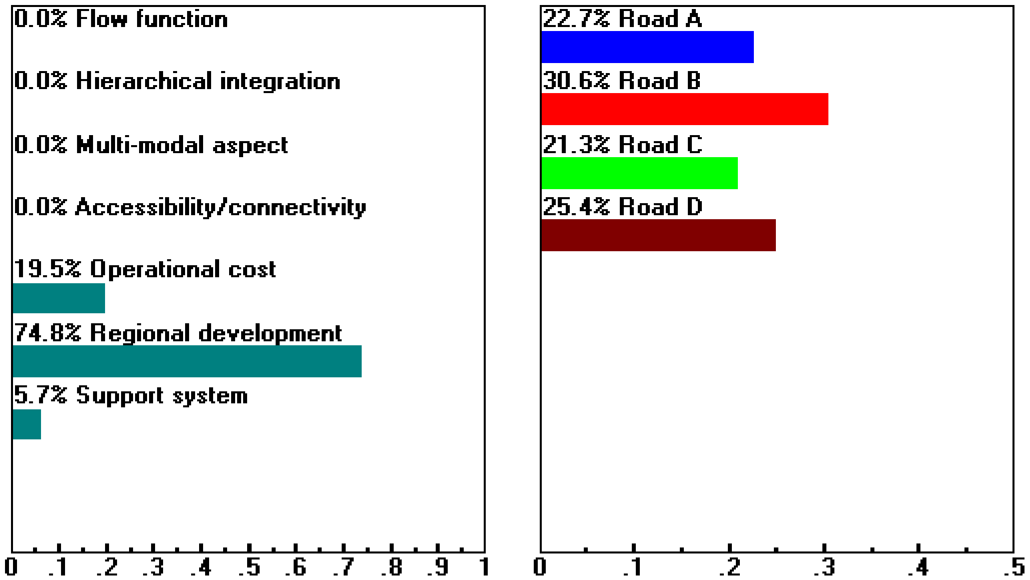

Figure 10. Sensitivity analysis of regional development, the new assigned weights (left) and the resulting scores of the alternatives (right).

5. CONCLUSION

It was observed that the developed analytic hierarchy process (AHP) model works sufficiently and yields adequate results as well as providing accurate decisions. This paper proposes a comprehensive framework, which takes a number of major quantitative and qualitative factors into consideration in the evaluation the feasibility of upgrading road category. Among the major criteria that guide decision maker in the evaluation, the main considerations are flow function, hierarchical integration, multi-modal aspect, accessibility and connectivity to inter region, regional development aspects and existence of support system.

This framework is based on the AHP method and a survey among government officials and transportation experts. The research reveals that Pettarani Rd. (Road D) has significant value; therefore, it is considered feasible to upgrade its category from provincially road to state funded road. Similiary, Barombong – Buludoang Rd. (Road B) also has considerable value to be proposed for upgrading its category from district road to provincial funded road.

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