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Fuzzy Analytic Hierarchy Process using Intuitive Vectorial Centroid for Eco-friendly Car Selection

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Abstract. Eco-friendly car is expected to be the next driving market force for global transportation and technology due to its paramount importance towards the sustainability of the environment and society. However, the actual sales of eco-friendly car are not that convincing and it is even decreasing because the consumer is still uncertain to consider eco-friendly as one of the criteria for them to buy their cars. This situation is worsen by the lack of information and awareness regarding sustainability transportation initiatives. Due to the uncertainty and vague understanding of the consumer about this problem, this paper attempts to investigate the current preference of consumer to buy their cars, and whether they really need to buy the eco-friendly car by using the Fuzzy Analytic Hierarchy Process (FAHP) which implements the Intuitive Vectorial Centroid (IVC). Based on FAHP, the imprecise or fuzzy judgment from the decision maker can be incorporated, to anticipate a better decision for eco-friendly car selection. The outcome of FAHP is compared with crisp Analytic Hierarchy Process (AHP), and the findings shows that FAHP can provide an accurate and consistent result with AHP, although it deals with fuzzy judgment inputs from multiple decision makers.

1. Introduction

The emergence of eco-friendly car can be traced back since 1837 when the first known electric cars powered by battery was invented by Robert Davidson. Since then, many scientist and engineers continues to develop electric car which is not expensive, compact with long lasting source of energy but to no avail [1]. In 1997, the world's first hybrid car, Toyota Prius was introduced and managed to be mass produced for global consumers. The demand for hybrid cars is rapidly increasing with various initiatives such as hybrid car rebates and charging station for electric cars started to be located at various cities' hotspot. Today, the global demand for electric cars is still expected to increase rapidly from 700,000 units in 2016 to three million units by 2021 [2]. Besides, car manufacturers such as BMW, Mercedes Benz, Hyundai, Toyota, Honda and Nissan also have continuously strive to improve the existing energy efficient, hybrid and electric cars.

All of these initiatives should promote a significant growth of eco-friendly cars but did the consumers really consider the eco-friendly criteria as their main preference when they decide to buy a car? [2] listed several challenges of the electric cars implementation which states that cleaner technology will be a trade off with higher energy usage. In addition, the adoption of technology requires time as the knowledge needs to be assimilated among the society. The technology of electric might still be irrelevant due to its relatively high development cost, high selling price, high maintenance fee, lack of government incentives and lack of infrastructures. This situation is worsened by the sales of hybrid vehicle which is declining [3].

As the contradiction exists between the rapid automotive technology advancement and the fuzzy nature of demand and readiness of the consumer for eco-friendly car, this research aims to examine the problem from the perspective of consumers's fuzzy decision making, and whether they really consider eco-friendly as one of the criteria to purchase their cars. This research implements Fuzzy Analytic Hierarchy Process(FAHP) using Intuitive Vectorial Centroid to to determine the preference of consumers for the eco-friendly cars.

2. Literature Review

2.1. Eco-friendly car selection

An eco-friendly car, green car, clean car, or environmentally friendly car can be classified as the car that produces less negative impacts towards the environment as compared to the conventional internal combustion engine car which relies on gasoline or diesel [4]. Types of eco-friendly car includes energy efficient vehicle (EEVs), electric car, hybrid car and plug-in hybrid car [4], [5]. The term eco-friendly car can also be applied to the car which uses alternative fuels such as biodiesel derives from palm oil, soy or canola oil, waste cooking oil and animal fats as it emits far lower greenhouse gas emission [6].

Based on eight previous studies from 2001 until 2017, the criteria of affordable price, fuel economy, design, maintenance cost, safety, performance, warranty, after sale service, sale services and emission had been identified as the main factors that influenced the consumers to buy cars [7-14]. However, after classification, maintenance cost, warranty, after sale service and sale services are redefined as service. Thus, the criteria which are considered in this research are services, affordable price, fuel economy, safety, design, performance and emission.

2.2. Analytic Hierarchy Process

In 1980, Saaty (1980) developed the Analytic Hierarchy Process (AHP) technique, which constructs a decision-making problem into hierarchy which consists of goal, criteria, sub-criteria, and decision alternatives. The AHP technique performs pairwise comparisons to measure relative importance among attributes at each level of the hierarchy, and evaluates alternatives in order to construct the best decision. AHP provides decision makers with a way to transform intangible judgments into quantitative value of measurement [15]. Due to its mathematical simplicity and flexibility, AHP has been a popular decision tool in many fields which includes engineering, food, business, ecology, health, and government [15-16].

In spite of that, most of the AHP application in real world decision making situation will probably faces severe practical constraint from criteria which may consists of imprecise or vague information [17]. The conventional AHP normally assume that all criteria and their respective weights are expressed in absolute precise numbers or crisp values which may simplify the rating and the ranking of the decision alternatives. Regrettably in many practical cases, the performance of the criteria may only be expressed qualitatively in words and sentences which appeal for a more proper method [18].

In addition, decision makers always find it more convincing to provide interval judgments rather than a fixed value of judgments. This happens as the decision makers are unable to explicit their preferences due to the fuzzy characteristics of the pair wise comparison process [19]. Hence, the diffusion of Fuzzy Sets Theory (FST) into MCDM is introduced by [17] and highly advocated by[18]. The concept of Fuzzy Multi Criteria Decision Making (FMCDM) is believed to be a better strategy to inquire the fuzziness nature which always occurs in the real world decision making situation.

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2.3. Fuzzy Analytics Hierarchy Process

The first attempt to incorporate fuzzy inputs into AHP is by[20]. They suggested a fuzzy logarithmic least squares (FLLS) method to obtain the triangular fuzzy weights from a triangular fuzzy comparison matrix. [21] utilized the geometric mean method to calculate fuzzy weights. [22] proposed an extent analysis method, which derives crisp weights for fuzzy comparison matrices.

Meanwhile, [23] suggested a fuzzy least squares priority (FLSP) method. [24] came up with λ-Max method, which is a direct defuzzification of the k-max method. [25] developed a fuzzy preference programming (FPP) method, which is inspired from the linear programming (LP) method. Lately, [26] presented a modified FFLS method which is the improved method based on [20]

To date, various novel defuzzification for fuzzy pairwise comparison is still being suggested as an alternative to derive crisp values for FAHP basis. This research will implement the relatively new types of defuzzification proposed [27] which is known as Intutive Vectorial Centroid (IVC) which is an extension of the classical vectorial centroid methods for fuzzy numbers. IVC is deemed to be more intelligent and able to cater all feasible cases of fuzzy numbers situation as compared to other centroid methods.

3. Methodology

In this research, the fuzzy pairwise comparison judgment is obtained from potential car buyers as opposed to experts as the car selection is the decision making process of a consumer. The decision problem of eco-friendly car selection is represented as fuzzy analytic hierarchy process (AHP) model. Seven criteria which are included in the FAHP are (1) affordable price (2) fuel economy (3) safety, (4) services, (5) design, (6) performance and (7) emission.

FAHP is a tool which can be used to solve complex yet subjective decision-making problems which accomodates the fuzzy judgment from the decision maker. The methodology used in the research is adapted from [14] and [15] with the modification at the defuzzification process.

Step 1: Identify the problem. The decision problem has been identified as the eco-friendly car selection.

Step 2: Construct a hierarchy by three level which are (i) goal, (ii) criteria and (iii) alternative as presented in Figure 1.

Table 1: Representation of Criteria

Criteria	Acronym
Affordable price	A
Fuel economy	F
Safety	ST
Services	SV
Design	D
Performance	P
Emission	E

Table 2: Representation of Alternatives

Alternatives	Acronym
Hyundai Ionic HEV (2017)	H
Toyota Prius 1.8 VVT-i Active (TRK) Auto	T
Perodua Myvi 1.3 Ezi(2017)	P
Mercedez Benz C350e (2016)	M
Nissan Leaf (2016)	N

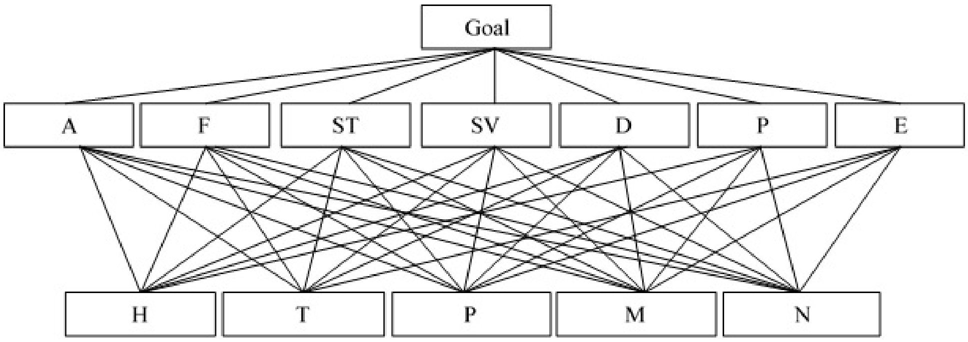

Figure 1: FAHP Hierarchy Structure

Step 3: Determine the pairwise comparison judgement using relative importance scale as shown in Table 3.

Table 3: Crisp and Fuzzy Relative Importance

Linguistic variable	Relative importance	Triangular fuzzy scale	Reciprocal fuzzy scale
Equal Importance	$\tilde{1}$	(1,1,1)	(1,1,1)
Intermediate value	$\tilde{2}$	(1,2,3)	(1/3,1/2,1)
Moderate Importance	$\tilde{3}$	(2,3,4)	(1/4,1/3,1/2)
Intermediate value	$\tilde{4}$	(3,4,5)	(1/5,1/4,1/3)
Strong Importance	$\tilde{5}$	(4,5,6)	(1/6,1/5,1/6)
Intermediate value	$\tilde{6}$	(5,6,7)	(1/7,1/6,1/5)
Very Strong Importance	$\tilde{7}$	(6,7,8)	(1/8,1/7,1/6)
Intermediate value	$\tilde{8}$	(7,8,9)	(1/9,1/8,1/7)
Extreme Importance	$\tilde{9}$	(8,9,9)	(1/9,1/9/1/8)

Step 4: Aggregate the judgement from respondents by using geometric mean to form fuzzy pairwise comparison matrix :

$$\tilde{r}_{ij} = (\tilde{a}_{ij}^1 \times \tilde{a}_{ij}^2 \times ... \times \tilde{a}_{ij}^n)^{1/k} \tag{1}$$

such that k is the number of decision makers, $i = 1, 2, ..., m; j = 1, 2, ..., n$.

Step 5: Defuzzify each fuzzy weights by using the defuzzification method of Intuitive Vectorial Centroid (IVC) by [27]:

$$IVC(\tilde{x}_{\tilde{A}}, \tilde{y}_{\tilde{A}}) = \left(\frac{2(a_1 + a_4) + 7(a_2 + a_3)}{18}, \frac{7h_{\tilde{A}}}{18} \right) \tag{2}$$

Step 6: Normalize the defuzzified weights.

Step 7: Rank the alternative based on the weights.

4. Results and Discussions

The total number of respondents involved in this research is 5, from various age, race, religion, profession, education level, marital status, household income, number of children and types of current car and dream car. The aggregated fuzzy judgment by these 5 respondents is represented in the form of fuzzy pairwise comaparison matrix in Table 4.

Table 4: Fuzzy pairwise comparison matrix

Criteria	A	F	ST	SV	D	P	E
A	1.0000	1.0275	0.4920	0.4476	1.8103	0.5380	4.4324
F	0.9732	1.0000	1.5526	1.3191	1.3935	1.9076	2.1715
ST	2.0325	0.6441	1.0000	2.6477	0.9899	0.2545	3.0112
SV	2.2341	0.7581	0.3777	1.0000	1.7724	0.3970	1.4182
D	0.5524	0.7176	1.0102	0.5642	1.0000	0.9214	1.3505
P	1.8587	0.5242	3.9293	2.5189	1.0853	1.0000	3.6650

The usage of fuzzy group judgment is suggested for this type of decision problem because the group judgement represents the eco-friendly car selection problem with multiple consumers as the decision makers. In addition, some of the respondents individual judgment may not be consistent. The usage of experts judgment may also be void in this context, as consumers preferences are highly varied and car buying decisions cannot be limited to the judgment from several experts only. Based on the given pairwise comparison, the weight of the criteria and its respective rank is obtained and shown in Table 5.

Table 5: AHP and FAHP Criteria weights

Criteria	AHP weight	AHP Rank	FAHP weight	FAHP Rank
Affordable price	0.1306	4	0.1408	4
Fuel economy	0.2001	2	0.1818	2
Safety	0.1547	3	0.1563	3
Services	0.1270	5	0.1302	5
Design	0.1002	6	0.1067	6
Performance	0.2115	1	0.2235	1
Emission	0.0752	7	0.0606	7

The FAHP results obtained from the respondents indicates that performance is the highest criteria preferred by them when they want to buy cars, followed by fuel economy, safety, affordable price, services, design and emission. The rank results for criteria weight from FAHP is consistent with AHP with slightly marginal difference. Two of the criteria which are closely related with eco-friendly, namely fuel economy is ranked at 2nd whereas emission is ranked at 7th. This shows that the consumer still taken into account eco-friendly factor as well, be it voluntarily or involuntarily.

For the decision alternatives which is the car models, five eco-friendly cars are selected from [28]. The five eco-friendly cars are Hyundai Ionic HEV (2017), Toyota Prius 1.8 VVT-i Active (TRK) Auto, Perodua Myvi 1.3 Ezi(2017), Mercedez Benz C350e (2016) and Nissan Leaf (2016). Only four from the seven criteria, which are price, fuel economy, performance and emission are discussed for the time being, with the exception of safety, services and design due to the limited data availability. Table 6 exhibits the information associated with these criteria for each car.

Table 6: Information of car

Car model	Price (RM)	Fuel (l/100 km)	Performance (hp)	CO2 Emission (g/km)
Hyundai Ionic HEV	100328	3.4	104	0
Toyota Prius 1.8	130704	2.7	98	78
Perodua Myvi 1.3 Ezi	42790	5.3	87	151
Mercedez Benz C350e	289888	2.1	211	48
Nissan Leaf	180556	0.1	109	0

Based on Table 6, the data is normalized into the scale of 1-9 according to the parameter as in Table 3. For (1) price (affordable price), the less price indicates the more affordable one thus higher weight, (2) fuel (fuel economy), the lower consumption indicates higher weight, (3) performance (performance) in which the higher horsepower (hp) represented by the higher weight and (4) CO2 emission, the lower emission is the highest weight. The final weight and rank of each car is summarized in Table 7.

Table 7: Normalized weight for each alternatives

Car model	Affordable Price	Fuel Economy	Performance	CO2 Emission
Hyundai Ionic HEV	0.1994	0.1477	0.1707	0.4901
Toyota Prius 1.8	0.1531	0.1860	0.1609	0.0063
Perodua Myvi 1.3 Ezi	0.4676	0.0948	0.1429	0.0033
Mercedez Benz C350e	0.0690	0.2392	0.3465	0.0102
Nissan Leaf (2016)	0.1108	0.3323	0.1790	0.4901

Table 8: Final weight of each alternatives with respect to criteria

Car model	AHP weight	AHP Rank	FAHP weight	FAHP Rank
Hyundai Ionic HEV (2017)	0.2050	3	0.2015	3
Mercedez Benz C350e (2016)	0.2074	2	0.2099	2
Nissan Leaf (2016)	0.2320	1	0.2244	1
Perodua Myvi	0.1871	4	0.1939	4
Toyota Prius (2015)	0.1686	5	0.1704	5

By referring to Table 8, the analysis of FAHP using IVC concluded that the most preferred eco-friendly by the consumers are Nissan Leaf (2016), followed by Mercedez Benz C350e (2016), Hyundai Ionic HEV (2017), Perodua Myvi 1.3 Ezi (2017), and Toyota Prius 1.8 VVT-i Active (TRK) Auto. The rank results for decision alternatives from FAHP is again consistent with AHP with slightly marginal difference. This outcome shows that FAHP can provide an accurate and consistent results with the conventional AHP although it deals with fuzzy judgment inputs from multiple decision makers.

5. Future work recommendations

The findings from this research can be compared with different fuzzy judgment scale and even trapezoidal scale. In addition, the height of triangular scale in this research is assumed to be 1, and the researcher will experiment with different values of heights to better represent the fuzzy environment, which may also include the factor of the decision maker's credibility. The eco-friendly car selection prolblem can also be applied by using the Analytic Network process (ANP) which can accommodate feedback and dependence among the criteria, as well as well as other multi criteria decision making (MCDM) methods.

In addition, the criteria used may also be re-examined to aligned with other global automotive initiatives. The number of decision alternative comprises of cars should also be increased in the future to improve the ranking pool of eco-friendly cars. Besides, the scare information of safety, services and design for each car model will be continuously searched and collected in the future. Finally, the involvement of respondents shall be increased and the demographic relationship with the preferences of car is worth to be investigated.

6. Conclusion

This research demonstrates the application of FAHP by using IVC which is proven to be efficient in solving the fuzzy nature of the decision making process for eco-friendly car selection. Based on finding, it is hypothesized that the consumer still prefer the eco-friendly car, with fuel economy remains to be the competitive factor. However, the consumer did not really consider the emission factor, which suggest more awareness needs to be done so that they will realize the negative impacts of carbon monoxide (CO) towards our environment and society.

The finding from this research can be an alternative for the global car manufacturer to design for the next future cars. Finally it can also be the indication, that more collaborative effort is needed and more improvement is sought for the global automotive industry to embrace the green movement much faster into their practice and to transfer the green thinking to consumers.

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