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Evaluation of Best Mobile Phone in India using Entropy based TOPSIS, EDAS and CODAS as MCDM methods.

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Abstract

Manufacturers frequently release new mobile phone models with improved features and technical characteristics to keep up with consumers' changing preferences. This illustrates a classic instance of multi-criteria decision making (MCDM) considering the difficulty of selecting a product with numerous selection criteria and numerous possibilities. To assist customers in making decisions, the major goal of this study is to rank the mobile phone among several viable possibilities. Ten alternate models (under Rs.30, 000 category) from various manufacturers have been chosen based on a website (Gadgets360.com) listing in July 2023 under the heading, 'Best mobile phones under 30000 in India'. Seven prominent characteristics that serve as distinguishing criteria are picked for ranking purposes. To eliminate any subjective ideas, the weights to these criteria are calculated using the Entropy approach to be applied to MCDM algorithms, namely TOPSIS, EDAS and CODAS to rank these mobile phones. The ranking was effectively attained, and the Spearman Correlation analysis revealed a strong positive correlation between the procedures and the outcomes.

Keywords: *MCDM, Mobile Phone Ranking, TOPSIS, EDAS, CODAS*

1. Introduction

Numerous technological advancements in recent years, such as Smartphones, Computers, household devices, industrial equipment, and the like have significantly improved and changed people's lives. Among other pieces of technical equipment, mobile phones have evolved into one of the most significant and essential elements in everyone's life. As technology advances, users have been moving away from old, featured phones to Smartphones. Simple feature phones and more sophisticated feature phones are differentiated by the term 'Smartphone'. Smartphones offer a variety of services, including voice and text communication, web surfing, data management, support for third-party applications, photo editing, gaming and other functions that turn them into entertainment devices, as well as 24/7 wallet services.

As customers began using phones for a variety of purposes due to the wide range of services they offer, their expectations and preferences changed as well. This makes it very challenging to select a suitable mobile model from among the numerous models that are currently available on the market because various companies are constantly releasing new models with new features and more updated technical specifications, and there are many competing criteria as well. Aspects like RAM, Battery, Talk Time, Stand-by Time, Internal Memory, Weight, Thickness, Screen Size, CPU Type, Aesthetics, Durability, and Camera and the like are all becoming distinguishing phone characteristics. The decision-makers are motivated to work in this area by the conditions since they present an overall multiple criteria decision making (MCDM) challenge (Velasquez & Hester, 2013; Bhole & Deshmukh, 2018).

This research project tries to address these confounding situations and provide a solution. Ten different Smartphone models from different manufacturers with a variety of specifications were chosen for this study. The Smartphone models are not chosen randomly, and a reference is taken from the list published on a popular website 'Gadgets360.com'(Gadgets360.com) under the heading of 'Best mobile phone under 30000 in India' in the month of July 2023 to start the study. The MCDM based algorithm namely, TOPSIS, EDAS and CODAS are used in the study to provide a ranking of the 10 selected mobile phones based on various criteria. The weights of the criterion are calculated using Entropy method to remove any subjectivity. After using the procedure of the MCDM methods, the ranking of the mobile phone is achieved successfully for all the three methods. To understand the relationship among the three methods, the Spearman correlation test was also done on the output obtained by the three methods. The resulting analysis revealed that all the three methods are positively correlated and in fact offered the same results.

2. Literature Review

When making logical decisions, it is occasionally necessary to select a competitive alternative from a group of alternatives while taking into account the benefits and drawbacks of each individual alternative (Vahdani et al., 2014). These problems, which can be categorized as linear or non-linear problems, are frequently involved in a single objective decision-making process and entail minimization or maximization. Operations research's field of 'multi-criteria decision-making (MCDM)' examines how people make decisions when there are numerous options (Kumar et al., 2017).

To rank or choose alternatives from a group of options, MCDM assists in gathering and evaluating a number of elements. These needs/options frequently conflict with one another. One objective issue is that some selection criteria are left out or that decision-making does not take into consideration their ambiguity. The decision-makers in MCDM evaluate each alternative and rank them based on features, considering all selection criteria (Mirzaei et al., 2015).

There are three steps to the MCDM process. It is necessary to set criteria before rating options. Then, to aid in the assessment of alternatives, criteria must be given numerical values (Mulliner et al., 2013). Several strategies, including ELECTRE, AHP, TOPSIS, VIKOR, EDAS, COPRAS, MOORA, PROMETHEE, SAW, SWARA, etc. have been developed to address MCDM difficulties (Mirzai et al., 2015; Patil and Prajapati, 2017; Zolfani and Saparauskas, 2013)

One of the most popular methods for applying MCDM to solve problems is TOPSIS (Technique for Order preference by Similarity to Ideal Solution). The units of criterion functions are removed in TOPSIS via vector normalization (Chatterjee et al., 2009). It is predicated on the idea that the selection option should be the furthest away from the Negative Ideal Solution (NIS) and the closest to the Positive Ideal Solution (PIS) geometrically (Tzeng et al., 2007)

M. K. Ghorabaee invented the EDAS (Evaluation Based on Distance from Average Solution), in which the distances from both the positive and negative directions from the average solution are calculated separately and in accordance with the beneficial or non-beneficial criteria selected (Ghorabaee et al., 2015). In this situation, the best answer or ideal solution from the average solution must be produced; it has the maximum positive distance from the average solution and the lowest negative solution values.

It is important to remember that not every decision maker in a group decision making (GDM) under uncertainty has the same level of expertise, training, and experience when discussing individual evaluations of decision makers. Their skills, personalities, and areas of interest can vary (Su et al., 2011 & Xia et al., 2012). The unique feature of EDAS is that the outcome is derived from the average answer, which in some way eliminates the possibility of expert bias towards an alternative. The data is already normalized when a result is obtained from an average solution, greatly reducing the possibility of deviating from the optimal solution. So, it provides a better and accurate solution than that of TOPSIS.

Ghorabaee et al. (2016) developed CODAS (Combinative Distance-Based Assessment) approach for the first time. It is founded on the principle of separation from a negative ideal solution. Therefore, the alternative that is further away from the unfavorable perfect solution is the preferable option. In addition to using Euclidean distance as a primary measure, it also prescribed Taxicab distance as a secondary measure. When two options cannot be compared based on Euclidean distance, Taxicab distance is employed (Ghorabaee et al., 2016)

3. Materials and Methods

3.1 Smartphone Selection

The choice of a Smartphone is made with the assistance of a popular website ‘Gadgets360.com’ in India. The search is done for ‘best mobile phone under Rs.30, 000’ and their website showed a result of 10 phone under the heading of ‘Best mobile phone under 30000 in India’ for July 2023 (Gadgets360.com). Then for each listed phone, the author went into full specifications to obtain the details about the phones. The availability of the phone and price was cross-checked with the listed websites (flipkart.com, amazon.in, croma.com). The original prices of the mobile phones are different and more than Rs.30K, however, after the discount offered by each of these e-commerce websites, mobile phones are available below Rs.30K range. As key selection criteria, the author identified some popular features – Display (C1), RAM (C2), Battery (C3), Primary Rear Camera (C4), Front Primary Camera (C5), Price (C6), and Weight (C7). Since the e-commerce websites are all offering these mobile phones at the same internal storage, hence, it is not chosen as a selection criterion. The details of the mobile phone selected for the ranking procedure are shown in Table 1 below.

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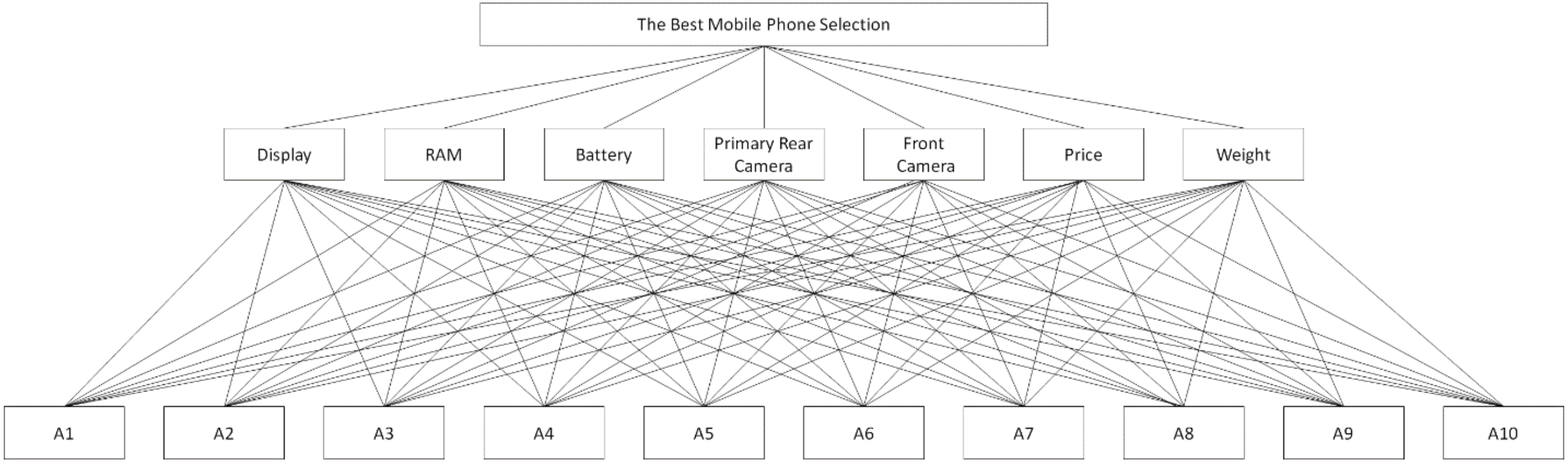
Table 1: Mobile phone and their specifications selected for the study

Alternative code	Criterion Code	C1	C2	C3	C4	C5	C6	C7
	Alternatives (Brand and product name)	Display (inch)	RAM (GB)	Battery (mAH)	Primary Rear Camera (MP)	Front camera (MP)	Price (Rs.)	weight (g)
A1	Samsung Galaxy F54 5G	6.7	8	6000	108	32	29999	199
A2	Realme 11 Pro+	6.7	12	5000	200	32	27999	189
A3	Poco F5 FG	6.67	12	5000	64	16	27999	181
A4	Motorola Edge 40	6.5	8	4500	50	32	29999	167
A5	Samsung Galaxy A34 5G	6.6	6	5000	48	13	28989	199
A6	IQOO Neo 7 5G	6.78	8	5000	64	16	27999	197
A7	Nothing Phone 1	6.55	12	4500	50	16	28999	193.5
A8	Oppo Reno 8	6.43	8	4500	50	32	28699	179
A9	OnePlus Nord 2T 5G	6.43	12	4500	50	32	28792	190
A10	Oppo Reno 7 5G	6.4	12	4500	64	32	29990	173

The hierarchical framework of the study is shown in Figure 1



3.2 Entropy Method

Wang and Lee in 2009, created a weighting approach based on Shannon's original 1948 concept of Entropy (Aytekin, Karamasa, 2017). The Entropy approach entails the following steps (Wang and Lee, 2009; Aytekin and Karamasa, 2017):

Step 1: Creation of decision matrix

The decision matrix (B_{ij}) is created with alternatives in the rows of the matrix and criteria representing the columns of the matrix. The decision matrix is shown below:

$$B_{ij} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{bmatrix} \quad (1)$$

Step 2: Normalizing the decision matrix

The B_{ij} decision matrix is normalized using equation 2.

$$t_{ij} = \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}} \quad ; \; j = 1, \ldots, n \quad (2)$$

Step 3: Calculation of entropy values

After normalizing the decision matrix, the entropy values for the criteria were calculated using equation (3).

$$e_j = -h \sum_{i=1}^{m} t_{ij} \ln t_{ij} \quad ; j = 1, \ldots, n \quad (3)$$

where h is a constant, let $h = (\ln(m))^{-1}$; where m is the number of alternatives.

Step 4: Calculating the degree of diversification.

The degree of divergence of the intrinsic information of each criterion calculated by using the following equation.

$$d_j = 1 - e_j \quad (4)$$

Step 5: Calculation of objective weight of criterion

The objective weight for each criterion can be calculated from following equation.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (5)$$

3.3 TOPSIS Method

A popular MCDM technique is the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) method. Hwang et al., proposed TOPSIS method (Hwang et al., 1993) which was further modified by Lai et al. (Lai et al., 1994). According to Ersoy 2021, the TOPSIS technique is based on the idea of calculating the distance between the alternatives up for evaluation and the positive and negative ideal solutions. The TOPSIS approach consists of the following steps (Hwang et al., 1993, Mohit & Garg, 2015):

Step 1: Creating the decision matrix (A)

There are $i=1, \ldots, m$, alternatives in the rows of the decision matrix A_{ij} and j, $j=1,\ldots, n$ and criteria in the columns. The decision matrix is shown below:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (6)$$

Step 2: Creating the normalized decision matrix (R)

The normalized decision matrix is calculated using the following equation

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad ; i = 1, \ldots, m \; ; j = 1, \ldots, n \quad (7)$$

R_{ij} normalized decision matrix is shown below:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (8)$$

Step 3: Creating the weighted, normalized decision matrix (Y)

First, the weight values (w_i) for the evaluation criteria are determined. Then the Y_{ij} matrix is created by multiplying the elements in each column of the matrix by the corresponding value of w_i. The weighted, normalized value y_{ij} is obtained as in following equation.

$$y_{ij} = w_j \times r_{ij} \quad (9)$$

Y_{ij} normalized decision matrix is shown below.

$$Y_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (10)$$

Step 4: Creating a positive ideal set (A^+) and negative ideal set (A^-)

To create the ideal solution set, the largest of the weighted column values in Y_{ij} matrix is chosen. The positive ideal solution set is obtained from the following equation.

$$A^+ = \{(\max_i y_{ij} \mid j \in J),\ (\min_i y_{ij} \mid j \in J')\} \quad (11)$$

The negative ideal solution set is created by choosing the smallest of the weighted column values in Y_{ij} matrix. The negative ideal solution set is obtained from the following equation.

$$A^- = \{(\min_i y_{ij} \mid j \in J),\ (\max_i y_{ij} \mid j \in J')\} \quad (12)$$

In both equations, J benefit (maximization) and J' loss (minimization) value.

Step 5: Calculating the distance of each alternative to the positive ideal solution and the negative ideal solution.

The distance to the positive ideal solution is S_i^+ and the distance to the negative ideal solution is S_i^-. The distance to the positive ideal solution is calculated using equation (13) and the distance to the negative ideal solution is calculated using equation (14).

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_i^*\right)^2} \quad (13)$$

$$S^- = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_i^-\right)^2} \quad (14)$$

Step 6: Compute the relative proximity of each alternative to the ideal solution.

The relative closeness (C_i^*) of each alternative to the ideal solution is calculated as in following equation.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^+} \quad (15)$$

where, $0 \leq C_i^* \leq 1$

3.4 EDAS Method

Ghorabaee et al. (2015) were the ones who initially created the Evaluation Based on Distance from Average Solution (EDAS) methodology (Ghorabaee et al., 2015). The average answer is employed in this newly devised method to assess the alternatives. Alternatives are assessed using two different metrics: positive distance average (PDA) and negative distance average (NDA). According to several studies (Ghorabaee et al., 2015; Chatterjee et al., 2018), the optimum option is chosen after taking these two distances into account. The EDAS method consists of the following steps (Ghorabaee et al., 2015, Chatterjee et al., 2018; Mathew and Sahu, 2018)

Step 1: Creation of decision matrix (X)

$$X = [X_{ij}]_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (16)$$

where X_{ij} demonstrates the performance value of *i*th alternative on *j*th criterion

Step 2: Determine the average solution considering all criteria.

$$AV = \lfloor AV_j \rfloor_{1xm} \quad (17)$$

where,

$$AV_j = \frac{\sum_{i=1}^{m} x_{ij}}{m} \quad (18)$$

Step 3: Calculate the positive distance from the average (PDA) and the negative distance from average (NDA) matrices according to the sort of criteria (cost and benefit)

$$PDA = \lfloor PDA_{ij} \rfloor_{nxm} \quad (19)$$

$$NDA = \lfloor NDA_{ij} \rfloor_{nxm} \quad (20)$$

If *j*th criterion is beneficial,

$$PDA_{ij} = \frac{\max\left(0,\ \left(x_{ij} - AV_j\right)\right)}{AV_j} \quad (21)$$

$$NDA_{ij} = \frac{\max\left(0,\ \left(AV_j - x_{ij}\right)\right)}{AV_j} \quad (22)$$

And if *j*th criterion is non-beneficial

$$PDA_{ij} = \frac{\max\left(0,\ \left(AV_j - x_{ij}\right)\right)}{AV_j} \quad (23)$$

$$NDA_{ij} = \frac{\max\left(0,\ \left(x_{ij} - AV_j\right)\right)}{AV_j} \quad (24)$$

Where, PDA_{ij} and NDA_{ij} demonstrate the positive and negative distance of *i*th alternative from average solution in terms of *j*th criterion, respectively.

Step 4: Calculate the weighted sum of PDA and weighted sum of NDA for all alternatives.

$$SP_i = \sum_{j=1}^{m} w_j . PDA_{ij} \quad (25)$$

$$SN_i = \sum_{j=1}^{m} w_j . NDA_{ij} \quad (26)$$

where, w_j is the weight of the *j*th criterion.

Step 5: Normalize the SP and SN values for all alternatives.

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \tag{27}$$

$$NSN_i = \frac{SN_i}{\max_i(SN_i)} \tag{28}$$

Step 6: Calculate the appraisal score (AS) for all alternatives.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{29}$$

where, $0 \leq AS_i \leq 1$

Step 7: Ranking of the alternatives considering the descending values of AS.

The alternative with the biggest AS value is the best.

3.5 CODAS method

Ghorabaee et al. (2016) created the CODAS (Combinative Distance-based Assessment) approach for the first time. The Euclidean and Taxicab distances are used in the CODAS technique, which chooses alternatives based on distances to the negative ideal solution (Ghorabaee et al., 2016), to identify which alternatives are preferred. Below are the CODAS technique application steps (Ghorabaee et al., 2016, Mathew and Sahu, 2018):

Step 1: Creating a decision matrix (X) with alternatives and criteria.

$$X = [x_{ij}]_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{30}$$

where, x_{ij} ($x_{ij} \geq 0$) denotes the performance value of ith alternative on jth criterion.

Step 2: Compute the normalized decision matrix.

$$n_{ij} = \begin{cases} \dfrac{x_{ij}}{\max_i x_{ij}} & if \quad j \in N_b \\ \dfrac{\min_i x_{ij}}{x_{ij}} & if \quad j \in N_c \end{cases} \tag{31}$$

The values N_b and N_c in equation (31) express the benefit and cost criteria, respectively.

Step 3: Compute the weighted, normalized decision matrix.

This calculation, which is based on multiplying the column elements belonging to the normalized decision matrix with the relevant weight coefficients, is realized with the following equation.

$$r_{ij} = w_j \,.\, n_{ij} \tag{32}$$

Step 4: Determine the negative-ideal solution point (NIS)

Using equation (33), the smallest values of the columns in the weighted matrix are selected.

$$ns = \lfloor ns_j \rfloor_{1\times m} \qquad ns_j = \min_i r_{ij} \tag{33}$$

Step 5: Calculate the Euclidean and Taxicab distances of alternatives from the negative ideal solution.

Calculation of Euclidean distances (E_i) and Taxicab distances (T_i) values was shown in equations (34) and (35) respectively,

$$E_i = \sqrt{\sum_{j=1}^{m} \left(r_{ij} - ns_j\right)^2} \tag{34}$$

$$T_i = \sum_{j=1}^{m} \left|r_{ij} - ns_j\right| \tag{35}$$

Step 6: Creation of comparative evaluation matrix

A comparative evaluation matrix is created from equation (36)

$$R_a = [h_{ik}]_{n\times n}$$

$$h_{ik} = (E_i - E_k) + \left(\Psi\,(E_i - E_k) \times (T_i - T_k)\right) \tag{36}$$

where $k \in \{1, 2, \ldots, n\}$ and Ψ denotes a threshold function recognizes the equality of the Euclidean and as given equation (37)

$$\Psi(x) = \begin{cases} 1, & if \quad |x| \geq \tau \\ 0, & if \quad |x| \leq \tau \end{cases} \tag{37}$$

In this function, τ is the threshold parameter that can be set by the decision-maker. It is recommended to set this parameter at a value between 0.01 and 0.05. If the difference between Euclidean distances of two alternatives is less than τ, these two alternatives are also compared by Taxicab distance (Ghorabaee et al., 2016, Mathew & Sahu, 2018).

Step 7: Calculate the assessment score of each alternative.

$$H_i = \sum_{k=1}^{n} h_{ik} \tag{38}$$

By ranking the H_i scores of the alternatives in descending order, the alternatives are ranked from the best to the worst.

4. Results and Discussion

The Entropy approach has allowed for the identification of the weight values of the study's criterion. Some criteria should be expressed as beneficial in the decision matrix used in the EDAS, TOPSIS and CODAS method, while others should be expressed as costs (non-beneficial criteria). In the study, price and weight are identified as non-beneficial criteria as their low value is desired, whereas, Display, RAM, battery, Camera (front and rear) and identified as beneficial criteria, as their highest value is desired. The results of the calculation of Entropy, MCDM methods (TOPSIS, EDAS and CODAS) are shown below:

4.1 Entropy method results

In the first stage of the Entropy method, the decision matrix, which includes the criteria and alternatives, was created in Table 3. In Table 3, alternatives were respectively expressed as A1, A2, … , A6 and criteria as C1, C2, … , C6

Table 2: Decision Matrix

Alternative	Criterion						
	C1	C2	C3	C4	C5	C6	C7
A1	6.70	8	6000	108	32	29999	199.0
A2	6.70	12	5000	200	32	27999	189.0
A3	6.67	12	5000	64	16	27999	181.0
A4	6.50	8	4500	50	32	29999	167.0
A5	6.60	6	5000	48	13	28989	199.0
A6	6.78	8	5000	64	16	27999	197.0
A7	6.55	12	4500	50	16	28999	193.5
A8	6.43	8	4500	50	32	28699	179.0
A9	6.43	12	4500	50	32	28792	190.0
A10	6.40	12	4500	64	32	29990	173.0

After the decision matrix was created, the normalized decision matrix shown in Table 4, was obtained using equation (2).

Table 3: Normalized decision matrix

Alternative	Criterion						
	C1	C2	C3	C4	C5	C6	C7
A1	0.1019	0.0816	0.1237	0.1444	0.1265	0.1036	0.1066
A2	0.1019	0.1224	0.1031	0.2674	0.1265	0.0967	0.1012
A3	0.1014	0.1224	0.1031	0.0856	0.0632	0.0967	0.0969
A4	0.0988	0.0816	0.0928	0.0668	0.1265	0.1036	0.0894
A5	0.1004	0.0612	0.1031	0.0642	0.0514	0.1001	0.1066
A6	0.1031	0.0816	0.1031	0.0856	0.0632	0.0967	0.1055
A7	0.0996	0.1224	0.0928	0.0668	0.0632	0.1002	0.1036
A8	0.0978	0.0816	0.0928	0.0668	0.1265	0.0991	0.0959
A9	0.0978	0.1224	0.0928	0.0668	0.1265	0.0995	0.1017
A10	0.0973	0.1224	0.0928	0.0856	0.1265	0.1036	0.0926

After the decision matrix was normalized, value of h (constant) is calculated by following equation.

$$h = 1/\ln(m); \text{ here m (no. of alternatives is 10), hence } h = 1/\ln(10) = 0.4343$$

Using the h value, entropy value and criterion weights are calculated using equation (3), (4) and (5). These calculated values are given in Table 5.

Table 4: Entropy values and criteria weights

	C1	C2	C3	C4	C5	C6	C7
e_j	0.9999	0.9880	0.9982	0.9393	0.9752	0.9998	0.9993
$d_j = 1 - e_j$	0.0001	0.0120	0.0018	0.0607	0.0248	0.0002	0.0007
w_j	**0.0008**	**0.1199**	**0.0179**	**0.6053**	**0.2474**	**0.0016**	**0.0071**

It is understood from Table 5 that the criterion with the highest weight is C1. Criteria weights obtained because of the Entropy method were used in EDAS, CODAS and TOPSIS methods.

4.2 TOPSIS Method Results

TOPSIS method has been implemented in the decision matrix given in Table 3. The normalized decision matrix shown in Table 6 has been obtained using equation (7).

Table 5: Normalized decision matrix

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	0.3221	0.2515	0.3895	0.3911	0.3803	0.3276	0.3364
A2	0.3221	0.3772	0.3246	0.7243	0.3803	0.3058	0.3195
A3	0.3207	0.3772	0.3246	0.2318	0.1901	0.3058	0.3060
A4	0.3125	0.2515	0.2922	0.1811	0.3803	0.3276	0.2823
A5	0.3173	0.1886	0.3246	0.1738	0.1545	0.3166	0.3364
A6	0.3260	0.2515	0.3246	0.2318	0.1901	0.3058	0.3330
A7	0.3149	0.3772	0.2922	0.1811	0.1901	0.3167	0.3271
A8	0.3091	0.2515	0.2922	0.1811	0.3803	0.3134	0.3026
A9	0.3091	0.3772	0.2922	0.1811	0.3803	0.3144	0.3212
A10	0.3077	0.3772	0.2922	0.2318	0.3803	0.3275	0.2925

Table 6: Weighted normalized matrix

Weights	**0.0008**	**0.1199**	**0.0179**	**0.6053**	**0.2474**	**0.0016**	**0.0071**
Alternative	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
A1	0.0003	0.0301	0.0070	0.2367	0.0941	0.0005	0.0024
A2	0.0003	0.0452	0.0058	0.4384	0.0941	0.0005	0.0023
A3	0.0003	0.0452	0.0058	0.1403	0.0470	0.0005	0.0022
A4	0.0003	0.0301	0.0052	0.1096	0.0941	0.0005	0.0020
A5	0.0003	0.0226	0.0058	0.1052	0.0382	0.0005	0.0024
A6	0.0003	0.0301	0.0058	0.1403	0.0470	0.0005	0.0024
A7	0.0003	0.0452	0.0052	0.1096	0.0470	0.0005	0.0023
A8	0.0003	0.0301	0.0052	0.1096	0.0941	0.0005	0.0022
A9	0.0003	0.0452	0.0052	0.1096	0.0941	0.0005	0.0023
A10	0.0002	0.0452	0.0052	0.1403	0.0941	0.0005	0.0021

Then, the distance to the positive ideal solution (S_i^+), the distance to the negative ideal solution (S_i^-) and the relative proximity of each alternative to the ideal solution (C_i*) was calculated. Values of S_i^+, S_i^- , C_i*and ranking of the alternatives was given in Table 7.

Table 7: Ranking of the alternatives according to the TOPSIS method

Alternative	S_i^+	S_i^-	**Ideal Solution** $C_i^* = (S_i^-/(S_i^- + S_i^+))$	**Rank**
A1	0.2022	0.1431	0.41	**2**
A2	0.0012	0.3386	1.00	**1**
A3	0.3018	0.0427	0.12	**7**
A4	0.3291	0.0565	0.15	**5**
A5	0.3386	0.0006	0.00	**10**
A6	0.3022	0.0369	0.11	**8**
A7	0.3321	0.0247	0.07	**9**
A8	0.3291	0.0565	0.15	**6**
A9	0.3288	0.0604	0.16	**4**
A10	0.2981	0.0697	0.19	**3**

According to the ranking in Table 7, it was understood that the best alternative is A2, second best is A1, third place is A10, and last rank holder is A5.

4.3 EDAS method results

EDAS method has been applied to the decision matrix can be seen in Table 3. Average solutions of the criteria were calculated with equation (18). Table 8 shows the average solutions (AV_j) of the criteria.

Table 8: Average solutions of criteria

	Beneficial	Beneficial	Beneficial	Beneficial	Beneficial	Non-beneficial	Non-beneficial
Alternative	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
A1	6.7	8	6000	108	32	29999	199
A2	6.7	12	5000	200	32	27999	189
A3	6.67	12	5000	64	16	27999	181
A4	6.5	8	4500	50	32	29999	167
A5	6.6	6	5000	48	13	28989	199
A6	6.78	8	5000	64	16	27999	197
A7	6.55	12	4500	50	16	28999	193.5
A9	6.43	12	4500	50	32	28792	190
A10	6.4	12	4500	64	32	29990	173
Average	6.5760	9.8000	4850.0000	74.8000	25.3000	28946.4000	186.7500
Weights	0.0008	0.1199	0.0179	0.6053	0.2474	0.0016	0.0071

After calculating the PDA and NDA, weighted total positive value (SP_i), weighted total negative value (SN_i), weighted, normalized positive values (NSP_i), weighted, normalized negative values (NSN_i) and appraisal scores (AS_i) were calculated.

Table 9 shows the EDAS method, results, and the ranking of alternatives. It is understood from Table 9 that the best alternative is A2. The second rank is A1, and the last is A5.

Table 9: Ranking of the alternatives according to the EDAS method

Alternative	SP_i	SN_i	NSP_i	NSN_i	AS_i	RANK
A1	0.3384	0.0225	0.3059	0.9413	0.6236	**2**
A2	1.1062	0.0001	1.0000	0.9998	0.9999	**1**
A3	0.0277	0.1783	0.0251	0.5357	0.2804	**4**
A4	0.0663	0.2241	0.0599	0.4166	0.2383	**7**
A5	0.0006	0.3841	0.0005	0.0000	0.0003	**10**
A6	0.0006	0.2007	0.0006	0.4774	0.2390	**6**
A7	0.0269	0.2932	0.0243	0.2367	0.1305	**9**
A8	0.0658	0.2240	0.0595	0.4168	0.2381	**8**
A9	0.0924	0.2021	0.0836	0.4738	0.2787	**5**
A10	0.0930	0.0888	0.0840	0.7689	0.4265	**3**

4.4 CODAS method results

The CODAS method was applied to the decision matrix given in Table 2. The decision matrix shown in Table 10 was obtained using equation (31)

Table 10: Normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7
A1	0.9882	0.6667	1.0000	0.5400	1.0000	0.9333	0.8392
A2	0.9882	1.0000	0.8333	1.0000	1.0000	1.0000	0.8836
A3	0.9838	1.0000	0.8333	0.3200	0.5000	1.0000	0.9227
A4	0.9587	0.6667	0.7500	0.2500	1.0000	0.9333	1.0000
A5	0.9735	0.5000	0.8333	0.2400	0.4063	0.9658	0.8392
A6	1.0000	0.6667	0.8333	0.3200	0.5000	1.0000	0.8477
A7	0.9661	1.0000	0.7500	0.2500	0.5000	0.9655	0.8630
A8	0.9484	0.6667	0.7500	0.2500	1.0000	0.9756	0.9330
A9	0.9484	1.0000	0.7500	0.2500	1.0000	0.9725	0.8789
A10	0.9440	1.0000	0.7500	0.3200	1.0000	0.9336	0.9653

Later, Euclidean distance (E_i) and Taxicab distance (T_i) values and the assessment score (H_i) of each alternative were calculated. Table 11 shows the Euclidean distance and Taxicab distances calculated using the calculations shown in equation (34) & (35). Then the comparative evaluation matrix is created using Equation (36 & 37) and then assessment score is calculated using Equation (38). In this study τ value was taken as 0.02. Table 12 shows the ranking of the alternative obtained from CODAS method.

Table 11: Distance calculations for each alternative

Alternative	Euclidean Distance (E_i)	Taxicab distance (T_i)
A1	0.2345	0.3530
A2	0.4866	0.6688
A3	0.0805	0.1338
A4	0.1484	0.1741
A5	0.0015	0.0016
A6	0.0573	0.0933
A7	0.0646	0.0894
A8	0.1484	0.1737
A9	0.1588	0.2132
A10	0.1659	0.2562

Table 12: Ranking of the alternatives according to the CODAS method

Alternative	H_i	Rank
A1	0.8050	**2**
A2	3.3548	**1**
A3	-0.7358	**7**
A4	-0.0581	**5**
A5	-1.5204	**10**
A6	-0.9664	**9**
A7	-0.8940	**8**
A8	-0.0581	**6**
A9	0.0458	**4**
A10	0.1170	**3**

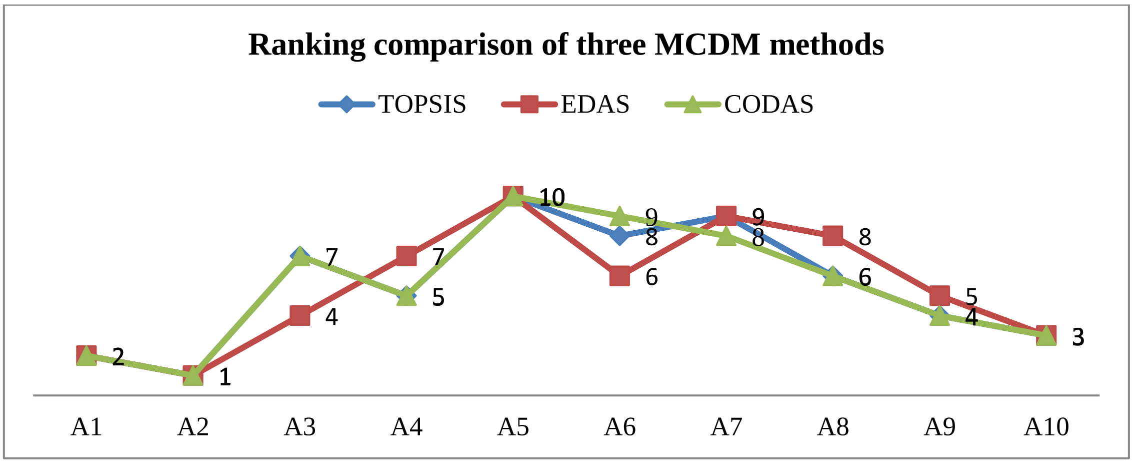
4.5 Discussion

In the study, 10 alternative mobile phones were ranked according to TOPSIS, EDAS and CODAS methods. Comparison of the alternatives according to the results of EDAS, CODAS, and TOPSIS methods can be seen in Table 13.

Table 13: Comparison of the ranking results

Brands	Alternatives	TOPSIS	EDAS	CODAS
Samsung Galaxy F54 5G	A1	2	2	2
Realme 11 Pro+	A2	1	1	1
Poco F5 FG	A3	7	4	7
Motorola Edge 40	A4	5	7	5
Samsung Galaxy A34 5G	A5	10	10	10
IQOO Neo 7 5G	A6	8	6	9
Nothing Phone 1	A7	9	9	8
Oppo Reno 8	A8	6	8	6
OnePlus Nord 2T 5G	A9	4	5	4
Oppo Reno 7 5G	A10	3	3	3

It can be understood from Table 13 that while A2 is in the first rank, A1 is in the second rank and A10 is in the third rank in all three methods. Model A5 is ranked last by all the three methods.



Besides, the correlation between the results of the TOPSIS, EDAS and CODAS methods has been examined with the Spearman Correlation approach. The correlation results can be seen in Table 14. When Table 14 is examined, it is possible to say that there is a strong positive significant relationship between the methods used and the results obtained.

Table 14. The Spearman's correlation coefficient between the methods and the results

Correlations

		TOPSIS	EDAS	CODAS
TOPSIS	Pearson Correlation	1	.867**	.988**
	Sig. (2-tailed)		.001	.000
	N	10	10	10
EDAS	Pearson Correlation	.867**	1	.830**
	Sig. (2-tailed)	.001		.003
	N	10	10	10
CODAS	Pearson Correlation	.988**	.830**	1
	Sig. (2-tailed)	.000	.003	
	N	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author's calculation in the SPSS 24 statistical software

5. Conclusions

Demand for mobile phones is rising gradually as more and more people use them for a variety of functions. Due to the need of mobile phones for a variety of uses, manufacturers are now incorporating a wide range of cutting-edge features and technologies. Customers have now access to a wide variety of mobile phone options as a result. An MCDM-based decision-making challenge involves selecting one option out of several possibilities based on a variety of criteria.

To handle this specific decision-making problem, TOPSIS, EDAS, and CODAS as MCDM approaches are applied in this study.

In this study, 10 different mobile phone alternatives were evaluated using TOPSIS, EDAS and CODAS methods according to the criteria of Display, RAM, Battery, Primary Rear camera, Primary front camera, Price, and Weight. The criterion weight which is required for the MCDM methods have been calculated by the Entropy method. According to the Entropy method results, the criterion with the highest weight is the Primary rear camera, with weight, 0.6053. This criterion is followed by Primary front camera (weight, 0.2474), RAM (weight, 0.1199), Battery (weight, 0.0179), Weight of the phone (weight, 0.0071) and Display (weight, 0.0008) criteria. The alternatives were ranked according to the TOPSIS, EDAS, and CODAS method, results and the best alternative was selected as A2 (Realme 11 Pro+) and the least preferred alternative was A5 (Samsung Galaxy A34). Analysis the result of Spearman Correlation test, it is possible to say that there is a strong positive relationship between the methods used and the results obtained.

This study has several limitations as do many other studies. The study's use of only seven criteria and 10 alternatives is one of its limitations. The outcomes could be affected by having more options. Additionally, only seven criteria were allowed, considering other criteria could have produced a different outcome. To provide some consistency in selection of alternatives in terms of price, the list of mobile phones was compiled from a single website; other websites might offer a different choice of Smartphones in the same price range. Future research may consider other MCDM techniques with various other choices and criteria. To further understand their linkages and relationships, other circumstances may also be studied using the MCDM techniques that were employed in the study.

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