Developing a decision support system software for cotton fibre grading and selection

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This paper reports the study on the development of a ‘decision support system (DSS)’ software for cotton fibre grading and selection, and its applications in the textile spinning industry. Two multi-criteria decision making approaches, namely ‘analytic hierarchy process (AHP)’ and ‘technique for order preference by similarity to ideal solutions (TOPSIS)’, have been amalgamated in the developed DSS software. AHP has been used to elicit the relative importance or weights of cotton fibre properties and TOPSIS to calculate the final quality value (closeness index) of cotton fibres with respect to yarn qualities. The developed software has been validated using the published cotton fibre and yarn data. The quality value of cotton fibres given by the DSS software shows good correlation with the yarn uneveness.

Keywords: Analytic hierarchy process, Cotton, Decision support system, Multi-criteria decision making

1 Introduction
Decision support systems (DSS) are a class of management information systems which support business and organizational decision-making activities. A properly designed DSS is generally an interactive software-based system intended to help decision makers to compile useful information from a combination of raw data, personal domain knowledge and business models to identify and solve problems and make decisions. The major components of a DSS are as follows:

- Inputs—Decision environment, criteria, variables and information data base
- User knowledge and expertise—Inputs requiring the domain knowledge of the expert or decision maker
- Outputs—Transformed data from which decisions are elicited
- Decisions—Results generated by the DSS based on user criteria

Textile industry is one of the traditional industries where most of the technical and managerial decisions are taken based on the age old thumb rules or intuition of the decision maker. These practices are generally devoid of any systematic or scientific methods which are in place for other engineering branches. However, the stringent requirement and precise tolerance of quality in the world market and availability of information plethora about the material and product characteristics have ushered in some positive changes in textile industries. Besides, the era of fibre to apparel engineering is also compelling the textile industries to shun the traditional methods and embrace scientific approaches.

The quality of spun yarns is largely (up to 80%) influenced by the characteristics of fibre. Moreover, the cost of cotton fibre contributes around 50% to the final yarn cost. Therefore, selection of cotton fibre is one of the most important strategic decisions for the spinning industries. This decision is as complex as any other decision of material selection for engineering industries. The level of influence of various fibre properties on different yarn quality attributes (tenacity, unevenness, hairiness, etc.) is not same and it is also dependent on the yarn manufacturing technology. Traditionally, fibre grade, length and fineness have been used by the classers to evaluate the quality of cotton fibres. Later, fibre quality index (FQI) and its variants were developed and they incorporated major cotton fibre properties in a multiplicative formula to determine the quality value of cotton. The spinning consistency index (SCI) has recently gained popularity in the spinning industries as it includes most of the high volume instrument (HVI) results in a linear regression equation. However, FQI and SCI mainly focus on yarn tenacity and other important yarn parameters like elongation, unevenness and hairiness are not given

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due consideration. Besides, it has been shown earlier \(^9,^{10}\) that the correlation between SCI and yarn tenacity is not very encouraging. Therefore, it is important to look for other avenues of DSS which can overcome the deficiencies of the existing systems and come up with ingenious solutions. The use of multi-criteria decision making (MCDM) for cotton fibre grading and selection has been reported by some researchers.\(^9,^{12}\) Majumdar et al.\(^{13}\) also conducted simulated trials of bale laydown and found that the MCDM approach is better than the SCI with respect to the control of variability of fibre properties. However, there is an utmost need to develop a user friendly DSS tool for cotton fibre selection in the spinning industries.

In this investigation, a DSS software has been developed which works on the principle of ‘analytic hierarchy process (AHP)’ and ‘technique for order preference by similarity to ideal solutions (TOPSIS)’ approaches of MCDM. The use of the DSS software has also been demonstrated for cotton fibre selection.

2 Methodology

2.1 Multi-Criteria Decision Making Process

The problem of MCDM involves a set of \(M\) alternatives \((i = 1, 2, ..., M)\) which have to be ranked with respect to a set of \(N\) criteria \((j = 1, 2, ..., N)\) for attaining a specified objective or goal. Various MCDM techniques such as weighted sum model (WSM), weighted product model (WPM), AHP, revised AHP, multiplicative AHP, TOPSIS, and elimination & choice translating reality (ELECTRE) have been successfully used in various engineering and management decision making problems.\(^3,^{4,15}\) The AHP is one of the most popular methods of MCDM.\(^{16,17}\) AHP can efficiently handle objective as well as subjective factors involved in a decision making process. In AHP, criteria weights and alternative scores are elicited through the formation of pair-wise comparison matrix. However, the total number of pair-wise comparisons to be made in a decision making problem having \(M\) alternatives and \(N\) criteria is expressed by the following equation:

\[
\frac{N(N-1)}{2} + N \cdot \frac{M(M-1)}{2} \quad \ldots \quad (1)
\]

This may be pragmatically unmanageable where a huge number of decision criteria and alternatives are involved. The TOPSIS is more potent in handling the tangible attributes and there is no limit in terms of number of criteria or alternatives.\(^{18}\)

The four main steps of MCDM are as follows:

- Determining the objective or goal, relevant criteria and alternatives of the decision problem.
- Determining the weights or relative importance of criteria with respect to the objective.
- Determining the scores of alternatives with respect to each of the decision criteria.
- Processing of criteria weights and alternative scores to determine the ranking of each alternative.

Grading of cotton fibre is a typical MCDM problem as each of the available alternatives (cotton fibre type) has to be evaluated with respect to a finite set of decision criteria (fibre length, strength, micronaire, short fibre content, etc.) keeping the objective or objectives (yarn strength, yarn unevenness, yarn hairiness) of the decision in mind. The situation may be more complex and involve multi-objective scenario as the spinner would like to attain highest yarn tenacity and minimum unevenness and hairiness. Therefore, the problem of cotton fibre grading and selection can be addressed by the MCDM methods.

2.2 Working Principle of DSS Software

The DSS software for cotton fibre grading and selection has been developed using the Java Development Kit (JDK) which is a Sun Microsystems product aimed at Java developers. The DSS software works in following four stages and it requires the intervention of user or decision maker at certain points.

Stage 1—Pair-wise Comparison Matrix

At this stage, the decision maker is first asked to input the number of decision criteria \((N)\) and number of decision alternatives \((M)\) involved in the problem. Once this information is fed and ‘Create comparison Matrix’ button is clicked, two matrices of \(N \times N\) and \(M \times N\) order are formed, which are known as pair-wise comparison matrix and decision matrix respectively. In pair-wise comparison matrix, the decision criteria are compared against each other and scores are given according to a nine point scale proposed by Saaty.\(^{16,17}\) The linguistic significance of the nine point scale is given in Table 1.

The software automatically calculates the scores at the lower part of the diagonal of pair-wise comparison matrix once the scores above the diagonal are entered and ‘Complete Comparison Matrix’ button is clicked. The software also considers that all the entries along
the diagonal are 1. Because, in the matrix, \( c_{ij} = 1 \) if \( i = j \) and \( c_{ji} = \frac{1}{c_{ij}} \). The screen shot of the software at this stage is depicted in Fig. 1. The pair-wise comparison matrix of criteria of \( N \times N \) order is shown below:

\[
\begin{bmatrix}
1 & c_{12} & \cdots & c_{1N} \\
c_{21} & 1 & \cdots & c_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
c_{N1} & c_{N2} & \cdots & 1
\end{bmatrix}
\]

**Stage 2—Determination of Criteria Weights**

At this stage, the software calculates the weights of decision criteria using the AHP method. The principal eigen vector of the above matrix represents the relative weights of decision criteria. The relative weight of the \( i \)th criterion \( (W_i) \) is determined by calculating the geometric mean of the \( i \)th row \( (GM_i) \) of the above matrix and then normalising the geometric means of rows. This can be represented as follows:

\[
GM_i = \left\{ \prod_{j=1}^{N} c_{ij} \right\}^{\frac{1}{N}} \\
W_i = \frac{GM_i}{\sum_{i=1}^{N} GM_i} \quad \ldots \quad (2)
\]

Once the ‘Calculate Normalised Weight’ button is clicked, the software performs the aforesaid mathematical operations and shows the normalised weights of criteria. Screen shot of the DSS software at this stage is shown in Fig. 2. The summation of normalised weights of all criteria results in value 1, i.e. \( \sum_{i=1}^{M} a_{ij} = 1 \).

If the decision maker wants to put weights of criteria directly without using the pair-wise comparison matrix, then the weights can directly be entered in the ‘Normalised Weight’ column corresponding to criteria \( C_1, C_2, \ldots, C_n \). Then the ‘Use Direct Weights’ button should be clicked for the use of entered weights in the decision matrix.

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**Table 1—Nine point scale for pair-wise comparisons**

<table>
<thead>
<tr>
<th>Intensity of importance on an absolute scale</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance of one over another</td>
<td>Experience and judgment slightly favour one activity over another.</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance</td>
<td>Experience and judgment strongly favour one activity over another.</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>An activity is strongly favoured and its dominance is demonstrated in practice.</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one activity over another is of the highest possible order of affirmation.</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values between two adjacent judgment</td>
<td>When compromise is needed.</td>
</tr>
<tr>
<td>Reciprocals</td>
<td>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.</td>
<td></td>
</tr>
</tbody>
</table>
Stage 3—Decision Matrix

At this stage, the operations are performed in the decision matrix which is having $M \times N$ order. After the stage 2, the weights (computed or directly given) of decision criteria are automatically transferred to the decision matrix. Now, the scores (test results) of $M$ alternatives (cotton types) have to be entered in the decision matrix. The user can either enter the scores manually or if the cotton test results are stored in computer (notepad .txt format) then that can be uploaded in the decision matrix by clicking the ‘Browse’ button and selecting the source file. Screen shot of the DSS software at this stage is shown in Fig. 3.

Stage 4—TOPSIS

At this stage, the software performs the operations of TOPSIS and produces final quality value (closeness index) of alternatives. The TOPSIS was developed by Hwang and Yoon\textsuperscript{18}. The basic philosophy of this method is that the selected alternative, in a geometrical sense, should have shortest distance from the ideal or best solution and longest distance from the worst solution. The decision matrix having an order of $M \times N$ is represented as follows:

$$D_{M\times N} = \begin{bmatrix}
    a_{11} & a_{12} & \ldots & a_{1N} \\
    a_{21} & a_{22} & \ldots & a_{2N} \\
    \ldots & \ldots & \ldots & \ldots \\
    a_{M1} & a_{M2} & \ldots & a_{MN} \\
\end{bmatrix}$$

where an element $a_{ij}$ of the decision matrix $D_{M\times N}$ represents the actual score of the $i$th alternative in terms of $j$th criterion. The decision matrix is converted to normalised decision matrix, so that the scores obtained in different scales or units become comparable. An element $r_{ij}$ of the normalised decision matrix can be calculated by the following equation:

$$r_{ij} = \frac{a_{ij}}{\sum_{j=1}^{N} (a_{ij})^{0.5}} \quad \ldots (3)$$

The normalised matrix is then converted to weighted normalised matrix by multiplying each column of the normalised decision matrix $R$ with the associated criterion weight. Hence, an element $v_{ij}$ of weighted normalised matrix $V$ is represented as follows:

$$v_{ij} = r_{ij}W_j \quad \ldots (4)$$

The criteria weights have already been determined in Stage 2. The next step produces the positive ideal solution ($A^*$) and negative ideal solution ($A^-$) in the following manner:

$$A^* = \left\{ (\max \ v_{ij} \ / \ j \in J), (\min \ v_{ij} \ / \ j \in J') \right\}$$

$$A^- = \left\{ (\min \ v_{ij} \ / \ j \in J), (\max \ v_{ij} \ / \ j \in J') \right\}$$

where

$$J={j=1,2,\ldots,N \ / \ j \ associated \ with \ benefit \ or \ positive \ criteria}$$

and

$$J'={j=1,2,\ldots,N \ / \ j \ associated \ with \ cost \ or \ negative \ criteria}$$

For the benefit criteria, the decision maker will prefer the maximum value among the alternatives. Therefore, $A^*$ indicates the positive ideal solution. Similarly, $A^-$ indicates the negative ideal solution. Then the $N$ dimensional Euclidean distance method is applied, as shown below, to measure the separation distances of each alternative from $A^*$ and $A^-$:

$$S_{i*}^* = \left\{ \sum_{j=1}^{N} (v_{ij}^* - v_{j}^*)^2 \right\}^{0.5}, \ i = 1,2,\ldots,M \ and$$

$$S_{i^-}^- = \left\{ \sum_{j=1}^{N} (v_{ij}^- - v_{j}^-)^2 \right\}^{0.5}, \ i = 1,2,\ldots,M \quad \ldots (5)$$

where $S_{i*}^*$ and $S_{i^-}$ are the separation distances of alternative $i$ from $A^*$ and $A^-$ respectively.

Finally, the closeness index ($C_{i*}^*$) value of each alternative is calculated using the following equation:

$$C_{i*}^* = \frac{S_{i^*}^-}{(S_{i*}^* + S_{i^-}^-)} \quad \ldots (6)$$
The value of $C_i^*$ lies within the range from 0 to 1. The alternative having the maximum $C_i^*$ is the most preferred one and vice versa.

In the DSS software, the decision maker needs to identify the benefit and cost criteria by assigning code 1 and 0 respectively. Screen shot of the DSS software at this stage is shown in Fig. 4. Now the DSS software has received all the information and inputs required to produce the final decision. The user can see the final results by clicking on the ‘View Results’ button. Screen shot of the DSS software at this stage is shown in Fig. 5. The software not only shows the alternatives and their quality value (closeness index) in a tabular form but also depicts the results in the form of a bar diagram for easy understanding.

### 3 Results and Discussion

The properties of spun yarns are influenced by the fibre properties and spinning process parameters. However, the effect of fibre quality on yarn properties can only be understood properly if the process parameters are kept at the same level. Therefore, U.S. cotton crop study results of 1997 conducted by International Textile Centre, Lubbock, Texas, USA, has been used for the validation of the software. Seventeen types of cotton fibres were spun into yarns of 22 Ne and 30 Ne under similar process conditions. It is assumed that the decision maker would like to select the best cotton fibre from yarn evenness point of view. The decision hierarchy of the problem is depicted in Fig. 6. The objective or goal of the problem, which is at the apex of the hierarchy, is to select the best cotton fibre from yarn evenness point of view. Seventeen alternatives or cotton fibre types are placed at the lowest level of the hierarchy. For the simplicity of the decision model, it is considered that yarn evenness is mainly influenced by cotton fibre length (upper half mean length), micronaire and short fibre content. Therefore, a pair-wise comparison matrix of criteria of 3 x 3 order has been prepared. Scores were given in the pair-wise comparison matrix as shown in Fig. 1. Here $C_1$, $C_2$ and $C_3$ represent upper half mean length, micronaire and short fibre content respectively. The relative weights of upper half mean length, micronaire and short fibre content with respect to yarn evenness is found to be 0.163, 0.297 and 0.54 respectively, as shown in Fig. 2. It implies that yarn evenness is most decisively influenced by the short fibre content, followed by micronaire and upper half mean length. Out of these three criteria, only upper half mean length ($C_1$) is the benefit criteria and micronaire ($C_2$) and short fibre content ($C_3$) are cost criteria. This has been indicated by the decision maker with suitable code as shown in Fig. 4. The quality value (closeness index) of all the seventeen cotton fibres was evaluated on the basis of TOPSIS method. The cotton fibre no. 3 is having the lowest closeness index of 0.145 and cotton fibre no. 5 is having the highest closeness index of 0.901. The
unevenness values of the yarns (22 Ne and 30 Ne) spun from these cotton fibres are shown in Table 2. This table shows the association between the quality value (closeness index) of cotton fibre and yarn unevenness. It is evident that as the quality value (closeness index) of cotton fibre increases, the yarn unevenness shows concomitant reduction. The coefficient of correlation between the closeness value of cotton fibre and unevenness value of yarn is -0.733 and -0.773 for the 22 Ne and 30 Ne respectively.

**Table 2—Closeness index of cotton fibre and yarn unevenness**

<table>
<thead>
<tr>
<th>Cotton fibre No.</th>
<th>Closeness index</th>
<th>Yarn unevenness, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.435</td>
<td>23.32</td>
</tr>
<tr>
<td>2</td>
<td>0.654</td>
<td>22.56</td>
</tr>
<tr>
<td>3</td>
<td>0.145</td>
<td>26.37</td>
</tr>
<tr>
<td>4</td>
<td>0.778</td>
<td>21.12</td>
</tr>
<tr>
<td>5</td>
<td>0.901</td>
<td>23.64</td>
</tr>
<tr>
<td>6</td>
<td>0.801</td>
<td>22.13</td>
</tr>
<tr>
<td>7</td>
<td>0.194</td>
<td>26.42</td>
</tr>
<tr>
<td>8</td>
<td>0.704</td>
<td>22.34</td>
</tr>
<tr>
<td>9</td>
<td>0.820</td>
<td>22.55</td>
</tr>
<tr>
<td>10</td>
<td>0.326</td>
<td>25.71</td>
</tr>
<tr>
<td>11</td>
<td>0.772</td>
<td>20.50</td>
</tr>
<tr>
<td>12</td>
<td>0.638</td>
<td>23.41</td>
</tr>
<tr>
<td>13</td>
<td>0.551</td>
<td>23.47</td>
</tr>
<tr>
<td>14</td>
<td>0.714</td>
<td>24.78</td>
</tr>
<tr>
<td>15</td>
<td>0.632</td>
<td>22.49</td>
</tr>
<tr>
<td>16</td>
<td>0.716</td>
<td>23.78</td>
</tr>
<tr>
<td>17</td>
<td>0.704</td>
<td>22.97</td>
</tr>
</tbody>
</table>

The developed DSS software has been validated using the published data collected from open source. The quality value (closeness index) of cotton fibre has been determined from yarn unevenness point of view. It is found that the quality value (closeness index) of cotton fibre and yarn unevenness has good correlation coefficient. Using the developed DSS software, it is possible to grade and select the cotton fibres from any yarn quality point of view.

**4 Conclusions**

A decision support system software for the cotton fibre selection and grading has been developed based on the principles of multi-criteria decision making. The proposed decision support system amalgamates two popular methods of multi-criteria decision making namely AHP and TOPSIS. The developed DSS software is very flexible. The criteria weights corresponding to the decision goal can be elicited either by using the AHP method or by assigning direct weights. The final quality value (closeness index) of the alternatives is calculated using the TOPSIS method.

**References**