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Combined Fuzzy Factor Analysis and Fuzzy Integral to Evaluate Strategies of Hybrid Electric Vehicle Trial

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Abstract — Introduced by Saaty in 1971, Analytic Hierarchy Process (AHP) is a very popular method applied in Multiple Attribute Decision Making problems. AHP assumes that the criteria in evaluation hierarchy are independent. In 1992, Yu et al. pointed out that even though the criteria are objectively independent; the subjective evaluations of decision makers will eliminate the criteria's independence. The fuzzy integral and multiplicative utility can be applied to solve this problem, but the large amount of information demand makes them hard to implement. In this research, fuzzy factor analysis and fuzzy integral are combined to solve the problems of AHP and fuzzy integral. An empirical example of evaluating the strategies of hybrid electric vehicles trial is analyzed and discussed in this paper. By applying the process introduced in this research, the problems mentioned above and the fuzzy scores of evaluation can be easily solved and found. After setting the α -cut of fuzzy scores of evaluation, the rank of each alternative can be determined.

Keywords — MCDM, fuzzy factor analysis, fuzzy integral, hybrid electric vehicle, α -cut

1. INTRODUCTION

Analytic Hierarchy Process (AHP) (Saaty 1980) is a very popular method used for Multiple Attribute Decision Making problems. This method assumes that the criteria in evaluation hierarchy are independent. Yu *et al.* (1992) pointed out that the criteria are objectively independent, but subjective evaluations by decision makers can remove the criteria independence. In 1974, Sugeno first introduced the concept of fuzzy integral, which applied multiplicative utility into evaluation problems. However, large information demand makes them hard to put into practice. For this reason, a clusterwise regression-type model (Sugeno and Kwon 1995) was introduced for evaluation problems. At the same time, Lee and Leekwang (1995) introduced a method applying Genetic Algorithm (GA) to find λ -fuzzy measure. Chen and Tzeng (2000) introduced a process that reduced the information demand of general fuzzy measure. Though this process can substantially reduce information demand, it can still cause problems in the evaluation process. Lin (2004) introduced a partitioned hierarchy model, which combined factor analysis and fuzzy integral to solve the problems. The studies above establish the foundation of fuzzy integral and fuzzy measure in the application of evaluation problems. There are two problems when implementing the problems of multiple criteria analysis (MCA). One of the problems is the assumption of AHP in which the evaluation criteria are independent of each other. The other problem arises from the application of fuzzy measure and fuzzy integral, because this approach needs a lot of information from the decision makers. These two problems have been solved by the previous studies mentioned in the introduction above, however MCA problems are related to human decisions, so capturing the fuzzy opinions of decision makers is necessary. In response, this paper proposes a fuzzy

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partitioned hierarchy model to not only solve the above two problems, but to capture the fuzzy opinions of decision makers as well.

In this research, fuzzy factor analysis is combined with partitioned hierarchy model to solve the problems of AHP and fuzzy integral. First, fuzzy factor analysis is applied to find the interrelations of criteria in the evaluation hierarchy. Fuzzy integrals and the SAW (Simple Additive Weighting) method are then applied to synthesize the ranking score of alternatives. This process makes it much easier and more reasonable to use fuzzy measures and fuzzy integral to evaluate problems. To verify that this process is effective, we will apply it to evaluate the strategies for trials of Hybrid Electric Vehicles (HEVs) in Taiwan. In Taiwan, the government intends to put HEVs into use because air pollution can cause serious health problems. HEVs get some high evaluation, such as low air pollution and noise pollution (Lin *et al.* 2009). After applying the process introduced in this research, the problems mentioned above and the vagueness of decision makers can be resolved. The results of these trials may even influence the decisions of the government administrations.

The rest of this paper is organized as follows. Section 2 discusses the fuzzy partitioned hierarchy model and related theories. Section 3 is an empirical study that applies the model discussed in this research to handle the problem of strategies for HEVs trial. Section 4 presents discussions and suggestions from this research, and the final section contains conclusions and recommendations.

2. THE FUZZY PARTITIONED HIERARCHY MODEL

This research combines fuzzy factor analysis with the partitioned hierarchy model, so this process will now be referred to as the fuzzy partitioned hierarchy model. The concepts and related theories for the fuzzy partitioned hierarchy model are briefly introduced below, including: fuzzy factor analysis, the concept of fuzzy integral, and the framework of the fuzzy partitioned evaluation model.

2.1 Fuzzy Factor Analysis

Fuzzy factor analysis, introduced by Nakamori *et al.* (1997), is applicable when an individual evaluates many objects. This analysis is based on the assumption that when fuzziness and uncertainty of subjective perception are taken into account, it will be more effective to resort to a statistical perspective with fuzzy explanation. In the empirical research of Tzeng *et al.* (2002), fuzzy data is employed as the input of fuzzy factor analysis. Fuzzification of correlation coefficients should be employed initially to show the fuzzy nature of data. In the investigation of this research, a fuzzy questionnaire is used to measure the specific utility function of each decision maker. Since the investigation results are fuzzy data, the fuzzy factor analysis of Nakamori is applied in a somewhat more reasonable way. The approaches are described in detail as follows:

Step 1 Find the fuzzy coefficient of correlation

Initially, fuzzification of correlation coefficients should be employed to show the fuzzy nature of the data. This is done by having every interviewee conduct their evaluation in regard to the nth service attributes, calculating the correlation matrix $\boldsymbol{R} = \left[r_{ij} \right]$ of responses and perceptions of decision makers towards each different criteria, and then determining the standard deviation, σ_{ij}, of the entire correlation coefficient matrix corresponding to criteria (*i, j*). α will then be the parameter for fuzzy width, and after it has been fuzzified the correlation coefficient is defined as follows:

$$\tilde{\boldsymbol{R}} = \left(\tilde{r}_{ij} \right) = \left([r_{ij}^L, r_{ij}^R] \right) = (r_{ij} - \alpha\sigma_{ij}, r_{ij} + \alpha\sigma_{ij}) \quad i, j = 1, 2, \cdots, N \tag{1}$$

where $\left[r_{ij}^L, r_{ij}^R \right]$ represents the fuzzy numbers of the interval, that is the upper and lower bounds of the fuzzy coefficient of correlation, and it can maintain the relative size of the fuzziness of the correlation coefficient. The following operations are revised from the fuzzy factor analysis presented by Nakamori *et al.* (1997) and Tzeng *et al.* (2002).

Step 2 Calculate the fuzzy eigenvalue and eigenvector

Before calculating fuzzy factor loading and factor rotation, the fuzzy eigenvalues and eigenveactors are first derived by fuzzy correlation matrix, shown as follows:

The fuzzy eigenvalues and eigenvector are denoted as follows:

$$\tilde{\lambda}_i = \left[\lambda_i^L, \lambda_i^R \right], \quad i = 1, 2, \cdots, N \tag{2}$$

$$e_{ki} = \left[e_{k1}, e_{k2}, \ldots, e_{kN} \right], \ \left\| e_k \right\| = 1, \quad k = 1, 2, \cdots, N \tag{3}$$

The problems are shown as below:

【Left】

$$\begin{aligned} & Maximize \ \sum_{i=1}^{N} \lambda_i^L \\ & subject \ to \ \ 0 \le \lambda_i^L \le \lambda_i \\ & \left| e_{ki} \lambda_k^L \right| \le \max \left\{ \left| \sum_{j=1}^{N} \left(e_{kj} \right) r_{ji}^L \right|, \left| \sum_{j=1}^{N} \left(e_{kj} \right) r_{ji}^R \right| \right\}, \qquad k, i = 1, 2, \cdots, N \end{aligned} \tag{4}$$

【Right】

$$\begin{aligned} & Minimize \ \sum_{i=1}^{N} \lambda_i^R \\ & subject \ to \ \ \lambda_i^R \ge \lambda_i \\ & \left| e_{ki} \lambda_k^R \right| \ge \min \left\{ \left| \sum_{j=1}^{N} \left(e_{kj} \right) r_{ji}^L \right|, \left| \sum_{j=1}^{N} \left(e_{kj} \right) r_{ji}^R \right| \right\}, \qquad k, i = 1, 2, \cdots, N \end{aligned} \tag{5}$$

For this problem, the first constraint is to maintain the rationality of the fuzzy eigenvalue, and the second constraint is to transform the $\boldsymbol{R}^L$ and $\boldsymbol{R}^R$ to find the min-max relation of eigenvalue.

Step 3 Calculate the fuzzy factor loadings

After the fuzzy eigenvalues are derived, the fuzzy factor loadings are derived as follows:

$$\tilde{\boldsymbol{A}} = \left(\tilde{a}_{ki} \right) = \left(\left[a_{ki}^L, a_{ki}^R \right] \right) = \begin{cases} \left[\left(e_{ki} \right) \sqrt{\lambda_i^L}, \left(e_{ki} \right) \sqrt{\lambda_i^R} \right], & e_{ki} \ge 0 \\ \left[\left(e_{ki} \right) \sqrt{\lambda_i^R}, \left(e_{ki} \right) \sqrt{\lambda_i^L} \right], & e_{ki} < 0 \end{cases} \tag{6}$$

Step 4 Rotate the fuzzy factor loadings

The rotated factor loading matrix $\boldsymbol{B} = \left(b_{ki} \right)$ can be derived by the orthogonal matrix $\boldsymbol{T} = \left(t_{kk} \right)$; *i.e.,* $\boldsymbol{TT}' = \boldsymbol{I}$ in traditional factor analysis. Utilizing this rotation matrix, we can find the fuzzy factor loadings after rotation as shown below:

$$\tilde{\boldsymbol{B}} = \left(\tilde{b}_{ki} \right) = \left(\left[b_{ki}^L, b_{ki}^R \right] \right) = \sum_{k=1}^{P} t_{kk} \times \left[a_{ki}^L, a_{ki}^R \right] \tag{7}$$

Where

$$t_{kk} \times \left[a_{ki}^L, a_{ki}^R \right] = \begin{cases} \left[t_{kk} a_{ki}^L, t_{kk} a_{ki}^R \right], t_{kk} \ge 0 \\ \left[t_{kk} a_{ki}^R, t_{kk} a_{ki}^L \right], t_{kk} < 0 \end{cases} \tag{8}$$

After finding the potential factors of the criteria, we apply the fuzzy integral to calculate the combining evaluation value of each alternative within each factor. The fuzzy integral is combined to the evaluation process mainly because this model does not need to assume independence among criteria, thus it can be applied to non-linear conditions. Even if some of the criteria are objectively independent from other criteria, decision makers might consider that it was not quite independent. For this reason, fuzzy integral is more appropriate for evaluating problems.

2.2 Fuzzy Integral Model

A traditional multi-criteria combining evaluation method uses the additive concept as the basis to determine whether or not criteria are independent from each other. However, often each individual criterion is not completely independent, which in turn does not comply with the requirements of this additivity type (Chen et al. 2000, Chen and Tzeng 2001, Ralescu and Adams 1980). Therefore, the partitioning type of fuzzy integral has to be applied to these criteria to regroup a new evaluation criteria hierarchy system; then the fuzzy integral proposed by Sugeno (1974) and Sugeno and Kwon (1995) is applied. This will combine the performance value of those relating criteria and develop a new combining performance value. A summary of the fuzzy integral is as follows.

Assuming under the general condition, $f(x_1^k) \geq \cdots \geq f(x_i^k) \geq \cdots \geq f(x_n^k)$, where $f(x_i^k)$ is the normalized performance value of the kth alternative of the ith criterion, the fuzzy integral of the fuzzy measures $g(\cdot)$ of $f(\cdot)$ on $X(g_\lambda : X \to [0,1])$ can be defined as the following Sugeno's integral equation (Mori and Murofushi 1989, Murofushi and Sugeno 1989,1991):

$$\text{(c)} \int^k f dg = f(x_n^k) g_\lambda(X_n^k) + [f(x_{n-1}^k) - f(x_n^k)] g_\lambda(X_{n-1}^k) + \cdots + [f(x_1^k) - f(x_2^k)] g_\lambda(X_1^k) \quad (9)$$

Where

$$g_\lambda(X_1^k) = g_\lambda(\{x_1^k\}), g_\lambda(X_2^k) = g_\lambda(\{x_1^k, x_2^k\}), \cdots, g_\lambda(X_n^k) = g_\lambda(\{x_1^k, x_2^k, \cdots, x_n^k\})$$

To express the fuzzy measures of the group in each individual criterion, $g_\lambda(X_n^k)$ can be expressed as follows (Chen and Tzeng 2001, Keeney and Raiffa 1976):

$$\begin{aligned} g_\lambda(X_n^k) &= g_\lambda(\{x_1^k, x_2^k, L, x_n^k\}) \\ &= \sum_{i=1}^{n} g_\lambda(\{x_i^k\}) + \lambda \sum \sum g_\lambda(\{x_i\}) g_\lambda(\{x_j\}) + L + \lambda^{n-1} g_\lambda(\{x_1\}) L g_\lambda(\{x_n\}) \quad (10) \\ &= \frac{1}{\lambda} [\prod_{i=1}^{n} (1 + \lambda g_\lambda(x_i^k)) - 1] \quad for -1 < \lambda < +1 \end{aligned}$$

where λ is the parameter showing the relationship among related criteria (if λ =0, then Eq. (10) is an additive form; if $\lambda \neq 0$, then Eq. (10) is a non-additive form). The basic concept of this Choquet integral equation can be illustrated as shown in Fig. 1, and the fuzzy integral defined by Equation (C) $\int fdg$ is the Sugeno Integral.

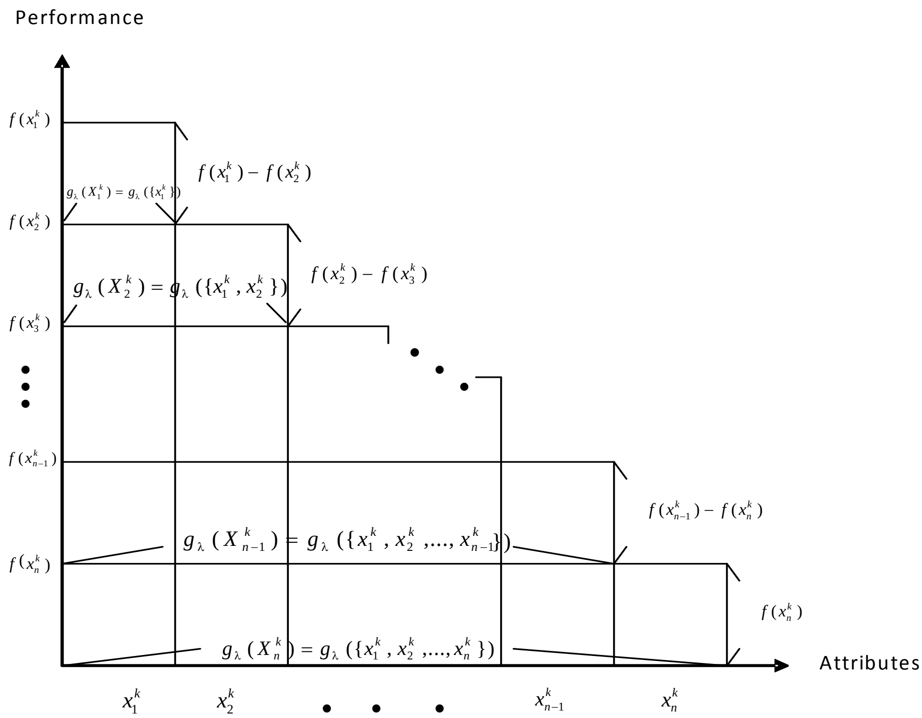

Figure 1. Basic concept of the fuzzy integral

2.3 Evaluation Process of the Fuzzy Partitioned Hierarchy Model

The evaluation process of the fuzzy partitioned hierarchy model can be divided into three parts. First, the fuzzy factor analysis is employed to find the potential factors of criteria. Second, the fuzzy measure and fuzzy integral are employed to calculate the synthesis evaluation value of each alternative in each aspect which part is the non-additive operation of this model. Finally, SAW method -additive part- is employed to calculate the synthesis evaluation value of alternatives. The concept of fuzzy partitioned hierarchy model is shown in Fig. 2 and Fig. 3.

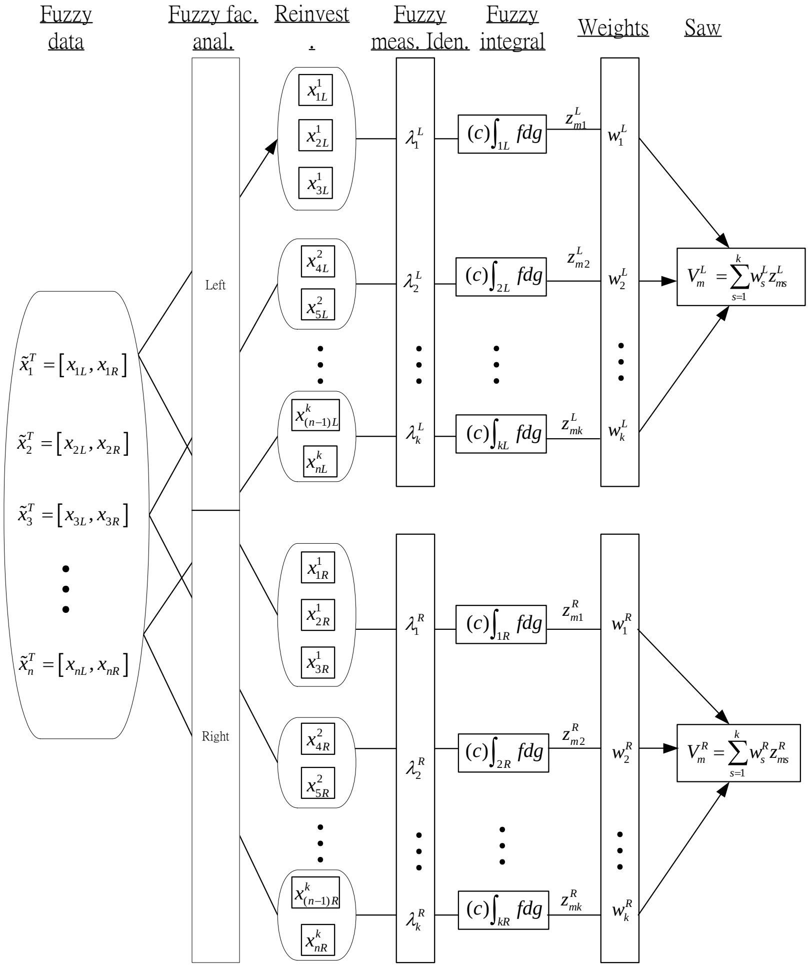

Figure 2. Concept of the Fuzzy Partitioned Hierarchy Model

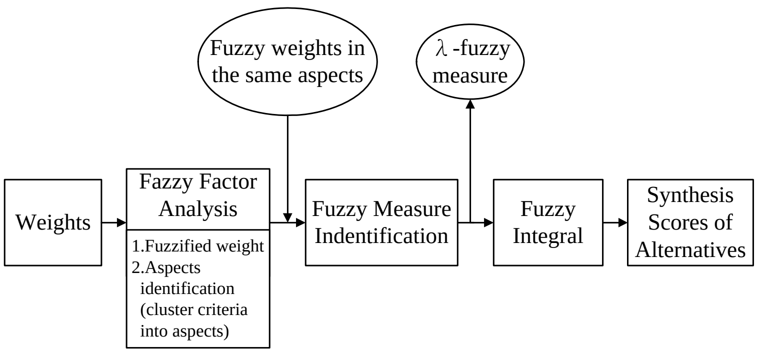

Figure 3. Framework of the Fuzzy Partitioned Hierarchy Model

2.3.1 Non-additive operation

In order to simplify the hierarchical system, this study first applies fuzzy factor analysis because it can reveal the original data structure with fewer dimensions, as well as preserve most of the information provided by the original data structure to extract those common factors within all the criteria. If these common factors are independent from each other, traditional additive measures can be employed to simplify the hierarchy systems. However, since some of the criteria are interrelated, the fuzzy integral is employed to conduct a non-additive operation to these dependent criteria and derive the combining evaluation value of each individual common criterion in factors. This can describe the characteristics of the system with fewer but more important criteria, while covering the mutual influence among criteria.

To show the contribution of various data items to the development and change of the system, this study employs a survey, multi-criteria decision-making, and Analytic Hierarchy Process (AHP) to calculate the relative weight among each data item.

2.3.2 Additive operation

The simple additive weight (SAW) is the sum of the product of the performance value of each criterion. Its relative weight stands for the combining evaluation value of each alternative, which is employed to compare the advantage or disadvantage of each alternative. Using simple additive weights to combine the value of $\boldsymbol{z}_{ms}$ and weight $\boldsymbol{w}_s$ will establish a combining index value. The formulation of the simple additive weights is shown as follows:

$$V_m = \sum_{s=1}^{k} \boldsymbol{w}_s \boldsymbol{z}_{ms} \tag{11}$$

where Vm : the combining evaluation value of the m th alternative,

$\boldsymbol{w}_s$: the relative weight of the sth aspect,

$\boldsymbol{z}_{ms}$: the combining values of the sth factor of the m th alternative.

3. EMPIRICAL STUDY: CASE OF EVALUATING STRATEGIES OF HEVS TRIAL

This section discusses the problem and the decision process of evaluating HEVs for practical application in Taiwan.

3.1 Problem Description

Environmental protection and quality of life have received increasing attention in recent years (Department of Energy's Freedom CAR and Vehicle Technologies Program 2008, Tzeng et al. 2005). Emissions from vehicles using petroleum fuels are among the most harmful pollutants to air quality (NREL 2005a). To prevent such airborne pollution and reduce the dependence on fossil fuel, increasing usage of substitute fuels becomes necessary (Bamitt and Chandler 2006, Romm 2006).

In Taiwan, the government has paid much attention to this problem and intends to put Electric Vehicles (EV) into practice. However, battery technology is a limiting factor, especially in terms of travel speed and cruising distance (Shinnar, 2003). At this stage, HEVs may be a second choice. HEVs also get some high evaluation and already on market for years, examples are Toyota Prius and Lexus RX400h (Lin et al. 2009). For this reason, the Environmental Protection Administration (EPA) (NREL 2005b) had drafted the strategies for HEVs trials in Taiwan. The detailed processes of investigation and evaluation are described below.

3.2 Investigation for constructing the Evaluation Criteria and Strategies

To ease the development of HEVs, the evaluation criteria and trial strategies should be constructed with a common consensus of experts from related fields. The elementary evaluation criteria and trial strategies were generated by using a literature review and experts' brainstorming. In addition, the Delphi approach was applied to identify the criteria and strategies.

First, criteria and strategies were collected and analyzed from related international studies. The initial investigation questionnaire was designed after considering the development of HEV technology, and was used to interview 13 experts from related entities, including Industrial Development Bureau, Transportation Vehicle Manufactures

Association, Environmental Protection Administration, Institute of Transportation, Institute of Technology Research, Energy Commission, Chung-Hwa Motor Company and Sanfu Motors Industrial Company.

The Delphi investigation steps used in this research are as follows:

Step 1: Establishing a planning group, including related decision-makers.

Step 2: Selecting the experts investigated generally 10 to 15 persons in total.

Step 3: The planning group designs the first Delphi questionnaire based on the collected data. The elementary evaluation criteria and trial strategies are then sent to the experts. The revised criteria and strategies were developed after discussion.

Step 4: The ranking order of criteria and strategies can be determined by analyzing and integrating the opinions of experts after the questionnaire were returned.

Step 5: Consulting the opinions from Step 4, the second Delphi questionnaire was designed and sent to experts to elicit their opinions.

Step 6: The same as Step 4.

Step 7: Check whether the different opinions converge in consensus (in this research, the coefficient of variation (Mean (X)/Standard deviation (S)) is set to be lower than 0.1). If a common consensus is not achieved, Step 5 to 7 should be repeated.

Step 8: When a common consensus is achieved, the ranking order is the final opinion of experts with common consensus.

By using the procedure above, a period of time will be required in order to attain satisfactory convergence. Also, the more time will be required with the more experts there is. Since 13 experts participated in this research, the investigation procedure was revised to obtain convergent results. During the period of investigation, a conference was convened to complete the investigation as soon as possible.

3.3 Evaluation Model

To understand the opinion about evaluation criteria and trial strategies of experts in related domains, we applied the Delphi method to find the final consensus of experts. The results of the investigation were analyzed, as shown below:

3.3.1 Evaluation Criteria

There were 14 evaluation criterias drawn up in the first Delphi investigation, and then it was increased to 19 evaluation criterias with the experts' consensus after collecting their opinions. The evaluation hierarchy was determined after the second Delphi investigation, as shown in Fig 4.

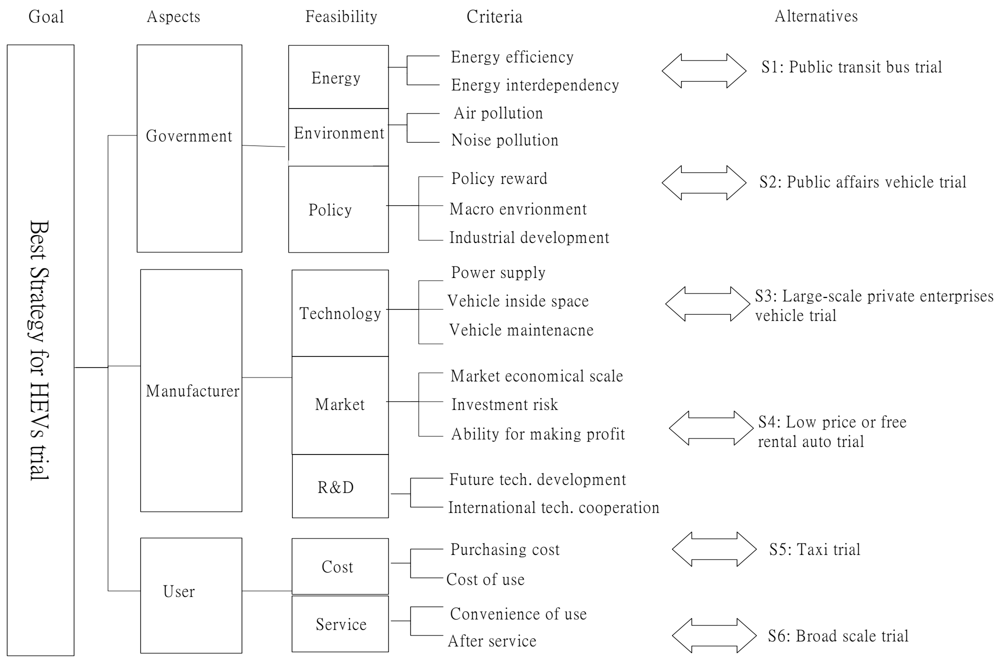

Figure 4. Evaluation Hierarchy of the strategies for HEV trials

3.3.2 Strategies of HEVs trial

In this research, the investigations of evaluation criteria and strategies were made at the same time. In consulting and analyzing the strategies in related research and the characteristic of HEVs, six kinds of possible strategies were recommended in the first Delphi questionnaire. They were provided to the experts for their reference, and the relative weights were investigated at the same time. The strategies were as shown below:

A. Public transit bus trial (Strategy A)

Start with the low capacity routes or feeder buses and then include popular common routes. This strategy lets people come into contact with HEVs and realizes their merits, which at the same time helps the development of HEVs go more smoothly.

B. Public affairs vehicle trial (Strategy B)

Government departments of public affairs use HEVs, making them more popular as private vehicles. Government and state-operated enterprises take the lead in using HEVs and make them popular.

C. Trial of low price or free rental auto (Strategy C)

In specific regions, the government lends HEVs to people at no cost or at low prices. This strategy increases the interest of people in using HEVs by letting them experience HEVs firsthand.

D. Large-scale private enterprises vehicle trial (Strategy D)

Large-scale private enterprises have many employees and businesses. If they use HEVs for commercial affairs or transportation vehicles, the government would offer rewards such as subsidies for purchasing HEVs or tax abatements.

E. Taxi trial (Strategy E)

In urban areas of Taiwan, taxis are a common transportation mode. If taxis have the priority for trial operation, passengers will appreciate the merits of HEVs better.

F. Broad scale trial (Strategy F)

To rationalize the use of HEVs, the government can increase their popularity by offering incentives such as: special parking areas, free parking lots along the roads, subsidies for purchasing HEVs, tax abatements or free service for setting battery recharge devices.

3.4 Evaluation Results

In this section, the fuzzy partitioned model is used first to evaluate the strategies for HEV trials. Relative criteria weights identification, performance measurements of strategy and the trial strategy evaluation are described thereafter.

3.4.1 Relative Criteria Weights

A pairwise comparison matrix of each criterion was obtained by investigating experts, and the relative importance of each criterion was calculated by AHP. The difference analyses of 19 evaluation criteria are shown in Table 1. According to the weights of each criterion, purchasing cost, cost of use and convenience of use are the most important ones among the 19 evaluation criteria; on the contrary, power supply, vehicle interior space and vehicle maintenance are considered to be least important. The criteria of investment risk, industry development and market economic scale have the biggest variations in the coefficient of variation, while the criteria of air pollution, purchasing cost and cost of use have the smallest variations.

Evaluation criteria	Mean value	Max	Min	Stand dev.	Coef. V	Range

Energy efficiency	0.0479	0.1386	0.0101	0.0431	0.8998	0.1285
Energy interdependency	0.0289	0.1386	0.0025	0.0361	1.2472	0.1361
Air pollution	0.0725	0.2325	0.0175	0.0596	0.8219	0.2150
Noise pollution	0.0371	0.1420	0.0035	0.0376	1.0146	0.1385
Policy reward	0.0406	0.1824	0.0023	0.0522	1.2834	0.1801
Macro environment	0.0395	0.1824	0.0038	0.0492	1.2435	0.1786
Industrial development	0.0327	0.1824	0.0019	0.0510	1.5579	0.1805
Power supply tech.	0.0210	0.0592	0.0009	0.0216	1.0278	0.0583
Vehicle inside space	0.0071	0.0221	0.0011	0.0074	1.0532	0.0210
Vehicle maintenance	0.0193	0.0592	0.0026	0.0179	0.9270	0.0566
Market economical scale	0.0621	0.3264	0.0004	0.0903	1.4533	0.3260
Investment risk	0.0464	0.3134	0.0039	0.0864	1.8624	0.3095
Making profits ability	0.0415	0.1282	0.0010	0.0382	0.9199	0.1272
Future tech. Development	0.0200	0.0718	0.0009	0.0211	0.9386	0.0709
International tech. cooperation	0.0317	0.1083	0.0018	0.0322	1.0169	0.1065
Purchasing cost	0.1842	0.4625	0.0022	0.1541	0.8366	0.4603
Cost of use	0.1111	0.1918	0.0061	0.0650	0.5851	0.1857
Convenience of use	0.1079	0.3198	0.0078	0.0959	0.8880	0.3120
After service	0.0458	0.1755	0.0078	0.0476	1.0380	0.1677

Table 1. Difference analyses of criteria weights

3.4.2 Alternative Performance

Since it is difficult to measure the extent to which strategies for evaluation criteria by objective and specific data are achieved, we rely on the experts' professional judgments based on their experience and knowledge. The achievement levels of trial strategies after being transformed are shown in Table 2.

Table 2. Alternatives performance

Alternatives\ Criteria	Public bus	Public affairs vehicle	Low price rental auto	Private enterprises vehicle	Taxi	Broad scale
Energy efficiency	0.0479	0.714	0.596	0.587	0.663	0.692
Energy interdependency	0.0289	0.518	0.5	0.558	0.615	0.654
Air pollution	0.0725	0.768	0.558	0.606	0.663	0.635
Noise pollution	0.0371	0.679	0.519	0.558	0.635	0.606
Policy reward	0.0406	0.75	0.663	0.548	0.75	0.625
Macro environment	0.0395	0.712	0.615	0.596	0.75	0.643
Industrial development	0.0327	0.673	0.625	0.548	0.731	0.518
Power supply tech.	0.021	0.635	0.5	0.558	0.673	0.714
Vehicle inside space	0.0071	0.558	0.471	0.49	0.558	0.661
Vehicle maintenance	0.0193	0.548	0.452	0.5	0.596	0.732
Market economical scale	0.0621	0.589	0.519	0.538	0.548	0.529
Investment risk	0.0464	0.536	0.587	0.577	0.606	0.596
Making profits ability	0.0415	0.482	0.433	0.49	0.538	0.481
Future tech. Development	0.02	0.606	0.644	0.577	0.654	0.589
International tech. cooperation	0.0317	0.625	0.654	0.577	0.644	0.673
Purchasing cost	0.1842	0.644	0.625	0.654	0.615	0.554
Using cost	0.1111	0.702	0.625	0.692	0.654	0.696
Use convenience	0.1079	0.625	0.538	0.558	0.567	0.577
After service	0.0458	0.607	0.558	0.577	0.635	0.548

3.4.3 Results of Fuzzy Partitioned Hierarchy Evaluation

When applying the fuzzy partitioned hierarchy model and the fuzzy integral, fuzzy factor analysis should first be applied to check the hierarchy constructed by brainstorming. Secondly,λ-fuzzy measure is applied to find the relative weights of each criterion in revised hierarchy. Finally, each alternative is ranked by the method of fuzzy integral. The results of each step are illustrated as below.

(1) Fuzzy Factor Analysis

Fuzzy factor analysis is applied to analyze the preference structure of the experts in order to obtain factor scores for criteria. Six potential factors are generated in this analysis: development, vehicle technology, energy, market, risk and pollution. New hierarchies can be reconstructed based on these results. Table 3 shows the fuzzy factor loading of each criterion.

Table 3. Fuzzy Factor loading for each criterion

Criteria\ Factors	Development		Vehicle tech.		Energy		Market		Risk		Pollution		Communality	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Policy reward	0.881	0.993	-0.401	-0.204	0.030	0.109	-0.241	-0.102	0.022	0.097	-0.012	0.037	0.997	1.060
Macro environment	0.976	1.000	-0.079	0.081	-0.057	-0.025	-0.064	0.039	0.075	0.145	-0.025	-0.003	0.972	1.030
Industrial development	0.912	0.939	-0.207	-0.057	-0.006	0.006	0.264	0.361	-0.005	0.050	0.000	0.004	0.944	1.019
Using cost	-0.659	-0.588	-0.507	-0.455	-0.304	-0.279	-0.277	-0.217	-0.445	-0.396	0.097	0.117	1.068	0.847
Power supply tech.	-0.267	-0.178	0.827	0.967	0.106	0.124	-0.225	-0.176	-0.094	-0.084	0.027	0.041	0.827	1.023
Vehicle inside space	-0.241	-0.135	0.868	1.000	-0.011	0.039	0.006	0.108	0.075	0.123	0.031	0.051	0.819	1.049
Vehicle maintenance	-0.278	-0.217	0.520	0.637	0.453	0.455	0.343	0.387	-0.361	-0.352	0.076	0.092	0.807	0.942
Future tech. Development	0.464	0.489	0.529	0.632	0.298	0.318	-0.151	-0.088	0.273	0.318	0.163	0.186	0.708	0.884
Purchasing cost	-0.423	-0.399	-0.601	-0.505	0.104	0.112	-0.542	-0.450	-0.095	-0.051	-0.478	-0.453	1.082	0.837
Use convenience	-0.353	-0.329	0.102	0.201	-0.616	-0.602	-0.363	-0.285	-0.524	-0.472	0.077	0.080	0.926	0.821
Energy efficiency	-0.070	0.001	0.011	0.145	0.879	0.923	-0.176	-0.096	0.050	0.074	0.038	0.038	0.813	0.890
Energy interdependency	0.019	0.091	0.133	0.301	0.833	0.858	-0.107	-0.026	0.085	0.131	0.444	0.451	0.928	1.056
Market economical scale	-0.135	-0.066	-0.262	-0.112	-0.017	0.045	0.873	0.977	0.287	0.330	-0.113	-0.097	0.944	1.092
International tech. coop.	0.140	0.205	0.045	0.216	-0.188	-0.127	0.876	1.000	0.249	0.317	-0.084	-0.063	0.893	1.209
After service	-0.198	-0.139	0.007	0.054	-0.241	-0.218	-0.187	-0.150	-0.793	-0.764	-0.165	-0.146	0.788	0.697
Making profits ability	0.011	0.060	0.059	0.193	-0.029	0.021	0.287	0.400	0.640	0.693	-0.344	-0.328	0.615	0.789
Investment risk	-0.069	0.037	0.515	0.686	-0.563	-0.444	0.128	0.297	0.540	0.623	-0.188	-0.109	0.930	1.157
Air pollution	0.162	0.234	0.277	0.431	0.453	0.470	-0.132	-0.043	-0.064	-0.027	0.715	0.725	0.841	0.990
Noise pollution	-0.254	-0.175	-0.106	0.010	0.112	0.146	-0.218	-0.142	-0.060	-0.055	0.924	0.939	0.994	0.957
Eigenvalue	7.688	12.052	2.951	28.065	1.701	2.620	0.812	1.222	0.674	1.086	0.384	0.901	-	-
Contribution (%)	0.239	0.324	0.193	0.253	0.117	0.260	0.108	0.115	0.069	0.081	0.054	0.055	-	-
Cum. Contribution	0.239	0.324	0.431	0.577	0.549	0.837	0.656	0.952	0.725	1.000	0.779	1.000	-	-

(2) Determining the value of λ -measure for the fuzzy integral

After fuzzy factor analysis, we verify that the aspects are mutually independent and criterias in aspects have interrelations. The concept of the λ -fuzzy measure is applied to solve the value of λ for each aspect. In practice, since it is difficult to investigate the interrelation of criteria in each aspect, this research uses the type I fuzzy measure identification, the Genetic Algorithm (GA) as introduced by Lee and Leekwang (1995), to solve the value of λ -fuzzy measure, as shown in Table 4. The interrelation of criteria is obtained based on the definition of λ -fuzzy measure.

Table 4. Evaluation Results

Factors		λ	Weights	S1	S2	S3	S4	S5	S6
Development	**Left**	-0.07	0.223	0.158	0.140	0.140	0.156	0.144	0.156
	Right	0.001	0.224	0.159	0.141	0.141	0.157	0.145	0.157
Vehicle tech.	**Left**	0.158	0.254	0.160	0.152	0.158	0.157	0.149	0.161
	Right	0.258	0.305	0.187	0.181	0.187	0.188	0.179	0.195
Energy	**Left**	-0.353	0.046	0.027	0.025	0.025	0.028	0.030	0.026
	Right	-2.763	0.203	0.129	0.126	0.131	0.125	0.117	0.131
Market	**Left**	-0.106	0.132	0.091	0.080	0.088	0.087	0.092	0.091
	Right	1.678	0.136	0.094	0.082	0.091	0.089	0.095	0.093
Risk	**Left**	2.63	0.183	0.125	0.111	0.116	0.123	0.120	0.123
	Right	3.427	0.156	0.108	0.098	0.102	0.105	0.101	0.107
Pollution	**Left**	1.558	0.136	0.094	0.082	0.091	0.089	0.095	0.093
	Right	4.79	0.161	0.112	0.101	0.104	0.108	0.103	0.110
Score	**Left**	-	-	0.1017	0.0925	0.0964	0.0995	0.0964	0.1013
	Right	-	-	0.1496	0.1398	0.1442	0.1474	0.1403	0.1514
Rank	**Left**	-	-	1	6	4	3	5	2
	Right	-	-	2	6	4	3	5	1

(3) Alternative Evaluation

After finding the interrelation between criteria in each factor, the fuzzy integral is utilized to calculate the evaluation scores of alternatives in each factor. Since the factors are independent, the alternatives will be evaluated separately by the criteria in the same factors. After completing the evaluation of each factor, the simple additive weighting method (SAW) is applied to integrate the score of each factor. The evaluation results are shown in Table 4.

4. DISCUSSIONS

In this paper, a fuzzy partitioned hierarchy model is introduced and compared with the results of AHP. Generally speaking, this model should be compared with Fuzzy AHP, ANP (Analytic Network Process) and find the difference among these three methods. However, the operation procedures of fuzzy AHP and ANP are different from AHP. There are additional steps when doing the investigation job. For example, the fuzzy AHP need to investigate each expert's perception and ANP need to identify the evaluation network previously. Under the consideration of simplifying questions, this research only compared the difference between the proposed model and AHP. It is also conforms to the goal of introduced model which intended to release the independent assumption of AHP.

Compared with the classic MCA, the fuzzy integral is more reasonable because it releases the assumption of independence by applying fuzzy measure. Since this method applies the multiplicative utility function, it can measure the objective preference of decision-makers and the interrelation of each criterion. In contrast, the related method of fuzzy measure uses the multiplicative utility function to estimate the interrelation of the criteria, so its calculations are complicated and it is inconvenient to use in practice. This paper introduces the partitioned hierarchy model which uses factor and cluster analysis, thus reducing the complexity of calculation while providing a reconstructed hierarchy. In addition, it can ensure the independence of each aspect/factor. Due to complexity, if there are too many evaluation criteria we must use a heuristic method to identify the λ- fuzzy measure, and this paper uses GA to identify the value of the λ-fuzzy measure. Combining fuzzy factor analysis with the partitioned model can measure the vagueness of experts' opinions, so the ranking results become more elastic.

Based on the weight analysis of evaluation criteria, investment risk found it to be with the biggest variation. The results of fuzzy factor analysis reveal that the left and right evaluation hierarchy is different with investment risk being classified into two clusters, which makes the evaluation results different. This outcome shows us the vagueness of experts' evaluation. In addition the decision makers should also pay more attention to evaluation results when implementing the HEVs trial.

Table 5. α -cut of alternatives' fuzzy scores

	α -cut	Public bus	Public affairs vehicle	Low price rental auto	Private enterprises vehicle trial	Taxi trial	Broad scale trial
Left	0.2	0.127	0.116	0.120	0.125	0.121	0.127
Right		0.161	0.149	0.154	0.158	0.151	0.162
Left	0.4	0.130	0.119	0.123	0.128	0.123	0.130
Right		0.155	0.144	0.149	0.153	0.146	0.156
Left	0.6	0.133	0.122	0.127	0.131	0.126	0.133
Right		0.150	0.139	0.144	0.148	0.141	0.151
Left	0.8	0.137	0.125	0.130	0.134	0.130	0.137
Right		0.145	0.134	0.139	0.143	0.137	0.146
Left	1.0	0.141	0.129	0.134	0.138	0.133	0.141
Right		0.141	0.129	0.134	0.138	0.133	0.141

During the process of evaluation, the fuzzy scores of alternatives can be found but the rank of each alternative cannot be determined. In Table 5, the α -cuts of fuzzy scores are calculated by setting α equal to 0.2, 0.4, 0.6, 0.8 and 1. The public transit buses trial is the best strategy among the six alternatives because when the α value is equal to 0.8 and 1, the rank of each alternative can be determined. It can be seen that α =0.8 is a critical point which can determine the rank of each alternative. The strategic alternatives are obtained after Delphi investigations, therefore these are feasible alternatives for HEV trials. Compared with these 6 alternatives, we can find that the transit bus trial and broad scale trial are comparatively without controversy. The large-scale private enterprise vehicle trial and taxi trial are concerned with the private enterprises and the individuals, which makes these two alternatives more difficult to carry out. If only a single alternative could be chosen, then the public transit bus trial will be the best alternative. The following problems should be considered when proceeding with the public transit bus trial in the future:

Suitable laws should be enacted because HEVs are a new transportation mode. Related laws and regulations should be carefully determined;

An appropriate government department should evaluate or solicit for the cooperation of organizations or businesses. In addition, related funds should be raised and the necessary staff should be trained;

Related departments should pay attention to the programming of trial regions and routes.

5. CONCLUSIONS

This research combines fuzzy factor analysis, fuzzy measure and fuzzy integral to develop multiple criteria evaluation. Combining fuzzy factor analysis with a partitioned model can measure the vagueness of experts' opinions, so the ranking results became more elastic. The partitioned model can ensure the interrelation of each criterion, as well as separately use the multiplicative utilities based on different relations.

In addition to releasing the assumption of independence for each criterion, the fuzzy partitioned model analyzes the interrelations among the groups by using additive utilities and multiplicative utilities of the criteria in the same group. At the same time, the calculation of fuzzy measure and fuzzy integral for criteria after clustering is simplified. There are fewer than 7 criteria in any single aspect, which avoids the generation of mistakes.

By applying fuzzy factor analysis and the fuzzy integral, the fuzzy score of each alternative can be calculated, and after setting α –cut the rank of each alternative can be determined. The evaluation results reveal that the public transit bus trials and broad scale trials are the most suitable alternatives. This result also shows the experts' evaluation vagueness. Although the result is more reasonable than classic Multiple Attribute Decision Making (MADM) method, decision makers should be more careful when implementing the evaluation results.

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