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Selection and Prioritization of Luggage Bag Designs Using Combined AHP and TOPSIS Methodology

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Abstract

The selection and prioritization of design alternatives has become an activity of prominent importance to the performance of organizations. It is one of the most difficult problems in today's manufacturing environment. This problem has become more challenging recently due to increasing specifications and complexity of the various designs. This paper proposes a study depicting the use of combination of the two Multi-Criteria Decision Making (MCDM) methods: Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to aid the design selection decision process. The main criteria which have been considered here are cost, quality, ergonomics and environmental factors. To illustrate the proposed model, a few design concepts of luggage bags are considered and prioritization is determined by using the combined AHP and TOPSIS methodology.

Keywords: MCDM, Combined AHP and TOPSIS, Luggage Bags, Prioritization, Design alternatives.

Introduction

The initial concept made at the conceptual design stage largely determines the level of success of product designs. Inappropriate decision making during the conceptual design stage can cause the product to be redesigned or remanufactured. To overcome such problem, this paper proposes a combination of two multi criteria decision making (MCDM) approaches[11][13][17][21] namely : Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP). The combined methodology assists in selecting the most appropriate design concepts and materials at the conceptual design stage. Cost, quality, ergonomics and environmental factors are the four criteria which are considered here.

AHP[1][2] is a decision-making tool that can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The top level of the hierarchy denotes the goal of the problem, and the intermediate levels denote the factors of the respective upper levels. Meanwhile, the bottom level contains the alternatives or actions considered when achieving the goal. AHP permits factors to be compared, with the importance of individual factors being relative to their effect on the problem solution.

Whereas TOPSIS[7][18][19] is one of the major techniques in dealing with Multi Criteria Decision Making (MCDM) problems. It is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measures. The underlying logic of TOPSIS[18][19] method is to define the positive-ideal solution (PIS) and the negative-ideal solution (NIS). The optimal alternative is the one which the shortest distance from the positive solution and the farthest distance from the negative solution, and preference order is determined according to their relative closeness combining two distance measures.

A descriptive quantitative approach is adopted in this research. Algorithms of the methods TOPSIS and AHP are developed in MATLAB and applied to the selection of design of luggage bags. In the second section, the methodology of both the MCDM techniques- AHP and TOPSIS and how these two can be used in a combination is explained in detail. The third section consists of the results and discussion where all the data and results have been tabulated followed by their ranking orders. In the last section, the conclusions of the study are presented.

Methodology

A combined approach for multi criteria decision making (MCDM) has been used to select the desired luggage bag. This approach uses Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to arrive at the final result.

AHP

The AHP method[1][9], through paired comparisons is used for establishing a hierarchical structure for the problem and establishing preferences (weight measurements). The procedure involves following steps[2][9][11]:

- Define problem objective - This process identifies the root cause, limiting assumptions and system boundaries. In short, the concerned problem has to be defined in such a way to describe both initial and desired condition.
- Identify Criteria – Criteria may be defined as attributes which may be considered before making a decision. A criterion should be such that which can discriminate among the available options (alternatives), operational and meaningful and as few as possible. A criterion should be chosen such that it can cover all aspects of the desired goal.

- Choose Alternatives – The alternatives are chosen based on the criteria. They may be viewed as options available to reach the desired solution to the problem.
- Model the problem as hierarchy – Once the criteria and alternatives are identified, the whole problem can be structures as an inverted hierarchal tree to visualise the problem in more simple terms (Figure 1).

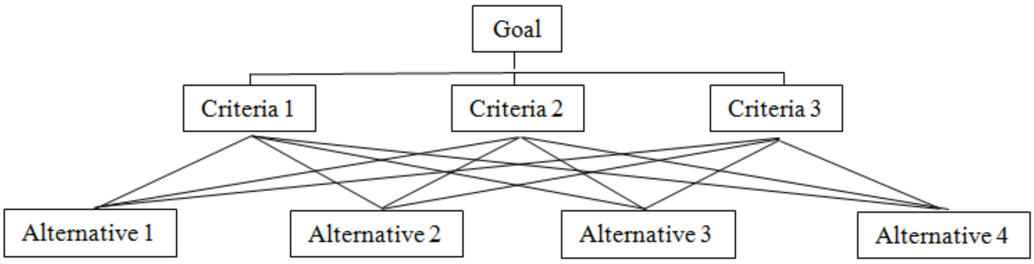

Figure 1: Problem depicted as hierarchy

Table 1: Construct pair-wise comparison matrix using Saaty's 9-point scale

Scale	**Level of Significance**
1	Equally Important
3	Weakly Important
5	Strongly Important
7	Very Strongly Important
9	Extremely Strongly Important
2 , 4 , 6 , 8	Intermediate Value between adjacent scales

- Construct a set of pair-wise comparison matrices- using the Saaty's 9-point scale[9] (Table 1) comparison matrices for criteria as well as for the alternatives with respect to each criteria are constructed on the basis of the priority given by the decision maker to each criteria and each alternative.
- Synthesize Judgements - Now using the comparison matrices priority vectors for alternatives with respect to each criterion are calculated and also the relative weights (priorities for overall goals) for the criteria are calculated.
- Calculate Consistency Index (CI) [1][9][15]- To assure the quality of the decision, consistency of the evaluation must be analysed. For this purpose Consistency ratio is calculated. It has been proposed that its value should not exceed more than 0.1.Finally, the Consistency Index (CI) for a matrix of size of m is calculated as follows:

$$CI = \frac{\lambda_{\max} - m}{m-1}$$

Table 2: Random Index Value for 'n' inputs

Matrix Order	1	2	3	4	5	6	7	8	9	10	11	12
Random Index	0	0	0.52	0.89	1.12	1.26	1.36	1.41.	1.46	1.49	1.52	1.54

Consistency Ratio, $CR = \frac{CI}{RI}$

- Establish Final Rankings – After the result has been validated using the Consistency Ratio (CR), the Products (alternatives) are ranked in descending order based on overall priority of the alternatives calculated by using the priority vectors for the criteria.

TOPSIS

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [4][19][20]based on the concept that the selected alternative should have the shortest geometric distance from the positive ideal solution . The positive Ideal Solution is one which maximises the benefit criteria and minimises the cost criteria and the Negative Ideal Solution is one which minimises the benefit criteria and maximises the cost criteria. The steps for TOPSIS[6][7][19] model are as follows –

- Calculation of normalized decision matrix for TOPSIS –

$$X = \left[x_{ij} \right] \quad (1)$$

Where, the i^{th} alternative (i = 1,……..,n) is evaluated with respect to j^{th} criteria (j =1,……,m).

To normalize the judgment matrix, the equation used to transform each element of [x_{ij}] by Deng et al [5] is as follows –

$$r_{ij} = \frac{x_{ij}}{\left(\sum_{i=1}^{n} x_{ij} \right)^{2}} \quad i = 1,2,\ldots.n \quad (2)$$

- Calculate the weighted normalised decision matrix

First to compute the entropy value (e_j) of each criterion C_1 ,C_2 ,....,Cn . Let e_j represents the entropy of the j^{th} criterion,

$$e_{ij} = -\frac{1}{\ln n}\left(\sum_{i=1}^{n} r_{ij} \ln r_{ij} \right) \quad (3)$$

Computation of weights. The objective weight for each criterion is given by –

$$w_j = \frac{1-e_j}{\left(\sum_{j=1}^{m} 1-e_j\right)} \quad j = 1, 2, 3, \ldots m \tag{4}$$

Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is:

$$v_{ij} = w_j \times r_{ij} \tag{5}$$

- Determine the Positive Ideal and Negative Ideal solutions.

Positive Ideal solution: $A^* = \{v_1^*, \ldots, v_n^*\}$, where $v_j^* = \{ \max_i(v_{ij})$ if $j \in J$; $\min_i(v_{ij})$ if $j \in J' \}$ Negative ideal solution: $A' = \{v_1', \ldots, v_n'\}$, where $v' = \{ \min_i(v_{ij})$ if $j \in J$; $\max_i(v_{ij})$ if $j \in J' \}$

- Calculate the separation measures for each alternative.

The separation from the positive ideal solution is:

$$S_i^* = \left[\sum_j (v_j^* - v_{ij})^2\right]^{\frac{1}{2}} \quad i = 1, \ldots, m \tag{6}$$

The separation from the negative ideal solution is:

$$S_i' = \left[\sum_j (v_j' - v_{ij})^2\right]^{\frac{1}{2}} \quad i = 1, \ldots, m \tag{7}$$

- Calculate the relative closeness to the ideal solution (C_i^*)

$$C_i^* = \frac{S_i'}{S_i^* + S_i'}, \quad 0 < C_i^* < 1 \tag{8}$$

- Rank in the order of preference. The criterion having highest closeness to 1 is to be given priority.

Combined Methodology of AHP And Topsis

The whole process starts with the identification of the criteria and then the corresponding alternatives are chosen. Then a hierarchy of criteria and alternatives is designed. Now the pair-wise comparison of the alternatives with respect to each criterion is established. Then the Eigen values and Eigen vectors are calculated for each of them. After that, the priority vector for alternatives with respect to each criterion is calculated. Then the consistency test is performed to validate the results. Now pair-wise comparison for the criteria is established. Then Eigen value and Eigen vector for the corresponding criteria are calculated. Consistency test is again performed to validate the result with respect to the criteria. Hence forth, the relative weights of the criteria are calculated with respect to each other. Weights of design alternatives for each criterion are computed. In the end, the overall weights (priority vectors) of the alternatives are computed.

The priority vectors (for alternatives) as calculated by AHP are taken as inputs for TOPSIS. Thereafter, the separation measures for each alternative with respect to the positive and negative ideal solution are determined using equations (6) and (7). The relative closeness to each alternative is found out using equation (8) and the design alternatives are ranked in ascending order.

Results and Discussion

The combination of AHP and TOPSIS methodology has been implemented for prioritization of 5 luggage bags. Four criteria have been considered here namely: Cost, quality, ergonomics and environment friendly.

A MATLAB program has been compiled which takes in input from the user, experts in our case, and gives the corresponding output ranking with scores. In order to get an idea of user input following are the two kinds of pair-wise ratings demonstrated in Table 3 and Table 4.

Table 3: Relative comparison matrix of four criteria as decided by the panel of experts

Criteria	Cost	Quality	Ergonomics	Environmental
Cost	1	1/5	3	4
Quality	5	1	9	7
Ergonomics	1/3	1/9	1	2
Environmental	1/4	1/7	1/2	1

Table 4: Relative comparison matrix for cost criterion of the five products

Criterion- Cost					
Product	A	B	C	D	E
A	1	3	2	2	3
B	1/3	1	1/5	1/7	1/4
C	1/2	5	1	2	4
D	1/2	7	1/2	1	1
E	3	4	1/4	1	1

The preference vector of criteria and the row averages are calculated using AHP. These values are then taken as input for TOPSIS. The row averages are taken as inputs for Product to Criteria rating and the priority vector is taken as the weight of the criteria.

MATLAB program for TOPSIS takes input from the preference vectors of AHP. The Table 5 shows the numerical scores of each product for the given set of criteria.

Table 5: Row averages obtained from AHP to be taken as input for TOPSIS

Product/Criteria	Cost	Quality	Ergonomics	Environmental
A	0.3362	0.1386	0.1042	0.0884
B	0.0552	0.0298	0.3966	0.4353
C	0.2897	0.3704	0.1019	0.0830
D	0.1870	0.3704	0.1242	0.2352
E	0.1318	0.1125	0.2730	0.1580

Weight vector of Criteria = [0.1993 0.6535 0.0860 0.0612]

The next step in the methodology is normalization of the above values. The normalized values are used in the computation of weight. But in this approach, the weights are proportionate in order to contribute to the similar nature of input data. The normalized values though will be the same as the above values. This is because each column sum equals one which happens due to the AHP part of the methodology which explains so.

Thereafter, the distances are obtained which indicates the position of the different products for each criterion from ideal solution and negative ideal solution. These distances, thereafter, are used in the calculation closeness to the ideal solution, as shown in the Table 6, i.e. the product having score closest to 1 will be considered to be the best.

Table 6: Distance Matrix From Ideal Solution

Products	**Cost**		**Quality**		**Ergonomics**		**Environmental**	
	D_{i1}^{+}	D_{i1}^{-}	D_{i2}^{+}	D_{i2}^{-}	D_{i3}^{+}	D_{i3}^{-}	D_{i4}^{+}	D_{i4}^{-}
A	0	0.0157	0.0351	0.0077	0.0074	0.0000	0.0074	0.0000
B	0.0157	0	0.0758	0	0	0.0075	0	0.0076
C	0.0004	0.0110	0.0003	0.0664	0.0075	0	0.0076	0
D	0.0044	0.0035	0	0.0758	0.0064	0.0000	0.0025	0.0014
E	0.0083	0.0012	0.0435	0.0045	0.0013	0.0025	0.0047	0.003

Following are the final scores of the products with their respective ranks shown in the Table 7. This is calculated based on the respective distances from the ideal solution. The product with the highest distance, thus the highest score, is ranked the highest and so on.

Table 7: Ranking of products based on final score values

PRODUCTS	Final Score	RANKING
A	0.40706	3
B	0.28861	4
C	0.68877	2
D	0.71149	1
E	0.27714	5

As we can infer from the Table 7, Product D has the highest score, i.e. 0.71149, thus is the best luggage bag. It is followed by the luggage bags C, A, B and E in the descending order of their respective scores.

Conclusion

This paper presents a new study of combination of AHP and TOPSIS methods. It evaluates the problem considering four criteria that closely influence the problem of design prioritization. There are two key phases to the methodology which distinguishes this approach from any individual MCDM technique. Firstly, it follows AHP and procures the priority vectors and weight of the criteria which is then taken as input in TOPSIS. Secondly, the processing of input in AHP gives a more accurate priority vector matrix (input for TOPSIS) which ultimately gives a more accurate score.

Luggage bags were designed mainly based on the four criteria mentioned in this study. Based upon the user-input, the result was obtained and the product D was deemed to be the best by this methodology. Even-though, the combined approach takes more time compared to the individual approaches, in terms of computational time of programs in MATLAB, the result obtained is more accurate. Combinations of other MCDM techniques like ELECTRE, SAW and VIKOR can also be used and compared with the ideal solution to find out the best possible approach for evaluation and prioritization in general.

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