Smartphone Selection using Analytic Hierarchy Process

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Abstract*: Analytic hierarchy process (AHP) is a measurement theory that is used to obtain ratio scales from distinct as well as continuous paired comparisons, and such comparisons can be selected from either tangible measurements or a basic scale that imitates virtual strength of feelings and predilections. AHP is a decision-making process that was developed by Prof. Thomas L. Saaty (1970), and it aims to quantify virtual significances for a given set of alternatives on a ratio scale—based on decision maker's judgment—and focuses on the importance of instinctive decisions of both a decision maker and the steadiness of comparison of alternatives. AHP has been an instrument at the hands of decision makers since its discovery and is one of the widely used multicriteria decision-making methods. There have been some exceptional works that have been broadcasted based on AHP in various fields such as scheduling, best alternative selection, allocation of resources, conflict resolution, and optimization. AHP's forte is its suppleness to be integrated with techniques such as linear programming and fuzzy logic that allows a user to excerpt benefits from all techniques and helps to achieve a desired goal. Similarly, we too use AHP to meet our desired goal. That is, in this study, we consider four smartphones (i.e., ph1, ph2, ph3, and ph4) and determine which smartphone is the best by considering numerous criteria such as cost, camera, internal memory, battery life, and style and generate a rank of alternatives using AHP.

Index Terms*: analytic hierarchy process, battery life, camera, cost, criteria, internal memory, smartphone, style

I. INTRODUCTION

Analytic hierarchy process (AHP) is a group of axioms that restricts the possibility of problem environment [1] and is based on definite mathematical structure of dependable matrices and their related right eigenvector's constancy in generating accurate or approximate weights [2–4]. AHP assesses criteria or alternatives apropos a criterion in a natural, pairwise mode. It uses an elementary scale of definite numbers that has been actually proven and authenticated by substantial and decision problem experiments. An elementary scale is the one that captures individual preferences concerning both quantitative and qualitative attributes [3–5].

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This scale converts individual predilections into ratio scale weights that can be united into a linear additive weight for each alternative. The resultant linear additive weight can be used to associate and rank alternatives and aid a decision maker in making a choice. As long as the abovementioned three basic steps are rational descriptors of how an individual emanates inherently to resolve a multicriteria decision making (MCDM) problem, AHP can be deemed to be an evocative as well as inflexible decision-making model. AHP is conceivably the most widely used decision-making method in today's world, and its soundness is based on thousands of applications wherein AHP results were acknowledged and used by decision makers [5]. AHP is more than an approach for choice—although it has been magnificently applied in countless choice decisions. AHP can be described in the best possible manner by its three basic functions, i.e., structuring of complexity, measurement on a ratio scale, and synthesis. AHP has been utilized in several applications. These functions help in comprehending why AHP is a universal methodology that is used in various applications.

A. Structuring of Complexity

Saaty wanted an easy tactic to deal with complexity so that amateur people with informal training could understand. He discovered one thing common in numerous examples of the ways humans dealt with complexity—that was the hierarchical structuring of complexity into homogeneous groups of factors.

B. Measurement on a Ratio Scale

Any structured method must use ratio scale priorities for elements above lowest hierarchy level because the weights of elements at any hierarchy level are determined by multiplying the weights of elements in that level by the weights of parent element. Ratio scales are required for multiplication because the product of two interval-level measures is mathematically meaningless [6]. AHP uses ratio scales for even lowest hierarchy level. Thus, resulting weights for alternatives in AHP will be ratio scale measures.

C. Synthesis

Analytic—the first word in AHP's name—is a form of the word "analysis," which means separating an abstract entity into its integral elements [7]. Analysis is the opposite of synthesis, i.e., combining parts into a whole. Because complex allocations involve many dimensions for humans to synthesize intuitively [8], we need a way to synthesize over many dimensions. High-level corporate decision meetings may have vice presidents of finance, marketing, operations, information systems, and human resources sitting around a conference table [6], each "armed" with analysis results that their departments have performed. They may have reached a different conclusion as to what is best for their organization. The bottleneck usually is not because of lack of good analysis but lack of ability to synthesize the analysis that has been made [9].

II. AHP's APPLICATIONS

A group decision-making problem is the one where decision makers express their adjudications in groups on a set of alternatives that are finite to obtain a conjoint solution. However, there are numerous problems—such as arrangements for expressing rulings, deriving priority weights, accumulating separable judgments into an illustrative group judgment, and procuring a degree of accord among judges—found when decision making is made in groups. Failure in the abovementioned problems would cause troubles in decision making when performed in groups. First, we need to select an appropriate method to express judgments in a group decision-making problem. In general, decision maker's judgments can be characterized through formats such as rankings, derivation of a utility function [10–13], fuzzy preference relations [14–17], linguistic preference relations [18–21], and pairwise comparisons. AHP has become a popular decision-making tool to help people in dealing with complex decision-making problems that include tangible as well as intangible factors [22–24]. In addition, because of its flexibility and adaptability, AHP is used in group decision making. Several studies have attempted to determine the importance of weights of decision makers [25–27]. Furthermore, these weights depend on criteria such as expertise, experience, and previous performance. However, in certain cases, it is difficult to obtain this type of evaluation. So, in such situations, one may use equal weights for a just about optimal solution of an unsuitability minimization problem of each individual from a representative group judgment [28]. There are two means to aggregate individual judgments into an appropriate group judgment [25, 26]: the aggregation of individual priorities and the aggregation of individual judgments. Many methods have been developed for systematically evaluating alternatives in various decision-making problems. These methods include goal programming (GP), multiattribute utility theory (MAUT), scoring models, and AHP. GP is a mathematical procedure for evaluating alternatives with limited resources [29]. MAUT can be used to model a decision-making group's unique preferences using utility functions [30]. AHP—developed by [3, 31, 32]—is a decision-making method for prioritizing alternatives when multiple criteria must be considered [33]. This method allows a decision maker to structure complex problems in the form of a hierarchy [34]. For example, a typical hierarchy will have at least three levels, i.e., goal, criteria, and alternatives. In cases where there are many alternatives, a hierarchy has at least three levels, i.e., goal, criteria, and rating scale. In such a situation, alternatives are rated pertaining to each criterion. AHP can successfully address all limitations of GP and MAUT. The advantage of AHP is its use of pairwise comparisons to get a measurement on a ratio scale. It uses pairwise comparisons to measure the impact of items from one level of hierarchy to the next higher level. The other advantage of AHP is it considers inconsistency in judgment. In addition, AHP measures the degree to which judgments are inconsistent and establishes a tolerance level [35]. Other AHP advantages and disadvantages have been described and debated elsewhere, such as a series of articles in management science addresses the comparisons of AHP with MAUT [36–40]. Recent developments in AHP have led to new options in the most recent version of AHP software package, known as expert choice for windows, version 9.0 [41]. AHP has been successfully applied in various decision-making environments [42–45]. Academic administrative applications of AHP include faculty evaluation [46–49], university strategic planning [50], university budgeting [51, 52], and Master of Business Administration curriculum redesign [53]. Furthermore, AHP has been applied to help an individual select a doctoral program [54] and make a career choice [55]. This shows that AHP can be a valuable decision-making tool within academic environment. Based on reviews of available MCDM methods, we wish to use AHP for determining the best phone from a set of four phones (i.e., ph1, ph2, ph3, and ph4) based on different criteria such as cost, camera, internal memory, battery life, and style.

III. AHP'S THEORETICAL BACKGROUND

AHP is a decision-making method developed by Prof. Thomas L. Saaty in 1970s that is used to solve complex MCDM problems. It requires a decision maker to offer judgments about each criterion's relative importance and specify a predilection for each decision alternative using each criterion. It is highly efficient in identifying the selected criteria, their weighting, and analysis, and it allows a logical data combination, which could be quantitative, qualitative, experience, insight, and intuition in its algorithmic framework. AHP enables decision makers to determine each criterion's weight. Anderson states that AHP is used to solve MCDM problems by following the given steps [56]: (1) identify alternatives, (2) identify criteria and subcriteria (if any), (3) build pairwise comparisons by establishing priorities for available criteria and then compare between each pair based on the most important criterion, (4) construct a pairwise comparison matrix to determine priorities for each criteria, and (5) calculate each criterion's priority in terms of its contribution to the overall goal of selecting the best among the alternatives (known as synthesis). To achieve a good approximation result, the following steps need to be followed: (a) determine the sum of each column in the matrix, (b) divide each element in the pairwise comparison matrix by its column total. The resulting matrix is referred to as normalized pairwise comparison matrix [57], (c) compute the average of elements in each row of the normalized pairwise comparison matrix, and this average shows each criterion's priorities, and (d) decide whether the pairwise comparison is consistent. AHP provides consistency measurement for pairwise comparisons by computing consistency ratio (CR). If CR $>$ 0.10, then it indicates an inconsistency in the pairwise comparison. If CR $\leq$ 0.10, then consistency value of the pairwise comparison is considered as reasonable.

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The following steps are used to solve AHP:
First, multiply each value in the first column of the pairwise comparison matrix by the priority of the first item, multiply each value in the second column of the pairwise comparison matrix by the priority of the second item, and so for the other columns. Second, sum the values across the rows to obtain a vector value known as weight sum. Third, divide the weight sum values by priority for each criterion. Fourth, compute the average of values. Fifth, compute consistency index (CI). The formula is CI = $(\lambda_{max} - n)/(n - 1)$. Sixth, compute CR. The formula for calculating CR is CI/RI, where random index (RI) is CI of a random generated pairwise comparison matrix. The value for RI depends on the number of items being compared, as shown in Table I.

TABLE I. CI OF RANDOM NUMBERS [58]

N	3	4	5	6	7	8
RI	0.58	0.90	1.12	1.24	1.32	1.41

AHP method is used globally in various decision-making fields such as government, business, industry, healthcare, and education. While it can be used by individuals working on straightforward decisions, AHP is the most useful method where a group of people can work on complex problems, particularly those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions [59]. It has a unique advantage when important decision elements are difficult to quantify where communication among team members is impeded by their different specializations, terminologies, or perspectives [60]. Situations to which AHP can be applied include the following [60]:

A. Choice

The selection of one alternative from a given set of alternatives usually where there are multiple decision criteria involved [61].

B. Ranking

Placing a set of alternatives in order from most to least desirable.

C. Prioritization

Determining the relative merit of members of a set of alternatives as opposed to selecting a single one or merely ranking them [61].

D. Resource Allocation

Apportioning resources among a set of alternatives [61].

E. Benchmarking

Comparing processes in one's own organization with those of other best-of-breed organizations [62].

F. Quality Management

Dealing with multidimensional aspects of quality and quality improvement.

IV. SMARTPHONE SELECTION PROBLEM

Let us consider four smartphones (i.e., ph1, ph2, ph3, and ph4). We need to select the best smartphone from ph1, ph2, ph3, and ph4. Camera (megapixel [mp]), internal memory (gigabytes [GB]), battery life (hours [h]), style, and cost (in thousand rupees [Rs.]) are the criteria to be considered while selecting the best smartphone. Table II lists the capacities of the abovementioned criteria for ph1, ph2, ph3, and ph4.

TABLE II. CRITERIA TO BE CONSIDERED WHILE SELECTING THE BEST SMARTPHONE

Smart phones	Camera [mp]	Internal memory [GB]	Battery life [h]	Style	Cost (in thousand Rs.)
ph1	8	4	8	Good	17.8
ph2	12	8	8.5	Very good	35.5
ph3	4	4	9	Average	12
ph4	40	16	7.5	Best	45.4

We need to generate the rank of alternatives using AHP.

Solution

The steps involved in selecting the best smartphone by taking into account different criteria are as follows:

Step 1: We prepare criteriawise performance matrix for camera, internal memory, battery life, style, and cost and take columnwise sum. In other words, when we prepare the criteriawise performance matrix for camera, internal memory, battery life, style, and cost, we always need to remember that diagonally we will have to take inverse values (i.e., if we consider the matrix for camera, we can see that if we consider rowwise the value of ph2 to be 4 [2nd row and 1st column], then 1/4 is taken as ph2 [1st row and 2nd column]). The similar procedure is followed for other values too. Furthermore, in each matrix (i.e., camera, internal memory, battery life, style, and cost), we have to diagonally consider 1 throughout, as shown below. Next, we have to take columnwise sum of ph1, ph2, ph3, and ph4 for camera matrix. The similar procedure is followed for internal memory, battery life, style, and cost, as shown below.

TABLE III. CAMERA'S CRITERIAWISE PERFORMANCE MATRIX AND COLUMNWISE SUM

	ph1	ph2	ph3	ph4
ph1	1	1/4	3	1/6
ph2	4	1	6	1/4
ph3	1/3	1/6	1	1/9
ph4	6	4	9	1
Total	**34/3**	**65/12**	**19**	**55/36**

TABLE IV. INTERNAL MEMORY'S CRITERIAWISE PERFORMANCE MATRIX AND COLUMNWISE SUM

	ph1	ph2	ph3	ph4
ph1	1	1/5	1/3	1/8
ph2	5	1	5	1/6
ph3	3	1/5	1	1/7
ph4	8	6	7	1
Total	**17**	**37/5**	**40/3**	**241/168**

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TABLE V. BATTERY LIFE'S CRITERIAWISE PERFORMANCE MATRIX AND COLUMNWISE SUM

	ph1	ph2	ph3	ph4
ph1	1	1/4	1/5	3
ph2	4	1	1/3	4
ph3	5	3	1	5
ph4	1/3	1/4	1/5	1
Total	**31/3**	**9/2**	**26/15**	**13**

TABLE VI. STYLE'S CRITERIAWISE PERFORMANCE MATRIX AND COLUMNWISE SUM

	ph1	ph2	ph3	ph4
ph1	1	1/6	3	1/4
ph2	6	1	7	1/3
ph3	1/3	1/7	1	1/8
ph4	4	3	8	1
Total	**34/3**	**181/42**	**19**	**41/24**

TABLE VII. COST'S CRITERIAWISE PERFORMANCE MATRIX AND COLUMNWISE SUM

	ph1	ph2	ph3	ph4
ph1	1	4	1/3	7
ph2	1/4	1	1/6	6
ph3	3	6	1	9
ph4	1/7	1/6	1/9	1
Total	**123/28**	**67/6**	**29/18**	**23**

Step 2: We divide all values in columns with the obtained sum and take rowwise average. For example, for camera matrix, the columnwise sum for ph1 is 1 + 4 + 1/3 + 6 = 34/3. Now, columnwise values for ph1 [i.e., 1, 4, 1/3, and 6] are divided by the obtained sum [i.e., 34/3] (e.g., 1 ÷ 34/3 = 3/34). The same procedure is followed for ph2 [i.e., 1/4, 1, 1/6, and 4 are divided by 65/12], ph3 [i.e., 3, 6, 1, and 9 are divided by 19], and ph4 [i.e., 1/6, 1/4, 1/9, and 1 are divided by 55/36]. Thereafter, we take rowwise average of ph1 (i.e., [3/34 + 3/65 + 3/19 + 6/65] ÷ 4 = 0.09614). The same procedure is followed for ph2 (i.e., [6/17 + 12/65 + 6/19 + 9/95] ÷ 4 = 0.23702), ph3 (i.e., [1/34 + 2/65 + 1/19 + 4/55] ÷ 4 = 0.04638]), and ph4 (i.e., [9/17 + 48/65 + 9/19 + 36/55] ÷ 4 = 0.59902]). The abovementioned procedure is followed for internal memory [average: 0.04949, 0.23010, 0.09452, and 0.62587], battery life [average: 0.12462, 0.27732, 0.52801, and 0.07003], style [average: 0.10778, 0.33124, 0.04709, and 0.51387], and cost [average: 0.27427, 0.12769, 0.55805, and 0.03997].

TABLE VIII. CAMERA

	ph1	ph2	ph3	ph4	Average
ph1	3/34	3/65	3/19	6/65	**0.09614**
ph2	6/17	12/65	6/19	9/95	**0.23702**
ph3	1/34	2/65	1/19	4/55	**0.04638**
ph4	9/17	48/65	9/19	36/55	**0.59902**

TABLE IX. INTERNAL MEMORY

	ph1	ph2	ph3	ph4	Average
ph1	1/17	1/37	1/40	21/241	**0.04949**
ph2	5/17	5/37	3/8	28/241	**0.23010**
ph3	3/17	1/37	3/40	24/241	**0.09452**
ph4	8/17	30/37	21/40	168/241	**0.62587**

TABLE X. BATTERY LIFE

	ph1	ph2	ph3	ph4	Average
ph1	3/31	1/18	3/26	3/13	**0.12462**
ph2	12/31	2/9	5/26	4/13	**0.27732**
ph3	15/31	2/3	15/26	5/13	**0.52801**
ph4	1/31	1/18	3/26	1/13	**0.07003**

TABLE XI. STYLE

	ph1	ph2	ph3	ph4	Average
ph1	3/34	7/181	3/19	6/41	**0.10778**
ph2	18/34	42/181	7/19	8/41	**0.33124**
ph3	1/34	6/181	1/19	3/41	**0.04709**
ph4	12/34	126/181	8/19	24/41	**0.51387**

TABLE XII. COST

	ph1	ph2	ph3	ph4	Average
ph1	28/123	24/67	6/29	7/23	**0.27427**
ph2	7/123	6/67	3/29	6/23	**0.12769**
ph3	84/123	36/67	18/29	9/23	**0.55805**
ph4	4/123	1/67	2/29	1/23	**0.03997**

Step 3: We prepare a matrix by considering all calculated average for each criterion. Here, we have considered all calculated average values from the above step for camera, internal memory, battery life, style, and cost, as shown below.

TABLE XIII. AVERAGE VALUES OF CRITERIA

Smartphones	Camera [mp]	Internal memory [GB]	Battery life [h]	Style	Cost (in thousand Rs.)
ph1	0.09614	0.04949	0.12462	0.10778	0.27427
ph2	0.23702	0.23010	0.27732	0.33124	0.12769
ph3	0.04638	0.09452	0.52801	0.04709	0.55805
ph4	0.59902	0.62587	0.07003	0.51387	0.03997

Step 4: We prepare a pairwise comparison matrix for each criterion and take columnwise sum. In other words, once pairwise comparison matrix is prepared, we take columnwise sum of camera, internal memory, battery life, style, and cost. For example, for camera, 1 + 3 + 5 + 7 + 8 = 24. The same procedure is followed for internal memory [49/3], battery life [289/20], style [947/210], and cost [99/56].

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TABLE XIV. PAIRWISE COMPARISON MATRIX FOR CRITERIA AND COLUMNWISE SUM

	Camera [mp]	Internal memory [GB]	Battery life [h]	Style	Cost (in thousand Rs.)
Camera [mp]	1	1/3	1/5	1/7	1/8
Internal memory [GB]	3	1	1/4	1/5	1/6
Battery life [h]	5	4	1	1/6	1/7
Style	7	5	6	1	1/3
Cost (in thousand Rs.)	8	6	7	3	1
Total	**24**	**49/3**	**289/20**	**947/210**	**99/56**

<u>Step 5</u>: We divide all values in the column with the sum and take rowwise average. Once columnwise average is calculated [as shown above], then we use these average values (i.e., 24, 49/3, 289/20, 947/210, and 99/56) to individually divide (i.e., rowwise) the values that are obtained in pairwise comparison matrix (i.e., for camera [1 ÷ 24 = 1/24], for internal memory [3 ÷ 24 = 3/24], for battery life [5 ÷ 24 = 5/24], for style [7 ÷ 24 = 7/24], for cost [8 ÷ 24 = 8/24]). The similar procedure is followed for internal memory, battery life, style, and cost. Next, we take rowwise average for camera (i.e., [1/24 + 1/49 + 4/289 + 30/947 + 7/99] ÷ 5 = 0.03566), internal memory (i.e., [3/24 + 3/49 + 5/289 + 42/947 + 28/297] ÷ 5 = 0.06843), battery life (i.e., [5/24 + 12/49 + 20/289 + 35/947 + 8/99] ÷ 5 = 0.12804), style (i.e., [7/24 + 15/49 + 120/289 + 210/947 + 56/297] ÷ 5 = 0.28466), and cost (i.e., [8/24 + 18/49 + 140/289 + 630/947 + 56/99 ÷ 5] = 0.48320) to obtain preference vectors.

TABLE XV. AVERAGE VALUES OF CRITERIA

	Camera [mp]	Internal memory [GB]	Battery life [h]	Style	Cost (in thousand Rs.)	Average
Camera [mp]	1/24	1/49	4/289	30/947	7/99	**0.03566**
Internal memory [GB]	3/24	3/49	5/289	42/947	28/297	**0.06843**
Battery life [h]	5/24	12/49	20/289	35/947	8/99	**0.12804**
Style	7/24	15/49	120/289	210/947	56/297	**0.28466**
Cost (in thousand Rs.)	8/24	18/49	140/289	630/947	56/99	**0.48320**

<u>Step 6</u>: The preference vector for each criterion is as follows. We have seen from the above step how preference vectors for each criterion (i.e., camera, internal memory, battery life, style, and cost) can be obtained.

TABLE XVI. PREFERENCE VECTOR

Criteria	
Camera [mp]	0.03566
Internal memory [GB]	0.06843
Battery life [h]	0.12804
Style	0.28466
Cost (in thousand Rs.)	0.48320

<u>Step 7</u>: We multiply Tables XVII and XVIII. Once we have performed matrix multiplication, Table XIX provides desired results for four smartphones (i.e., ph1, ph2, ph3, and ph4). With the help of Table XIX, we can perform the ranking of the four smartphones.

TABLE XVII. AVERAGE VALUES OF CRITERIA

Smartphones	Camera [mp]	Internal memory [GB]	Battery life [h]	Style	Cost (in thousand Rs.)
ph1	0.09614	0.04949	0.12462	0.10778	0.27427
ph2	0.23702	0.23010	0.27732	0.33124	0.12769
ph3	0.04638	0.09452	0.52801	0.04709	0.55805
ph4	0.59902	0.62587	0.07003	0.51387	0.03997

TABLE XVIII. PREFERENCE VECTOR

Criteria	
Camera [mp]	0.03566
Internal memory [GB]	0.06843
Battery life [h]	0.12804
Style	0.28466
Cost (in thousand Rs.)	0.48320

TABLE XIX. RESULTANT MATRIX

Smartphones	Scores
ph1	0.18597
ph2	0.21569
ph3	0.35878
ph4	0.23874

TABLE XX. RANKING OF RESULTANT MATRIX

Smartphones	Scores	Rank
ph1	0.18597	**4**
ph2	0.21569	**3**
ph3	0.35878	**1**
ph4	0.23874	**2**

<u>Step 8</u>: We can see from the above result that smartphone ph3 has the highest score (i.e., 0.35878), and so, it is denoted by Rank 1. Subsequently, we have ranked ph4, ph2, and ph1 as

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Rank 2, Rank 3, and Rank 4, respectively. Therefore, we can say that ph3 is the best smartphone from the given set of four smartphones.

ph3 > **ph4** > **ph2** > **ph1**

V. CONCLUSION

AHP offers a suitable approach for solving complex MCDM problems. This study demonstrated with an illustrative example as to how the best smartphone can be selected from four smartphones (i.e., ph1, ph2, ph3, and ph4) using AHP, and we finally came to a conclusion that ph3 is the best smartphone from a given set of four smartphones. The closer the final values are with each other, the more careful a user should be. This is true with any MCDM method. The example in this paper strongly suggests that when some alternatives appear to be very close with each other, then the decision maker needs to be very cautious. An apparent remedy is to try to consider additional decision criteria that can assist in discriminating among alternatives.

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