INTRODUCTION

The Textile yarns are used in a wide range of applications: warp and weft weaving, knitting, garment industry. The Quality of yarn directly affects the yield of production and the quality of the final product. For a long period, yarn quality was qualified through its strength [1–6].

Quality of yarn is a multi-criteria problem that needs the simultaneous satisfaction of a lot of properties (mechanical, physical properties …)

Yunus [7] proposed a yarn quality index considering yarn strength, elongation, and uniformity. This index was used in some research papers to optimise the quality of waste yarn [8–9].

Recently, Wannssi proposed to use AHP method to optimise the global quality of yarns with different waste ratio taking into account the fiber price [11].

In the textile industry, it is very useful to use a Global Quality Index, especially when purchasing in order to make a rapid comparison between yarn quality from different suppliers and when comparison of a new yarn quality to standard is necessary. This Index should be determined according to customer satisfaction criteria that varies from one final product application to another.

In this paper, we propose a new method to determine the Quality Yarn Index QYI based on Analytic Hierarchy Process AHP and Fuzzy theory.

Materials and methods

Yarn Quality Index

According to Yunus [7], a Yarn Quality Index can be expressed by the following formula:

\[
YQI = \frac{YSI \times YEI}{YCv}
\]

where YSI is Yarn Strength, YEI – Yarn Elongation, YCv – Yarn Unevenness.

This index has many advantages, it is simple and takes into account most of the important properties of yarn but also has disadvantages:
– Some other important properties of the yarn are missing (Neps, Hairiness, Elasticity…);
– The index considers that all the properties have the same importance (weight = 1).

Taking into account these remarks, we propose in our study a new empirical index of yarn quality. This index can be expressed by the following formula:

$$YQI = \sum_{i=1}^{n} WGi \cdot GPI$$

$$\sum_{i=1}^{n} WGi = 1$$

where $GPI$ is Global property $i$ of the yarn (Dynamometric property, Unevenness, Hairiness…), $WGi$ – Weight of the global property $l$, $n$ – Number of yarn properties to take into account.

Each global property $GPI$ can be expressed as a function of Relative Properties of the yarn $RPj$ (for example the Global property of the yarn: dynamometric properties, can be expressed by the relative properties: tenacity, breaking elongation and elasticity).

$$GPI = \sum_{j=1}^{m} WRji \cdot RPji$$

$$\sum_{j=1}^{m} WRji = 1$$

where $RPji$ is Relative property $j$ of the Global property $i$ of the yarn, $WRji$ – Weight of the relative property $j$ to the global property $i$ of the yarn, $m$ – Number of relative properties related to the global property $l$ of the yarn.

The objective of our study is to propose an appropriate approach based on AHP and Fuzzy methods to determine respectively the weights of Global properties of the yarn WGI and the weights of relative properties WRji based on customer satisfaction and final application of the yarn (weaving, knitting…).

**Fuzzy AHP process**

AHP is a common multi-criteria decision making method. It is developed by Saaty [12] to assist in solving complex decision problems by capturing both subjective and objective evaluation measures. The fuzzy AHP method includes the uncertain (imprecise) judgment of experts by utilizing linguistic variables (table 1). Recently many researchers have used this approach in various areas [13–15].

In fuzzy AHP, $\tilde{A} = (\tilde{a}_{ij})$ is a fuzzy pairwise comparison judgment matrix, with $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ the pairwise comparisons between the elements $i$ and $j$ and a triangular fuzzy number where $l_{ij}$ and $u_{ij}$ are the lower and upper limits respectively and $m_{ij}$ the modal value and $l_{ij} \leq m_{ij} \leq u_{ij}$. If $l_{ij} = m_{ij} = u_{ij}$ it is considered a non-fuzzy number by convention. The membership function $\mu_x$ is defined as:

$$\mu(x) = \begin{cases} x & \text{if } m - l \leq x \leq m - u, \text{ } x \in [l,m] \\ \frac{x}{m-u} & \text{if } m - u < x \leq m, \text{ } x \in [m,u] \\ 0 & \text{otherwise} \end{cases}$$

The procedure for applying fuzzy AHP is as follows [16,17]:

- Define the hierarchical structure of the decision problem.
- Make pairwise comparisons of criteria at the same level of hierarchy using fuzzy numbers to construct the matrix $\tilde{A}$.
- The fuzzy synthetic extent value ($S_i$) with respect to the $i^{th}$ criterion is defined as:

$$S_i = \sum_{j=1}^{n} a_{ij} \cdot hgt(\tilde{a}_i \cap \tilde{a}_j) = \mu_{\tilde{a}_{ij}}(d) = \begin{cases} 1, & \text{if } m_j \geq m_i \\ 0, & \text{if } l_j \geq u_i \\ \frac{l_i - u_j}{(m_j - u_i) - (m_i - l_j)}, & \text{otherwise} \end{cases}$$

where $g_i$ are the goals of the hierarchy and $\tilde{a}_{ij}$ is a triangular fuzzy number of the decision matrix $\tilde{A}$ with $n$ objects and $m$ goals.

- The degree of possibility is calculated by:

$$S_i = \sum_{j=1}^{n} a_{ij} \cdot hgt(\tilde{a}_i \cap \tilde{a}_j) = \mu_{\tilde{a}_{ij}}(d)$$

Where $d$ is the ordinate of the highest intersection point $D$ between $\mu_{\tilde{a}_i}$ and $\mu_{\tilde{a}_j}$.

- The minimum degree of possibil of $V(\tilde{S}_j \geq \tilde{S}_i)$ for $i, j = 1, 2, ..., n$ is calculated:

$$V(\tilde{S}_j \geq \tilde{S}_i) = V(\tilde{S}_j \geq \tilde{S}_i)$$

and...

$$V(\tilde{S}_j \geq \tilde{S}_n) = \min V(\tilde{S}_j \geq \tilde{S}_i), i = 1, 2, ..., n$$.  

**Table 1**

<table>
<thead>
<tr>
<th>Preference of pairwise comparisons</th>
<th>Fuzzy scale</th>
<th>Fuzzy reciprocal scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Just equal</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
</tr>
<tr>
<td>Very weakly more important</td>
<td>(1/2,1,3/2)</td>
<td>(2/3,1,2)</td>
</tr>
<tr>
<td>Weakly more important</td>
<td>(1.3/2,2)</td>
<td>(1/2,2/3,1)</td>
</tr>
<tr>
<td>Moderately more important</td>
<td>(3/2,2,5/2)</td>
<td>(2/5,1,2/2,3)</td>
</tr>
<tr>
<td>Strongly more important</td>
<td>(2,5/2,3)</td>
<td>(1/3,2,5/1,2)</td>
</tr>
<tr>
<td>Absolutely more important</td>
<td>(5/2,3,7/2)</td>
<td>(2/7,1,3/2,5)</td>
</tr>
</tbody>
</table>

![Fig. 1. Intersection between $\tilde{a}_i$ and $\tilde{a}_j$](image-url)
• If $d(A) = \min V(S_j \geq S_i)$ for $j = 1, 2, ..., n$ and $j \neq i$.

The weight vector is:

$$W = (\hat{d}(A_1), \hat{d}(A_2), ..., \hat{d}(A_n))^T$$  \hspace{1cm} (10)

• Via normalization, the normalized weight vectors are given as follow:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T$$  \hspace{1cm} (11)

• Notice that $\hat{A}$ is considered consistent if $\hat{A} \times W = \lambda \times W$.

The consistency ratio ($CR$) is calculated from as:

$$CR = \frac{CI}{RCI} = \frac{\text{Consistency Index}}{\text{Random Consistency of } A}$$  \hspace{1cm} (12)

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1}$$  \hspace{1cm} (13)

where $\lambda_{\text{max}}$ is equal to the sum of the elements of the column vector $\hat{A}W$.

$RCI$ is generated by a random matrix of similar dimension. Random consistency index ($RCI$) for the matrix of the order of 1 to 15 as shown in table 2.

If $CR$ is less than 0.1, the judgments given in a comparison matrix are adequate.

### RESULTS AND DISCUSSION

Contrary to knitting fabric technology where only one set of yarns are used, in woven fabric manufacturing two types of yarns are needed: warp and weft yarns. To ensure the quality of each kind of fabric, different yarn properties are required.

Most of the spinners work continuously to predict and translate a set of requirements for spinning guidelines that satisfy weaver and knitters standards.

For this purpose, a fuzzy AHP model has been developed to assess the yarn importance for the three yarn types: warp, weft, and knitting.

Firstly, the weight of each yarn properties will be determined and then for each application, a Global Yarn Quality index will be defined.

Based on literature review then spinners, weavers and knitters managers interviewing, four main criteria were defined for the most important yarn properties required for weaving (wrap and weft) and knitting technologies: Dynamometric properties, Neps & Hairiness, Evenness properties, and structural characteristics. Within each main criterion, there are various sub-criteria to which we assign specific descriptors (figure 2).

Two experts provided judgments for each yarn types: warp, weft, and knitting. These experts used for obtaining the fuzzy numbers have over ten years’ experience in weaving and knitting fields. Fuzzy numbers have been used to assign weightings to the criteria and sub-criteria. They were asked to evaluate the importance of the criteria and sub-criteria applying the triangular fuzzy scale shown in table 1. The pairwise comparison matrix for the criteria given by the experts is shown in table 3.

Upon completing the model analysis, the criterion with the highest weightage was found for each yarn employment: weaving warp, weaving weft and knitting yarn (table 4). It was found that the dynamometric property is the most important criterion throughout.

It is worth noting that the mechanical properties of the yarn affect both mechanical properties of fabric and

![Fig. 2. Hierarchical Structure of Yarn Properties](image-url)
yarn breakage during the process of transformation. For example, a yarn with high tenacity leads to a fabric with high tenacity. On the other hand, when the elasticity of the yarn decreases the probability to cause breakage in weaving preparation (for example) increases.

Evenness Properties is the second important criterion for both weaving weft and knitting yarn with a weight of (0.317) and (0.283), respectively. A defect on yarn affects both yield of production (for example when the number of thin places increases the yield of knitting process decreases) and final declassification of fabric (Fabric with a high rate of defects will be considered as a poor quality product).

All these conclusions are in agreement with previous studies [18–20]. The variation in the weight values can be explained by the difference in the final use of the yarn. For example, mechanical constraints applied to warp yarns during weaving are more important than that for weft yarns.

Figure 3 presents the relative weight and the ranking of each property studied for the three yarn employments. Since $CR$ is less than 0.1, the consistency ratio of $A$ is acceptable [16, 17]. Results indicate for each yarn the characteristic that spinner or knitter should give the priority to improve the quality and therefore, the customer satisfaction.
CONCLUSION
The evaluation of the global quality of the yarn is a multi-criteria problem. In many cases, especially when we make a survey to optimise the properties of yarns, we need a Global Quality Index.
In this paper, we used the ‘new approach’ Analytic Hierarchy Process AHP and Fuzzy theory to determine a simple Quality Yarn Index QYI taking into account important properties of the yarn and their weights.
This same approach can be used in other textile fields when different properties affect the quality of the final product.
Further studies are necessary to apply the method for a specific application (optimization of the quality of waste yarn for example).

REFERENCES

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