Individual Project: Decision making and analysis.

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1. Problem Definition

The objective is to analyse and rank Samsung phones based on Multi-criteria decision-making (MCDM) methods. The analysis is conducted on a dataset consisting of $m = 7$ criteria and $n = 143$ alternatives. Let $A = \{A_1, \ldots, A_{143}\}$ represent the set of alternatives. Let $C = \{C_1, \ldots, C_7\}$ represent the criteria for evaluation. Each alternative A_i has a performance value x_{ij} for each criterion C_j. The criteria are classified as either *benefit* or *cost*.

The ranking process involves determining the weights $w_1, w_2, \ldots, w_7$ for each criterion. Each alternative A_i is then assigned a score based on its performance across all criteria by ranking methods.

The goal is to rank or outrank Samsung phones based on their scores, helping users identify the best options according to their preferences. The expected output is a ranked list of phones, denoted as:

$$R = \text{rank}(A_1, A_2, \ldots, A_{143})$$

where R is the ordered list of phone alternatives based on the selected ranking methods. The following sections will describe dataset, methods to calculate weights, ranking techniques, and experimental results.

2. Methodology

2.1. Data Description

The dataset used in this report is obtained from Kaggle [Link]. The dataset is filtered to include only **Samsung brand**. The unnecessary columns and missing rows are dropped. 'release_date' is converted to an integer by computing days since release (20 March 2025 - release date) (Code's ref: [Code]).

Model	**popularity**↑	**best_price**↓	**high_price**↓	**screen_size**↑	**memory_size**↑	**battery_size**↑	**release_date**↓
G920F Galaxy S6 32GB (White Pearl)	845	3529	3959	5.1	32	2550	3650
Galaxy A01 2/16GB Black (SM-A015FZKD)	1163	2950	3158	5.7	16	3000	1883

Table 1: First 2 rows of the processed dataset

The processed dataset (Tab. 1) contains information about 143 Samsung models evaluated based on 7 criteria.

2.2. Smartphone Ranking

Ranking involves two main steps: criteria weighting and alternative evaluation. Criteria weights w_j are determined based on AHP (user priorities) [Code] and Entropy method (data variation) [Code]. Performance data x_{ij} are then normalized by benefit/cost criteria: *benefits* (popularity, screen_size, memory_size, battery_size) and *costs* (best_price, highest_price, release_date) [Code].

After normalizing performance data x_{ij}, alternatives are ranked using 6 ranking methods [1]: WSM, WPM, WASPAS, TOPSIS, VIKOR, and PROMETHEE. Each method calculates a final score S_i reflecting the overall performance of each alternative. Results are analyzed and compared based on variability, sensitivity, and computational efficiency.

3. Experiment and Discussions

3.1. Experimental Setting

3.1.1. Configurations

Criteria	popularity	best_price	highest_price	screen_size	memory_size	battery_size	release_date
popularity	1.00	0.50	2.00	1.00	1.00	0.50	2.00
best_price	2.00	1.00	6.00	2.00	2.00	2.00	6.00
highest_price	0.50	0.17	1.00	0.33	0.33	0.25	1.00
screen_size	1.00	0.50	3.00	1.00	1.00	1.00	3.00
memory_size	1.00	0.50	3.00	1.00	1.00	1.00	3.00
battery_size	2.00	0.50	4.00	1.00	1.00	1.00	4.00
release_date	0.50	0.17	1.00	0.33	0.33	0.25	1.00

(a) Pairwise Comparison Matrix for AHP1

Criteria	popularity	best_price	highest_price	screen_size	memory_size	battery_size	release_date
popularity	1.00	0.33	2.00	0.50	0.50	0.50	2.00
best_price	3.00	1.00	6.00	2.00	2.00	2.00	6.00
highest_price	0.50	0.17	1.00	0.33	0.33	0.25	1.00
screen_size	2.00	0.50	3.00	1.00	1.00	0.50	3.00
memory_size	2.00	0.50	3.00	1.00	1.00	0.50	3.00
battery_size	2.00	0.50	4.00	2.00	2.00	1.00	4.00
release_date	0.50	0.17	1.00	0.33	0.33	0.25	1.00

(b) Pairwise Comparison Matrix for AHP2

Table 2: Pairwise Comparison Matrix for AHP

The AHP1 and AHP2 are presented as weights calculated by Pairwise Comparison Matrices (PCMs) matrices (Tab. 2) to evaluate **sensitivity** of ranking methods. For fair comparison, the following parameter values are set:

- ◇ $\lambda = 0.5$ for **WASPAS** (equal weight for WSM and WPM approaches).
- ◇ $v = 0.5$ for **VIKOR** (equal consideration of group utility and individual regret).

3.1.2. Evaluation Metrics

Consistency Ratio (CR) measures AHP matrix consistency (if $CR < 0.1$):

$$CR = \frac{CI}{RI} \tag{1}$$

where CI is **Consistency Index**. **Random Index** $(RI) = 1.32$ (from Saaty's table when $n = 7$).

Coefficient of Variation (CV) quantifies ranking variability, highlighting score differences among alternatives. As a unitless measure, it allows comparison across criteria with different scales.

$$CV = \frac{\sigma}{\mu} \tag{2}$$

where σ is **standard deviation**, and μ is **mean score**. A **higher CV** indicates greater score differences, making alternative rankings **more distinguishable**.

Kendall's Tau Value analysis the **sensitivity** of rankings to input variations (for AHP1 ad AHP2):

$$\tau = \frac{C - D}{\frac{1}{2}n(n-1)} \tag{3}$$

where C and D are the concordant (same in both ranking) and discordant (different in both ranking) pairs. A **lower** τ suggests greater ranking **sensitivity**, indicating small changes in input can lead to significant shifts in ranking.

Computation Time[*] is recorded at the beginning and end of execution.

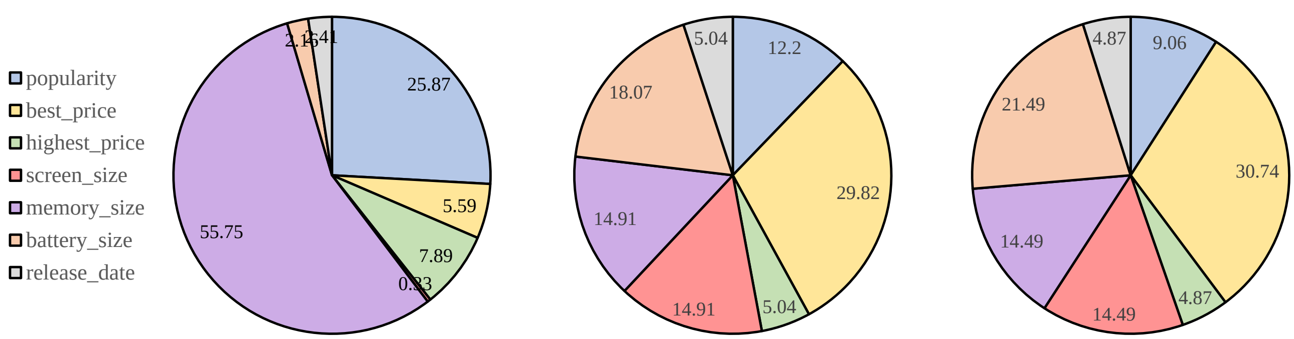
$$T_{\text{comp}} = T_{\text{end}} - T_{\text{start}} \tag{4}$$

where T_{start} and T_{end} represent timestamps recorded at the beginning and end of execution.

3.2 Results and Discussion

This section presents and analyzes the experimental output, inspired by MCDM softwares (e.g., 123ahp, DECERNS).

3.2.1. Criteria Weights Evaluation



(a) Entropy Weights for each criterion
Computation Time: 0.0191s

(b) AHP1 Weights for each criterion
CR = 0.0076; Computation Time: 0.0397s

(c) AHP2 Weights for each criterion
CR = 0.0087; Computation Time: 0.0378s

Figure 1: Weight for each criterion

For Entropy-based weights, criteria are assigned based on data variability. Fig. 1(a) shows 'memory_size' holds the highest weight (55.75%) as its standard deviation (184.4) exceeds its mean (181.69), indicating high variation. In

[*]Computation time is measured using `time.perf_counter()` in Python, providing timing for precise performance evaluation.

	popularity	best_price	highest_price	screen_size	memory_size	battery_size	release_date
Mean (±std)	735.57 (±398.24)	15936 (±10774)	18589 (±13278)	6.4 (±0.43)	181.69 (±184.4)	4062.5 (±713.4)	2026.5 (±381.8)
Range	0 - 1176	0 – 52994	0 - 57446	0 - 2.6	0 - 984	0 - 445	0 - 2133

Table 3: Summary statistics of criteria [Code]

contrast, 'screen_size' has the lowest weight (0.3%) due to minimal *std*(0.43), meaning most alternatives have similar screen sizes. This approach effectively captures data-driven importance but results in 'memory_size' dominating the decision, **potentially biasing rankings.**

For AHP-based weights, AHP distributes weights more evenly based on PCMs. The Fig. 1(b and c) show that 'best_price' is the most critical factor (≈30%), while 'highest_price' and 'release_date' are the least influential (≈4%-5%). **The low CR values (0.0076 and 0.0087), below the 0.1 threshold, indicate high consistency**. AHP incorporates subjective preferences, **ensuring balanced criteria importance without extreme bias**. The small differences between AHP1 and AHP2 help analyze the method's sensitivity (Sec. 3.2.2).

Entropy is useful for data-driven analysis but risks overweighting certain features. AHP, by contrast, offers a practical, user-aligned ranking, making it preferable for consumer decision-making.

3.2.2. Ranking of Alternatives

Assessment of Ranking Variability

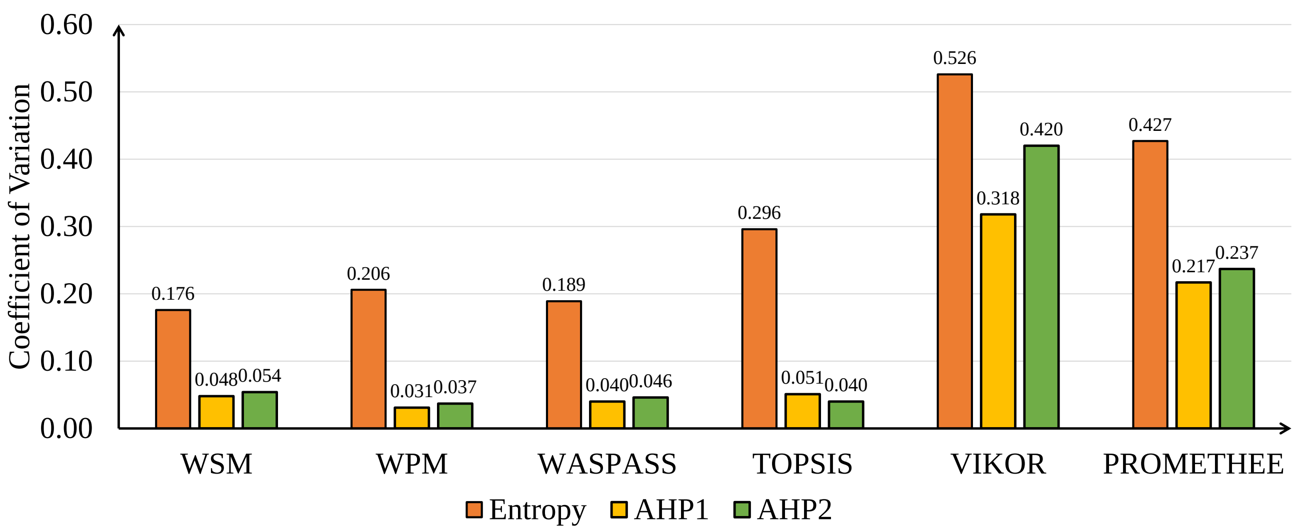


Figure 2: Coefficient of Variation for different ranking methods using Entropy, AHP1, and AHP2-based weights.

Fig. 2 shows the Coefficient of Variation (CV), comparing ranking variability. Clearly, ranking with Entropy-based weights exhibit significantly higher variability than those using AHP-based weights. This occurs because Entropy assigns disproportionate importance to highly variable criteria, thereby amplifying differences in alternative scores.

Regarding ranking algorithm, VIKOR and PROMETHEE achieve the higher CV values compared to other methods. This reflects their superior clarity in distinguishing alternatives. Consequently, both methods show the clarity and confidence of decision-making outcomes.

Due to space limitation, Appendix.2 only provides top-five alternatives. All results are available at [Code].

Assessment of Sensitivity in Ranking

This section analyzes the sensitivity of ranking methods by computing AHP-based weights using two different PCMs (Tab. 2). Fig. 3 presents Kendall's Tau values, measuring ranking sensitivity to weight variations. WASPAS demonstrates high robustness, maintaining ranking consistency ($\tau = 1$). This stability arises from its balanced integration of WSM and WPM, mitigating the impact of criterion weight fluctuations.

In contrast, VIKOR exhibits the lowest Kendall's Tau value ($\tau = 0.824$), implying a 17.6% change in its ranking order. This suggests that VIKOR is more sensitive to changes in AHP-based weights, making it a less stable choice in scenarios with uncertain or shifting criteria.

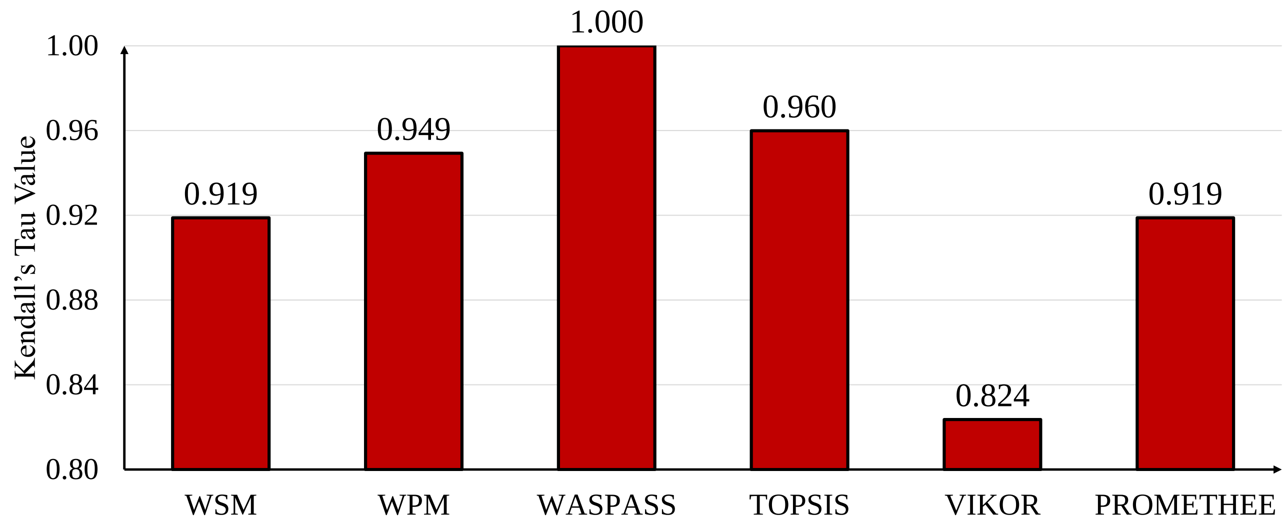


Figure 3: Kendall's Tau values for different MCDM methods, assessing ranking sensitivity [Code].

3.2.3. Comparison of Computation Time

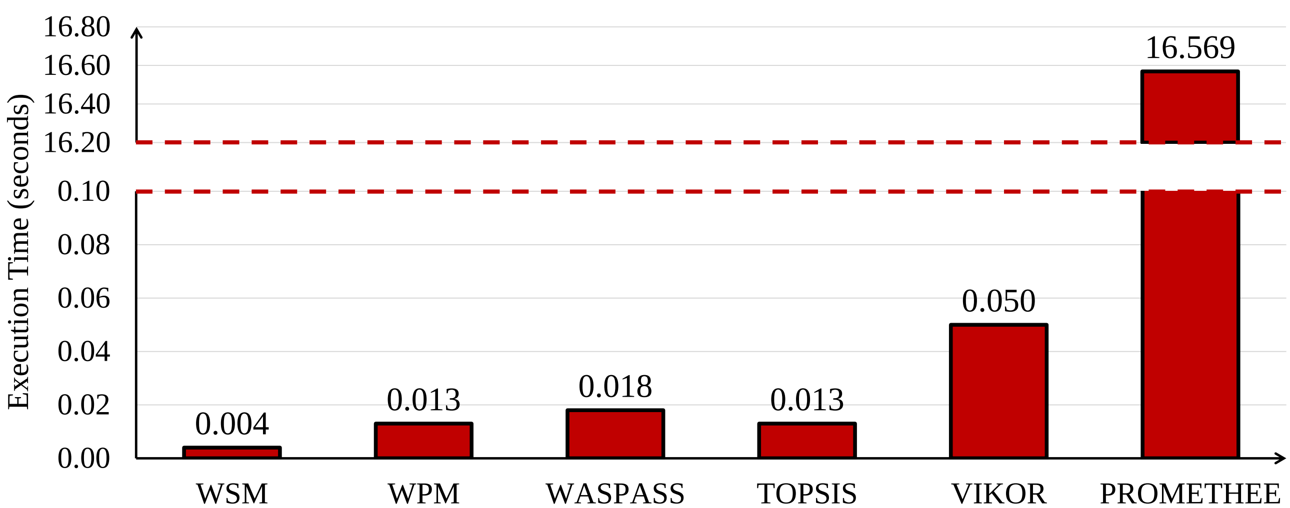


Figure 4: Execution time comparison of MCDM methods.

Fig. 4 presents the computation time of the ranking methods. PROMETHEE has the longest computation time (16.569s) due to its pairwise alternative comparisons across all criteria, leading to a complexity of $O(n^2 \times m)$.

VIKOR runs slower than TOPSIS (0.05s vs. 0.013s) as VIKOR computes both the distance to ideal solutions and an additional compromise measure (Q-index). This extra step increases its computation times slightly, despite having the same complexity $O(n \times m)$. The methods (e.g., WSM, WPM, WASPAS) have same computation times (approximately 0.01s) due to their simpler linear operations, having complexity $O(n \times m)$.

4. Conclusion

This report presented a comprehensive evaluation of multiple ranking methods (WSM, WPM, WASPAS, TOPSIS, VIKOR, PROMETHEE) combined with different weighting methods (Entropy, AHP) to rank Samsung phones based on seven key criteria. Experimental results indicated that Entropy-based weights emphasized criteria with higher variability, causing ranking bias, while AHP-based weights offered balanced, practical rankings. For ranking methods, PROMETHEE and VIKOR showed clarity and confidence in decision-making outcomes, but higher sensitivity and computational cost. WASPAS provided stable and reliable results. Future research could explore hybrid MCDM methods and apply robustness analysis under dynamic weighting conditions.

References

[1] Mostafa AMELI. "Decision-making and analysis for intelligence systems" *Master M2 SIA*, January,2024.

Appendix 1. Guideline and Application

Web Application Description

A Flask-based web application has been developed and deployed at **Website** [Code].

Users can upload the dataset (`cleaned_samsung_phones.csv`) and pairwise comparison file (`pairwise_matrix.xlsx`) if utilizing the AHP method.

Upon clicking the **"Execute"** button, all specified ranking methods are executed automatically.

Results (e.g., criteria weights, ranking tables, coefficient of variation, and computation time), are then visually presented, mirroring the analyses detailed in Section 3.2.

Code Execution Instructions [Details]

1. **Download Code and Data**: Clone full code from github.com/CongSon01/UGE-IndividualDecisionMaking.git
2. **Create Virtual Environment (Recommended)**:

```
python -m venv mcdm_env
source mcdm_env/bin/activate  # Windows: mcdm_env\Scripts\activate
```

3. **Install Required Packages**:

```
pip install -r requirements.txt
```

4. **Run the Code**: Use the following command structure to execute the `main.py`:

```
python main.py --weight_method [ahp|entropy] \
               --pairwise_file [if using ahp] \
               --rank_method [topsis|waspas|...]
```

Examples: Entropy-based weights with WASPAS ranking:

```
python main.py --weight_method entropy \
               --rank_method waspas
```

Appendix 2. Top-five alternatives

WSM	Score	WPM	Score	WASPAS	Score	Rank
Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.8025	Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.7420	G920F Galaxy S6 32GB (White Pearl)	0.7722	1
Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.7908	Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.7290	Galaxy A01 2/16GB Black (SM-A015FZKD)	0.7599	2
Galaxy S10+ SM-G9750 DS 1TB Black	0.6670	Galaxy Note 9 N960 8/512GB Midnight Black	0.5824	Galaxy A01 Core 1/16GB Black (SM-A013FZKD)	0.6247	3
Galaxy Note 9 N960 8/512GB Midnight Black	0.5979	Galaxy Note 9 N960 8/512GB Metallic Copper	0.5558	Galaxy A02s 3/32GB Blue (SM-A025FZBE)	0.5768	4
Galaxy S21 Ultra 16/512GB Phantom Black (SM-G998BZKHSEK)	0.5707	Galaxy S10+ SM-G975 DS 512GB Black (SM-G975FCKG)	0.5367	Galaxy A10s 2019 SM-A107F 2/32GB Black (SM-A107FZKD)	0.5537	5
TOPSIS	**Score**	**VIKOR**	**Score**	**PROMETHEE**	**Score**	**Rank**
Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.9131	Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.0000	Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	62.9354	1
Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.9093	Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.0209	Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	61.2802	2
Galaxy S10+ SM-G9750 DS 1TB Black	0.8524	Galaxy S10+ SM-G9750 DS 1TB Black	0.2841	Galaxy S10+ SM-G9750 DS 1TB Black	43.7007	3
Galaxy Note 9 N960 8/512GB Midnight Black	0.5144	Galaxy Note 9 N960 8/512GB Midnight Black	0.3607	Galaxy Note 9 N960 8/512GB Midnight Black	33.8879	4
Galaxy S21 Ultra 16/512GB Phantom Black (SM-G998BZKHSEK)	0.5124	Galaxy S21 Ultra 16/512GB Phantom Black (SM-G998BZKHSEK)	0.3814	Galaxy S21 Ultra 16/512GB Phantom Black (SM-G998BZKHSEK)	30.0289	5

(a) Top 5 alternatives with Entropy-based weights.

WSM	Score	WPM	Score	WASPAS	Score	Rank
Galaxy M51 6/128GB Black (SM-M515FZKD)	0.7208	Galaxy M51 6/128GB Black (SM-M515FZKD)	0.5581	G920F Galaxy S6 32GB (White Pearl)	0.6394	1
Galaxy M31 6/128GB Black (SM-M315FZKU)	0.6835	Galaxy M31 6/128GB Black (SM-M315FZKU)	0.5545	Galaxy A01 2/16GB Black (SM-A015FZKD)	0.6190	2
Galaxy M21 4/64GB Black (SM-M215FZKU)	0.6802	Galaxy Note 9 N960 8/512GB Midnight Black	0.5531	Galaxy A01 Core 1/16GB Black (SM-A013FZKD)	0.6166	3
Galaxy M31s 6/128GB Blue (SM-M317FZBN)	0.6732	Galaxy Note 9 N960 8/512GB Metallic Copper	0.5472	Galaxy A02s 3/32GB Blue (SM-A025FZBE)	0.6102	4
Galaxy A31 4/64GB Black (SM-A315FZKU)	0.6361	Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.5377	Galaxy A10s 2019 SM-A107F 2/32GB Black (SM-A107FZKD)	0.5869	5
TOPSIS	**Score**	**VIKOR**	**Score**	**PROMETHEE**	**Score**	**Rank**
Galaxy S10+ SM-G9750 DS 1TB Black	0.6783	Galaxy M51 6/128GB Black (SM-M515FZKD)	0.0522	Galaxy M51 6/128GB Black (SM-M515FZKD)	30.1579	1
Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.6780	Galaxy M31 6/128GB Black (SM-M315FZKU)	0.0944	Galaxy M31 6/128GB Black (SM-M315FZKU)	24.8655	2
Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.6748	Galaxy M31s 6/128GB Blue (SM-M317FZBN)	0.1062	Galaxy M21 4/64GB Black (SM-M215FZKU)	24.3892	3
Galaxy Note 9 N960 8/512GB Metallic Copper	0.6419	Galaxy M21 4/64GB Black (SM-M215FZKU)	0.1244	Galaxy M31s 6/128GB Blue (SM-M317FZBN)	23.3901	4
Galaxy Note 9 N960 8/512GB Midnight Black	0.6299	Galaxy A31 4/128GB Black (SM-A315FZKV)	0.1491	Galaxy A31 4/64GB Black (SM-A315FZKU)	18.1236	5

(b) Top 5 alternatives with AHP1-based weights.

WSM	Score	WPM	Score	WASPAS	Score	Rank
Galaxy M51 6/128GB Black (SM-M515FZKD)	0.7266	Galaxy M51 6/128GB Black (SM-M515FZKD)	0.5664	G920F Galaxy S6 32GB (White Pearl)	0.6465	1
Galaxy M31 6/128GB Black (SM-M315FZKU)	0.6825	Galaxy M31 6/128GB Black (SM-M315FZKU)	0.5577	Galaxy A01 2/16GB Black (SM-A015FZKD)	0.6201	2
Galaxy M21 4/64GB Black (SM-M215FZKU)	0.6799	Galaxy Note 9 N960 8/512GB Midnight Black	0.5384	Galaxy A01 Core 1/16GB Black (SM-A013FZKD)	0.6092	3
Galaxy M31s 6/128GB Blue (SM-M317FZBN)	0.6728	Galaxy Note 9 N960 8/512GB Metallic Copper	0.5364	Galaxy A02s 3/32GB Blue (SM-A025FZBE)	0.6046	4
Galaxy A02s 3/32GB Blue (SM-A025FZBE)	0.6305	Galaxy M31s 6/128GB Blue (SM-M317FZBN)	0.5302	Galaxy A10s 2019 SM-A107F 2/32GB Black (SM-A107FZKD)	0.5804	5
TOPSIS	**Score**	**VIKOR**	**Score**	**PROMETHEE**	**Score**	**Rank**
Galaxy S10+ SM-G9750 DS 1TB Black	0.6786	Galaxy M51 6/128GB Black (SM-M515FZKD)	0.0205	Galaxy M51 6/128GB Black (SM-M515FZKD)	31.6511	1
Galaxy S10+ SM-G975 DS 1TB Black (SM-G975FCKH)	0.6678	Galaxy M31 6/128GB Black (SM-M315FZKU)	0.0701	Galaxy M31 6/128GB Black (SM-M315FZKU)	25.3817	2
Galaxy S10+ SM-G975 DS 1TB Ceramic White (SM-G975FCWH)	0.6650	Galaxy M31s 6/128GB Blue (SM-M317FZBN)	0.0810	Galaxy M21 4/64GB Black (SM-M215FZKU)	25.0163	3
Galaxy Note 9 N960 8/512GB Metallic Copper	0.6423	Galaxy M21 4/64GB Black (SM-M215FZKU)	0.0982	Galaxy M31s 6/128GB Blue (SM-M317FZBN)	24.0006	4
Galaxy Note 9 N960 8/512GB Midnight Black	0.6283	Galaxy A31 4/128GB Black (SM-A315FZKV)	0.1299	Galaxy A02s 3/32GB Blue (SM-A025FZBE)	18.0068	5

(c) Top 5 alternatives with AHP2-based weights.

Figure 5: Comparison of top 5 alternatives using Entropy, AHP1, and AHP2-based weights across MCDM approaches.