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MULTI-CRITERIA DECISION MAKING FOR SMARTPHONE BRAND SELECTION USING NEUTROSOPHIC SOFT SET

(*Pembuatan Keputusan Pelbagai Kriteria untuk Pemilihan Jenama Telefon Pintar Menggunakan Set Lunak Neutrosophic*)

FIRDAWATI MOHAMED*, NUR AIN SABRINA ADI SABRI, ZAKIRA FADHLINA ZA'ABAR, NORARIDA ABD RHANI & SITI NURUL FITRIAH MOHAMAD

ABSTRACT

This study explores the use of Neutrosophic Soft Set (NSS) in selecting the best smartphone brand for consumers, as the market is flooded with numerous brands and criteria, making it challenging for consumers to choose a smartphone that aligns with their preferences and interests. NSS is a mathematical tool that is effective in resolving decision-making problems involving uncertainty and inconsistent data. The study's objective is to demonstrate that NSS successfully handles complex decision-making problems involving uncertainty and inconsistent data. The study's results indicate that NSS can effectively manage high levels of uncertainty in smartphone selection, making it a valuable tool for consumers faced with such decisions. The result obtained by NSS for the chosen criteria and alternative is then used in comparative analysis to assess the accuracy of the method.

Keywords: multi criteria decision making; neutrosophic soft set; neutrosophic set

ABSTRAK

Kajian ini meneroka penggunaan Set Lunak Neutrosofik (NSS) dalam memilih jenama telefon pintar terbaik bagi pengguna, memandangkan pasaran dibanjiri dengan pelbagai jenama dan kriteria, menjadikan ia mencabar bagi pengguna untuk memilih telefon pintar yang selari dengan keutamaan dan minat mereka. NSS merupakan alat matematik yang berkesan dalam menyelesaikan masalah pembuatan keputusan yang melibatkan ketidakpastian dan data yang tidak konsisten. Objektif kajian ini adalah untuk membuktikan bahawa NSS berjaya mengendalikan masalah pembuatan keputusan yang kompleks yang melibatkan ketidakpastian dan data yang tidak konsisten. Hasil kajian menunjukkan bahawa NSS dapat menguruskan ketidakpastian yang tinggi dalam pemilihan telefon pintar dengan berkesan, menjadikannya alat yang berharga bagi pengguna yang dihadapi dengan keputusan sedemikian. Keputusan yang diperoleh oleh NSS berdasarkan kriteria dan alternatif yang dipilih kemudiannya dibandingkan melalui analisis perbandingan untuk melihat kejituan kaedah tersebut.

Katakunci: keputusan pelbagai kriteria; set lunak neutrosofik; set neutrosofik

1. Introduction

Numerous real-world problems in diverse fields, including business management, economics, insurance, statistics, meteorology, medical science, and engineering, involve uncertainty. Researchers have examined a variety of theories and methods for addressing these issues. Fuzzy set (FS) theory (Zadeh 1965), intuitionistic fuzzy set (IFS) theory (Atanassov 1986), soft set theory (Molodtsov 1999), and neutrosophic set (NS) theory (Smarandache 2005) are among the approaches introduced to address complex decision-making problems involving uncertainty.

Zadeh (1965) introduced the concept of fuzzy set (FS) which expanded on the classical notion of set. Atanassov (1986) later proposed the intuitionistic fuzzy set (IFS), which became a crucial development in fuzzy set theory by accounting for truth-membership and falsity-membership values in the presence of insufficient information. However, IFS does not account for indeterminate or inconsistent information that exists in real-life problems. To address this limitation, Molodtsov (1999) introduced the soft set theory, a mathematical tool that deals with uncertainties in a way that is free from the limitations of parametrization tools. The soft set theory is easy to apply in practice as it does not require a membership function. Soft set theory was further studied by researchers such as Pawlak and Skowron (2007). The neutrosophic set (NS), introduced by Smarandache (2005), is another mathematical tool used to deal with issues involving indeterminacy, imprecision, and inconsistency. A proposition in NS has a degree of truth (T), a degree of indeterminacy (I), and a degree of falsity (F) expressed on the non-standard $]^{-}0, 1^{+}[$ unit interval. NS is an evolution from FS and is effective in dealing with uncertainties arising from vagueness, although it cannot model all types of uncertainties in actual problems, such as issues involving incomplete information. NS has also been extended to single value neutrosophic sets (SVNS) and interval-valued neutrosophic sets (IVNS). Maji (2013) combined NS with soft set theory to introduce neutrosophic soft set (NSS) and applied it to object recognition problem decision-making.

Multi criteria decision making (MCDM) typically deals with decisions involving the selection of the best alternative based on several criteria. Nowadays, making decisions is an everyday occurrence in our lives. Decision making is a complex act of choosing between two or more possible alternatives, and decision-makers must make their choices based on complete or incomplete information, (Mondal & Pramanik 2015). To make final conclusions from data available for review, the decision making process necessitates a number of steps. The conclusion is to choose the best option that is most likely to be successful or profitable and meets the consumer’s goals, preferences, values, and conditions. The current problem in decision making is associated with uncertainty and ambiguity as a result of a lack of information and knowledge, less time to think and consider, and other complex problems. Therefore, classical mathematics is inefficient in dealing with such complex problems.

Mobile phones play an important role because they are used by many people all over the world. The advancement of technology in the telecommunications sector has resulted in smartphones, which are advanced mobile phones. These smartphones have extra features such as internet access, the ability to download applications, and so on. According to Koliby and Rahman (2018), there are a large number and variation of smartphone applications that allow users to simply change things by adding new capabilities that can assist users in completing various tasks such as banking, navigation, gaming, taking notes or touring. Smartphones have a greater capacity for storing photographs, videos, and applications on Micro SD cards than older mobile phones, according to Nasir *et al.* (2019). Many researchers have studied smartphone selection using various MCDM methods to select the most valuable ones. Saqlain *et al.* (2020) used the Generalised Fuzzy TOPSIS method to incorporate TFNs into FMCGDM. Kumar *et al.* (2020) then used the simple additive weighting (SAW) and weighted product method (WPM) to determine the rankings of mobile phones. Büyüközkan and Güleryüz (2016) used the concept of IF-TOPSIS along with group decision making to identify the best smartphone options. Bakar *et al.* (2019) proposed a case study in smartphone selection using graph theory and matrix method by consumer’s preferences. All of them considered more criteria when making decisions in their studies. Such criteria include things like price offer, warranty offer, storage capacity, memory, display, camera, and so on. The criteria considered by other researchers when choosing the best smartphone are listed in the table below.

Table 1: Criteria chosen from other researchers

Criteria/ Author	Mishra *et al.* (2021)	Saqlain *et al.* (2020)	Okfalisa *et al.* (2019)	Bakar *et al.* (2019)	Nasir *et al.* (2019)
Price	/	/	/	/	/
Operating System	/				/
Memory				/	/
Display		/			/
Camera	/	/	/	/	/
Battery	/		/		/
RAM	/	/	/		
Storage Capacity	/		/		
Screen Size	/		/		
Processor	/	/			

Price is simply the amount of money a customer is willing to pay for smartphone that they believe are worthwhile. Price can attract consumer purchasing smartphone by offering smartphone with a low price. Some of the consumer believe that a high price equates to great quality, while others do not as state by Roseli *et al.* (2016). Operating systems such as Windows, iPhone OS (iOS), Symbian, Bada, Maemo, Google Android, and RIM Blackberry are all used to administer smartphones and the operating system on a smartphone allows third-party applications to run on it (Rahim *et al.* 2016). As for the memory, data is stored in the memory when a smart phone is used where the inbuilt memory allows for high- speed access, large capacity, and low power consumption. Aside from that, smartphone displays are typically associated with screen size, type, multi-touch, and phone protection. As for the camera, a built-in camera is useful in assisting photography related tasks and nowadays, a phone camera in smartphone allows users to take instant photography and share their photographs using social media applications installed on their smartphones (Katuk *et al.* 2019). Finally, battery is usually associated with the duration of a rechargeable battery of a smartphone (Büyüközkan & Güleryüz 2016).

Malaysia's first cellular network was launched by Telekom Malaysia in 1985, and the country made history by becoming one of the first countries in the Asia-Pacific region to introduce mobile phones, Rahim *et al.* (2016). According to survey by Koliby and Rahman (2018) in Malaysia, some of the smartphone brands are commonly used by a consumer are Apple, Oppo, Sony, Samsung, Huawei, Lenovo, HTC, Ninethology, LG, Motorola, Asus, Xiaomi and Blackberry. In this study, the alternative chosen as case study are Oppo, Samsung and Apple. While the chosen criteria are price, operating system, memory, display, camera, and battery.

2. Methodology

In this study, the methodology consists of eight steps, which are data collection, input the neutrosophic soft set, construct the normalised parameter matrix, $\widehat{d}$, compute the weight of each criteria, $w(e_j)$, construct the comparison matrix for each criteria, compute membership degree for all, $y_j \in Y, W_{f(e)}(y_j)$, construct decision set, D_E and obtain the optimal solution as in Figure 1.

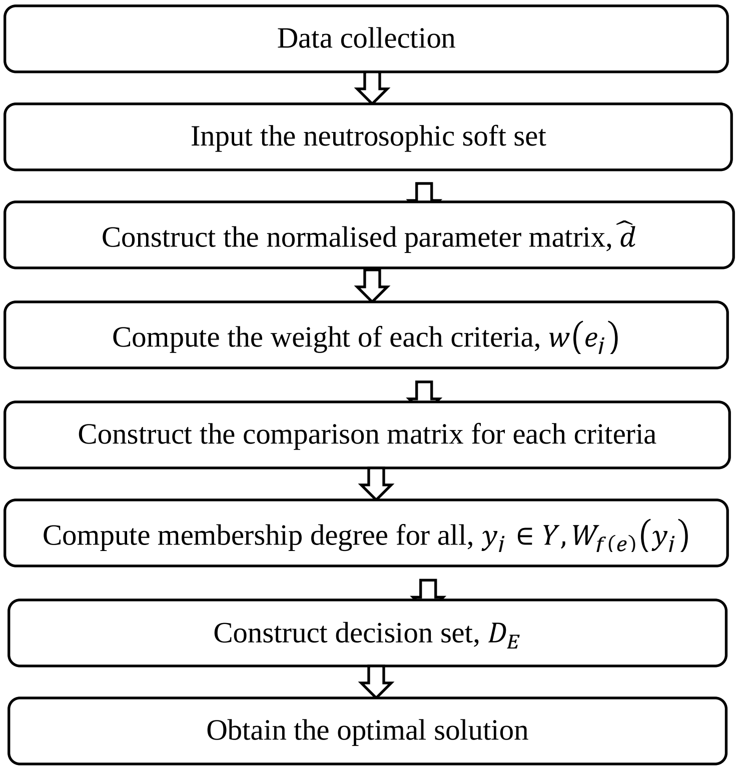

Figure 1: The steps of methodology

STEP 1: Data collection

Online questionnaires were distributed to selected experts (people with working experience selling smartphone brands) to determine the value of membership of each element $y \in$ in the set E. To change the characteristics of the alternatives (smartphone brand), experts can divide their opinions into three categories: degree of truth, degree of indeterminacy, and degree of falsity (Broumi 2013). The experts rate the alternatives using linguistic variables such as very low, low, satisfactory, high, and very high, as shown in Table 2. This table is from the linguistic variable used by Saaty (1980) in his study.

Table 2: Linguistic variables, codes and neutrosophic number obtained by expert opinion

No.	Linguistic Variable	Code	Neutrosophic Number
1	Very Low	VL	(0.1, 0.3, 0.7)
2	Low	L	(0.3, 0.5, 0.6)
3	Satisfactory	S	(0.5, 0.5, 0.5)
4	High	H	(0.7, 0.3, 0.4)
5	Very High	VH	(1.0, 0.1, 0.2)

The set of alternative Y = {y1, y2, y3} are smartphone brands where y1 = Oppo, y2 = Samsung and y3 = Apple. Then, a set of parameter E = {e1, e2, e3, e4, e5, e6} are criteria where e1 = Price, e2 = Operating system, e3 = Memory, e4 = Display, e5 = Camera and e6 = Battery. Thus, according to expert opinion, the data obtained for price and operating system are shown in Table 3.

Table 3: Some of expert opinion of the criteria

Parameter	Alternatives	Expert 1	Expert 2	Expert 3
Price	Y1	S	S	S
	Y2	H	S	H
	Y3	VH	VH	VH
Operating system	Y2	S	S	S
	Y2	S	H	VH
	Y3	S	S	S

As a result, the opinion in Table 3 is converted to a neutrosophic number using Table 2 as Table 4.

Table 4: Converted data from expert opinion to the neutrosophic number

Parameter	Alternatives	Expert 1	Expert 2	Expert 3	Average
Price	Y1	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.50,0.50,0.50)
	Y2	(0.7,0.3,0.4)	(0.5,0.5,0.5)	(0.7,0.3,0.4)	(0.63,0.37,0.43)
	Y3	(1.0,0.1,0.2)	(1.0,0.1,0.2)	(1.0,0.1,0.2)	(1.00,0.10,0.20)
Operating system	Y2	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.50,0.50,0.50)
	Y2	(0.5,0.5,0.5)	(0.7,0.3,0.4)	(1.0,0.1,0.2)	(0.73,0.30,0.37)
	Y3	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.5,0.5,0.5)	(0.50,0.50,0.50)

According to Ertugrul and Oztas (2014), the average value is calculated among experts in order to convert it to a triangular fuzzy number. The price average is calculated as

$$y1 = \left(\frac{0.5+0.5+0.5}{3}, \frac{0.5+0.5+0.5}{3}, \frac{0.5+0.5+0.5}{3}\right) = (0.5,0.5,0.5)$$

$$y2 = \left(\frac{0.7+0.5+0.7}{3}, \frac{0.3+0.5+0.3}{3}, \frac{0.4+0.5+0.4}{3}\right) = (0.63,0.37,0.43)$$

$$y3 = \left(\frac{1.0+1.0+1.0}{3}, \frac{0.1+0.1+0.1}{3}, \frac{0.2+0.2+0.2}{3}\right) = (1.0,0.1,0.2)$$

STEP 2: Input the neutrosophic soft set.

In this step, the data from step 1 are compiled in a neutrosophic soft set function as follows:

$$f(Price) = \{\langle y_1, 0.5,0.5,0.5\rangle, \langle y_2, 0.63,0.37,0.43\rangle, \langle y_3, 1,0.1,0.2\rangle\}$$
$$f(Operating\ system) = \{\langle y_1, 0.5,0.5,0.5\rangle, \langle y_2, 0.73,0.3,0.37\rangle, \langle y_3, 0.5,0.5,0.5\rangle\}$$
$$f(Memory) = \{\langle y_1, 0.63,0.37,0.43\rangle, \langle y_2, 0.5,0.5,0.5\rangle, \langle y_3, 0.67,0.37,0.4\rangle\}$$
$$f(Display) = \{\langle y_1, 0.67,0.37,0.4\rangle, \langle y_2, 0.5,0.5,0.5\rangle, \langle y_3, 0.83,0.23,0.3\rangle\}$$
$$f(Camera) = \{\langle y_1, 0.67,0.37,0.4\rangle, \langle y_2, 0.83,0.23,0.3\rangle, \langle y_3, 0.83,0.23,0.3\rangle\}$$
$$f(Battery) = \{\langle y_1, 1,0.1,0.2\rangle, \langle y_2, 1,0.1,0.2\rangle, \langle y_3, 0.3,0.43,0.6\rangle\}$$

STEP 3: Construct the normalised parameter matrix, $\widehat{d}$.

Relative criteria matrix was constructed as:

$$d_E = \begin{bmatrix} 1 & d_E(e_1, e_2) & K & d_E(e_1, e_n) \\ d_E(e_2, e_1) & 1 & K & d_E(e_2, e_n) \\ M & M & M & M \\ d_E(e_n, e_1) & d_E(e_n, e_2) & K & 1 \end{bmatrix}$$

Based on the matrix provided, the value of d_{34} represents the level of importance of e_3 in relation to e_4. Because e_3 is greater than e_4, and d_{34} = 9. The transposition of d_{34} is d_{43}. Thus, d_{43} =1/9, which is a reciprocal value of d_{43}, as stated by Saaty (1987). As a result, the relative parameter for this study was constructed as follows:

$$d_E = \begin{bmatrix} 1 & 2 & 3 & 5 & \frac{1}{6} & \frac{1}{7} \\ \frac{1}{2} & 1 & 1 & 4 & 7 & 6 \\ \frac{1}{3} & 1 & 1 & 9 & \frac{1}{5} & 8 \\ \frac{1}{5} & \frac{1}{4} & \frac{1}{9} & 1 & 8 & \frac{1}{9} \\ 6 & \frac{1}{7} & 5 & \frac{1}{8} & 1 & \frac{1}{9} \\ 7 & \frac{1}{6} & \frac{1}{8} & 9 & 9 & 1 \end{bmatrix}$$

While the calculation score of criteria was computed by using the Eq. (1).

$$c_i = \sum_{j=1}^{n} d_{ij} \tag{1}$$

Hence, score of criteria for $c_1 = 11.31, c_2 = 19.50, c_3 = 19.50, c_4 = 9.67, c_5 = 12.38$ and $c_6 = 26.29$. Thus normalised criteria matrix was constructed as follows:

$$\hat{d} = \begin{bmatrix} 0.09 & 0.18 & 0.27 & 0.44 & 0.01 & 0.01 \\ 0.03 & 0.05 & 0.05 & 0.21 & 0.36 & 0.31 \\ 0.02 & 0.05 & 0.05 & 0.46 & 0.01 & 0.41 \\ 0.02 & 0.03 & 0.01 & 0.10 & 0.83 & 0.01 \\ 0.48 & 0.01 & 0.40 & 0.01 & 0.08 & 0.01 \\ 0.27 & 0.01 & 0.00 & 0.34 & 0.34 & 0.04 \end{bmatrix}$$

STEP 4: Compute the weight of each criteria, $\boldsymbol{w(e_j)}$.

From normalised matrix, weight of criteria is obtained using Eq. (2).

$$w(e_j) = \frac{1}{|E|} \sum_{i=1}^{n} d_{ij} \tag{2}$$

By this, the weight vector for $w(e_1) = 0.15$, $w(e_2) = 0.05$, $w(e_3) = 0.13$, $w(e_4) = 0.26$, $w(e_5) = 0.27$ and $w(e_6) = 0.13$.

STEP 5: Construct the comparision matrix for each criteria.

The following matrices are constructed for each criterion:

$$Y_{f(Price)} = \begin{bmatrix} 0.50 & 0.34 & -0.10 \\ 0.67 & 0.50 & 0.07 \\ 1.10 & 0.94 & 0.50 \end{bmatrix} \qquad Y_{f(OS)} = \begin{bmatrix} 0.50 & 0.22 & 0.50 \\ 0.78 & 0.50 & 0.78 \\ 0.50 & 0.22 & 0.50 \end{bmatrix}$$

$$Y_{f(Memory)} = \begin{bmatrix} 0.50 & 0.67 & 0.47 \\ 0.34 & 0.50 & 0.30 \\ 0.54 & 0.70 & 0.50 \end{bmatrix} \qquad Y_{f(Display)} = \begin{bmatrix} 0.50 & 0.70 & 0.30 \\ 0.30 & 0.50 & 0.10 \\ 0.70 & 0.90 & 0.50 \end{bmatrix}$$

$$Y_{f(Camera)} = \begin{bmatrix} 0.50 & 0.30 & 0.30 \\ 0.70 & 0.50 & 0.50 \\ 0.70 & 0.50 & 0.50 \end{bmatrix} \qquad Y_{f(Battery)} = \begin{bmatrix} 0.50 & 0.50 & 1.22 \\ 0.50 & 0.50 & 1.22 \\ -0.22 & -0.22 & 0.50 \end{bmatrix}$$

STEP 6: Compute membership degree for all $\boldsymbol{y_j} \in \boldsymbol{Y}, \boldsymbol{W_{f(e)}}(\boldsymbol{y_j})$.

For all $y_j \in Y$ and $e \in E$, the membership degree obtained are $W_{f\ (e_1)}(y_1) = 0.59$, $W_{f\ (e_1)}(y_2) = 0.76$, $W_{f\ (e_1)}(y_3) = 0.16$, $W_{f\ (e_2)}(y_1) = 0.59$, $W_{f\ (e_2)}(y_2) = 0.31$, $W_{f\ (e_2)}(y_3) = 0.59$, $W_{f\ (e_3)}(y_1) = 0.46$, $W_{f\ (e_3)}(y_2) = 0.62$, $W_{f\ (e_3)}(y_3) = 0.42$, $W_{f\ (e_4)}(y_1) = 0.50$, $W_{f\ (e_4)}(y_2) = 0.70$, $W_{f\ (e_4)}(y_3) = 0.30$, $W_{f\ (e_5)}(y_1) = 0.63$, $W_{f\ (e_5)}(y_2) = 0.43, W_{f\ (e_5)}(y_3) = 0.43$, $W_{f\ (e_6)}(y_1) = 0.26, W_{f\ (e_6)}(y_2) = 0.26$, $and\ \ W_{f\ (e_6)}(y_3) = 0.98$.

STEP 7: Construct decision set, $\boldsymbol{D_E}$.

By using step 4 and step 6, D_E is constructed as follows:

$$D_E = \{(y_1, 0.090), (y_2, 0.086), (y_3, 0.072)\}$$

STEP 8: Obtain the optimal decision.

According to the decision made in step 7, the membership degree of y_1 is greater than that of y_2 and y_3. As a result, the optimal decision for this decision is y_1, which represents Oppo.

3. Findings

The method is applied in neutrosophic soft set by inputting the neutrosophic soft set, which defines the relative parameter matrix and calculates the score of criteria. The normalised criteria matrix is then computed by using the relative parameter and the parameter score. All of the weight criterion calculations are compiled in Table 5.

Table 5: Weight of criteria and its rank

Parameter	Weight	Rank
Price ($\boldsymbol{e_1}$)	0.15	3
Operating system ($\boldsymbol{e_2}$)	0.05	5
Memory ($\boldsymbol{e_3}$)	0.13	4
Display ($\boldsymbol{e_4}$)	0.26	2
Camera ($\boldsymbol{e_5}$)	0.27	1
Battery ($\boldsymbol{e_6}$)	0.13	4

According to Table 5, the criterion with the highest weight, which is 0.27, is camera. This indicates that the camera was the most important criterion considered by a consumer when purchasing a smartphone, followed by display (0.26) and price (0.15). This means that a consumer prefers to buy a smartphone with a good camera. This is undoubtedly because most people nowadays prefer to update and share their lives on social media platforms such as Facebook, Instagram, TikTok, and Twitter. Memory and battery were both ranked fourth, with a weight of 0.13. The operating system, which was weighted at 0.05, was the least important criterion chosen by a consumer when purchasing a smartphone brand.

The optimal solution is obtained by considering all the criteria set and computing the membership degree. The following Table 6 shows the value of the decision set, which is the optimal solution based on the computed membership degree of the considered criteria sets.

Table 6: Value of decision sets

$\boldsymbol{y_1}$	Oppo	0.090
$\boldsymbol{y_2}$	Samsung	0.086
$\boldsymbol{y_3}$	Apple	0.072

According to Table 6, it is obviously that the Oppo brand has the optimal decision, while the least preferred brand is Apple brand.

3.1 *Comparative analysis*

As shown in Table 7, this study's comparison of rank using NSS is compared to the study conducted by Nasir *et al.* (2019) for discussion purposes. Based on their research, they evaluate and rank the criteria using Fuzzy AHP, but the smartphone brands are ranked using the PROMETHEE method. By comparison, the weight of criteria and decision value of the alternative (smartphone brand) are shown in Tables 5 and 6.

Table 7: Weight of criteria uisng NSS and Fuzzy AHP

Parameter	**Weight**			
	NSS	Rank	Fuzzy AHP (Nasir *et al.* 2019)	Rank
Price ($\boldsymbol{e_1}$)	0.15	3	0.13	4
Operating system ($\boldsymbol{e_2}$)	0.05	5	0.20	2
Memory ($\boldsymbol{e_3}$)	0.13	4	0.23	1
Display ($\boldsymbol{e_4}$)	0.26	2	0.08	5
Camera ($\boldsymbol{e_5}$)	0.27	1	0.14	3
Battery ($\boldsymbol{e_6}$)	0.13	4	0.20	2

Table 7 shows that the majority of the weight values obtained by using NSS are significantly greater than the weight values obtained by Fuzzy AHP for all criteria. This means that the NSS value is more acceptable. Furthermore, the result for alternative, as shown in Table 8, has a higher value of rank 1 by NSS than rank 1 by PROMETEE method.

Table 8: Comparison result of smartphone brand using NSS and PROMETEE method

Smartphone brand	**NSS**	**Rank**	**PROMETHEE (Nasir et al. (2019)**	**Rank**
Oppo	0.090	1	0.0483	1
Samsung	0.086	2	-0.0319	3
Apple	0.072	3	-0.0164	2

Table 8 demonstrates that Oppo is the best option. Both studies ranked the Oppo brand first, but there was a slight difference in second and third place. It could be due to the use of different linguistic variable values chosen, as we can use any linguistic variable declared by other researchers. In our study, we used neutrosophic set numbers, whereas they used a five-point likerd scale. As previously stated, a neutrosophic set is a mathematical tool used to solve problems involving vague and indeterminant data. In some real-world problems, we must deal with indeterminate and incomplete information in order to properly describe an object in an uncertain and ambiguous environment. However, fuzzy sets are incapable of dealing with indeterminate and inconsistent data. Based on the findings of this NSS study, we can conclude that the ranking of smartphone brands is more accurate because we are using a neutrosophic set number.

4. Conclusion

The camera is the criterion rank in this study. This means that, when compared to others, a consumer prefers to buy a smartphone with a good camera. This is most likely due to the fact that most people nowadays prefer to update and share their lives on social media platforms such as Facebook, Instagram, TikTok, and Twitter. Oppo brand is successfully ranked as an alternative for this smartphone selection. The study's findings will be useful to industries such as mobile manufacturing firms. The company may use the results to improve their smartphone development by taking into account the most important consumer criteria. More alternatives and criteria for selecting smartphone problems should be considered in the future. This smartphone is also recommended for experimenting with NSS in conjunction with other methods such as the possibility neutrosophic soft (PNS) decision making method, the Generalised Multipolar Neutrosophic Soft Set (GmPNSS), bipolar neutrosophic soft sets, or Q-neutrosophic soft entropy.

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Kolej Pengajian Pengkomputeran, Informatik dan Matematik,
Universiti Teknologi MARA (UiTM) Cawangan Kelantan,
Kampus Machang, Bukit Ilmu,
18500 Machang,
Kelantan Darul Naim, MALAYSIA.
E-mail: firdawati02@uitm.edu.my, sabrina.adisabri@gmail.com, zakirafadhlina@gmail.com, norarida@uitm.edu.my, sitif315@uitm.edu.my*

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*Corresponding author