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SELECTION OF SMARTPHONE BRANDS BY USING FUZZY TOPSIS APPROACH

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Abstract

This study investigates the selection of smartphone brands using the Fuzzy TOPSIS approach, a multi-criteria decision-making method. A smartphone is an essential need, thus choosing the best option among various brands is a crucial process for consumers. Five criteria; price, RAM, storage, battery and camera were used to evaluate five popular smartphone brands; Samsung, Apple, Oppo, Vivo and Huawei. A questionnaire was assessed by a committee of ten decision makers from diverse backgrounds and the linguistic variables used were converted to triangular fuzzy numbers. The Fuzzy TOPSIS steps involve constructing decision matrices, determining the weight of criteria, normalizing values and calculating distances from ideal solutions. The findings ranked the brands, with Apple as the most preferred, which has a closeness coefficient of 0.689. This study demonstrates the effectiveness of Fuzzy TOPSIS in handling ambiguous data, optimizing decisions, and providing insights for consumers and companies to enhance product selection and marketing strategies in complex environments.

Keywords: Smartphone, consumers, MCDM, Fuzzy TOPSIS, decision makers

1. Introduction

The sophistication of technology today is aimed at easing people's daily lives, including the development of communication technologies. The first telephone was invented in the 1980s and continues to evolve to this day [7]. Now, smartphones are one of the most essential electronic devices in daily life. Smartphones can be defined as communication tools with computer-like features and functionality [14]. Smartphones have become a worldwide phenomenon. In today's world, the most well-known smartphone brands are Apple, Samsung, Oppo, Vivo, Realme and others [14].

Multi-Criteria Decision Making (MCDM) is a method of assessing several criteria and selecting the best alternative among the alternatives provided [13]. MCDM can be applied to daily life problems as it involves the decision-making process, which is a common problem in human life. Today, complex decision-making problems can be addressed by using mathematical equations, economic theories, advanced statistics and computer technology that will calculate and estimate solutions automatically [15].

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is the classical method of MCDM where decision alternatives are ranked and the alternative which is the closest to the positive ideal solution (PIS) and the farthest to the negative ideal solution (NIS) are chosen [10]. Fuzzy TOPSIS is an extended version of the classical TOPSIS approach. Fuzzy set theory was applied to problems that are unclear and ambiguous [1]. When there was a lack of accurate data or when there were subjective judgments involved, it was very helpful to use the Fuzzy TOPSIS approach.

Nowadays, every individual needs to have a smartphone as one of the essential electronic devices in daily life. However, the variety of smartphones in the marketplace makes it difficult for consumers to choose the most suitable smartphone for their daily use. In addition, consumers also undergo difficulty



in determining the criteria in choosing a smartphone because there are too many criteria to consider before buying a smartphone, such as price, random access memory (RAM), processor and other criteria [6]. On the other hand, there are many Multi-Criteria Decision Making (MCDM) approaches that can be applied to the selection of smartphone brands.

There are three objectives involved in this study. Firstly, this study needs to identify the main criteria that influence the selection of smartphone brands. Next, this study needs to apply the Fuzzy TOPSIS approach for the selection of smartphone brands using the main criteria found in the first objective. Lastly, this study aims to analyze the most preferred smartphone brands using the Fuzzy TOPSIS approach.

The study used the most suitable MCDM approach that will provide a better understanding in the selection of smartphone brands under a fuzzy environment. Firstly, this study allows the decision-making process in a complex market. Consumers can make the best choice of a smartphone when they focus on several main criteria and alternatives. Next, this study helps in handling imprecise and uncertain information. Ambiguous data can be calculated by applying the Fuzzy TOPSIS approach and obtaining the desired results. Furthermore, this study will optimize multi-criteria decision-making processes. Consumers will be able to minimize the cost of purchasing, but at the same time obtain the best choices among others by focusing on the main criteria.

This study is to observe the preferences of consumers among smartphone brands in the marketplaces. The committee of ten decision makers are formed, which consists of smartphone promoters, smartphone repair technicians, smartphone sellers and experienced consumers of different smartphone brands. The main criteria chosen were price, RAM, storage, battery and camera. The smartphone brands used as alternatives for this study were Samsung, Apple, Oppo, Vivo, and Huawei. The most suitable MCDM approach used in this study was the Fuzzy TOPSIS approach. Therefore, the best smartphone brand among the five chosen alternatives needs to be analyzed by observing the most considered criteria using one of the approaches applied in an uncertainty environment, which is the Fuzzy TOPSIS approach.

2. Literature Review

A smartphone is a mobile phone with computer features, has an LCD touchscreen and includes software functionality such as browser and email [1]. A study by [7] has stated the idea of the first transportable telephone was the Motorola DynaTAC 8000X, which was developed in 1973 by Martin Cooper and was released ten years later in 1983. According to [7], as technology advanced, mobile phones evolved into smartphones, with Apple creating the first touchscreen smartphone in 2007. Now, smartphones in the marketplaces are using touchscreens that are equipped with software and apps and are much easier to use.

There are many criteria that consumers should consider when selecting a smartphone. There are five common criteria in selecting smartphone brands, which are price, RAM, storage, battery and camera. There are five main criteria used in [5] to determine the best smartphone models among ten smartphone models by using Fuzzy-AHP and PROMETHEE methods. In addition, a study by [2] has used all five main criteria in their study to evaluate the best smartphone brands among consumers.

The Fuzzy TOPSIS approach is an extension of TOPSIS, which involves solving decision-making problems by applying the concept of FST to the problem. Based on a study by [4] on selecting the most suitable candidate to fulfil the system analysis engineer position, linguistic variables were applied to the solutions and then the FPIS and FNIS were determined. Many studies were conducted using Fuzzy TOPSIS, especially when the problems involved an uncertain environment and imprecise data.

In the context of selecting smartphone brands, there are several studies that apply the Fuzzy TOPSIS approach. The Fuzzy TOPSIS approach has been used in a study by [11] regarding smartphone selection and the study resulted in the Q-Mobile smartphone brand being the best smartphone among six alternatives. The criteria used in this study were RAM, ROM, processor, camera, display size, model and price. In addition, [3] has applied the Intuitionistic Fuzzy Set (IFS) to the TOPSIS approach in the selection of a smartphone. The criteria considered in this study were battery backup-related criteria, weight-related criteria, camera-related criteria, cost/price-related criteria and looks and design-related criteria. The study resulted in alternative 3 being the most selected smartphone among the four smartphones.



3. Methodology

3.1. Mathematical Concept and Definitions

3.1.1. Fuzzy Set Theory (FST)

The definition of FST is referred as a set of fuzzy numbers in the universal set of U [4]. The idea of FST was introduced by Zadeh in 1965, where it involves solving the situations that are highly complex using fuzzy numbers instead of crisp values. Let U be the universal set, a fuzzy set A in U can be described with a membership function of $\mu_A(x)$ which takes the values in interval $[0,1]$. The closer the value to 1, the higher the degree of membership of the element x in the fuzzy set A . Other than that, a fuzzy set A in universal set U is said to be normal if the fuzzy set A satisfy $\exists x_i \in U, \mu_A(x_i) = 1$. Based on Figure 1, it is explained that a fuzzy subset in universal set U is defined as fuzzy number A where the membership function is convex and normal [4].

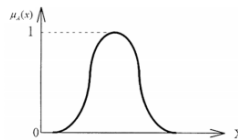


Figure 1: A fuzzy number A

3.1.2. Triangular Fuzzy Number (TFN)

Triangular Fuzzy Number (TFN) is one of the membership functions that can be used to represent linguistic variables [12]. There are several types of membership functions, which include triangular, trapezoidal, Gaussian and quadrilateral [12]. Figure 2 shows the triangular fuzzy number A , which consists of (a_1, a_2, a_3) .

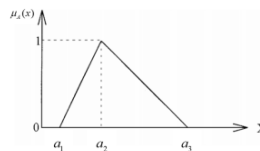


Figure 2: A triangular fuzzy number A

3.1.3. Operations of Triangular Fuzzy Number

Let A and B be two fuzzy numbers expressed in intervals $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$ and these are defined as real numbers. There are four main operations which involve two positive fuzzy numbers represented as A and B [8].

a) Addition:

$$A + B = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{1}$$

b) Multiplication:

$$A \cdot B = (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3) \tag{2}$$

c) Subtraction:

$$A - B = (a_1 - b_1, a_2 - b_2, a_3 - b_3) \tag{3}$$

d) Division:

$$\frac{A}{B} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1} \right) \tag{4}$$



3.2. Implementation of Fuzzy TOPSIS Approach

There are 9 main steps in using this approach, which was obtained from a previous study by [4]. The significant results are explained in the steps of the Fuzzy TOPSIS approach.

Step 1: The decision makers are identified and the criteria are determined.

A committee of ten decision makers has been formed. The decision makers are assigned from D1 to D10. Several alternatives and criteria to evaluate smartphone brands are determined. The alternatives and criteria chosen are as in Table 1.

Table 1: List of Criteria and Alternatives

Criteria		Alternatives	
C1	Price	A1	Samsung
C2	RAM	A2	Apple
C3	Storage	A3	Oppo
C4	Battery	A4	Vivo
C5	Camera	A5	Huawei

Step 2: The suitable linguistic variable for the weight of criteria and rating of alternatives are determined.

Linguistic variables were used to represent the scale of ratings. The linguistic variables then were converted into TFN since this study used triangular membership functions. The linguistic variables used for the weight of criteria and rating of alternatives are as in Table 2 and Table 3. The linguistic variables are derived from [4].

Table 2: Linguistic variables for the weight of criteria [4]

Linguistic Variables	Fuzzy Numbers
Very Low (VL)	(0, 0, 0.1)
Low (L)	(0, 0.1, 0.3)
Medium Low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very High (VH)	(0.9, 1.0, 1.0)

Table 3: Linguistic variables for rating of alternatives [4]

Linguistic Variables	Fuzzy Numbers
Very Poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium Poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Step 3: The weight of criteria and rating of alternatives are aggregated and the aggregated fuzzy weight of criteria and rating of alternatives are obtained.

The weight of criteria and rating of alternatives are aggregated to obtain the aggregated fuzzy weight, w_j of criteria, C_j and aggregated fuzzy rating, x_{ij} of alternatives, A_i . Let N be the group of decision



makers, the aggregated fuzzy weight of criteria and aggregated fuzzy rating of alternatives can be calculated using (5) and (6) respectively.

$$\text{Weight of criteria, } w_j = \frac{1}{N} [w_j^1 + w_j^2 + \dots + w_j^N] \tag{5}$$

$$\text{Rating of alternative, } x_{ij} = \frac{1}{N} [x_{ij}^1 + x_{ij}^2 + \dots + x_{ij}^N] \tag{6}$$

where w_j^N and x_{ij}^N are the weight of criteria and rating of alternatives respectively of the N th decision makers. The weight of criteria and rating of alternatives of the decision makers then can be expressed in matrix form as (7) and (8) respectively.

$$W = [w_1, w_2, \dots, w_n] \tag{7}$$

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{8}$$

where $x_{ij}, \forall i, j$ and $w_j, j = 1, 2, \dots, n$ are linguistic variables. The linguistic variables are written in the form of triangular fuzzy numbers, $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $w_j = (w_{j1}, w_{j2}, w_{j3})$. Table 4 and Table 5 show the evaluation from ten decision makers on the weight of criteria and rating of alternatives respectively. The aggregated fuzzy weight of criteria and aggregated fuzzy rating of alternatives are displayed in Table 6 and Table 7 respectively.

Step 4: The normalized fuzzy decision matrix is formed.

The normalized fuzzy decision matrix can be written as matrix R. The matrix is calculated using (9) and (10).

$$R = [r_{ij}]_{m \times n}$$

$$r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+} \right), j \in B; \tag{9}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), j \in C; \tag{10}$$

where c_j^+ is the maximum value of TFN and preferable for benefit criteria and a_j^- is the minimum value of TFN and preferable for cost criteria. The benefit criteria used in this study are C2, C3, C4 and C5. C1 is the cost criteria used in this study. Table 7, which is also the fuzzy decision matrix is used to calculate the normalized fuzzy decision matrix. The normalized fuzzy decision matrix is presented in Table 8.

Step 5: The weighted normalized fuzzy decision matrix is formed.

The weighted normalized fuzzy decision matrix is calculated by using (11).

$$V = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2n} \\ \vdots & \vdots & \dots & \vdots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix}, v_{ij} = r_{ij} \cdot w_j \tag{11}$$



The matrix can be formed by multiplying the normalized fuzzy decision matrix in Table 8 and aggregated fuzzy weight of criteria in Table 6. The weighted normalized fuzzy decision matrix is presented in Table 9.

Step 6: The Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) are computed.

The elements of the weighted normalized fuzzy decision matrix are in the interval of [0, 1]. Therefore, the TFN of FPIS, A^+ and FNIS, A^- used in this study are as below:

$$A^+ = [(1,1,1), (1,1,1), (1,1,1), (1,1,1), (1,1,1)]$$

$$A^- = [(0,0,0), (0,0,0), (0,0,0), (0,0,0), (0,0,0)]$$

Step 7: The distance of FPIS and FNIS to each alternative are computed.

The distance of FPIS and FNIS are calculated using (12). Then, the summation of all distances is calculated. This step is known as the defuzzification process from three values of TFN to one crisp value. The TFN values must be divided by three to obtain the crisp value. Therefore, the total distances of FPIS and FNIS are shown in Table 10.

$$d(A,B) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \tag{12}$$

Table 10: Total distances of FPIS and FNIS to each alternative

Alternatives	A^+	A^-
A1	1.791	3.503
A2	1.648	3.657
A3	1.869	3.406
A4	1.916	3.389
A5	1.766	3.546

Step 8: The closeness coefficient for each alternative is computed.

Table 11 indicates the closeness coefficient for each alternative. The closeness coefficient value is calculated using (13).

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, \dots, m \tag{13}$$

Table 11: The closeness coefficient for each alternative

CC ₁	0.662
CC ₂	0.689
CC ₃	0.646
CC ₄	0.639
CC ₅	0.668

Step 9: The alternatives are ranked based on the closeness coefficient.

The closeness coefficient values are used to rank the alternatives. As the value approaches 1, it is the most preferred alternative, while if the value approaches 0, it is the least preferred alternative. In this study, the values are arranged in descending order. The highest value is considered the most preferred alternative, while the lowest value is considered the least preferred alternative. Therefore, the ranking of alternatives is A2, A5, A1, A3 and A4.



Table 4: Evaluation of ten decision makers for weight of criteria

Criteria	Decision Makers									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
C1	MH	MH	M	M	M	H	H	MH	VH	H
C2	MH	VH	M	H	VH	VH	H	H	VH	H
C3	VH	VH	M	VH	M	VH	H	VH	VH	H
C4	VH	VH	M	H	VH	MH	VH	VH	VH	VH
C5	MH	VH	M	VH	VH	MH	ML	MH	VH	VH

Table 5: Evaluation of ten decision makers for rating of alternatives

Criteria	Alternatives	Decision Makers									
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
C1	A1	MP	MP	P	MG	G	F	VG	G	VG	VG
	A2	P	MP	VG	F	G	F	MP	G	MG	VG
	A3	F	F	VG	G	MG	G	VG	VG	VG	MG
	A4	F	F	MP	G	MG	G	VG	VG	VG	MG
	A5	F	MP	P	MG	G	MG	G	G	G	MP
C2	A1	MG	VG	MP	G	MG	G	VG	G	VG	VG
	A2	VG	G	VG	VG	VG	G	VG	VG	VG	VG
	A3	MG	VG	VG	MG	MG	G	F	MG	VG	G
	A4	G	VG	F	G	MG	MG	F	G	VG	MG
	A5	G	VG	VP	VG	VG	G	VG	VG	VG	MP
C3	A1	VG	VG	F	G	MG	G	VG	G	VG	VG
	A2	VG	VG	F	VG	VG	G	VG	VG	VG	VG
	A3	VG	VG	F	VG	MG	G	G	VG	VG	VG
	A4	VG	VG	F	G	MG	G	G	MG	VG	VG
	A5	VG	VG	F	VG	MG	G	VG	G	VG	MP
C4	A1	G	VG	MG	F	VG	MG	VG	F	VG	VG
	A2	VG	MG	MG	F	MG	P	G	MG	G	VG
	A3	G	G	VG	VG	VG	G	G	VG	VG	VG
	A4	G	G	VG	MG	VG	MG	G	G	VG	VG
	A5	G	G	VG	VG	VG	G	G	VG	VG	F
C5	A1	VG	VG	VG	G	G	G	MG	G	VG	VG
	A2	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
	A3	VG	G	VG	MG	F	VG	MG	F	G	G
	A4	VG	VG	VG	G	F	G	MG	MG	G	G
	A5	VG	VG	VG	VG	G	VG	VG	G	G	F

Table 6: Aggregated fuzzy weight of criteria

Criteria	Weight
C1	(0.540, 0.730, 0.880)
C2	(0.720, 0.880, 0.960)
C3	(0.740, 0.880, 0.940)
C4	(0.780, 0.910, 0.960)
C5	(0.640, 0.790, 0.890)



Table 7: Aggregated fuzzy rating of alternatives

Alternatives	Criteria				
	C1	C2	C3	C4	C5
A1	(5.100, 6.700, 7.900)	(6.800, 8.400, 9.300)	(7.400, 8.900, 9.600)	(6.800, 8.300, 9.200)	(7.800, 9.300, 9.900)
A2	(4.500, 6.200, 7.600)	(8.600, 9.800, 10.000)	(8.200, 9.400, 9.700)	(5.500, 7.200, 8.600)	(9.000, 10.000, 10.000)
A3	(6.600, 8.200, 9.200)	(6.400, 8.100, 9.300)	(7.600, 9.000, 9.600)	(8.200, 9.600, 10.000)	(6.400, 8.100, 9.200)
A4	(5.800, 7.500, 8.700)	(6.000, 7.800, 9.100)	(7.000, 8.600, 9.500)	(7.400, 9.000, 9.800)	(6.800, 8.500, 9.500)
A5	(4.300, 6.200, 7.800)	(6.900, 8.100, 8.600)	(6.800, 8.300, 9.100)	(7.600, 9.100, 9.700)	(7.800, 9.200, 9.700)

Table 8: The normalized fuzzy decision matrix

Alternatives	Criteria				
	C1	C2	C3	C4	C5
A1	(0.544, 0.642, 0.843)	(0.680, 0.840, 0.930)	(0.763, 0.918, 0.990)	(0.680, 0.830, 0.920)	(0.780, 0.930, 0.990)
A2	(0.566, 0.694, 0.956)	(0.860, 0.980, 1.000)	(0.845, 0.969, 1.000)	(0.550, 0.720, 0.860)	(0.900, 1.000, 1.000)
A3	(0.467, 0.524, 0.652)	(0.640, 0.810, 0.930)	(0.784, 0.928, 0.990)	(0.820, 0.960, 1.000)	(0.640, 0.810, 0.920)
A4	(0.494, 0.573, 0.741)	(0.600, 0.780, 0.910)	(0.722, 0.887, 0.979)	(0.740, 0.900, 0.980)	(0.680, 0.850, 0.950)
A5	(0.551, 0.694, 1.000)	(0.690, 0.810, 0.860)	(0.701, 0.856, 0.938)	(0.760, 0.910, 0.970)	(0.780, 0.920, 0.970)

Table 9: The weighted normalized fuzzy decision matrix

Alternatives	Criteria				
	C1	C2	C3	C4	C5
A1	(0.294, 0.469, 0.742)	(0.490, 0.739, 0.893)	(0.565, 0.808, 0.931)	(0.530, 0.755, 0.883)	(0.499, 0.735, 0.881)
A2	(0.306, 0.507, 0.841)	(0.619, 0.862, 0.960)	(0.625, 0.853, 0.940)	(0.429, 0.655, 0.826)	(0.576, 0.790, 0.890)
A3	(0.252, 0.383, 0.574)	(0.461, 0.713, 0.893)	(0.580, 0.817, 0.931)	(0.640, 0.874, 0.960)	(0.410, 0.640, 0.819)
A4	(0.267, 0.418, 0.652)	(0.432, 0.686, 0.874)	(0.534, 0.781, 0.920)	(0.577, 0.819, 0.941)	(0.435, 0.672, 0.846)
A5	(0.298, 0.507, 0.880)	(0.497, 0.713, 0.826)	(0.519, 0.753, 0.882)	(0.593, 0.828, 0.931)	(0.499, 0.727, 0.863)



4. Results and Discussions

The results of this study provide an extensive analysis of the selection of smartphone brands using the Fuzzy TOPSIS approach. In this study, each criterion and alternative were evaluated using linguistic variables. The linguistic variables were then converted into TFN and aggregated to obtain the aggregated fuzzy weight of criteria and rating of alternatives. Then, the fuzzy decision matrix obtained is normalized. The weighted normalized fuzzy decision matrix is formed and the closeness coefficient for each alternative was calculated. The alternatives were ranked based on the closeness coefficient value. The alternative that has the closeness coefficient value approaching 1 is considered the most preferred alternative, while the value that approaches 0 is the least preferred alternative.

The ranking of alternatives is presented in Table 12 and illustrated in graphical form in Figure 3. It is observed that the closeness coefficient values are slightly different from each other. A2 has the highest closeness coefficient, which is 0.689, compared to other alternatives. Thus, Apple has ranked in the first place among other smartphone brands evaluated by ten decision makers. A5 follows closely behind A2 with the closeness coefficient value of 0.668. Huawei is ranked as the second brand after Apple, with a closeness coefficient difference of 0.021. On the other hand, the closeness coefficient value of 0.662 belongs to A1, which is nearly tied with A5. With the closeness coefficient difference of 0.006, A1 or Samsung brand is ranked as the third smartphone brand evaluated by decision makers. Next, the ranking continues with A3, which has a closeness coefficient value of 0.646. The Oppo brand is ranked in fourth place because the closeness coefficient value is lower than Samsung brand. Lastly, with the closeness coefficient value of 0.639, A4 or Vivo is ranked as the fifth smartphone brand as evaluated by the decision makers.

Table 12: Ranking of alternatives

Alternatives	Smartphone Brands	Closeness Coefficient	Rank
A1	Samsung	0.662	3
A2	Apple	0.689	1
A3	Oppo	0.646	4
A4	Vivo	0.639	5
A5	Huawei	0.668	2

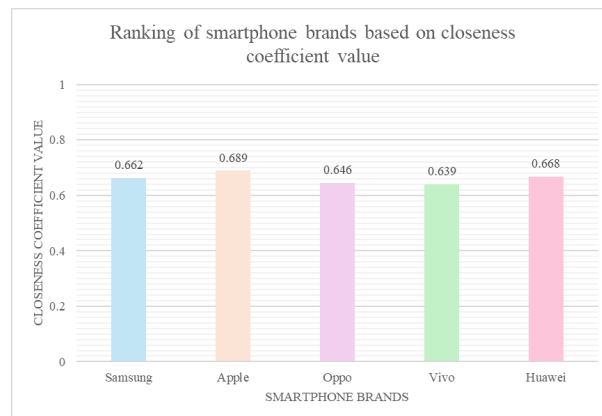


Figure 3: Ranking of smartphone brands based on closeness coefficient value

The findings emphasized the use of MCDM methods in the complex decision-making process. For instance, the use of linguistic variables has significantly helped decision makers to evaluate the criteria and alternatives. By converting the linguistic variables into triangular fuzzy numbers, the subjective opinions from decision makers can be evaluated. Other than that, this method is suitable to be used in



solving complex problems because decision makers are able to evaluate the criteria and alternatives based on their importance. In addition, the method is also straightforward and easy to implement, which makes it understandable even when people do not have extensive knowledge of the method. Furthermore, the implementation of the Fuzzy TOPSIS approach also helps in handling ambiguous and uncertain data. By normalizing the fuzzy decision matrix and applying the fuzzy weight of criteria, the small differences between the values are determined. This makes the approach more reliable to use in ranking some real-world systems. Moreover, this approach has a simpler ranking method compared to other methods, where the alternatives were ranked by using their closeness coefficient value. This approach also helps to minimize inconsistency and bias in the decision-making process because the calculation steps are very detailed and precise. Lastly, this approach promotes balanced assessment as it calculates the distances of alternatives from both positive and negative ideals solutions.

5. Conclusions and Recommendations

Overall, this study aims to apply the Fuzzy TOPSIS approach to the selection of smartphone brands. The first objective of this study is to identify the main criteria that will influence consumers in selecting a smartphone brand before making a purchase on the best smartphone. This study has chosen five main criteria, which are price, RAM, storage, battery and camera, while the alternatives are Samsung, Apple, Oppo, Vivo and Huawei. Since there are too many smartphone brands and models in the marketplace, this study has helped decision makers to focus on several alternatives. To conclude, the first objective is successfully achieved as the main criteria and alternatives are identified.

Furthermore, this study has applied the Fuzzy TOPSIS approach to determine the best smartphone brand among the alternatives listed and using the five main criteria. The Fuzzy TOPSIS approach is an extension of the TOPSIS approach, where this method uses TFN instead of crisp values. Questionnaires are distributed among the committee of ten decision makers and the data obtained was calculated using the Fuzzy TOPSIS approach. The evaluation of decision makers on the weight of criteria and rating of alternatives uses linguistic variables, which are then converted into TFN. The TFN for the weight of criteria and fuzzy decision matrix were obtained by calculating its average. Next, the fuzzy decision matrix was normalized, obtained the weighted normalized fuzzy decision matrix, obtained the FPIS and FNIS and lastly calculated the closeness coefficient values. The closeness coefficient values are used in ranking the smartphone brands.

The smartphone brands were ranked in descending order, starting from A2, followed by A5, A1, A3 and lastly A4. The value that is much closer to 1 is considered the most preferred alternative, while the value that is much closer to 0 is considered the least preferred alternative. This study has found that the most preferred alternative is A2 because it has the highest value of the closeness coefficient, while A4 has the lowest value, thus it was the least preferred alternative. This can be concluded that A2, which stands for Apple brand, is the most preferred alternative among decision makers, followed by A5 or Huawei, A1 which is Samsung, A3 which stands for Oppo and lastly A4 which is Vivo as the least preferred smartphone brand among decision makers.

Based on the findings, there are some recommendations that can be applied to this study for the future. For further extensions of the study, other MCDM methods, such as Analytic Hierarchy Process (AHP) or VIKOR, which can rank both criteria and alternatives can be suggested to be used. This approach will provide a more precise analysis framework based on the future study objectives [1], [15]. Next, other weighting methods that are superior can be suggested to be used to determine the weight of criteria. The suggested weighting methods are subjective methods, which highlight the preferences of decision makers, objective methods that do not consider decision makers' preferences or hybrid methods, which combine both subjective and objective methods [9]. By addressing the suitable recommendations, the study can be extended and the application of the Fuzzy TOPSIS approach and other MCDM methods can be expanded. Therefore, a more precise and flexible output from decision-making problems can be obtained.



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