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Establishing the Index System for Sustainable Urban Transport Project Selection: an Application of Group MCDM based on the Fuzzy AHP Approach

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ABSTRACT: *The selection of urban transport projects can be viewed as a multiple criteria decision making problem (MCDM). This type of project typically has to achieve multiple targets such as economic, social, and environmental targets simultaneously; and it plays an important part in the future of the ecosystem in urban areas, and the country as a whole. The aim of this study is to propose a method for the sustainable urban transport selection problem. This method is based on two groups of criteria, namely, the expected impact of a project and the main barriers in the implementation of a project. After structuring the hierarchy, the fuzzy AHP is applied to determine the relative weights of the evaluation criteria. The results show that safety is the most important criterion of the future expected impacts and, at the same time, having support from relevant agencies is the most difficult job in the implementation. It is expected that the proposed method may serve as a reference for selecting urban transport projects.*

KEYWORDS: *Decision making process, Fuzzy analytical hierarchy process, Fuzzy sets, Urban transport project*

I. INTRODUCTION

In order to provide safe, fast, convenient and efficient transportation of passengers and goods, the transportation network must be adequate as it plays a vital role in the promotion of a country's development. The transport projects typically have a high investment capital and a long payback period. The costs and benefits of the project occur over an extended period of time. This means that when planning a transportation network, planners must predict the future impacts for an extended period of time. In Vietnam and other countries, the selection of a project in general and transport project in particular is based on the economic and financial analysis in which the comparison of the cash flow of all costs and benefits resulting from the project's activities is made [1]. There are four commonly used methods of comparing alternative investments, namely, net present value (NPV), rate of return, benefit-cost analysis, and payback period. Mahmoodzadeh et al. [2] reviewed these methods and pointed out the advantages and limitations of each method. These methods are very useful in evaluating and selecting projects from an economic perspective. However, applying the methods to evaluate the transport project is sometimes inadequate, especially in developing countries in which the complexity of computational tools and lack of information are barriers. In addition, the transport project has a direct impact on the performance of all social and economic sectors, and it is also one of the potential threats to the ecosystem. To achieve a sustainable transport system is one of the three major development goals of a liveable city [3]. Hence, the transport project should also be evaluated and selected on the basis of social, economic effect and sustainability.

Various studies have addressed the transport project selection problem in which some innovative approaches have been utilized. Nosoohi and Shetab-Boushehri [4] applied a fuzzy inference system for selecting infrastructure transportation projects. Gercek et al. [5] used the AHP method to evaluate three alternative rail transit network proposals in Istanbul. The above mentioned studies are significant ones which have differences in their theoretical approaches. In our research, we determine the relative weights of criteria for urban transport project selection based on experts' opinions. Specifically, the criteria are identified through literature investigation and guidelines. Then, we employ the fuzzy analytic hierarchy process (FAHP) to calculate the weights of criteria and attributes. Group multiple criteria decision making (MCDM) is an overlapping field of group decision making and multiple criteria decision making. Decision making is the study of identifying and choosing alternatives based on the judgments of the decision makers. It has been proved that a decision made by a group tends to be more objective and effective than a decision made by an individual. Therefore, group decision making is an aggregate decision making process in which individuals' decisions are grouped together to solve a particular problem. A major part of decision making involves the analysis of a set of alternatives described in terms of some evaluative criteria. In order to find the most suitable alternative or determine the relative priority of each alternative, it requires to rank these alternatives.

Solving such problems is the focus of Multiple Criteria Decision Making (MCDM) in decision and information sciences. MCDM is supported by a set of techniques; some of the main techniques are the analytic hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS), preference ranking organization method for enrichment evaluation (PROMETHEE), and elimination and choice translating reality (ELECTRE). Among these, the AHP approach has appeared to be a very popular method and has been widely applied to deal with various complex decision making problems. In the AHP, each alternative is compared with every other alternative in terms of the relative importance of its contribution to the criterion under consideration. The pair-wise comparisons are represented in the form of crisp values. The comparison is repeated for each criterion and the pair-wise comparison matrix is then formed. The weight vector can be obtained from the pair-wise comparison matrix. The pure AHP method tends to be less effective when dealing with the uncertainty in the decision making process.

This led to the development of fuzzy AHP methods. Since its appearance, the fuzzy AHP method has been widely used by many researchers to solve different decision making problems in various areas. Mikhailov and Tsvetinov [6] used fuzzy AHP to deal with the uncertainty and imprecision of the service evaluation process. Chan and Kumar [7] presented a fuzzy extended AHP approach to select the best supplier considering risk factors. Chang et al. [8] applied the fuzzy AHP method to construct an expert decision making process. Celik et al. [9] applied the fuzzy extended AHP method to structure a practical decision support system in shipping registry selection. Lee [10] developed an intellectual capital evaluation model based on fuzzy AHP for assessing the performance contribution in a university. Apart from the aforementioned applications, there are still many studies of fuzzy AHP for solving other different managerial problems. Therefore, fuzzy AHP is appropriate for determining the weights in the evaluation index system. In this paper, the fuzzy AHP method proposed by Buckley [11, 12] is utilized to calculate the criterion and attribute weights for urban transport project selection structure. On the basis of the structure, the evaluation of the projects and the selection of the best alternative projects can be carried out. The remainder of the paper is organized as follows. After introduction, the fuzzy AHP and some related concepts are presented in Section 2. In Section 3, the structure for sustainable urban transport project selection is introduced. Section 4 presents the proposed framework in group MCDM, and its application in determining the attribute weights for sustainable urban transport project selection; finally, Section 5 includes the conclusions.

II. FUZZY ANALYTIC HIERARCHY PROCESS

1.1. Fuzzy sets and fuzzy numbers

Fuzzy set theory was first introduced by Zadeh [13] to deal with the uncertainty due to imprecision or vagueness. A fuzzy set $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$ is a set of ordered pairs and X is a subset of real number R, where $\mu_{\tilde{A}}(x)$ is called the membership function which assigns to each object x a grade of membership ranging from zero to one. A fuzzy number is a special case of a convex normalized fuzzy set [14]. Triangular and trapezoidal fuzzy numbers are usually adopted to deal with the vagueness of the decision related to alternatives' performances with respect to each criterion. When two most promising values of a trapezoidal fuzzy number are the same number, it becomes a triangular fuzzy number. This means that a triangular fuzzy number (TFN) is a special case of a trapezoidal fuzzy number. It is possible to use different fuzzy numbers under the particular situation. Because of its intuitive appeal and computational efficiency, the TFN is the most widely used membership function in many application fields. It is usually employed to capture the vagueness of the parameters related to the decision-making process. In this paper, in order to reflect the fuzziness which surrounds the decision makers when they conduct a pair-wise comparison matrix, TFN is expressed with boundaries instead of crisp numbers. A triangular fuzzy number, denoted as $\tilde{A} = (l, m, u)$, has the following membership function:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0 & otherwise \end{cases} \quad (1)$$

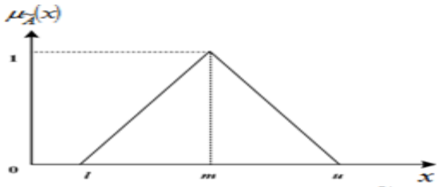

Figure 1: A triangular fuzzy number, $\tilde{A} = (l, m, u)$

A triangular fuzzy number $\tilde{A}$ is shown as in Fig. 1. The parameter m is the most promising value. The parameters u and l, respectively, are the smallest possible value and the largest possible value which limit the

field of possible evaluation. The triplet *(l,m,u)* can be used to describe a fuzzy event.
Consider two TFNs $\tilde{A}_1$ and $\tilde{A}_2$, $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the main operational laws for two triangular fuzzy numbers, $\tilde{A}_1$ and $\tilde{A}_2$, are as follows [15]:
Addition of the fuzzy number

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Multiplication of the fuzzy number

$$\tilde{A}_1 \otimes \tilde{A}_2 \approx (l_1 l_2, m_1 m_2, u_1 u_2) \text{ , for } l_1, l_2 > 0, m_1, m_2 > 0, u_1, u_2 > 0 \text{ , } i = 1, 2 \quad (3)$$

Division of the fuzzy number

$$\tilde{A}_1 \phi \tilde{A}_2 = (l_1 / u_2, m_1 / m_2, u_1 / l_2) \text{ , for } l_1, l_2 > 0, m_1, m_2 > 0, u_1, u_2 > 0 \text{ , } i = 1, 2 \quad (4)$$

Reciprocal of the fuzzy number

$$\tilde{A}_1^{-1} \approx (1/u_1, 1/m_1, 1/l_1) \text{ , for } l_1 > 0, m_1 > 0, u_1 > 0 \quad (5)$$

1.2. Fuzzy AHP method

In this following section, we will give a brief description of how to carry out the fuzzy AHP.
A matrix $\tilde{A}$ is constructed according to fuzzy pair-wise comparison.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (6)$$

where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is the fuzzy comparison value of criterion *i* to criterion *j*
The fuzzy weights of each criterion are calculated

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{1/n} \text{ , for } i = 1,2,\dots,n \quad (7)$$

$$\tilde{w}_i = \frac{\tilde{r}_i}{\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n} \text{ , for i} = 1,2,\dots,n \quad (8)$$

where $\tilde{r}_i$ is the geometric mean of fuzzy comparison value of criterion *i* to each criterion, and $\tilde{w}_i$ is the fuzzy weight of the *i*th criterion.
The fuzzy weight vector $\tilde{W}$ is constructed as:

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n)^T \quad (9)$$

III. THE STRUCTURE FOR SUSTAINABLE URBAN TRANSPORT PROJECT SELECTION

The urban transport project selection is based on two hierarchical groups of criteria. *Impacts of the project* represents the expected impacts of a project, and *Barriers of the project implementation* represents the main barriers in implementation of the project. Regarding *impacts of the project*, the society expects four major characteristics: mobility, safety, environmental, friendly and economic efficiencies from a sustainable urban transport system [16]. Barriers of the project relate to the feasibility of the project at the implementation level. This group of criteria is used to estimate the difficulty level in getting the requirements in the implementation of a project. The criteria and attributes of structures are derived from the previous studies [1, 16], and the guidelines and textbooks in transport planning and development.

1.3. Impacts of the project

The objective of this hierarchical structure is to evaluate the expected impact of the project on the transport system. The criteria which are considered are mobility, safety, environment and resource, and economic improvement. Each criterion consists of several attributes. The criteria are denoted by C_{Ii}, attributes by A_{Ij} (where *i,j* =1,2…). The hierarchy of the effectiveness evaluation is represented in Fig. 2.

Mobility (C_{I1}): This criterion is one of the important criteria in evaluating the project because it represents the goal to ensure the mobility for all transport demands. The attributes affecting this criterion can be expressed as follows:

Equality (A_{I1}): This attribute focuses on the equal right and opportunity of using a transport area. The urban transport property should be used by all social groups, including disabilities, children, elders, and economically challenged people.

Transport productivity and efficiency (A_{I2}): This indicates the capacity of utilization of the transport property, such as total transported passengers and the number of passengers per available road per hour.

Service quality (A_{I3}): The transport property provides services that meet the need of users.

Safety (C_{I2}): To evaluate one urban transport project, the traffic safety of all traffic movements must be considered. The impact of transport property on safety is seen in the reduction of accident frequency and reduction in the severity of accidents. Hence, the two attributes represent the safety criterion as follows:

Accident frequency (A_{I4}): This attribute represents the ability of preventing conflicts by eliminating the high potential conflicting points in the traffic flow.

Accident severity (A_{I5}): The transport property's ability to prevent or reduce the risk of having mass fatality accidents.

Environmental benefits (C_{I3}): This criterion represents the capacity to protect the environment and natural resources. Achievements of this criterion are realized by the obtainments of four following targets, which are: (1) to reduce air pollution, (2) to reduce noise, (3) to save energy consumption, and (4) to save urban space.

Air (A_{I6}): This attribute indicates the transport property's ability to prevent polluted vehicles from traveling in the urban transport system.

Noise (A_{I7}): The transport property's ability to prevent noisy vehicles from traveling in the urban transport system.

Energy (A_{I8}): The transport property helps to reduce the use of high energy consumption.

Space (A_{I9}): The transport property helps to reduce the use of high space consumption transport modes.
Economic benefits (C_{I4}): This criterion represents the capacity to improve the economy of the city and the region.

Transport cost (A_{I10}): This presents the capacity of the transport property to reduce the transporting costs.
Travel time (A_{I11}): This is the capacity to reduce the distance and time of trips of passengers and goods.

Economic attractiveness (A_{I12}): This attribute indicates the ability to enhance the regional economic competitiveness level such as creating new jobs and revenues which are created directly or indirectly by urban transport projects.

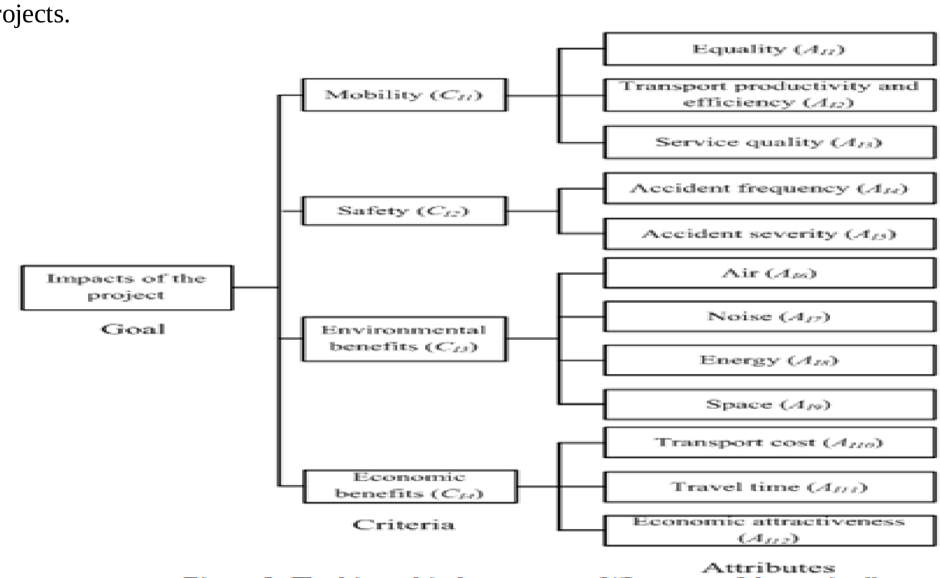

Figure 2: The hierarchical structure of "Impacts of the project"

1.4. Barriers to project implementation

The objective of the system is to evaluate the level of difficulty of the barriers to implementing the project. The criteria which are considered are cost of measure, technical system, institutional participation, and public acceptance. These criteria represent four major barriers. Each criterion is decomposed into several attributes. The criteria are denoted by C_{Bi}, attributes by A_{Bj} (where, i,j =1,2…). The hierarchy of the feasibility evaluation is represented in Fig. 3.

Costs (C_{B1}): The cost is the first barrier in implementing the project. It represents the affordability. The transport property is affordable when its cost does not exceed the financial ability.
Investment cost (A_{B1}): This includes the cost of developing new transport infrastructure, the additional information technology, and power supply infrastructures.

Operation and maintenance costs (A_{B2}): To operate the new transport property, a new organization or operational unit with required equipment and operators needs to be established.
Technical system issues (C_{B2}): The technical systems are identified as the operation, control systems and information systems that require being changed for implementation of the transport property.

Operation and control systems (A_{B3}): This attribute presents the extent to which the traffic operation and control centers have to be changed when the transport property is in implementation.

Information systems (A_{B4}): This attribute presents the extent to which the traffic information services have to be changed when the transport property is in implementation.

Support from relevant agencies (C_{B3}): To implement the new transport property, it is necessary to get the required support and participation of the institution. The relevant agencies are classified into two groups.
Government transport administration agency (A_{B5}): This is defined as the level of transport related institutions, such as, operators, enforcers, and authorities.

Government at different levels (A_{B6}): These bodies are political decision making institutions. This attribute presents the required approval of national or state governments.
Support from local residents (C_{B4}): For implementing a transport project, two main public groups are involved.
Users (A_{B7}): Users are the people who directly use the transport service. When implementing the project, users may have to change their mode of transport, time and destination.

Affected people (A_{B8}): They are non-users who are affected when implementing the project. For example, non-users would have to resettle their houses, business or manufacturing locations.

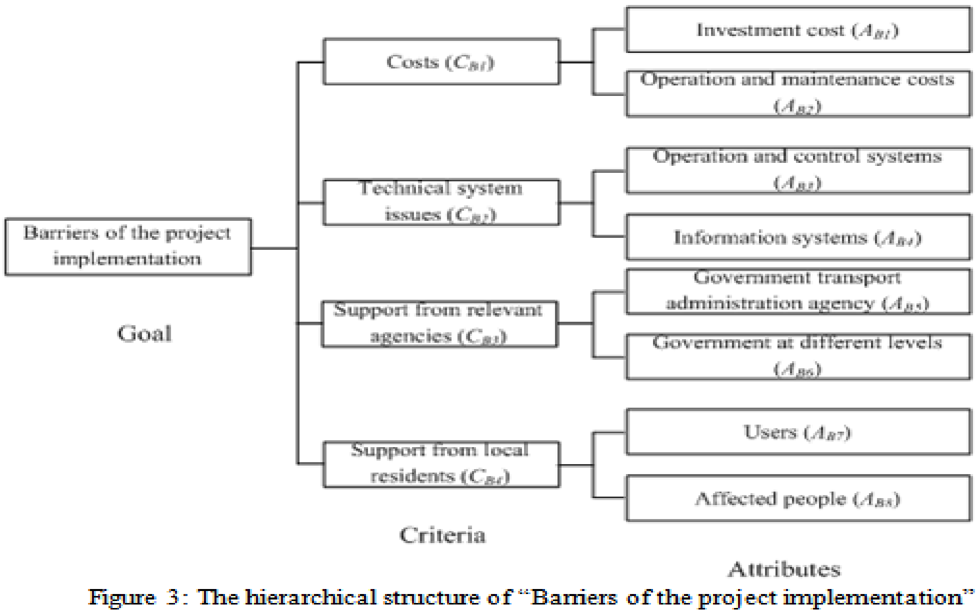

Figure 3: The hierarchical structure of "Barriers of the project implementation"

IV. FUZZY AHP APPROACH IN THE SELECTION OF TRANSPORT PROJECT

In this section, the framework based on fuzzy AHP for determining the weights of criteria and attributes is described. The steps of the fuzzy AHP utilization in group multiple criteria decision making are as follows:

Step 1: Selecting decision makers for assessment

A committee of decision makers was formed. In order to obtain an objective decision, the background of the decision makers should be considered. Each member in the committee was required to provide their judgments on the basis of their knowledge and expertise. In our research, 18 experts were invited to evaluate the criteria and attributes, and 16 of these 18 experts sent back their completed questionnaire. They are six lecturers from the University of Transport Technology-Vietnam, six consultants of transport research and development projects, and four project managers. These experts have significant experience in the research area. The research period is from January 2013 to May 2013.

Step 2: Making pair-wise comparisons and obtaining the individual judgment matrices

The decision-makers make pair-wise comparisons of the importance or preference between each pair of criteria. The comparison of one criterion over another is in the form of linguistic variables and can be done with the help of questionnaires. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language [17]. In this paper, TFNs are used to represent subjective pair-wise comparisons of decision-makers namely “Equally important”, “Moderately more important”, “Strongly more important”, “Very strongly more important” and “Absolutely more important”. The linguistic variables and fuzzy scales for importance, which are proposed by Chen and Chen [18], are used to convert such linguistic variables into triangular fuzzy numbers. They are shown in Fig. 4 and Table 1.

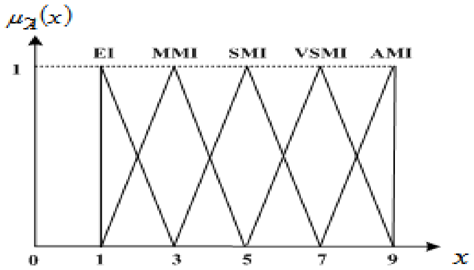

Figure 4: Fuzzy membership functions for linguistic variables

Table 1: Linguistic variables and fuzzy scales for importance

Linguistic variable for importance	Triangular fuzzy number
Equally important (EI)	(1,1,3)
Moderately more important (MMI)	(1,3,5)
Strongly more important (SMI)	(3,5,7)
Very strongly more important (VSMI)	(5,7,9)
Absolutely more important (AMI)	(7,9,9)

Through the use of questionnaires and the fuzzy comparison scale, a fuzzy reciprocal comparison matrix can be constructed from the results of pair-wise comparison.

Let us consider a problem at one level with *n* criteria, where the relative importance of criterion *i* to *j* is represented by triangular fuzzy numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ For example, one decision-maker considers criterion *i* is strongly more important as compared with the criterion *j*; he may set $\tilde{a}_{ij} = (3,5,7)$. If criterion *j* is thought to be strongly more important than criterion *i*, the pair-wise comparison between *i* and *j* could be presented by $\tilde{a}_{ij} = (1/7, 1/5, 1/3)$.

As in the traditional AHP, the comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ can be constructed, such that

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & 1 \end{bmatrix} \quad (10)$$

Step 3: Checking the consistency of individual comparison matrices

To assure a certain quality level of a decision, the consistency of an evaluation has to be analyzed. Saaty [19] proposed a consistency index to measure consistency. This index can be used to indicate the consistency of the pair-wise comparison matrices (for the more than 2x2 matrices). To investigate the consistency, the fuzzy comparison matrices need to be converted into crisp matrices. When the crisp matrix is consistent, it means that the fuzzy matrix is also consistent. The operation of converting a fuzzy number into a crisp number is called defuzzification. There are various defuzzification methods reported in the literature. Some significant works are the weighted distance method by Saneifard [20], the simple centroid method by Chang and Wang [21] to get the best nonfuzzy performance value (BNP), the converting fuzzy data into crisp scores (CFCS) method [22], the fuzzy mathematical programming method introduced [23], and the lamda-max method proposed [24]. In this paper, the fuzzy mean and spread method [25] is utilized to defuzzify the fuzzy numbers. This method ranks fuzzy numbers according to the probabilities of fuzzy events. Assume that $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is a TFN with uniform distribution. Its mean $x(\tilde{a}_{ij})$ is calculated as:

$$x(\tilde{a}_{ij}) = (l_{ij} + m_{ij} + u_{ij})/3 \tag{11}$$

After all the elements in the comparison matrix are converted from triangular fuzzy numbers to crisp numbers, the comparison matrix is now expressed as follows:

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

The consistence index, CI, for a comparison matrix can be computed with the use of the following equation.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{13}$$

where $\lambda_{\max}$ is the largest eigenvalue of the comparison matrix, n is the dimension of the matrix.

The consistency ratio (CR) [19] is defined as a ratio between the consistency of a given evaluation matrix and consistency of a random matrix.

$$CR = \frac{CI}{RI(n)} \tag{14}$$

where $RI(n)$ is a random index [26] that depends on n, as shown in Table 2.

Table 2: Random index (RI) of random matrices

n	3	4	5	6	7	8	9
RI(n)	0.58	0.9	1.12	1.24	1.32	1.41	1.45

If the CR of a comparison matrix is equal or less than 0.1, it can be acceptable. When the CR is unacceptable, the decision-maker is encouraged to repeat the pair-wise comparisons.

In this step, the MATLAB package is employed to calculate the eigenvalues of all comparison matrices.

Step 4 Constructing the group judgment matrices

Since each individual judgment matrix represents the opinion of one decision maker, aggregation is necessary to achieve a group consensus of decision-makers. In the conventional AHP, there are two basic approaches for aggregating the individual preferences into a group preference, namely, aggregation of individual judgments (AIJ) and aggregation of individual priorities (AIP) [27]. The concepts and ideas employed in the conventional AHP can be also utilized in the fuzzy AHP. In this research, the AIJ approach is used. In the AIJ approach, the group judgment matrix is obtained from the individual judgment matrices. This means that the group judgment matrix is considered as the judgment matrix of a "new individual" and the priorities of this individual are derived as a group solution. Here, the geometric mean method is used to establish the representative comparison fuzzy matrix for group decision. We consider a group of *K* decision-makers involved in the research. They make pair-wise comparison of *n* criteria. As a result of the pair-wise comparison, we get a set of K matrices $\tilde{A}_k = \{\tilde{a}_{ijk}\}$, where $\tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$ represents a relative importance of criterion i to j, as assessed by the expert k. The triangular fuzzy numbers in the matrix can be obtained by using the following equation [8, 28]:

$$l_{ij} = \min_{k=1,2,..K} (l_{ijk})$$

$$m_{ij} = \sqrt[K]{\prod_{k=1}^{K} m_{ijk}}$$

$$u_{ij} = \max_{k=1,2,..K} (u_{ijk}) \qquad (15)$$

When making comparisons all elements with respect to the upper level, the comparison matrices of decision-makers at the level were derived. Then, the *CR* value for each matrix was determined by employing (11)-(14). From the consistency test results of the individual comparison matrices, it was found that they are all less than 10%. Therefore, the comparison matrices were accepted. The group judgment matrices were then obtained by employing (15) and they are shown in Tables 3-12.

Table 3: The group judgment matrix of the criteria with respect to the goal "Impacts of the project"

	C_{I1}	C_{I2}	C_{I3}	C_{I4}
C_{I1}	(1,1,1)	(0.333,1,1)	(1,1.855,5)	(1,2.473,7)
C_{I2}	(1,1,3)	(1,1,1)	(1,3,5)	(1,3.999,7)
C_{I3}	(0.2,0.539,1)	(0.2,0.333,1)	(1,1,1)	(1,1.316,5)
C_{I4}	(0.143,0.404,1)	(0.143,0.25,1)	(0.2,0.76,1)	(1,1,1)

Table 4: The group judgment matrix of the attributes with respect to the criterion "Mobility"

	A_{I1}	A_{I2}	A_{I3}
A_{I1}	(1,1,1)	(0.2,1.586,7)	(1,3.873,7)
A_{I2}	(0.143,0.63,5)	(1,1,1)	(1,1.654,7)
A_{I3}	(0.143,0.258,1)	(0.143,0.605,1)	(1,1,1)

Table 4: The group judgment matrix of the attributes with respect to the criterion "Mobility'

	A_{I1}	A_{I2}	A_{I3}
A_{I1}	(1,1,1)	(0.2,1.586,7)	(1,3.873,7)
A_{I2}	(0.143,0.63,5)	(1,1,1)	(1,1.654,7)
A_{I3}	(0.143,0.258,1)	(0.143,0.605,1)	(1,1,1)

Table 6: The group judgment matrix of the attributes with respect to the criterion "Environmental benefits"

	A_{I6}	A_{I7}	A_{I8}	A_{I9}
A_{I6}	(1,1,1)	(1,1,1)	(0.2,0.709,1)	(0.2,0.709,1)
A_{I7}	(1,1,1)	(1,1,1)	(0.2,0.709,1)	(0.2,0.709,1)
A_{I8}	(1,1.41,5)	(1,1.41,5)	(1,1,1)	(0.2,0.47,1)
A_{I9}	(1,1.41,5)	(1,1.41,5)	(1,2.128,5)	(1,1,1)

Table 7: The group judgment matrix of the attributes with respect to the criterion "Economic benefits"

	A_{I10}	A_{I11}	A_{I12}
A_{I10}	(1,1,1)	(0.143,0.669,1)	(1,1.617,5)
A_{I11}	(1,1.495,7)	(1,1,1)	(1,2.418,7)
A_{I12}	(0.2,0.618,1)	(0.143,0.414,1)	(1,1,1)

Table 8: The group judgment matrix of the criteria with respect to the goal "Barriers of the project implementation"

	C_{B1}	C_{B2}	C_{B3}	C_{B4}
C_{B1}	(1,1,1)	(1,1,3)	(0.333,1,1)	(1,1.855,5)
C_{B2}	(0.333,1,1)	(1,1,1)	(0.2,0.539,1)	(1,1.147,5)
C_{B3}	(1,1,3)	(1,1.855,5)	(1,1,1)	(1,2.837,7)
C_{B4}	(0.2,0.539,1)	(0.2,0.872,1)	(0.143,0.353,1)	(1,1,1)

Table 9: The group judgment matrix of the attributes with respect to the criterion "Costs"

	A_{B1}	A_{B2}
A_{B1}	(1,1,1)	(0.2,0.618,1)
A_{B2}	(1,1.617,5)	(1,1,1)

Table 10: The group judgment matrix of the attributes with respect to the criterion "Technical system issues"

	A_{B3}	A_{B4}
A_{B3}	(1,1,1)	(1,1,3)
A_{B4}	(0.333,1,1)	(1,1,1)

Table 11: The group judgment matrix of the attributes with respect to the criterion "Support from relevant agencies"

	A_{B5}	A_{B6}
A_{B5}	(1,1,1)	(0.2,0.503,1)
A_{B6}	(1,1.987,5)	(1,1,1)

Table 12: The group judgment matrix of the attributes with respect to the criterion "Support from local residents"

	A_{B7}	A_{B8}
A_{B7}	(1,1,1)	(0.111,0.232,1)
A_{B8}	(1,4.304,9)	(1,1,1)

Step 5. Calculating the weights

Fuzzy AHP was then employed to identify the weights of criteria and attributes. Taking pair-wise comparison matrix of the criteria in Table 3 as an illustration, the weights of the criteria were acquired as follows:

Using (7) for each criterion, we determined the TFN values of the geometric mean of fuzzy comparison value of criterion C_{I1} to each criterion to be the following:

$\tilde{r}_{I1} = (\tilde{c}_{I11} \otimes \tilde{c}_{I12} \otimes \tilde{c}_{I13} \otimes \tilde{c}_{I14})^{1/4}$ = ((1*0.333*1*1)$^{1/4}$, (1*1*1.855*2.473)$^{1/4}$, (1*1*5*7)$^{1/4}$) = (0.76, 1.463, 2.432)

Similarly, we obtained $\tilde{r}_2$ and $\tilde{r}_3$:

$\tilde{r}_{I2}$ = (1, 1.861, 3.201)

$\tilde{r}_{I3}$ = (0.447, 0.697, 1.495)

$\tilde{r}_{I4}$ = (0.253, 0.526, 1)

Subsequently, the weight of each criterion ($\tilde{w}_{CIi}$) can be calculated as follows:

$\tilde{w}_{CI1} = \tilde{r}_{I1} \otimes (\tilde{r}_{I1} \oplus \tilde{r}_{I2} \oplus \tilde{r}_{I3} \oplus \tilde{r}_{I4})^{-1}$

= (0.76, 1.463, 2.432)$\otimes$ (1/(2.432+3.201+1.495+1), 1/(1.463+1.861+0.697+0.526), 1/(0.76+1+0.447+0.253))

= (0.093, 0.322, 0.989)

Likewise, $\tilde{w}_{CI2}$ =(0.123, 0.409, 1.301), $\tilde{w}_{CI3}$ =(0.055, 0.153, 0.608), and $\tilde{w}_{CI3}$ =(0.031, 0.116, 0.407)

Thus, the fuzzy weight vector is as follows:

$\tilde{W} = (\tilde{w}_{CI1}, \tilde{w}_{CI2}, \tilde{w}_{CI3}, \tilde{w}_{CI4})^T$
$=((0.093, 0.322, 0.989), (0.123, 0.409, 1.301), (0.055, 0.153, 0.608), (0.031, 0.116, 0.407))^T$

The weight of each criterion is calculated by employing the defuzzification procedure. Thus,
$W = (w_{CI1}, w_{CI2}, w_{CI3}, w_{CI4}) = (0.468, 0.611, 0.272, 0.184)^T$
We then normalized the weight vector and obtained the relative weights of the four criteria.
$W= (w_{CI1}, w_{CI2}, w_{CI3}, w_{CI4}) = (0.305, 0.398, 0.177, 0.120)^T$

The calculation results show that the weight of “Safety” is largest. Hence, this criterion plays the most important part, followed by “Mobility”.

The local weights from Tables 4-12 were calculated in a similar way. These calculated weights are given in Tables 13-14. The global weight of each attribute was calculated by multiplying its local weight with its corresponding weight along the hierarchy. These global weights represent the rating of the attributes. Table 13 summarizes the local weights and global weights of the structure “Impacts of the project”; whereas, Table 14 summarizes the local weights and global weights of the structure “Barriers of the project implementation”.

Table 13: Local and global weight of the structure “Impacts of the project”

Criteria	Local weight	Attribute	Local weight	Global weight	Ranking
Mobility (C_{I1})	0.305	Equality (A_{I1})	0.472	0.144	3
		Transport productivity and efficiency (A_{I2})	0.395	0.120	4
		Service quality (A_{I3})	0.133	0.040	8
Safety (C_{I2})	0.398	Accident frequency (A_{I4})	0.594	0.236	1
		Accident severity (A_{I5})	0.406	0.162	2
Environmental benefits (C_{I3})	0.177	Air (A_{I6})	0.152	0.027	10
		Noise (A_{I7})	0.152	0.027	10
		Energy (A_{I8})	0.279	0.050	7
		Space (A_{I9})	0.416	0.074	5
Economic benefits (C_{I4})	0.120	Transport cost (A_{I10})	0.281	0.034	9
		Travel time (A_{I11})	0.553	0.066	6
		Economic attractiveness (A_{I12})	0.166	0.020	12

Table 14: Local and global weight of the structure “Barriers of the project implementation”

Criteria	Local weight	Attribute	Local weight	Global weight	Ranking
Costs (C_{B1})	0.265	Investment cost (A_{B1})	0.329	0.087	6
		Operation and maintenance costs (A_{B2})	0.671	0.178	2
Technical system issues (C_{B2})	0.199	Operation and control systems (A_{B3})	0.594	0.118	4
		Information systems (A_{B4})	0.406	0.081	7
Support from relevant agencies (C_{B3})	0.403	Government transport administration agencies (A_{B5})	0.316	0.127	3
		Government at different levels (A_{B6})	0.684	0.275	1
Support from local residents (C_{B4})	0.134	Users (A_{B7})	0.236	0.032	8
		Affected people (A_{B8})	0.764	0.102	5

In Table 14, results show the opinions of decision-makers that ensuring safety is the most important expected impact from urban transport project with a weight of 0.329, ensuring mobility ranked second (0.296), while environmental benefits and economic benefits ranked third and fourth with a weight of 0.227 and 0.149, respectively. Regarding barriers to project implementation (Table 15), achievement of support from relevant agencies is the most difficult job in project implementation with a weight of 0.313, followed by costs with a weight of 0.277. The technical system issues and support from local residents are ranked lower a weight of 0.245 and 0.166, respectively.

The impact score and the barrier score of a project can now be calculated by the use of above derived weights and one numerical scoring approach. There are several numeric scoring approaches [29] can be utilized. A project would be more effective if the impact score is higher, and vice versa. While the project would have more difficulties in implementation if the barrier score is higher, and vice versa. The project can be selected if it has a high impact score and a low barrier score. For simplicity in application, the ratio of the overall value score of impacts to the overall value score of difficulties for each alternative should be calculated; then the alternative with the highest ratio is selected.

V. CONCLUSION

The selection of projects in general and urban transport projects in particular is a decision that is commonly made by a committee of experts. How to get the consensus of decision-makers and deal with the uncertainty in decision making environment is an important and necessary work. In this paper, we proposed a group decision-making method based on fuzzy AHP for sustainable urban transport project selection. The selection will be done by evaluating the benefits and difficulties of projects. The fuzzy AHP by Buckley was employed to determine the weights of the criteria and attributes in the hierarchical structure. Based on these results, the urban transport project selection can be carried out to find the best alternative. An example which illustrates the application of the method related to the urban transport project selection in Vietnam was also presented in this paper. It is expected that this study may be used as a reference for the planning and provision of the urban transport projects.

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