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# A CONSISTENT METHOD TO DETERMINE FLEXIBLE CRITERIA WEIGHTS FOR MULTICRITERIA TRANSPORT PROJECT EVALUATION IN DEVELOPING COUNTRIES

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**Abstract**: In transport project evaluation, the impacts can be viewed from various aspects. So there is always a conflict of analysis in regard with the impacts of the project. From some aspects point of view, the impacts are often difficult to be valued in monetary terms. These conditions make the application of monetary evaluation such Cost-Benefit Analysis alone often inadequate for transport evaluation. These limitations have led to the development of non-monetary evaluation method known as multicriteria analysis. The use of multicriteria analysis in transportation project evaluation enable decision maker to express his/her view in decision making process. It could also encourage public involvement in the evaluation. The main challenge of multicriteria analysis application is how to determine criteria weights. Different decision maker is likely to give different weight on a criterion. Thus, criteria weights determination in turn could be time consuming and costly. This paper introduces a multicriteria analysis method, called proportion method that is suitable to be applied in developing countries.

**Key Words:** Multicriteria analysis; Criteria weight; Transport project evaluation.

## 1. BACKGROUND

Problems of selecting an alternative out of a set of alternative are commonly experienced by many organizations from the simplest one such as an individual to a complex one such as a nation. The decision to select an alternative is often uneasy. The selection process often involves several criteria to value. In decision making field such decision making processes are handled using multicriteria analysis (MCA) methods.

The use of multicriteria analysis in transport project evaluation is considered since there is always a conflict of analysis in regard with the impacts of the project. The conflict arises as the impacts can be viewed from various aspects (i.e. technical, socio-economic, environmental and political), so that the transport evaluation will be characterised with a process to find acceptable compromise alternatives. From some aspects point of view, the impacts are often difficult to be valued in monetary terms. These conditions make the application of CBA alone often inadequate for transport evaluation. Even when all the impacts can be converted in monetary terms, we still cannot take into account explicitly non-monetary important criteria such as political priorities in the CBA (Tsamboulas, Yiotis and Panou, 1999).

Bristow and Nellthrop (2000) stated that transport project evaluation is generally seen as a toll that provides relevant information to decision-makers in order to prioritising projects within a programme; choosing between alternative solution to a common problem; determining social value for money of particular projects; and deciding when an investment should be undertaken. Thus, evaluation of transport project must be able to follow a situation where decision is made based on consensus and compromise as it will be characterised by a plurality of actors, ideas, and interest (Giorgi and Tandon, 2002).

The use of multicriteria analysis in transportation project evaluation enable decision maker to express his/her view in decision making process. It could also encourage public involvement in the evaluation. The main challenge of multicriteria analysis application is how to determine criteria weights. Different decision maker is likely to give different weight on a criterion. Thus, criteria weights determination in turn could be time consuming and costly.

The main objective of this paper is to present a criteria weight determination method that have consistency and flexibility. The consistency side is represented by method algorithm and the flexibility side is represented by the role of public community and the decision taker in setting criteria weights. A special attention is given to the degree of applicability of the method, so that it could be applied in developing countries.

## 2. MULTICRITERIA TRANSPORT PROJECT EVALUATION

Amongst many multi-criteria analysis methods, Tsamboulas, Yiotis and Panou (1999) identified five most suitable methods for transport evaluation after reviewing the methods on the basis of their track record of application and user acceptance in the appraisal practice, and also examining methods on the basis of their applicability, data requirements, ease of use, and utility of results to different set of problem situation. Those five methods are REGIME, ELECTRE family, analytical hierarchy process (AHP), multiple attribute utility approach (MAUT), and ideal point approach (ADAM method). The last three methods (AHP, MAUT, and ADAM) can be classified in one class namely additive method.

Furthermore, Tsamboulas, Yiotis and Panou (1999) evaluated those five methods based on their adequacy in handling complex and multidimensional evaluation of transportation projects. A method is considered to be adequate if it has four main characteristics namely transparency, simplicity, robustness, and accountability. A method is considered to be transparent if it is understood and well interpreted by decision makers. A method is considered to be simple if it can provide a crisp and well-defined method to represent complex and multidimensional decision situations. A method is considered to be robust if it can be used to analyse inputs related to the performance of different transport initiatives and to produce simple output able to be used to evaluate direct and indirect effects of the initiatives. Accountability of multicriteria analysis methods means that the methods must be able to be used to track back the decision through different stages of the process.

Tsamboulas, Yiotis and Panou (1999) did not arrive to a conclusion that a certain method is the optimum method for transport project evaluation. They suggested that the additive methods are the most straightforward methods for transport project appraisal and Analytic Hierarchy Process (AHP) is the method that satisfies almost all the listed criteria. In addition, based on the application of those five methods, Tsamboulas, Yiotis and Panou (1999) stated that the outcome of AHP method might be considered as a compromise solution.

Sayers, Jessop and Hills (2003) also recommended the use of additive methods, especially the linear additive model (SAW). As stated in the previous section AHP is a variant of SAW. The linear additive model is widely used in the public sector decisions. It is a method that is robust and largely intuitive response to the problem of rank ordering of transport initiatives. Within this method, the various impacts of each alternative of transport project are weighted using numerical values called criteria weights. The weighted criteria are then totalled up to derive a single value for each alternative by which the alternatives are ranked (see formula 5.4). This method is similar to the cost benefit analysis (CBA) where monetary weightings are applied. In general the basic form of simple additive weighting (SAW) method is (Voogd, 1983; Jankowski, 1995):

$$S_i = \sum_{j=1}^{n} c_{ij} w_j \tag{1}$$

or

$$\begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_m \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_n \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ c_{m1} & c_{m2} & \cdots & c_{mn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{2}$$

Where $S_i$ is appraisal score for alternative $i$, and $c_{ij}$ is the score of alternative $i$ with respect to criteria $j$ (usually normalised) and $w_j$ is the weight of criteria j are as before. It implies that the higher the value of $S_i$ the higher is the rank. If we have $n$ criteria, then we will have weight vector ($W$) shown in the equation 4.1 (Chen and Hwang, 1992).

$$\underline{W}^T = (w_1, w_2, ......, w_n) \quad \text{and} \quad \sum_{j=1}^{n} w_j = 1 \tag{3}$$

The main difficulty in applying linear additive model to transport project appraisal is in determining criteria weights ($w_j$). The use of the decision maker value of judgments to determine criteria weights was unsuccessful in France, where it wasted public funds and produced clearly irrational decisions. It also happened that large differences between modes in important criteria such as the value of time or index of efficiency. For these reasons, the multi-criteria evaluation is left and returns to the use of monetary evaluation where standardised monetary values are used for most criteria (Quinet, 2000).

Setting a standard set of criteria weights could actually solve it, but it is argued that the weight of a criterion could be varying in different cases. It can also reduce flexibility of the method in taking into account the particular objectives of each project. On the other hand, giving full freedom to the decision-takers could lead to the problem experienced in France and to the lack of transparency and accountability. It could then be highlighted that there is a need of criteria weights determination method that are both consistent as well as flexible (Sayers, Jessop and Hills, 2003).

## 3. ANALYTIC HIERARCHY PROCESS

The definition and the interpretation of criteria weights are different between authors. Because of the difficulties in measuring and interpreting the criteria weights, it is generally stated that criterion weight measures the importance of a criterion in the multicriteria analysis problem under consideration.

The roles of criteria weights are also different depending on multicriteria analysis methods (Choo, Schoner and Wedley, 1999). Criteria weights determination is an important part of multicriteria analysis as alternatives are selected based on several criteria and criterion weight. Criteria weights are the key point in obtaining the total scores of alternatives and most importantly the conclusion of multicriteria analysis problems. Most multicriteria analysis methods use criteria weights to assess the overall scores of the alternatives.

The criteria weights determination methods could be classified into two main groups namely objective approaches and subjective approaches. In the objective approaches, criteria weights are derived from information contained in each criterion through mathematical models (without decision makers intervention) (Diakoulaki, Mavrotas and Papayannakis, 1995).

In subjective approaches, criteria weights are derived form decision makers subjective judgment. In order to get the subjective judgments, analyst usually gives decision makers a set of designed questions. Subjective criteria weight determination is an uneasy task. It is the point where decision makers have to make compromise before taking final decision. It is often time consuming, especially when there is no agreement between decision makers of the problem under consideration. Subjective weights are generally applied in multicriteria transportation projects evaluation.

There are many methods to derive subjective preference of decision makers regarding criteria weights in transport projects evaluation. One of the most and widely applied method to derive criteria weights in multicriteria analysis is Analytic Hierarchy Process (AHP) (Ramanathan, 1997). It is applied in various disciplines such as regional planning, physical planning, politics, etc. (Saaty, 1994a).

In the AHP method, Saaty (1980) uses the principle eigenvector of positive pairwise comparison matrix to derive criteria weights from decision makers' subjective judgment. Interpretation of criteria weights in subjective approaches is very important. Most subjective approaches assume that all decision makers clearly understand the interpretation of criteria weights. This assumption is rarely happen in reality. Proper interpretation will lead to better design of question given to decision makers in the elicitation process (Choo Schoner and Wedley, 1999).

In AHP, decision makers are asked to compare the relative importance of two criteria. For example, in evaluating transportation project alternatives in which the main goal is to reduce congestion on a particular route (say route 19), the typical question would be: "Of the two criteria, travel time and safety, which one is you consider more important, and by how many times, with respect to alternatives to reduce congestion on route 19?" The decision makers give their judgments based on the judgment scale shown in table 1. The judgements are then summarised in the pairwise comparison matrix. If we call equation 4 as matrix $A = a_{ij}$, then:

$$A = \begin{bmatrix} a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & a_{22} & ... & a_{2n} \\ : & : & ... & : \\ a_{n1} & a_{n2} & ... & a_{mn} \end{bmatrix} = \begin{bmatrix} 1 & w_1 / w_2 & ... & w_1 / w_n \\ w_2 / w_1 & 1 & ... & w_2 / w_n \\ : & : & ... & : \\ w_2 / w_1 & w_n / w_2 & ... & 1 \end{bmatrix} \quad (4)$$

Equation 4 is a reciprocal matrix where all the elements are positive. It contains the derived pairwise comparison, $a_{ij} = w_i/w_j$ ($w_i$ and $w_j$ are the relative importance of criteria $i$ and $j$, respectively), their reciprocals, $a_{ji} = 1/a_{ij}$, and unity as its diagonal elements $a_{ji} = 1$. Zahedi (1995) described that in general all diagonal elements in square matrix $A$ are equal to unity and the triangle under the diagonal line are always the reciprocal of the corresponding triangle above the diagonal line. As a consequence, the number of pairwise comparison is ($n(n-1)/2$), where $n$ is the number of criteria. In other words, we do pairwise comparison only on a half of the matrix (Saaty, 1994b). Saaty (1980) advised that the maximum number of decision elements (e.g. criteria) to be pairwise compared should be less than or equal to nine.

Table 1 – Judgment scale of relative importance for pairwise comparison (Saaty's 1-9 scale)

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective. |
| 3 | Moderate importance | Experience and judgment slightly favour one activity over another. |
| 5 | Strong importance | Experience and judgment strongly favour one activity over another. |
| 7 | Very strong or demonstrated importance | An activity is favoured very strongly over another, its dominance demonstrated in practice. |
| 9 | Extreme importance | The evidence favouring one activity over another is of the highest possible order of affirmation. |
| 2, 4, 6, 8 | For interpolation between the above values | Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it. |

Source: Saaty (1994b), p.26

If we multiply matrix $A$ with vector of weights, $W$, (assuming that the vector of weights, $W$, are known) yields in $AW = nW$ (a system of homogenous linear equations) where $w$ is termed as a principal right eigenvector of $A$ and $n$ is therefore the eigenvalue of $A$:

$$(A - nI)W = 0 \quad (5)$$

or

$$Aw = \begin{bmatrix} 1 & w_1 / w_2 & ... & w_1 / w_n \\ w_2 / w_1 & 1 & ... & w_2 / w_n \\ : & : & ... & : \\ w_n / w_1 & w_n / w_2 & ... & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ : \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ : \\ w_n \end{bmatrix} = nw \quad (6)$$

If decision makers judgments are perfectly consistent in which all pairwise comparisons are equal to $a_{ik} = a_{ij} \times a_{ji}$ (for $i$, $j$, and $k$ = 1, 2, 3, …, n), then the principal right eigenvector of $A$ is equal to $n$ (Saaty, 1990). However, perfectly consistent judgments (equation 6) are rarely happen in reality, so that the eigenvalue of $A$ equal to $n$ is also rarely happen. As consequence, the largest eigenvalue ($\lambda_{max}$) will be always greater than or equal to $n$ and equation 6 is transformed to:

$$AW = \lambda_{\max} W \tag{7}$$

The system of linear equation (equation 6) can be used to determine the relative importance for all pairwise-compared elements. The vector of weights, $W$, is obtained from normalising the eigenvector connected to the largest eigenvalue ($\lambda_{max}$) to sum 1. Because all columns of $A$ differ by a multiplicative constant, the solution of $W$ of equation 5 is unique (Saaty, 1980; Hwang and Yoon, 1981).

Several methods have been developed in order to calculate the principal right eigenvector ($W$) as well as its largest eigenvalue ($\lambda_{max}$) of the square matrix A (equation 5.5). Those methods are eigenvalue method, the Average of Normalised Columns (ANC) method, the Normalisation of Row Averages (NRA) method, and the Normalisation of the Geometric Mean of the row (NGM) method. Amongst those methods, the eigenvalue method has been found to be the best method (Saaty 1980; Saaty and Vargas 1982). The NGM has an advantage that it is mathematically easy to apply (Klungboonkrong 1998). Equation 8 is the NGM method to estimate the principal right eigenvector (W) and equation 9 is its largest eigenvalue.

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{kj}\right)^{1/n}} \tag{8}$$

and

$$\lambda_{\max} = \sum_{i=1}^{n}\left\{\left(\sum_{j=1}^{n} a_{ij}\right) \times w_i\right\} \tag{9}$$

The closeness between $\lambda_{max}$ and $n$ can be used to measure the degree of inconsistency of the square matrix $A$. The closer $\lambda_{max}$ to $n$ the more consistent is the square matrix $A$. Saaty (1980) established Consistency Index (CI) of the square matrix A.

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{10}$$

In order to decide whether the CI is acceptable or not, Saaty (1980) also provided the Random Consistency Index (RI), which is the average CI of a randomly generated reciprocal matrices (500 sample size) with dimension *n*. The degree of inconsistency of the square matrix A can be measured by the ratio of CI to RI, which is called the Consistency Ratio (CR). We can conclude that the matrix is sufficiently consistent and accept the matrix when CR≤0.1. If CR>0.1, it can be concluded that the inconsistency is too large and unacceptable, so that decision makers must revise their judgments.

Table 2 – The Random Consistency Index (RI)

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 |

Source: Saaty (1994b), p.42

There are some applications of AHP in transport evaluation. Saito (1987) used AHP to evaluate bridge improvement programs. AHP were employed to derive numerical values to be used in evaluation as well as to transform and aggregate different judgments of different decision makers.

Tracz and Wawrzynkiewicz (1993) used AHP in the selection of public transport system alternatives. Khasnabis and Chaudry (1994), based on their application of AHP to evaluate transit privatisation projects in Detroit metropolitan area, found that AHP is feasible tool for priority ranking of transportation projects. Tabucanon and Lee (1995), in their study of evaluation of rural highway improvement projects in Korea, concluded that the application of AHP gave more balanced outcomes for various conflicting criteria compared to traditional economic evaluation method.

Gercek, Karpak and Kilncaslan (2004) employed AHP to evaluate three alternatives of rail transit networks in Istanbul, AHP was found to be useful for multifaceted planning process. Although the AHP has been found to be the best method for transportation projects evaluation, its application in transportation project evaluation is relatively scarce, especially in developing countries. The application of AHP in developing countries could face a problem in which decision makers would not understand the decision process, leading to a loss of transparency. The hierarchical structure and the use of the additive compositional rule may also reduce the degree of accountability of the AHP, especially when there are large decision elements, as decision makers would be hard pressed to backtrack their judgments.

Some adjustments of AHP to apply in developing countries might be needed, so that it will be easier for decision makers to follow the decision process. If the method is easy to understand as well as to apply, it could encourage public involvement in the decision making process, which might be rare in the case of developing countries.

The Highway Development and Management manual (HDM-4), a system for road project evaluation usually applied in developing countries, suggested applying multicriteria analysis if non-monetary impacts such as environmental impacts will be included in the evaluation. To avoid problems such as in France, so that there is a strong need of multicriteria analysis procedure that can be applied in developing countries. The procedure must have both consistency and flexibility. Consistency means that the procedure is accepted as guidance so that can be used to reach an agreement between decision maker and flexibility means that the procedure can follow different objectives. Otherwise the problem of wasting public fund and irrational decision will happen. If such problem occurred in developed countries where debate and changed ideas are common in decision making, so it could also happen in developing countries.

## 4. DEVELOPMENT OF MULTICRITERIA ANALYSIS METHOD FOR DEVELOPING COUNTRIES

Transport project evaluation is a process where decision makers, mostly elected politicians, analyse information provided by professional transport planners regarding advantages and disadvantages of available alternatives. Decision making for transport project alternatives is most likely done by decision makers of different backgrounds of knowledge and expertise.

The central part of the decision making process using multicriteria analysis is the criteria weights determination process. In the criteria weights determination process, decision makers from different institutions with different objective would try to harmonise their objectives, which is then reflected in term of criteria weights.

In the development of transport project evaluation, it is necessary to identify conditions of decision makers in relation to factors such as level of education and educational background. It is considered that most decision makers in developing countries would have difficulty in understanding the criteria weights determination process using the AHP. For this reason, a simpler method is developed.

### 4.1. Assumptions

Assumptions of this method are: a). All alternatives score with respect to all criteria are known or has been estimated by the analyst. The task of decision maker is to determine criteria weights only. b). All criteria are normalised, so that they have commensurable unit. The following formulae, called ideal point concept (Hwang and Yoon, 1981), are typically employed for criteria normalisation. For benefit criterion the normalised values are calculated using the following formulae:

$$c_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{11}$$

and for the cost criterion the normalised values are calculated using the following formula

$$c_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{12}$$

where $x_{ij}$ is the score of alternative $i$ with respect to criteria $j$ before normalisation. After normalisation all criteria are in benefit criteria where higher $c_{ij}$ is preferred.

### 4.2. Criteria Weights Determination

Subjective criteria weight in general could be determined using the direct method (or absolute measurement) and relative measurement. The direct method or absolute measurement is an easy one. In the direct method, decision maker is only required to rank the criteria and give subjective judgment or quantitative values to the criteria based on the defined rank. In direct method or absolute measurement, the criteria are independent of each other. In relative measurement (e.g. the AHP), the criteria are dependent each other. The direct method has been applied in many multicriteria analysis problems (see for example Hwang & Yoon 1981; Cheng, Yang & Hwang 1999; Yeh, Deng & Chang 2000; Aldian & Taylor 2003).

Criteria weights determination in this method is considered to be in the midway between absolute measurement and relative measurement. In this method, a decision maker is first asked to rank the available criteria and then asked to decide the proportion of each criterion in each pair of criteria. A consistent subjective judgment is achieved when the order of criteria weights is the same as the order of criteria rank determined previously.

A decision maker is more likely to be able to rank the criteria, but it could find difficulty in directly providing specific values for criterion weight, especially when relatively large numbers of criteria are used. To ease this situation, the decision maker is asked to give direct weight for criteria in each pair of criteria only. The verbal judgments of Saaty's 1-9 scale could be then used to determine the direct weight of a criterion, which is a proportion of each criterion in a pair of criteria (see Table 3).

Table 3 – Proportion of criterion *i* and *j* and the definition

| Criterion i (%) | Criterion j (%) | Definition |
|---|---|---|
| 50 | 50 | i and j are equally important |
| 60 | 40 | i is moderately more important than j |
| 70 | 30 | i is strongly more important than j |
| 80 | 20 | i is very strongly more important than j |
| 90 | 10 | i is extremely more important than j |
| 50 + z | 50 - z | intermediate terms (0<z<50) |

This method follows the main principle of the simple additive weighting method. In simple additive weighting, the weight of a criterion *j* could be interpreted as a proportion of criterion *j* in 1 unit of overall value (final score of an alternative). Thus, $w_j$ = 0.2 means that the proportion of criterion *j* in 1 unit of overall value is 20 percent.

For example, we have two criteria *i* and *j*, and the scores of alternative *k* with respect to criterion *i* and criterion *j* are both 1, and $w_i$ is 0.4 and $w_j$ is 0.6. Using the simple additive weighting method, we have final score of alternative *k* = 1 ((1 x 0.4) + (1 x 0.6)). We could say that in the final score of alternative *k*, the proportion of criterion *i* is 0.4 and the proportion of criterion *j* is 0.6.

In order to obtain the subjective judgment of decision makers, an example of a question to be given to decision maker could be: "In order to value alternatives to reduce congestion on route 19, please rank the importance of the criteria and determine the relations between a given criterion and a lower rank criterion".

The main element of this method is the proportion of a criterion in each pair, so that we might call the method the proportion method. The proportion method is easier to interpret as pairwise comparison is based on common terms used by many people when stating the proportion of an element composed by several different elements, such as fifty percent, forty percent, etc. People are more likely to use the term of fifty-fifty (which means fifty percent-fifty percent) to express their view that two things are equally strong, equally important, or equally probable rather than other statements such us one-one. The fifty-fifty statement can also easily be found when someone wants equal share of something such as benefit, investment, etc. The statement such as fifty-fifty, sixty-forty, and so on are very familiar in everyday life almost everywhere.

In the proportion method, the proportion of all pairs are inserted into a proportion matrix where $a_{ij}+a_{ji}=1$ and $0< a_{ij}<1$, and its diagonal elements are all zero. Equation 4 then become:

$$A=\begin{bmatrix} 0 & a_{12} & \dots & a_{1n} \\ 1-a_{12} & 0 & \dots & a_{2n} \\ : & : & \dots & : \\ 1-a_{1n} & 1-a_{2n} & \dots & 0 \end{bmatrix} = \begin{bmatrix} 0 & b_{12} & \dots & b_{1n} \\ b_{21} & 0 & \dots & b_{2n} \\ : & : & \dots & : \\ a_{n1} & a_{n2} & \dots & 0 \end{bmatrix} \tag{13}$$

and

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{(n \times ((n-1)/2))} \tag{14}$$

For example we have criteria as follows: safety, environmental, travel time, and accessibility in a road project evaluation. The decision maker is then asked to rank the level of importance of each criterion with respect to the objective/s. If the decision maker ranks the criteria as follows: 1) environmental, 2) safety, 3) travel time, and 4) accessibility, and the decision maker gives proportion of each criterion in each pair consistently, then the matrix will be:

Table 4 – An example of weights determination using the proportional method

| | **Environmental** | **Safety** | **Travel Time** | **Accessibility** | **Total** | **Weight** |
|---|---|---|---|---|---|---|
| **Environmental** | 0 | 0.6 | 0.7 | 0.8 | 2.1 | 0.35 |
| **Safety** | 0.4 | 0 | 0.6 | 0.7 | 1.7 | 0.28 |
| **Travel Time** | 0.3 | 0.4 | 0 | 0.6 | 1.3 | 0.22 |
| **Accessibility** | 0.2 | 0.3 | 0.4 | 0 | 0.9 | 0.15 |

Table 4 can be read as follows: for example if only two criteria (say accessibility and safety) are used in the evaluation and the decision maker gives 70 percent for safety and 30 percent for accessibility, then we must put the proportion of safety in the cell where safety row meet accessibility column and put the proportion of accessibility in the cell where accessibility row meet safety column. Table is 100 percent consistent where the order of criteria weights is equal to the order of previously defined rank.

### 4.3. Comparison Between the Proportion Method and AHP

If the decision maker wants to use AHP to calculate his/her subjective judgments (using Equation 8), then the results are as shown in Table 5.

Table 5 – Pairwise comparison matrix

| | Environmental | Safety | Travel Time | Accessibility | Weight |
|---|---|---|---|---|---|
| **Environmental** | 1 | 3 | 5 | 7 | 0.56 |
| **Safety** | 0.33 | 1 | 3 | 5 | 0.26 |
| **Travel Time** | 0.20 | 0.33 | 1 | 3 | 0.12 |
| **Accesibility** | 0.14 | 0.20 | 0.33 | 1 | 0.06 |

Based on Table 4 and Table 5, it can be seen that the differences between weights calculated using the proportion method are much lower than those calculated using AHP. The results of AHP give more than 50 percent of the total of criteria weights to environmental criteria. It shows that the proportion method produce more balanced weights.

For comparison, recalculation of the half of the matrix above diagonal line is done. The recalculation uses the estimated weights instead of the subjective judgments. The comparison results are shown in Table 6, Figure1, and Figure 2.

The estimated results of the proportion method are closer to the subjective judgments (the total percentage of difference is 0.51). All the estimated comparison values of the proportion method are lower than the actual comparison values. For example actual comparison value between environmental criteria and safety criteria is 0.6 and the estimated comparison value is 0.55.

The total percentage of difference of AHP is 1.7. The estimated values of pairwise comparison show that the AHP tends to give higher importance to the more favourable alternatives or criteria than to the less favourable ones. Based on the estimated pairwise comparison, environmental criteria is 10.25 times more important that accessibility criteria, while the actual pairwise comparison gives environmental criteria 7 times more important that accessibility criteria.

Table 6 – Actual and estimated value of the half of matrix

| AHP | | | | Proportion | | | |
|---|---|---|---|---|---|---|---|
| Ratio | Actual | Estimated | % of difference | Proportion | Actual | Estimated | % of difference |
| Env/Saf | 3 | 2.14 | 0.40 | Env/(env+Saf) | 0.6 | 0.55 | 0.09 |
| Env/TT | 5 | 4.79 | 0.04 | Env/(env+TT) | 0.7 | 0.62 | 0.13 |
| Env/Acc | 7 | 10.25 | 0.46 | Env/(env+Acc) | 0.8 | 0.70 | 0.14 |
| Saf/TT | 3 | 2.24 | 0.34 | Saf/(Saf+TT) | 0.6 | 0.57 | 0.06 |
| Saf/Acc | 5 | 4.79 | 0.04 | Saf/(Saf+Acc) | 0.7 | 0.65 | 0.07 |
| TT/Acc | 3 | 2.14 | 0.40 | TT/(TT+Acc) | 0.6 | 0.59 | 0.02 |
| Total | | | 1.70 | Total | | | 0.51 |

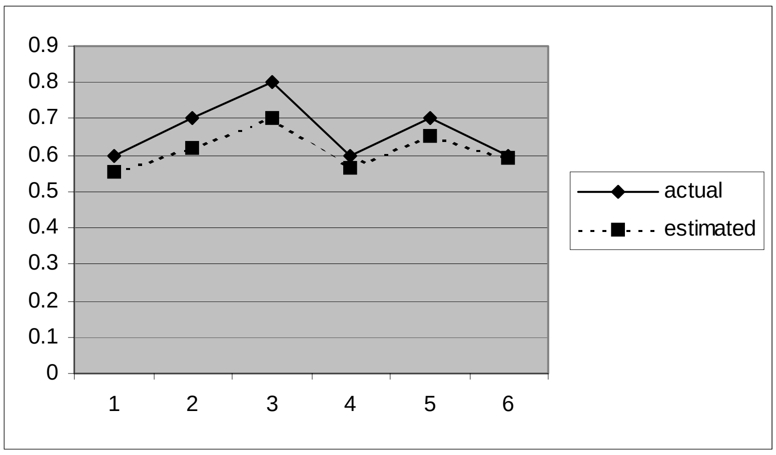


Figure 1 – Actual and estimated weights using the proportion method

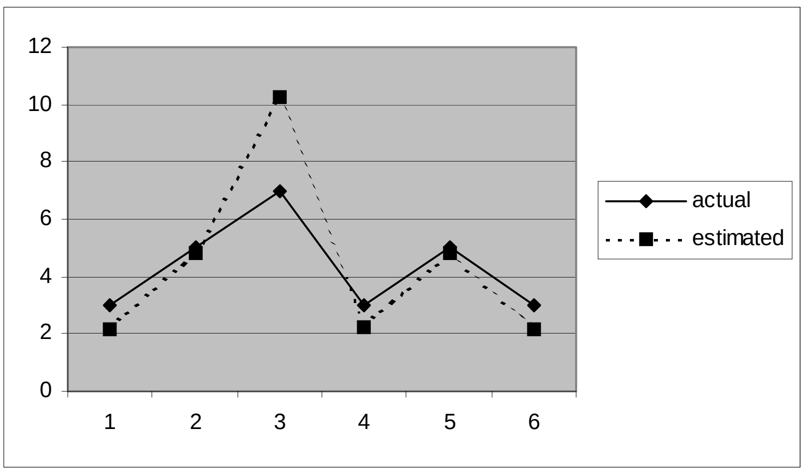


Figure 2 - Actual and estimated weights using AHP

### 4.3. Group Decision Making

In the proportion method, group decision making is also considered. The subjective judgments are not aggregated directly, the relation of subjective judgments of different decision makers are taken into account. Coefficient of correlation between subjective weights of different decision makers involved in the decision making could be used to measure this relation. The higher the coefficient of correlation of the subjective judgments between two decision makers the closer is the agreement between these two decision makers. In contrast if the correlation is negative, it measures the degree of disagreement.

The coefficients of correlation are then used to determine the weight of subjective judgments of each decision maker in determining the criteria weights in the group decision making. The weight of each decision maker in the decision process can be determined using Equation 16, where $w_d$ is the weight of decision maker, $t$ is the number of decision maker, and $r_{dl}$ is the coefficient of correlation between subjective judgment of decision maker $d$ and $l$. The exponential value is used to convert all coefficients of correlation into a positive sign.

$$c_d = \left( \sum_{l=1}^{t} \exp(r_{dl}) \right) - \exp(r_{dd}) \qquad (15)$$

and

$$w_d = \frac{c_d}{\sum_{l=1}^{t} c_l} \qquad (16)$$

The criteria weights from group decision making ($w_{jg}$) can be determined using Equation 17 where $w_{jd}$ is weight of criteria $j$ according to decision maker $d$.

$$w_{jg} = \sum_{d=1}^{t} w_d w_{jd} \qquad (17)$$

For example considering four decision makers involve in a decision process and four criteria weights, environmental, safety, travel time and accessibility that must be assessed. The criteria weights assessed using the proportion method by each decision maker is as follows:

| | DM 1 | DM 2 | DM 3 | DM 4 |
|---|---|---|---|---|
| Environmental | 0.35 | 0.29 | 0.32 | 0.18 |
| Safety | 0.28 | 0.25 | 0.3 | 0.32 |
| Travel Time | 0.22 | 0.24 | 0.23 | 0.24 |
| Accessibility | 0.15 | 0.22 | 0.15 | 0.26 |

We have a matrix of coefficient of correlation as follows:

| | DM 1 | DM 2 | DM 3 | DM 4 |
|---|---|---|---|---|
| DM 1 | 1.000 | 0.970 | 0.970 | -0.379 |
| DM 2 | 0.970 | 1.000 | 0.882 | -0.588 |
| DM 3 | 0.970 | 0.882 | 1.000 | -0.165 |
| DM 4 | -0.379 | -0.588 | -0.165 | 1.000 |

Then finally we have the weight of each decision maker as follows

| | DM 1 | DM 2 | DM 3 | DM 4 | $C_d$ | $W_d$ |
|---|---|---|---|---|---|---|
| DM 1 | 2.718 | 2.637 | 2.637 | 0.684 | 5.958 | 0.305 |
| DM 2 | 2.637 | 2.718 | 2.416 | 0.555 | 5.608 | 0.287 |
| DM 3 | 2.637 | 2.416 | 2.718 | 0.848 | 5.901 | 0.302 |
| DM 4 | 0.684 | 0.555 | 0.848 | 2.718 | 2.088 | 0.107 |

The final weights (the combined weights) of environmental, safety, travel time, and accessibility are 0.306, 0.282, 0.231, and 0.182 respectively. The correlation coefficient between the group subjective criteria weights and the subjective criteria weights of each decision maker, started from decision maker 1 to decision maker 4, are 0.986, 0.916, 0.996, and –0.227. It can be seen that the group subjective criteria weights do not reflect the subjective criteria weights of decision maker 4. This is because the subjective weights of decision maker 4 contradict the subjective weights of the other decision makers. This decision maker has a high degree of disagreement with other decision makers.

In this method, the decision maker then knows their position amongst other decision makers, which can reduce conflict between decision makers. Group decision making using the proportion method would ensure that the process is transparent.

Overall this method could be used as a rule in transport project evaluation in developing countries and could ensure the consistency of the process. On the other hand, decision makers are given full freedom to decide criteria weights using easy and transparent multicriteria analysis method, so that the flexibility of the evaluation process to meet the objectives of any projects can be assured.

## 5. CONCLUSION

In this paper a method to determine criteria weights using multicriteria analysis is presented. The method, called proportion method, gives more transparent results in which it is easy to understand and could encourage involvement of any parties, affected by the project, to participate in the decision making process. However, real application of this method is needed to detect real problems that the method may encounter.

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