Combining the AHP and TOPSIS to Evaluate Car Selection

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ABSTRACT

Car manufacturing is recently growing rapidly along with the development of technology and science. Consequently, car manufacturers have to improve their products, i.e., the cars, to meet customers' requirement. This study tried to evaluate car selection by utilizing nine criteria that are considered by the customers when they are willing to purchase the cars, namely, exterior, convenience, performance, safety, price, fuel efficiency, resale, spare part warranty, and dealer. The analytic hierarchy process (AHP) and technique for others reference by similarity to ideal solution (TOPSIS) were combined to accomplish the objective of this study. Firstly, the AHP was used to determine the weights of each criterion. The weights that have been identified by the AHP were then employed to select the best alternative using TOPSIS method. A case study to exhibit the applicability of the methods was conducted to evaluate two types of cars that have similar engine capacity and price range, i.e., All New Avanza 1.3 E and All New Xenia 1.3 R. Data were collected and compiled from three experts consist of a car rental owner, a car workshop owner, and a car dealer employee. The AHP result showed that the price was labelled as the most important criterion with weight of 0.182. The All New Avanza 1.3 E were regarded preferable than All New Xenia 1.3 R based on TOPSIS calculation. The finding of this study might offer the car manufacturers with valuable insight into the criteria that reflect customer's assessment in car selection.

CCS Concepts

Applied computing→ Multi-criterion optimization and decision-making

Keywords

Analytic hierarchy process; car selection; multi-criteria decision making; TOPSIS

1. INTRODUCTION

While the first car was invented in Germany and France in the late 1800s, the United States ever dominated the automotive industry in the first half of the twentieth century. The motor vehicle industry in the U.S. began with hundreds of manufacturers, but by the end of the 1920s it was dominated by three large companies, i.e., General Motors, Ford, and Chrysler, all based in Metro Detroit [1]. Afterwards, the car was developed in accordance with technological advances. In 1925 to 1948, it was considered as the era of classic cars; and in 1946 after a lull during World War II, it was the era of European postwar designs. Subsequently, it was the era of Japanese cars; and now in the late 20th century, it is the era of diesel engines and electric cars [2].

As science and technology escalate exponentially, the number of cars produced in the world reached 72.10 million unit in 2016, led by China about 24.4 million unit, Japan at 7.87 million unit, and Germany at 5.74 million unit [3]. Furthermore, the cars are projected to reach the two billion mark by 2040 [4]. The prediction is supported by a report from Macquarie Bank that in 2016, 88.1 million cars and light commercial vehicles were sold worldwide, up 4.8% from a year earlier [5]. In sum, it can be assumed that the need for cars increases.

As time goes by and as competition goes more intense, car manufacturers struggle to deliver their best products to meet customers' needs with an increasing range of criteria [6]. Manufacturing such products according to the wide range of criteria which are taken into customers' considerations is considered challenging since the criteria would conflict each other. Therefore, it is essential to apply an effective tool for recognizing and prioritizing relevant criteria to develop a robust assessment method. This method also should develop consensus decision making. The multi-criteria decision making (MCDM) theory could be applied in analyzing the quality of the products regarding to some criteria. This MCDM theory is a discipline that take aim at supporting decision makers who are faced with formulating various and conflicting evaluations.

There are numerous tools in MCDM which have been successfully applied in several fields. However, the analytic hierarchy process (AHP) proposed by [7] is considered as one of the most popular and powerful MCDM tool for decision making that has been used for years, (see [8]–[11] for the example of the application of the AHP). The AHP is considered as an intuitive method; easy to handle multiple criteria; user friendly since it allows the users to structure complex problems in the form of a hierarchy levels; and has an advantage as seeking consistency in judgments [12]. The AHP regulates basic rationality by solving the problem into small parts and then asks for a simple pairwise assessment in developing priorities in a hierarchy [13].

In this study, we attempted to combine the AHP with technique for order preference by similarity to ideal solution (TOPSIS) by [14] to determine the importance criteria and the best alternative among alternatives in respect to the customers' needs. The TOPSIS method is used here to identify the ranking of all alternatives to be considered. It is simultaneously consider the distance to the

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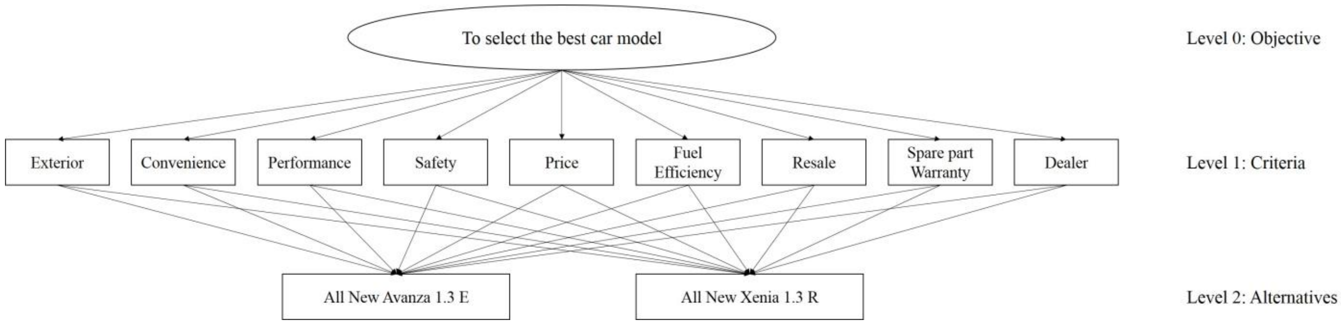

Figure 1. The Hierarchy for Evaluating Car Model Selection

"positive ideal solution" and the "ideal negative solution" associated with each alternative and choose the nearest to the ideal solution as the best alternative [15]. This technique has high flexibility so it can accommodate further extensions to make better choices in various situations [16]. The combination of these techniques is widely used in several researches, see for example [17]–[20].

In order to demonstrate the applicability of the methods, a case study was conducted on two types of cars which are regarded as two most popular cars in Indonesia, i.e., All New Avanza 1.3 E and All New Xenia 1.3 R. Indonesia was chosen since it is the country that has the highest car sales in Southeast Asia. The low ratio of ownership, the growth of income per capita which increased 11% annually in a decade, and the largest Indonesian population which reached 41% of the total population in Southeast Asia are considered as factors that supporting the huge amount of car sales in Indonesia [21]. Thus, the objectives of this research are twofold. The first is to show how to determine the importance of assessment criteria using the AHP method. The second is to identify the ranking of each alternative. The finding of this research is useful in determining the best criteria chosen by the customers when they are purchasing the cars.

2. RESEARCH DESIGN

In this study, the criteria for evaluating car selection between two alternatives aforementioned were determined as nine criteria, i.e., exterior, convenience, performance, safety, price, fuel efficiency, resale, spare part warranty, and dealer. They were selected and chosen by literature review [6], [22], [23] and deep interview with some experts. The first criterion is exterior, which is related to physical appearance from both inside and outside of the car. This criterion includes some aspect, such as color, dimension, tires, and headlamp. The second criterion is convenience that is defined by how the design can help users to operate the car easily. It involves the available space inside the car, comfortable seats, and the quality of audio system. The criterion that associated with the functionality of the car is performance, as the third criterion of this study. It involves acceleration, maximum speed, brake, and turning ability. The fourth criterion is related to how the car features can help users to stay safe while driving. Some features such as airbag, anti-lock braking system, seat belt, and alarm are included in this criterion. The fifth criterion is price. It is defined as how much money the customers have to purchase for the car. The next criterion is fuel efficiency which is related to fuel consumption of the car while it is operated. In addition, it can be identified by how far the car can travel in some unit of fuel volume. The seventh criterion is resale. It is defined by how much money the owner of the car would get when he/she would like to sell the used-car. It is assumed that the used car is in a normal condition when it would like to be sold. Subsequently, spare part warranty, which is the eighth criterion is related to warranty from the manufacturer in case some spare parts of the car are broken. It includes the service coverage and duration of warranty. The last criterion is dealer, which involves the availability of car dealers near to the customers. It also includes the service quality of the dealers.

Another objective of this research is to find out the best car model between two aforementioned alternatives. All New Avanza 1.3 E was chosen since it has the highest market share in period of June to July 2017. While All New Xenia 1.3 R was chosen since it has almost same physical characteristics and the other specifications with the first alternative.

In order to apply the AHP and TOPSIS methods to the prioritizing of criteria for evaluating car selection between those two alternatives, the criteria abovementioned are initially structured into different hierarchy levels. The hierarchy of the decision model is shown in Figure 1, where the objective is to select the best car between two alternatives. This hierarchy of criteria is the subject of a pairwise comparison. Data are collected from three respondents who have different occupation, i.e., car rental owner, car workshop owner, and car dealer employee.

The evaluation process was divided into two steps. The first is to assess the weight of each criterion using the AHP and the second is to compare two alternatives based on the weights that have been identified in the first step using TOPSIS. For the first, the decision makers are asked to compare the elements on a pairwise basis in order to estimate their relative importance. A nine point scale questionnaire [24] is used to show the decision makers' judgment among options as equally, moderately, up to extremely important (or unimportant); see Table 1 for the detail.

Table 1. One to nine scale questionnaire

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over another
5	Strong importance	Experience and judgement strongly favor one over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the criteria
Reciprocals of above non-zero numbers	If criterion *i* has one of the above non-zero numbers assigned to it when compared with criterion *j*, then *j* has the reciprocal value when compared with *i*.	

After the weight of each criterion was identified, a calculation to rank the alternatives was employed using TOPSIS technique. Detail of calculation and process involved in each step are described in the following subsections.

2.1 The Analytic Hierarchy Process

The AHP is a decision-making tool which was developed in 1980 by Thomas L. Saaty [7]. This method is usually used in explaining complex decision-making problems and has several attributes by modeling the amorphous problems studied into hierarchical elements. An important component of a hierarchical system is the main objective, the criteria that affect the objective, and alternatives available for the problem. Seven steps of implementation procedure of the AHP is presented as follows.

1) Step 1: Describe the problem and determine the criteria to be used.

The problem of this study that has been previously stated is to select the best car model between two alternatives, i.e., All New Avanza 1.3 E and All New Xenia 1.3 R. The figure of those two alternatives is depicted in Figure 2. While the criteria that are considered are exterior, convenience, performance, safety, price, fuel efficiency, resale, spare part warranty, and dealer.

(a) All New Avanza 1.3 E **(b) All New Xenia 1.3 R**

Figure 2. Two Alternatives

2) Step 2: Arrange the problem into the hierarchy by considering the objective.

The hierarchy of the problem is depicted in Figure 1, where the objective is located on the top of the hierarchy as the level 0; the criteria are located in the second layer as the level 1; and the alternatives are located in the third layer as the level 2.

3) Step 3: Collect the data from respondents or decision makers.

Three respondents have been selected in this research to evaluate car model selection, i.e., car rental owner, car workshop owner, and car dealer employee.

4) Step 4: Develop a paired comparison matrix for the criteria.

This step is to conduct the pairwise comparisons for each criterion according to the hierarchical tree structure that has been identified before. Nine scale questionnaire which has been mentioned previously is used in this pairwise comparison. Based on the pairwise comparisons, the relative importance degrees are estimated. A total number of $n(n - 1)/2$ pair-wise comparisons are evaluated, where n is the number of criteria. Let A represent an $n \times n$ pairwise comparison matrix as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}. \quad (1)$$

The diagonal elements in the matrix **A** are self-compared of the criteria, and thus $a_{ij} = 1$, where $i = j$, $i, j = 1, 2, \ldots, n$. The values on the left and right sides of the matrix diagonal represent the strength of the relative importance degree of the ith element compared to the jth element. Let $a_{ij} = 1/a_{ji}$, where $a_{ij} > 0$, $i \neq j$.

5) Step 5: Calculate the importance degrees for each criterion.

The NGM (normalization of the geometric mean) method is used to determine the importance degrees for each criterion. Let W_i denotes the importance degree for the ith criterion, then

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}, \; i, j = 1, 2, \ldots, n. \quad (2)$$

6) Step 6: Test the consistency.

To ensure that the evaluation of the pairwise comparison matrix is reasonable and acceptable, a consistency check is performed. Let C denote an n-dimensional column vector describing the sum of the weighted values for the importance degrees of the criteria, then

$$C = [c_i]_{n\times 1} = A \cdot W^T, \; i = 1, 2, \ldots, n, \quad (3)$$

where

$$A \cdot W^T = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix}. \quad (4)$$

The consistency values for can be represented by the vector $CV = [cv_i]_{1\times n}$, with a typical element cv_i is defined as

$$cv_i = \frac{c_i}{w_i}, \; i = 1, 2, \ldots, n. \quad (5)$$

However, to avoid the inconsistency occur when using different measurement scales in the evaluation process, Saaty [7] suggested use the maximal eigenvalue λ_{max} to evaluate the effectiveness of measurements, which can be determined by

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} cv_i}{n}, \; i = 1, 2, \ldots, n. \quad (6)$$

A consistency index (CI) is then can be determined by

$$CI = \frac{\lambda_{\max} - n}{n - 1}. \quad (7)$$

If CI = 0, the evaluation for the pairwise comparison matrix is implied to be completely consistent. Notably, the closer of the maximal eigenvalue is to n, the more consistent the evaluation is. Generally, a consistency ratio (CR) [7] can be used as a guidance to check for consistency.

$$CR = \frac{CI}{RI}, \quad (8)$$

where RI denotes the average random index with the value obtained by different orders of the pairwise comparison matrices. If the value of CR is below than the threshold of 0.1, then the evaluation of the importance degrees of each criteria is considered to be reasonable.

7) Step 7: Determine the relative overall importance degrees.

This last step is the ultimate goal of the first objective of this research. After the degrees of importance for each criterion have been identified, to accomplish the second objective of the research, the TOPSIS technique is applied.

2.2 TOPSIS

TOPSIS technique was first developed by Hwang and Yoon in 1981 [14], with further developments by Yoon in 1987 [25] and Hwang, Lai, and Liu in 1993 [26]. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). The steps of TOPSIS technique implementation are presented as follows.

1) Step 1: Establish a normalized decision matrix.

Let Z denote a normalized decision matrix representing the relative performance of the generated design alternatives, with typical element Z_{ij} which can be calculated as

$$Z_{ij} = \frac{y_{ij}}{\sqrt{\sum_{j=1}^{K} y_{ij}^2}}, \tag{9}$$

where y_{ij} is the performance score of alternative j against criterion i ($i = 1, 2, \ldots, n$ (number of criteria) and $j = 1, 2, \ldots, K$ (number of alternatives).

2) Step 2: Calculate the weighted decision matrix.

Let X_{ij} be the weighted normalized decision matrix ($i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, K$). It can be determined by

$$X_{ij} = w_i \cdot Z_{ij}, \tag{10}$$

where w_i is the weight of each criterion. These weights have been identified by using the AHP.

3) Step 3: Calculate the PIS and NIS.

The PIS and NIS are defined as

$$\text{PIS} = A_i^+ = \left\{ \left(\min_j X_{ij} \middle| i \in I \right), \left(\max_j X_{ij} \middle| i \in I' \right) \right\}, \tag{11}$$

$$\text{NIS} = A_i^- = \left\{ \left(\max_j X_{ij} \middle| i \in I \right), \left(\min_j X_{ij} \middle| i \in I' \right) \right\}, \tag{12}$$

where $I = \{i = 1, 2, \ldots, n$ and i is associated with the beneficial criterion of $X_{ij}\}$, and $I' = \{i = 1, 2, \ldots, n$ and i is associated with the cost-effective criterion of $X_{ij}\}$.

4) Step 4: Compute the distance of each alternative from PIS and NIS.

Let the S_j^+ denotes the distance of each alternative from PIS and S_j^- denotes the distance of each alternative from NIS.

$$S_j^+ = \left[\sum_{i=1}^{n} \left(X_{ij} - A_i^+ \right)^2 \right]^{1/2}, \tag{13}$$

$$S_j^- = \left[\sum_{i=1}^{n} \left(X_{ij} - A_i^- \right)^2 \right]^{1/2}. \tag{14}$$

5) Step 5: Compute the closeness coefficient (CC_i) of each alternative.

The ranking score can be calculated by employing the CC_i as follows

$$CC_i = \frac{S_j^-}{S_j^+ + S_j^-}. \tag{15}$$

6) Rank the alternatives.

The different alternatives are ranked according to the closeness coefficient in decreasing order. The best alternative is closest to the PIS and farthest from the NIS.

3. CASE STUDY RESULT

The following is the application of the AHP and TOPSIS to evaluate car model selection. The methods were employed based on the aforementioned criteria. First, the decision makers filled the pairwise comparison to express their preferences between the alternatives and criteria in a nine point scale questionnaire. The AHP was then applied to calculate the weights or the importance degrees for each criterion. Note that consistency test was conducted to ensure that the pairwise comparison matrix is reasonable and acceptable; and thus can be used for further analysis. The result which is the weights that indicated the importance of criteria for car model selection is shown in Table 2.

Table 2. The weights for each criterion

Criterion	Weight
Exterior	0.172
Convenience	0.128
Performance	0.068
Safety	0.056
Price	0.182
Fuel efficiency	0.152
Resale	0.129
Spare part warranty	0.048
Dealer	0.065

The weights for each criterion are exterior with 0.172, convenience with 0.128, performance with 0.068, safety with 0.056, price with 0.182, fuel efficiency with 0.152, resale with 0.129, spare part warranty with 0.048, and dealer with 0.065. According to this result, price, exterior, and fuel efficiency are regarded as the first, second, and third-most important criteria. In other words, it seems that the buyers view those criteria as major factors to be noticed by the manufacturers when they produce the cars.

The price is regarded as the most important criteria since most car buyers in Indonesia, as a developing country, still view the cars as luxury products; thus, the price is considered as a very influential factor for the buyers when they purchase such cars. The second-most important criterion is exterior. Indonesians are very concerned about the look of the products they buy. This situation also influences the experts so that they infer that the buyers do not bother to purchase a car with better exterior design in spite of having higher price. Some Indonesians also consider fuel efficiency as the vital criterion in purchasing cars since they generally use the cars for a long distance travel. Afterwards, resale, convenience, and performance are considered as less important; while dealer, safety, and spare part warranty are labelled as the least important criteria in evaluating car selection.

After the weights of each criterion have been calculated, the TOPSIS technique is then applied to select the best alternative between two aforementioned alternatives. The result, which is the alternative priority weights, is depicted in Table 3.

Table 3. Alternative priority weights for each criterion

Criterion	All New Avanza 1.3 E	All New Xenia 1.3 R
Exterior	0.558	0.442
Convenience	0.409	0.591
Performance	0.558	0.442
Safety	0.500	0.500
Price	0.409	0.591
Fuel efficiency	0.442	0.558
Resale	0.825	0.175
Spare part warranty	0.500	0.500
Dealer	0.631	0.369

As we can see in Table 3, the first alternative, i.e., All New Avanza 1.3 E surpasses the second alternative, i.e., All New Xenia 1.3 R for criteria of exterior (55.8% vs. 44.2%), performance (55.8% vs. 44.2%), resale (82.5% vs. 17.5%), and dealer (63.1% vs. 36.9%); while the second alternative exceeds the first in criteria of convenience (40.9% vs. 59.1%), price (40.9% vs. 59.15), and fuel efficiency (44.2% vs. 55.8%). Safety and spare warranty criteria are considered same for both alternatives (50% vs. 50%).

Finally, TOPSIS technique ranked the best alternative according to the relative proximity to the ideal solution. The result shows that the first alternative beats the second alternative across all nine criteria. The All New Avanza 1.3 E scores 0.63 while the All New Xenia 1.3 R scores 0.37. Although the first alternative has higher price than the second one, however, it has better resale price (the depreciation price is 12% comparing to 24%).

4. CONCLUSION AND FUTURE RESEARCH DIRECTION

The study aims to develop a model to evaluate car model selection as a basis for the buyers to purchase the cars, especially in Indonesia. Data are collected from three experts who have abundant experiences. The result of this research as depicted in Table 2 and 3 show that the manufacturers should focus on price (it has highest weights among all, i.e., 0.182), exterior (0.172), and fuel efficiency (0.152) aspects to attract buyers to purchase their products.

The ranking of two alternatives based on the calculations (the AHP and TOPSIS technique) is: All New Avanza 1.3 E with 63% and All New Xenia 1.3 R with 37%. Although the first alternative surpasses the second, it does not mean that the first is a gorgeous product comparing to the other. In fact, other car should improve the quality considering those criteria. These findings can provide the car manufacturers with valuable insights into the criteria that reflects customers' perceptions when they purchase the cars.

For further research, it is recommended to use other multi-criteria decision making tools to evaluate car model selection. For example, if is suspected that there are interdependent relationships among criteria, the analytic network process (ANP) [27] can be used (Note that in this study, the criteria are assumed independent.) Another consideration can be used if the linguistic assessment of human feelings and perceptions, which are the answers of the experts are considered as fuzzy. Human's judgments in the AHP are represented as precise; yet in real life situations, it is not. Hence, it is not reasonable to represent it in terms of precise numbers; is more convenience to give interval judgments than fixed value judgments. Thus, the concept fuzzy AHP (as well as fuzzy TOPSIS) can be utilized in evaluating such multi-criteria decision making problems. They have been successfully applied in several fields, see for example: [28]–[30]. Comparing the results generated by those methods with this research is an interesting area to be pursued.

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