SELECTION OF HANDLOOM FABRICS FOR SUMMER CLOTHING BY AHP METHOD OF MULTI-CRITERIA DECISION MAKING (MCDM) TECHNIQUES

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Abstract:

Multi-criteria Decision Making (MCDM) is a very popular discipline of Operations Research (OR). It deals with the selection of optimal alternatives according to their preferential rank from all feasible alternatives/options under the presence of multiple (finite number of) decision criteria. Although MCDM techniques have wide range of applications in different areas including production and other engineering fields, their application in the domain of textiles is very limited. There is no reported attempt for ranking of fabrics and thereby selecting the best fabric for a specific application using MCDM methods. However, selection of best fabric for a particular end-use requirement, like for the purpose of summer clothing, in this case, is not a very easy task. Here, multiple criteria have to be taken into consideration while ranking the fabrics or selecting the best fabric. This is a typical situation which involves multi-criteria decision making (MCDM). In the present article, an attempt has been made to develop an index of handloom fabric quality, which should be a benchmark for choosing the handloom fabrics as summer clothing. The Analytic Hierarchy Process (AHP) of MCDM technique have been used here for ranking 25 handloom cotton fabrics in terms of their quality value considering their applicability towards summer clothing on the basis of three important comfort attributes namely drape coefficient, air permeability and thermal resistance.

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1. Introduction

Ranking of handloom fabrics and thereby selecting the best fabric for a particular end-use requirement like for the purpose of summer clothing, in this case, is not a very easy task. Here, multiple criteria have to be taken into consideration while ranking the fabrics or selecting the best fabric. This is a typical situation which involves multi-criteria decision making (MCDM). In this case, the objective should be to device an index, which would reflect the true quality value of handloom fabric with respect to end-use requirement as summer clothing. MCDM techniques have wide range of applications in different areas including production and other engineering fields. However, there is no reported attempt to select the textile fabrics by MCDM methods so far. In the present work, an attempt has been made using MCDM approach to develop an index of the handloom fabric quality which should be a benchmark for selecting the handloom fabrics as summer clothing.

2. General Overview of the MCDM and AHP

Multi-criteria decision making (MCDM) is a very popular discipline of Operations Research (OR), having relatively short history of about 40 years. MCDM deals with a selection problem under the presence of multiple (a finite number of) decision criteria and alternatives. Many exponents of MCDM are available which have enjoyed a wide acceptance in the academic area and many real-world applications. Weighted sum model (WSM), Weighted product model (WPM), the Analytic hierarchy process (AHP), Revised analytic hierarchy process (RAHP), Technique for order preference by similarity to ideal solutions (TOPSIS), and Elimination and choice translating reality (ELECTRE) are among the most popular ones. Each of these methods has its own characteristics and background logic, as well as merits and demerits. It is almost impossible to decide which one is the best decision making method. The choice of the method depends on the complexity of the decision problem[1-3].

The AHP was invented by T. L. Saaty[4-9] and further analysed by Belton[10], Harker and Vargas[11-12], Dyer[13-14], and many other researchers. Although Belton and Gear[1] raised serious concerns over the theoretical basis of AHP, it has proven to be an extremely useful method of multi-criteria decision making. The reason for the popularity of AHP lies in the fact that it can handle the objective as well as subjective factors, and the criteria weights and alternative scores are elicited through the formation of a pair-wise comparison matrix, which is the heart of the AHP method.

2.1 Details of AHP Methodology

The details of AHP methodology can be summarized as follows.

Step 1: *Formation of decision hierarchy*

The decision hierarchy of the problem is developed by positioning the overall objective or goal of the problem at the top of the hierarchy, and the decision alternatives at the bottom. Relevant attributes of the decision problem such as criteria and sub-criteria are placed at the intermediate levels. The number of levels in the hierarchy depends on the complexity of the problem.

Step 2: *Formation of pairwise comparison matrix*

In this step, the relational data for comparing the alternatives or options are generated. This requires the decision maker to formulate pair-wise comparison matrices of elements at each level of the hierarchy relative to each activity at the next higher level. In AHP, if a problem involves M alternatives and N criteria, then the decision maker has to construct N judgement matrices of alternatives of $M \times M$ order and one judgement matrix of criteria of $N \times N$ order. When comparing two criteria (or alternatives) with respect to an attribute in a higher level, the relational scale proposed by Saaty[9], which is shown in Table 1, is used.

Step 3: *Determination of relative weights or importance of attributes*

In this step, the relative importance of different criteria with respect to the goal of the problem and the alternative scores with respect to each of the criteria is determined. For N criteria the size of the comparison matrix (C_1) will be $N \times N$ and the entry c_{ij} will denote the relative importance of criterion i with respect to the criterion j. In the matrix, $c_{ij} = 1$, when $i = j$ and $c_{ji} = \frac{1}{c_{ij}}$.

$$C_1 = \begin{bmatrix} 1 & c_{12} & \dots & c_{1N} \\ c_{21} & 1 & \dots & c_{2N} \\ \dots & \dots & 1 & \dots \\ c_{N1} & c_{N2} & \dots & 1 \end{bmatrix}$$

The relative weight or importance of the *i* th criteria (W_i) is determined by calculating the geometric mean (*GM*) of the *i* th row and then normalizing the geometric means of rows of the above matrix. This can be represented by the following relations.

$$GM_i = \left\{ \prod_{j=1}^{N} cij \right\}^{\frac{1}{N}} \text{ and } W_i = \frac{GM_i}{\sum_{i=1}^{N} GM_i} \quad (1)$$

Then matrix C_3 and C_4 are calculated such that $C_3 = C_1 \times C_2$ and $C_4 = \frac{C_3}{C_2}$, where

$$C_2 = [W_1 \quad W_2 \quad \dots \quad W_N]^T$$

The principal Eigen vector (λ_{max}) of the original pairwise comparison matrix (C_1) is calculated from the average of matrix C_4. To check the consistency in pairwise comparison, consistency index (*CI*) and consistency ratio (*CR*) are calculated from the following equations.

$$CI = \frac{\lambda_{\max} - N}{N - 1} \text{ and } CR = \frac{CI}{RCI} \quad (2)$$

where *RCI* is random consistency index and its value is given in Table 2. If the value of *CR* is 0.1 or less then the judgement is considered to be consistent and hence acceptable. Otherwise, the decision-maker has to reconsider the entries of the pair-wise comparison matrix.

Similarly, *N* numbers of pairwise comparison matrices (one for each criterion) of order *M x N* are formed, where each alternative is pitted against all of its competitors. The Eigen vector of each of these *N* matrices represents the performance scores of alternatives in the corresponding criterion and from a column of the final decision matrix. The decision matrix appears as follows.

	Criterion				
Alternative	C_1 (W_1)	C_2 (W_2)	C_3 (W_3)	… …	C_N (W_N)
A_1	a_{11}	a_{12}	a_{13}	…	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2N}
…	…	…	…	…	…
A_M	a_{M1}	a_{M2}	a_{M3}	…	a_{MN}

Here $\sum_{i=1}^{M} a_{ij} = 1$

where a_{ij} is the score of the i th alternative in terms of j th criterion and M is the number of alternatives or options.

Step 4: *Synthesising the final priority values of alternatives*

In this step, the final priority values of all the alternatives is determined by considering the alternative score (a_{ij}) in each criterion and the weight of the corresponding criterion (W_j) using the following equation.

$$A_{AHP} = max \sum_{j=1}^{N} a_{ij} W_j \quad \text{for } i = 1,2,3, \ldots..M \qquad (3)$$

3. Materials and Methods

3.1 Data Collection and Analysis

The test results include three important comfort attributes namely drape coefficient, air permeability and thermal resistance of 25 handloom cotton fabrics. The details of the test results and the fabric construction parameters of all the samples are shown in Table 3. The ranking of 25 handloom fabrics, and thereby selecting the best fabric for the summer clothing were done according to their quality value by AHP method.

3.2 Decision Hierarchy of the Problem

The objective of this particular study was to select a handloom fabric from the available 25 alternatives which would serve as the best choice for summer clothing. This objective (to determine the quality value of handloom fabric) was placed at the topmost position (Level 1) of the hierarchy. The decision criteria of the present problem, namely, drape coefficient, air permeability and thermal resistance of the fabrics were placed at the next position in the hierarchy, i.e., Level 2. At the lowest level of the hierarchy (Level 3), there were 25 handloom fabrics to be ranked with respect to the objective of the problem. The schematic diagram of the hierarchical structure of the quality value of the handloom fabric is depicted in Figure 1.

3.3 Determining the Criteria Weights

With respect to overall objective of the problem, the pair-wise comparison matrix of three criteria is given in Table 4. Here the comparisons were made according to the Saaty's 9-point scale given in Table 1.

It can be inferred from Table 4 that air permeability was having moderate predominance over the thermal resistance. However, dominance of air permeability over drape coefficient, and the dominance of drape coefficient over thermal resistance were somewhat between equal and moderate. The relative weights of criteria are shown in the last column of Table 4. It is observed that the air permeability is having the most dominant influence on the quality value of the handloom fabrics with a relative weight of 0.5396. The relative weights of drape coefficient% and the thermal resistance are 0.2970 and 0.1634 respectively. For the measurement of consistency of judgement, the original pair-wise comparison matrix was multiplied by the priority vector or weight vector to get the product as shown below:

$$\begin{bmatrix} 1 & 1/2 & 2 \\ 2 & 1 & 3 \\ 1/2 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.2970 \\ 0.5396 \\ 0.1634 \end{bmatrix} = \begin{bmatrix} 0.894 \\ 1.624 \\ 0.492 \end{bmatrix}$$

$$\lambda_{max} = \left(\frac{0.894}{0.2970} + \frac{1.624}{0.5396} + \frac{0.492}{0.1634}\right) / 3 = 3.0092$$

Therefore,

$$\text{Consistence Index (C.I.)} = \frac{3.0092-3}{3-1} = 0.0046$$

$$\text{Consistency Ratio (C.R.)} = \frac{C.I.}{R.C.I.} = \frac{0.0046}{0.58} = 0.0079 < 0.1$$

As the value of C.R. was well below the critical value of 0.10, therefore the pairwise comparison matrix is consistent and acceptable.

Since, there was no sub-criterion, the relative weights of the decision criteria represented the corresponding global weights with respect to the objective. Hence, the global weights of the three decision criteria, namely drape coefficient, air permeability, and thermal resistance with respect to the goal were 0.2970, 0.5396, and 0.1634 respectively.

3.4 The Analytic Hierarchy Process

After determining the weights of criteria, the remaining steps of AHP were performed and the final priority values of 25 handloom fabrics were determined. As the fabric properties were measured by various instruments in a continuous scale having different units, the measured values cannot be directly used in the decision matrix of AHP. They must be normalized within the range from 0 to 1, so that the effects of different units are neutralized. The normalization was done according to the revised AHP method using the following expressions.

$$N_{ij} = \frac{a_{ij}}{Max\ a_{ij}} \text{ (for benefit criterion) and } N_{ij} = \frac{Min\ a_{ij}}{a_{ij}} \text{ (for cost criterion)}$$

where *aij* is the score of *i*-th alternative with respect to *j*-th criterion.

The final expression for the quality value of handloom fabrics according to AHP method is shown in equation 4.

$$AHP = 0.2970 \text{ Normalized } DC + 0.5396 \text{ Normalized } AP + 0.1634 \text{ Normalized } TR \quad (4)$$

where *DC*, *AP*, and *TR* are the fabric drape coefficient, air permeability and thermal resistance respectively.

DC and *TR* were considered as a cost or negative criteria here. The reason for considering *DC* and *TR* as the cost criteria in this particular case is that for any fabric to be considered as summer clothing, *DC* and *TR* have negative impacts on the overall clothing comfort of the textile material.

The decision matrix of the AHP formed by the weights of various fabric functional properties and the normalized scores of 25 handloom fabrics is shown in Table 5.

4. Results and Discussion

The quality values and rankings of 25 handloom fabrics, with respect to applicability towards summer clothing, determined by the AHP method of MCDM approach are shown in Table 6.

From Table 6 it is noted that, sample number 19 acquires 1st rank according to the AHP method followed by sample 10 (rank 2) and sample 1 (rank 3). So, fabric sample 19 can be selected as the best fabric for the summer clothing, which possesses the four basic constructional parameters like EPI, PPI, warp count (Ne) and weft count (Ne) of 70.60, 66.20, 33.70 and 36.60 respectively, as shown from Table 3. However, this ranking is only valid for the particular set of handloom fabrics used in this investigation, and it should not be generalized for other fabrics.

5. Conclusion

MCDM approaches have been demonstrated to evaluate the quality value of handloom cotton fabrics, thereby selecting the best alternative in terms of applicability towards summer clothing. All the fabric properties were given commensurate weights based on their influence on overall objective. As the MCDM approach is very flexible, new weight combinations can be developed by modifying the pairwise comparison matrix to cope with the new situation of decision making. However, 25 handloom fabrics were used here only to demonstrate the analysis, and the results should not be generalized to other fabric datasets.

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Table 1: The fundamental relational scale for pairwise comparisons proposed by Saaty

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favour one activity over another.
5	Essential or strong importance	Experience and judgement strongly favour one activity over another.
7	Very strong importance	An activity is very strongly favoured and its dominance is demonstrated.
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between two adjacent judgement	When compromise is needed.
Reciprocals	If activity *p* has one of the above numbers assigned to it when compared with activity *q*, then *q* has the reciprocal value when compared with *p*.	

Table 2: RCI values for different numbers of attributes (N)

N	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 3: Summary statistics of fabric construction parameters and test results of three comfort attributes

Sample No.	EPI	PPI	Warp count [Ne]	Weft count [Ne]	Air permeability $[cm^3.s^{-1}.cm^{-2}]$	Drape coefficient [%]	Thermal resistance $[m^2.K.W^{-1}]$
1	69.20	68.90	34.10	36.70	243.42	65.90	11.00
2	77.00	56.70	30.80	32.70	217.92	67.62	11.13
3	69.30	57.20	33.10	43.20	244.14	68.28	12.01
4	67.20	59.60	30.30	35.20	216.45	67.25	11.68
5	67.40	63.90	28.55	24.30	218.56	66.00	12.67
6	69.60	51.40	33.60	38.10	241.52	80.09	12.05

7	87.60	78.30	33.10	36.40	224.44	75.76	14.17
8	68.80	48.40	26.30	42.50	214.23	63.34	13.16
9	67.00	67.00	34.30	36.00	253.97	70.04	15.98
10	101.50	105.20	85.20	90.30	241.38	76.24	7.97
11	65.90	55.60	31.40	38.05	246.62	79.53	13.66
12	71.20	55.80	15.60	18.50	214.45	78.43	10.90
13	68.80	73.50	36.40	33.40	242.45	64.81	12.24
14	66.60	103.00	49.80	43.95	238.67	68.76	12.04
15	69.50	66.10	32.30	35.40	241.26	65.39	12.44
16	31.20	24.40	5.60	6.10	246.72	65.08	24.65
17	64.50	96.70	39.10	35.60	236.61	67.01	12.01
18	66.90	65.70	35.70	35.40	258.50	70.97	13.27
19	70.60	66.20	33.70	36.60	258.50	66.65	13.69
20	70.00	95.30	25.50	56.00	214.69	68.09	13.62
21	69.40	53.40	25.70	39.10	215.00	64.72	12.54
22	64.20	42.50	25.00	13.30	217.62	68.31	12.22
23	68.60	62.40	34.70	38.20	244.50	80.00	14.22
24	67.30	115.50	35.40	50.60	236.54	65.48	13.85
25	82.20	112.00	51.70	51.60	239.28	77.94	12.08
Mean	69.66	69.79	33.88	37.89	234.70	70.07	13.01
S.D.	11.44	22.85	14.01	15.50	14.69	5.56	2.85
CV%	16.43	32.74	41.36	40.92	6.26	7.94	21.91

Table 4: Pairwise comparison matrix of criteria

Criteria	Drape coefficient	Air permeability	Thermal resistance	Geometric mean (GM)	Normalized GM or Relative weights
Drape coefficient	1	1/2	2	1.000	0.2970
Air permeability	2	1	3	1.817	0.5396
Thermal	1/2	1/3	1	0.550	0.1634

Table 5: Decision matrix of the analytic hierarchy process (AHP)

Sl. No.	Drape coefficient [DC] (0.2970)	Air permeability [AP] (0.5396)	Thermal resistance [TR] (0.1634)
1	0.961	0.942	0.725
2	0.937	0.843	0.716
3	0.928	0.944	0.664
4	0.942	0.837	0.683
5	0.960	0.845	0.629
6	0.791	0.934	0.662
7	0.836	0.868	0.562
8	1.000	0.829	0.606
9	0.904	0.982	0.499
10	0.831	0.934	1.001
11	0.796	0.954	0.583
12	0.808	0.830	0.731
13	0.977	0.938	0.651
14	0.921	0.923	0.662
15	0.969	0.933	0.641
16	0.973	0.954	0.323
17	0.945	0.915	0.664
18	0.892	1.000	0.601
19	0.950	1.000	0.582
20	0.930	0.831	0.585
21	0.979	0.832	0.636
22	0.927	0.842	0.652
23	0.792	0.946	0.560
24	0.967	0.915	0.575
25	0.813	0.926	0.660

Table 6: Quality values and ranking of handloom fabrics

Sample No.	Quality values by AHP methods
1	0.9120 (3)
2	0.8502 (13)
3	0.8936 (7)
4	0.8431 (19)

5	0.8441 (17)
6	0.8472 (15)
7	0.8087 (24)
8	0.8431 (20)
9	0.8803 (9)
10	0.9141 (2)
11	0.8467 (16)
12	0.8070 (25)
13	0.9028 (4)
14	0.8800 (10)
15	0.8960 (6)
16	0.8569 (12)
17	0.8831 (8)
18	0.9028 (5)
19	0.9170 (1)
20	0.8201 (23)
21	0.8433 (18)
22	0.8362 (22)
23	0.8371 (21)
24	0.8751 (11)
25	0.8487 (14)

Values in the parenthesis indicate the raking of the fabric

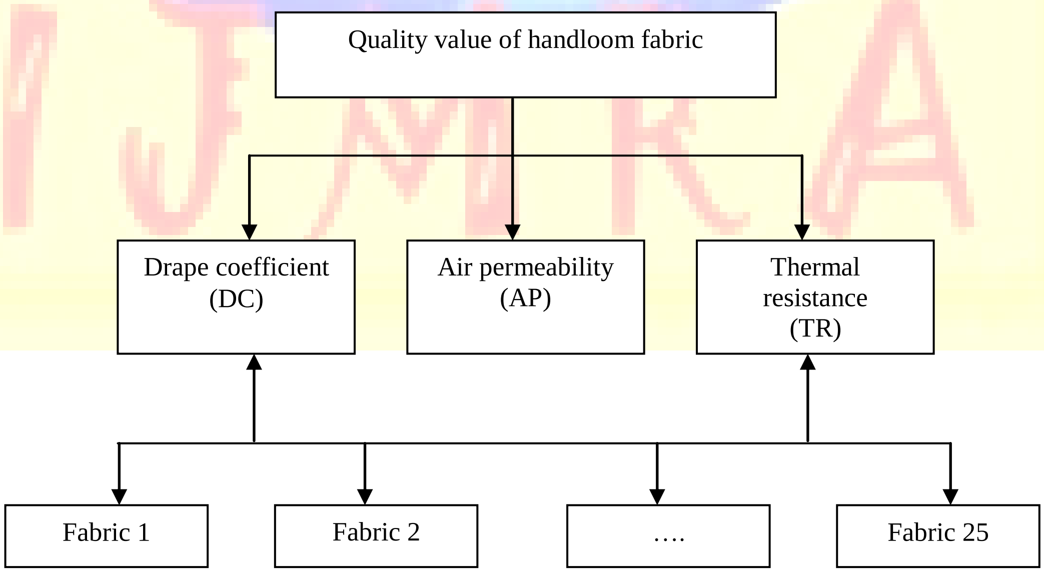

Figure 1: Hierarchical structure of handloom fabric quality