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Evaluation and Selection of Mobile Phones using Integrated AHP-TOPSIS Model

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ABSTRACT

Mobile phones are electronic telecommunication devices that have become a necessary part of life. The advances in technology will directly influence the attitude of the users in the selection of mobile phones. There are multiple criteria that need to be considered in selecting a mobile phone. Therefore, the evaluation and selection of mobile phones is a Multi-Criteria Decision Making (MCDM) problem. This paper aims to propose a MCDM model to identify the decision criteria' priority in the mobile phones' selection using integrated AHP-TOPSIS model. Furthermore, the goal of the study is to find out the most desired mobile phone among Samsung, Apple, Oppo, Huawei, and Vivo. A case study is conducted to determine the priority of decision criteria and mobile phones among the undergraduate students with AHP-TOPSIS model. The results indicate that Apple is the most desired mobile phone, followed by Huawei, Samsung, Oppo, and Vivo. Besides, technical specification and user related features are the most significant decision factors in the mobile phones' selection. The contribution of the study is to find out the most desired mobile phone and the most significant decision factor in the mobile phones' selection among undergraduate students with AHP-TOPSIS model.

1. Introduction

In the current era, mobile phones are an essential part of our daily lives. Mobile phone is a portable scientific device which can be used to send and receive the voice messages [1]. Due to the advancement and rapidly changing pace of technology nowadays, the mobile phone companies need to enhance and improve the features of the mobile phone and changing the outlook of the mobile phone in order to attract the new customers and retain the existing customers [2]. Initially, the mobile phone is used to communicate with others. At present, the mobile phone has shifted from a verbal communication tool to multimedia tool. For instance, mobile phone can help the users to manage their daily utilities such as paid bills through online without spending time in the traveling. Furthermore, it also helps the users to communicate with their family and friends, obtain the latest and updated information. Since the interest in mobile phones is increasing, the mobile phone

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manufacturers have produced various models to meet the market demand. In decision making process, the mobile phone users need to consider multiple criteria in choosing the best mobile phone. Therefore, the evaluation and selection process of mobile phones is treated as multi-criteria decision making (MCDM) problem.

According to research done by Chen *et al.,* [3], they proposed the Analytic Hierarchy Process (AHP) model to find out the preference of the mobile phones among mobile phone users. In their study, the decision criteria are basic built-in functions, hardware features, price, and brand. Hu *et al.,* [4] proposed DEMATEL-based ANP and VIKOR model to enhance the product value in order to fulfill the customers' satisfactions and demands. The decision criteria are mobile convenience, product function, and customer equity. Chakraborty *et al.,* [5] presented an AHP model to prioritize the criteria that consumers will consider while purchasing the smart phones in India. The listed criteria that considered in the study are affordability, design, brand, operating system, functionality, and lastly user experience. In their research, the results demonstrated that brand is the most crucial criterion with the highest weights, followed by operating system, user experience, functionality, affordability, and finally design. Yildiz and Ergul [6] have done a study in the selection process of the best mobile phones by using two-phased MCDM model. HTC One M8, Iphone 6 Plus, Sony Xperia Z3, and Samsung Galaxy Note 4 are the four decision alternatives that considered in the paper while the decision factors comprise technical specifications, physical properties, and user related features. In recent studies, the researchers [7,8] have assessed the selection of the mobile phone brands among consumers with the aid of statistical approaches.

Analytic Hierarchy Process-Technique for Order of Preference by Similarity to Ideal Solution (AHP-TOPSIS) is an integrated MCDM model which assists to determine the best alternatives based on multiple factors [9,10]. AHP model is capable to identify the priority of the decision factors whereas TOPSIS model is proposed to identify the ranking of the decision alternatives according to the idea of selecting the decision alternative that gives the shortest proximity to the positive ideal solution (PIS) and the farthest proximity from the negative ideal solution (NIS). AHP-TOPSIS model has been successfully applied in numerous areas, for example low-carbon energy technology policy [11], shopping mall site selection [12], key organizational capabilities [13], wind turbines [14], supplier selection [15], flood hazards [16], web application [17], agricultural risk management [18], hybrid renewable energy systems [19], and E-learning during COVID-19 [20].

In today's world, smartphone is quite important to teenagers and undergraduate students. Smartphone is one of the essential tools in our daily lives. Few applications have been done by past researchers toward the usage of smartphones among teenagers. Hou *et al.,* [21] have investigated a mobile application among adult residents in the United States with the aid of hierarchical linear regression analysis. Park *et al.,* [22] have conducted a study on the mediating effect of insecure adult attachment on the relationship between self-directed learning and smartphone addiction among undergraduate students. Do *et al.,* [23] have examined the relationship between 1-year change in refractive error and smart device usage among children and adolescents. Roig-Vila *et al.,* [24] have done research on the smartphone usage profile of Italian and Spanish undergraduate students. Lee and Shepley [25] have assessed the association between student perceptions of them with smartphone use and college campus walking route characteristics. According to these past studies, the usage of the smartphone among teenagers and undergraduate students is quite crucial and the selection of the smartphone should be greatly focused on and pay attention to in order to avoid abusive use of the smartphone among students.

According to our best understanding, there are no comprehensive studies done on the evaluation and selection of mobile phones among undergraduate students with AHP-TOPSIS model. Thus, the study aims to propose a MCDM model for the evaluation and selection of mobile phones with AHP-

TOPSIS model. Furthermore, the study aims to consider all important decision criteria and sub-criteria according to past studies. According to a study done by Yildiz and Ergul [6], basic built-in functions is not considered in their research framework. In addition, another motivation of the study is to identify the preference of undergraduate students in the mobile phones' selection among top global smartphone makers. Samsung, Apple, Oppo, Huawei, and Vivo are listed as the top five global smartphone makers [26]. However, the mobile phone brand such as Oppo and Vivo are not considered in the past studies [7,8,27]. In this research paper, a case study is carried out to identify the most preferred mobile phone among Samsung, Apple, Oppo, Huawei, and Vivo by the undergraduate students using the proposed AHP-TOPSIS model. The reduction in cost of mobile phones and new technology have contributed to the rapid adoption rate by young people such as the undergraduate students [28].

The structure of the paper is constructed in the following way: Section 2 discusses the materials and methodology of the study. Section 3 demonstrates the empirical results of the study. Section 4 ends with conclusions.

2. Materials and Methodology

2.1 Research Development

In this research paper, integrated TOPSIS and AHP model is proposed for the selection and evaluation of mobile phones. The advantage of AHP model is to find out the decision criteria' priority based on the inputs from the decision maker. In addition, the optimal decision is determined based on the PIS and NIS with TOPSIS model [15]. Figure 1 displays the proposed research framework which consists of three stages.

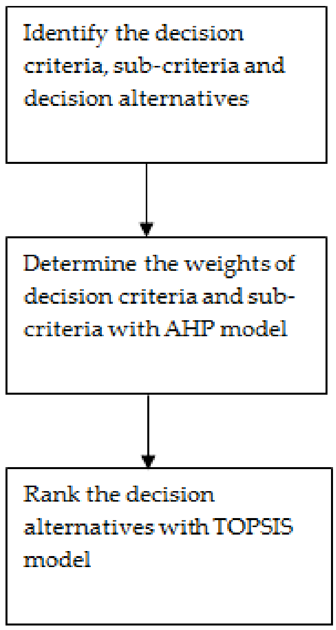

Fig. 1. Proposed framework of research

As displayed in Figure 1, the proposed framework of research consists of three stages as follows:

i. Stage 1: Identification of the decision alternatives, decision criteria, and sub-criteria for the evaluation and selection of mobile phones.
ii. Stage 2: Application of AHP methodology to find the importance of decision criteria' and sub-criteria' weight. At this stage, the overall ranking of decision criteria and sub-criteria are identified.
iii. Stage 3: The TOPSIS model is proposed for ranking of the best decision alternative for mobile phone selection. The TOPSIS model is suitable to address the complex decision-making problem. The preference of mobile phones is determined based on the PIS and NIS.

Table 1 depicts the proposed hierarchy structure for the evaluation and selection of mobile phones among Samsung, Apple, Oppo, Huawei, and Vivo using AHP-TOPSIS model. The first level in the proposed hierarchy structure is the aim of the study, and the second level enumerates four decision criteria. A total of five decision alternatives are illustrated in the third level.

Table 1
Proposed hierarchy structure

Level	
Level 1 (Purpose)	Selection of mobile phones
Level 2 (Decision criteria)	Technical specification
	Physical properties
	User related features
	Basic built-in functions
Level 3 (Decision alternative)	Samsung
	Apple
	Oppo
	Huawei
	Vivo

The decision criteria and sub-criteria for the selection of mobile phones presented in Table 2.

Table 2
Main decision criteria and sub-criteria

Main decision criteria	Sub-criteria
Technical specification	Pixel Density
	RAM
	Processor
	Battery Power
	Standby Time
Physical Properties	Weight
	Thickness
	Durability
	Screen Size
	Shape
User Related Features	Ease to use
	Cost
	Aesthetic
	Brand
Basic Built-In Functions	Polyphonic ring tones
	Phone book capability
	Password lock
	Calendar

A case study is conducted to determine the preference of 150 undergraduate students in choosing the mobile phones based on multiple criteria with the proposed AHP-TOPSIS model. As shown in Table 2, the main decision criteria consist of technical specification, physical properties, user related features, and basic built-in functions [3–6]. The available mobile phones that considered in this study are Samsung, Apple, Oppo, Huawei, and Vivo.

2.2 AHP

The AHP model was first introduced by Saaty [29–32]. AHP is a scientific model in MCDM which has been broadly applied by the decision makers to tackle the complex decision-making problem [12]. Determination of decision criteria' and sub-criteria' weights are crucial for ranking the optimal mobile phone selection. The AHP model is a pairwise comparison approach which is utilized to get the relative importance of decision criteria and sub-criteria [12]. In the study, AHP model is proposed to find the weights of the decision criteria and sub-criteria at the second stage [28–31]. The procedures of AHP model are depicted below [33].

i. Step 1: Defining the decision problem and constructing the hierarchy structure. The hierarchy structure consists of three levels.
ii. Step 2: Collection of data from target respondents. Establish the decision criteria' pairwise comparison matrix (PCM) by using pairwise comparison scale as presented in Table 3 [33].

Table 3
Ratio scale used for pairwise comparison

Scale	Importance Definition
1	Equally important
3	Moderately important
5	Strongly important
7	Very powerful important
9	Extremely important
2, 4, 6, 8	Intermediate values

iii. Step 3: Construction of a PCM [34,35].

$$A = \begin{bmatrix} 1 & c_{12} & \cdots & \cdots & c_{1n} \\ 1/c_{12} & 1 & & & c_{2n} \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ 1/c_{1n} & \cdots & \cdots & \cdots & 1 \end{bmatrix} \tag{1}$$

where c_{ij} is the preference degree of criterion *i* to criterion *j*.

iv. Step 4: Normalization of the matrix and calculating each decision criterion' relative weights. Firstly, each element in the column divides by the sum of the entries of the corresponding column and the normalized matrix is formed. Secondly, find the mean of each row in the normalized matrix. The mean of each row denotes the priorities of the decision criteria.

v. Step 5: Checking on the PCM's consistency by using consistency ratio (*CR*). If the PCM shows inconsistencies, hence the decision maker needs to re-evaluate or re-judge the preferences of the elements. The *CR* formula is presented as follows:

$$CR = \frac{CI}{RI} \tag{2}$$

where *RI* denotes the random index and *CI* denotes the consistency index [32].

The consistency's degree in the PCM is satisfactory if the *CR* value is at most 0.10 [33,36,37]. It shows that the AHP outcome is reliable and acceptable and no further evaluation is required. On the other hand, the consistency's degree in the PCM is considered as unsatisfactory if the value of *CR* is more than 0.10. This implies that serious inconsistencies may exist and therefore, the decision maker needs to re-evaluate or re-judge the preferences of the elements.

2.3 TOPSIS

TOPSIS is a MCDM model that used to rank the alternatives and select the most preferred alternative based on multiple criteria [38]. TOPSIS model is classified as a distance measure method in which the optimal alternative seeks to achieve the farthest proximity to the NIS and the shortest proximity from the PIS [15,39-42]. TOPSIS model is easy to use [43]. Moreover, the step numbers for TOPSIS model are still the same regardless of the number of criteria and alternatives [44]. The procedures of TOPSIS model are presented below [38].

i. Step 1: Create a decision matrix $(x_{ij})_{m\times n}$.

$$(x_{ij})_{m\times n} = \begin{array}{c} \\ L_1 \\ L_2 \\ \vdots \\ \vdots \\ L_m \end{array} \begin{array}{c} \begin{array}{ccccc} c_1 & c_2 & \cdots & \cdots & c_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & & & x_{2n} \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ x_{m1} & \cdots & \cdots & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{3}$$

where L_i = alternative $(i = 1, 2, 3, \ldots\ldots, m)$
c_j = criterion $(j = 1, 2, 3 \ldots\ldots, n)$
j = criterion index $(j = 1, 2, 3 \ldots\ldots, n)$
i = alternative index $(i = 1, 2, 3, \ldots\ldots, m)$

ii. Step 2: Evaluate the normalized decision matrix. The normalized value r_{ij} is expressed as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

iii. Step 3: Establish the weighted normalized decision matrix.
The weights of the decision criteria that determined by the AHP model is utilized to measure the relative importance of different selection criteria. The weighted normalized decision matrix is established by multiplying the weights of the decision criteria, w_j with each element in the normalized decision matrix. The weighted normalized value v_{ij} is obtained by means of Eq. (5).

$$v_{ij} = w_j \times r_{ij} \text{ , } j = 1, 2, 3, \ldots\ldots, n; \; i = 1, 2, 3, \ldots\ldots, m \tag{5}$$

iv. Step 4: Calculate the PIS and NIS.

$$A^+ = \left\{ v_1^+, v_2^+, \ldots\ldots, v_n^+ \right\} \text{ where } v_j^+ = \left\{ \left(\max v_{ij} \mid i \in I \right), \left(\min v_{ij} \mid i \in I' \right) \right\} \tag{6}$$

$$A^- = \left\{ v_1^-, v_2^-, \ldots\ldots, v_n^- \right\} \text{ where } v_j^- = \left\{ \left(\min v_{ij} \mid i \in I \right), \left(\max v_{ij} \mid i \in I' \right) \right\} \tag{7}$$

where A^+ denotes the PIS and A^- denotes the NIS.

v. Step 5: Determine the geometric distance of each decision alternative from the NIS (S^-) and PIS (S^+).

$$s_i^+ = \sqrt{\sum_{j=1}^{n} (v_j^+ - v_{ij})^2} \text{ , } i = 1, 2, 3, \ldots\ldots, m \tag{8}$$

$$s_i^- = \sqrt{\sum_{j=1}^{n} (v_j^- - v_{ij})^2} \text{ , } i = 1, 2, 3, \ldots\ldots, m \tag{9}$$

vi. Step 6: Obtain the relative closeness coefficient (c_i) of each alternative with respect to the ideal solutions.

$$c_i = \frac{s_i^-}{(s_i^+ + s_i^-)} \text{ , } 0 \le c_i \le 1 \tag{10}$$

vii. Step 7: Rank the alternatives according to c_i. The larger value of c_i indicates that the alternative has longer proximity to the NIS and shorter proximity to the PIS. Therefore, the alternative that has the larger value of c_i signifies the better alternatives.

3. Results

Based on the second stage of the proposed MCDM model with AHP, Figure 2 displays the weights of the decision criteria.

As presented in Figure 2, technical specification has the largest weights which is 0.3218, followed by user related features with 0.3117. This implies that technical specification is the main factor to be considered by the undergraduate students, followed by user related features in the selection of mobile phones. The next priority of decision criteria is basic built-in functions, and finally physical properties with 0.1875 and 0.1790 weights, respectively. In this study, technical specification and user related features are the most important criteria in the mobile phones' selection among undergraduate students. For instance, the virtual reality in the smartphone can help students to learn and study more interestingly during teaching and learning sessions [45].

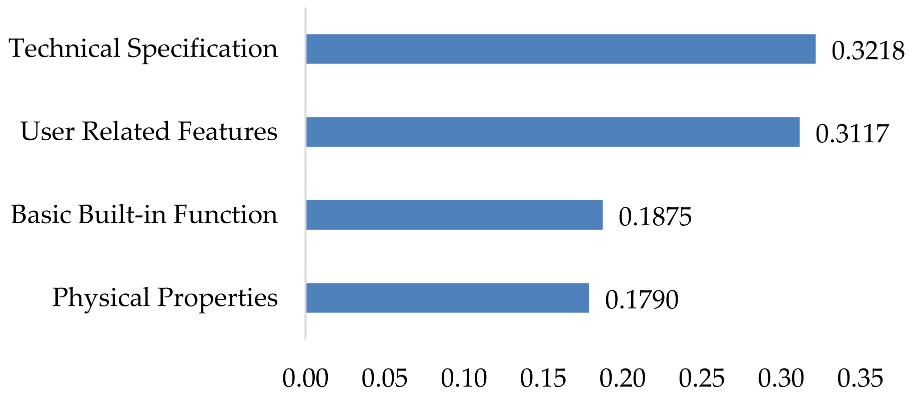

Fig. 2. Weights of the decision criteria

Figure 3 to 6 depict the mobile phones' preference based on each decision criterion. In this study, Apple and Huawei are ranked as the top two mobile phones among the undergraduate students based on technical specification, physical properties, user related features and basic built-in functions.

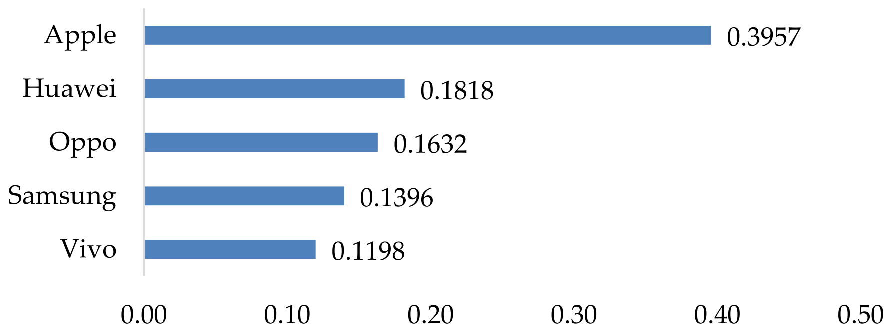

Fig. 3. Preference of mobile phones based on technical specification

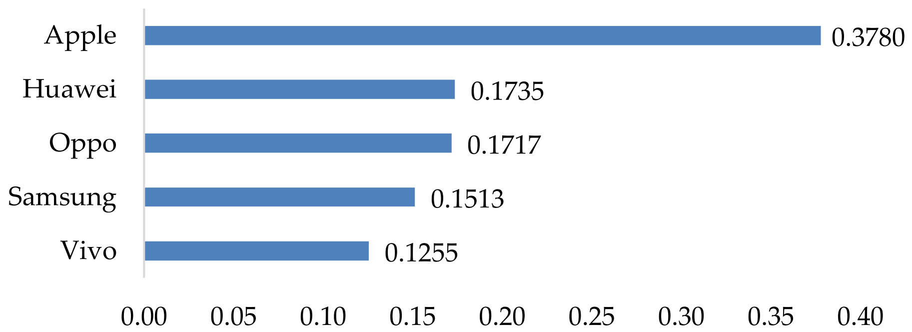

Fig. 4. Preference of mobile phones based on physical properties

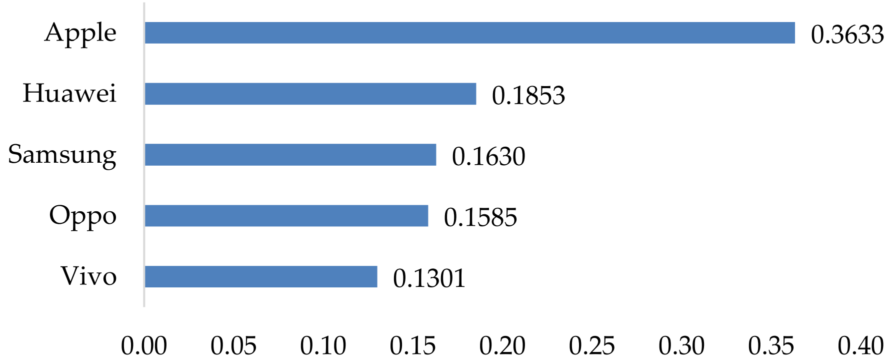

Fig. 5. Preference of mobile phones based on user related features

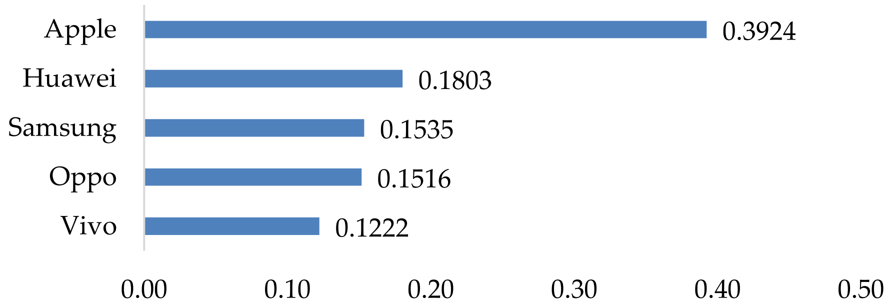

Fig. 6. Preference of mobile phones based on basic built-in functions

Table 4 provides the priority weights among criteria and sub-criteria. The sub-criteria' normalized weights within the criteria and their ranking within each of the main criteria have been identified according to the proposed research framework and shown in the third and fourth columns of Table 4. When considering the sub-criteria under each main criterion, the sub-criteria such as pixel density, weight, aesthetic, and polyphonic ring tones are the least considerable factors for the main criteria of technical specification, physical properties, user related features, and basic built-in functions, respectively. On the other hand, battery power is the most considerable factor in technical specification criterion with the weight of 0.2841, while durability is the most preferable factor in physical properties with the weight of 0.3249. Cost and password lock are the most influential factors in the selection of mobile phones for the criteria user related features and basic built-in functions with the weight of 0.3403 and 0.3699, respectively.

Table 4
Priority weights in the AHP decision tree

Criteria	Weight between the criteria (%)	Weight within the criteria (%)	Ranking within the criteria	Weight among sub-criteria (%)	Overall ranking
Technical Specification	0.3218				
Pixel Density		0.1049	5	0.0338	14
RAM		0.2198	3	0.0707	6
Processor		0.2589	2	0.0833	3
Battery Power		0.2841	1	0.0914	2
Standby Time		0.1324	4	0.0426	12
Physical properties	0.1790				
Weight		0.1072	5	0.0192	18
Thickness		0.1373	4	0.0246	17
Durability		0.3249	1	0.0582	8
Screen Size		0.2565	2	0.0459	11
Shape		0.1742	3	0.0312	15
User Related Features	0.3117				
Ease to use		0.2319	3	0.0723	5
Cost		0.3403	1	0.1061	1
Aesthetic		0.1822	4	0.0568	9
Brand		0.2456	2	0.0766	4
Basic built-in functions	0.1875				
Polyphonic ring tones		0.1570	4	0.0294	16
Phone book capability		0.2464	2	0.0462	10
Password lock		0.3699	1	0.0694	7
Calendar		0.2268	3	0.0425	13

The normalized weight of the sub-criteria is given in Figure 7. At the final stage of the proposed MCDM model with TOPSIS, the ranking of the mobile phones is determined. The weighted normalized decision matrix v_{ij} is formed by multiplying the decision weights that are results of the AHP model at the second stage with each element of each column in the normalized decision matrix. The weighted normalized decision matrix is presented in Table 5.

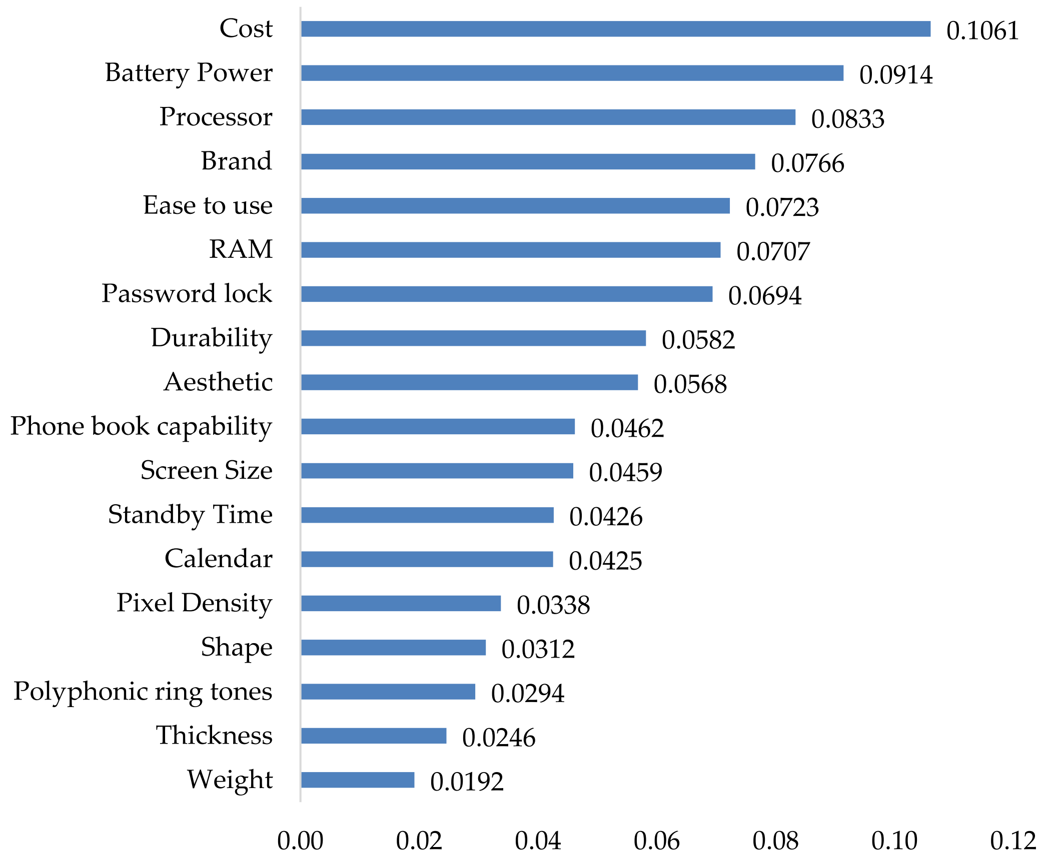

Fig. 7. The normalized weight of sub-criteria

Table 5
The weighted normalized decision matrix

Mobile phone	Technical specification	Physical properties	User related features	Basic built-in functions
Samsung	0.1337	0.0792	0.1409	0.0844
Apple	0.1814	0.0975	0.1593	0.0994
Oppo	0.1353	0.0763	0.1341	0.0799
Huawei	0.1421	0.0769	0.1357	0.0800
Vivo	0.1195	0.0673	0.1246	0.0733

After that, the NIS and PIS of each decision criterion are identified and displayed in Table 6. As shown in Table 6, the PIS for the technical specification, physical properties, user related features, and basic built-in functions are 0.1814, 0.0975, 0.1593, and 0.0994, respectively. The NIS for the technical specification, physical properties, user related features, and basic built-in functions are 0.1195, 0.0673, 0.1246, and 0.0733, respectively.

Table 6
NIS and PIS of each decision criterion

Decision criteria	Positive ideal solution (PIS)	Negative ideal solution (NIS)
Technical specification	0.1814	0.1195
Physical properties	0.0975	0.0673
User related features	0.1593	0.1246
Basic built-in functions	0.0994	0.0733

The proximity of each mobile phone from NIS (S^-) and PIS (S^+) is shown numerically in Table 7. As displayed in Table 7, Apple gives the shortest geometric distance from S^+ among mobile phones, followed by Huawei, Samsung, Oppo, and lastly Vivo. This implies that Apple is the closest to the PIS. Apple gives the largest geometric distance from S^- , followed by Huawei, Samsung, Oppo, and finally Vivo. This shows that Apple is the farthest from the NIS. This implies that Apple outperforms the other four mobile phones among undergraduate students in this study.

Table 7
Proximity of each mobile phone from NIS (S^-) and PIS (S^+)

Mobile phone	S^+	S^-
Samsung	0.0563	0.0270
Apple	0.0000	0.0814
Oppo	0.0599	0.0216
Huawei	0.0539	0.0277
Vivo	0.0814	0.0000

The c_i of the mobile phone with respect to the ideal solutions and its ranking is given in Table 8. Based on surveys conducted and data analysis performed, the ranking is obtained. The c_i depicts the ranking. The larger value of c_i indicates the most preferred alternatives. According to Table 8, the results of this study show that Apple scores the maximum c_i of 1.0000 among studied mobile phones. This indicates that Apple has excelled other mobile phones in terms of all decision criteria such as technical specification, physical properties, user related features, and basic built-in functions. Therefore, Apple is determined as the most preferred mobile phone in the study. The results are in line with the past study [8]. Huawei, Samsung, and Oppo are placed in the second, third, and fourth ranking with the c_i of 0.3400, 0.3243, and 0.2648, respectively. Huawei outperforms Samsung is supported by the study [27]. Lastly, Vivo achieves the lowest ranking with the c_i of 0.0000. In the study, the result of the *CR* is 0.0079 which is below 0.1000. This implies that serious inconsistencies did not occur in the PCM. Thus, the outcome of the study is reliable and acceptable. The outcomes obtained demonstrate that the AHP-TOPSIS model is robust.

Table 8
Ranking of mobile phones

Mobile phone	Relative closeness coefficient (c_i)	Rank
Apple	1.0000	1
Huawei	0.3400	2
Samsung	0.3243	3
Oppo	0.2648	4
Vivo	0.0000	5

4. Conclusions

Mobile phone selection process is a MCDM problem as it involves multiple factors that need to be taken into consideration in the process of evaluation. AHP-TOPSIS model is proposed in the study to identify the decision criteria' priority in the mobile phones' selection. Besides, the study aims to identify the most preferred mobile phone as well as the overall ranking of mobile phones among

Samsung, Apple, Oppo, Huawei, and Vivo with the proposed model. In this study, the results demonstrate that Apple has been identified as the most desired mobile phone among undergraduate students, followed by Huawei, Samsung, Oppo, and finally Vivo. In addition, technical specification is the most influential criterion in the mobile phones' selection, followed by user related features, basic built-in functions, and finally physical properties. In this study, cost, battery power, and processor have been identified as the top three important sub-criteria among undergraduate students.

This study's contribution is to propose a MCDM model for evaluation process and mobile phones' selection among undergraduate students. The hybrid of AHP and TOPSIS model assists the decision maker to consider and determine the optimal decision based on the PIS as well as NIS. AHP-TOPSIS model addresses the important research direction of obtaining AHP weighted features for use in the mobile phone selection process. Apart from academic implication, this study also assists to find out the most desired mobile phone and the most significant decision criteria and sub-criteria in the mobile phones' selection. The proposed model in the research is a suggestive method and it may be a useful tool and give a crucial clue to decision makers in their final decision. Moreover, this study also provides a valuable and practical implication to the less favourable mobile phones to determine the potential improvement based on the most significant decision criterion. For future research, the AHP-TOPSIS model can be adopted and extended for evaluation process and selection of mobile phones among working-age adults.

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