Sensory evaluation based fuzzy AHP approach for material selection in customized garment design and development process

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Abstract. Material selection is the most difficult section in the customized garment product design and development process. This study aims to create a hierarchical framework for material selection. The analytic hierarchy process and fuzzy sets theories have been applied to mindshare the diverse requirements from the customer and inherent interaction/interdependencies among these requirements. Sensory evaluation ensures a quick and effective selection without complex laboratory test such as KES and FAST, using the professional knowledge of the designers. A real empirical application for the physically disabled people is carried out to demonstrate the proposed method. Both the theoretical and practical background of this paper have indicated the fuzzy analytical network process can capture expert’s knowledge existing in the form of incomplete, ambiguous and vague information for the mutual influence on attribute and criteria of the material selection.

1. Introduction
Material selection has been considered to be the main task for the designers in the garment design and development process. Utilizing the ideal material assists enterprises to follow market position, satisfy the customers, and shorten the product development cycle, permitting to quick feedback from the market. The increasing requirement for customized design strengthened the importance of the fabric selection, especially for the design with special requirement such as disability, functionality and protection [1].

Traditionally, designers select an appropriate fabric material based on their knowledge and experience for fashion product development. When preparing a customized design collection, the designers will search a collection of fabric, referring to the current trend and the requirement of the customer. Then, based on the desired style of the garment, fabrics are generally selected by garment designers according to a number of physical and basic sensory criteria such as fabric hand and fabric appearance. The sensory evaluation based on individual sensory criteria can be fast and effective for
the designers, but the decision-making can be difficult. Also, as the designers have no specific training about the physical parameters of the fabric, there are test systems developed to help the designers acquire the mechanical properties such as KES. But the test is time consuming and the KES test machine is expensive. The result can be very precise but it is not so applicable because of the time and expense problem [2].

In practice, the issues for selecting the most suitable fabric have emerged as the most crucial topics for the designers. The requirements from the market and the similarity among the fabrics influentially affect the designers to make the decision. The selection of fabrics for specific market is a multi-criteria decision making problem. There are considerable numbers of decision models have been developed to analysis the factors from the goal, such as the preference ranking organization method, the analytical hierarchy process (AHP), discrete choice analysis, and data envelopment analysis. Using these models, the weight and the grade of importance can be quantized to demonstrate the preference of different factors in the material selection. If the importance of a criterion can be captured properly, the quality of the decision-making for material selection will be enhanced correspondingly. However, the available information in a multi-criteria decision process is usually uncertain, vague, or imprecise, and the criteria are not independent in the real situation. In the real world, this usually exists when the brand image selection is full of uncertainty and the imprecision of human subjective judgment. Thus, in this paper fuzzy sets theory is used to cope with these situations [3].

In this context, a sensory evaluation based fuzzy AHP approach is proposed for material selection in customized garment design and development process.

2. Methodologies and scope of study
It can be easily found that, the main difficulties of in this study are as follows:
(1) Acquisition of customer’s requirements and needs;
(2) Application of textile knowledge for the analysis and comparison of customer’s requirements and needs;
(3) Knowledge representation and classification. The methodologies and scope will be discussed in these aspects.

2.1. Knowledge acquisition and classification
For the acquisition of the customer’s requirement and expert’s experience and knowledge, fuzzy set, fuzzy numbers and fuzzy semantic representation will be applied.

Fuzzy sets and fuzzy numbers: The applications of fuzzy techniques are mainly concentrated on domestic appliances like washing machines, air conditioners, cameras and camcorders as well as public devices such as water treatment systems, port cranes, subways and ventilation systems.

Compared with other tools of artificial intelligence, fuzzy techniques are particularly efficient for processing information uncertainty and imprecision related to human factors. It is for this reason that researchers have paid much attention to fuzzy techniques when developing decision support systems in uncertain environments, such as finance and medical diagnosis [4].

Fuzzy semantic representation: Normally, when in the evaluation of certain things, people will use descriptive language to express their feelings at most of the time. In order to make the computer identify these things, a way to quantify the human thought patterns with different semantics to be expressed in the form of the number must be chosen. This study uses semantic variables method to convert fuzzy semantic value in the form of Triangular Fuzzy Numbers [5].

2.2. Multi-criteria decision-making (MCDM)
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 their 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 [6].

3. General research scheme using fuzzy AHP method based on sensory evaluation
In this study, a sensory evaluation based fuzzy AHP approach is proposed for material selection in customized garment design and development process. A real empirical application for the physically disabled people is carried out to demonstrate the proposed method. The general research scheme is described in figure 1.

![Figure 1. General research scheme using fuzzy AHP method based on sensory evaluation.](image)

Firstly, the requirements from the market (consumer) will be analyzed. Then, the related wearing characteristics will be discussed. Fuzzy set will be applied in the following procedure to capture the importance of the requirements and wearing characteristics. Next, a collection of sensory evaluation experiment will be carried out to compare the pre-selected fabrics based on different wearing characteristics.

The final fabric will be selected based on the score ranking, determined by the sensory evaluation score and their corresponding weight value given from the analytical hierarchy process.

4. Construction of fuzzy AHP in material selection
The analytic hierarchy process (AHP) is developed to help decision makers modeling a complex problem in a hierarchical structure showing the relationships of the goal, objectives (criteria), sub-objectives, and alternatives (figure 2). All influencing factors can also be included. AHP enables decision-makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. AHP has the following functions: (1) helping the decision-makers structure the issues into goal, attributes (criteria) and alternative, (2) permitting to obtain the weight of all alternatives that are deficient with respect to one or more objectives can compensate by their performance with respect to other objectives. The AHP procedure involves six essential steps [7].
1. Define the unstructured problem
2. Developing the AHP hierarchy
3. Pair-wise comparison

3
4. Estimate the relative weights

- **Objective**

![Hierarchy structure of decision problem.](image)

4.1. **Formation the structure of decision hierarchy and developing the AHP hierarchy**

4.2. **The goal in the analytical hierarchy process is to select the most suitable fabric aiming at the specific target market. To get the goal, the requirements should be considered. Then, the wearing characteristics related to the requirements can be defined.**

Let $B$ be a set of $n$ requirement criteria, denoted as $B=\{b_1, ..., b_n\}$. Let $C$ be a set of $m$ wearing characteristics, denoted as $C=\{c_1, ..., c_m\}$. Then, the problem of material selection can be decomposed into a hierarchical structure.

4.3. **Pair-wise comparison**

In this step, the relational data for comparing the alternatives or options are generated. This requires the decision maker to evaluate the relative importance and then 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 $N$ judgment matrices of alternatives of $M \times M$ order and one judgment matrix of criteria of $N \times N$ order.

The Triangular Fuzzy Numbers was introduced to quantify the 7-point scales of linguistic description of the intensity of importance. Table 1 shows the relation between the intensity of importance on an absolute scale and Triangular Fuzzy Numbers [8].

| Linguistic Descriptions | Triangular Fuzzy Numbers |
|------------------------|-------------------------|
| Extreme Unimportant    | (0,0,1)                 |
| Very Unimportant       | (0,1,3)                 |
| Rather Unimportant     | (1,3,5)                 |
| Average                | (3,5,7)                 |
| Rather Important       | (5,7,9)                 |
| Very Important         | (7,9,10)                |
| Extreme Important      | (9,10,10)               |

4.4. **Estimate the relative weights**

The relative importance of different elements in each pair-wise comparison matrix can be determined using the Triangular Fuzzy Numbers in table 1.

First, the relevant importance of the fabric requirements with respect to the goal should be discussed. In this process the experience of wearer should be acquired. Sensory evaluation method was
applied in the process. M disabled people were interviewed to compare the importance of the fabric requirements with respect to the goal.

N experts in textile engineering were interviewed compare the importance and the wearing characteristics. In this process the experience and knowledge was applied and simulated.

If m is the wearing characteristics, m=1, 2, ……, 9, i is the fabric requirement, i=1, 2, 3, 4, n is the number of experts, n=1, 2, ……, N, the result can be represented with Triangular Fuzzy Numbers in the format as

\[ \tilde{t}_{im} = (t_{im1}, t_{im2}, t_{im3}) = \left( \frac{1}{k} \sum_{i=1}^{n} t_{im1}, \frac{1}{k} \sum_{i=1}^{n} t_{im2}, \frac{1}{k} \sum_{i=1}^{n} t_{im3} \right) \]  

For H criteria the size of the comparison matrix (H1) will be H*H and the entry \( H_{ij} \) will devote the relative importance of criterion i with respect to the criterion j. in the matrix, \( H_{ij} = 1 \) and \( H_{ji} = \frac{1}{H_{ij}} \).

The relative weights (W) of matrix A is obtained from following equation:

\[ AW = \lambda_{max} W, \]  

Where \( \lambda_{max} \) is the biggest eigenvalue of matrix A, I = unit matrix.

\[ \lambda = \frac{1}{n} \sum_{i=1}^{n} (\lambda W) \]  

4.5. Check the consistency and Obtain the overall rating

In this step the consistency property of matrices is checked to ensure that the judgments of decision makers are consistent. For this end some pre-parameter is needed. Consistency Index (CI) is calculated as:

\[ CI = \frac{\lambda_{max} - N}{n - 1} \]  

The consistency index of a randomly generated reciprocal matrix shall be called to the random index (RI), with reciprocals forced. Using a sample size of 100 generated an average RI for the matrices of order 1–15. The table of random indexes of the matrices of order 1–15 can be seen in Saaty. The last ratio that has to be calculated is CR (Consistency Ratio). Generally, if CR is less than 0.1, the judgments are consistent, so the derived weights can be used. The formulation of CR is:

\[ CR = \frac{CI}{RI} \]  

Then the relative weights of decision elements are aggregated to obtain an overall rating for the alternatives as follows:

\[ w_k = \frac{\sum_{j=1}^{n} a_{kj}}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}}, \quad W = (w_1, w_2, \ldots, w_n)^T \]  

where \( \lambda_{max} \) means the maximum Characteristic root of the pairwise comparison matrix A, W is the corresponding eigenvector of the maximum Characteristic root. After this, the weight values should be synthesized to get the relevant importance of the wearing characteristics.

| Table 2. Relative weights of the wearing characteristics. |
|-----------------|--------|
| Wearing Characteristics | Weight |
| C1               | \( U_1 \) |
| C2               | \( U_2 \) |
| C3               | \( U_3 \) |
| ...              | ...    |
| Cm               | \( U_m \) |

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5. Empirical study
This study investigates a fabric selection for disabled people in the customized garment design and development process to demonstrate the proposed sensory evaluation based fuzzy AHP method.

5.1. Identifying the customer’s requirements
The need for disabled people is more complicated than that of normal people, leading to the different and special requirement of fabric selection. Elements of fabric requirement for physical disabilities should be investigated and analyzed.

In order to understand the current needs and indeed thoughts of physically disabled people about fabrics, interviews and survives were conducted in this research. These requirements includes:

Requirements from the disabled body part: Terminals of the disabled body part, such as stump of the amputation, feet of polio patients, etc., often face the problems of poor blood circulation, low skin temperature and prone to skin allergies. More soft and warm fabric is needed in these areas.

Requirements from the auxiliary tools: Auxiliary tool plays a very important role in daily life of physically disabled. Usually auxiliary tools will have a direct contact with human body. In this case, fabrics with moisture management and air management can meet the requirements for wearers well.

Requirements from safety and protection: Most of persons with disabilities have the problem of the mobility so the safety and protection performance should be put forward to meet wearer requirements. For example, physically disabled are easy to tumble, so the fabric should have a good wearing continuance.

5.2. Identifying the fabric wearing characteristics related to customer’s requirements
Based on the interview and survey of the fabric requirements for disabled people, we can also easily find that most of the requirements have a lot of relationship with the fabric wearing characteristics. From the view of product design, relationship should be investigated and analyzed between the requirements and fabric wearing characteristics. Wearing characteristics include: moisture management, air management, warmth retention property, flexibility, wearing continuance, antimicrobial resistance, stain resistance, flame resistance, antistatic, softness and other properties. But not all of these wearing characteristics will influence the wearer’s requirements a lot, so a rough selection should be conducted. After the interview of the textile expert, the following wearing characteristics are considered to be the most important criteria related to the wearer’s requirements: Softness, flexibility, moisture management, warmth retention property and wearing continuance.

5.3. Establishing the hierarchical structure
The Investigation of user requirements and fabric wearing characteristics can offer the information for the formation of decision hierarchy and also it can easily to be found that the user requirements and fabric wearing characteristics have the relationship of Hierarchy. Based on this the decision hierarchy can be formatted as figure 3.
5.4. Experiment I (Fabric selection modelling)

20 disabled people were interviewed to compare the importance of the fabric requirements with respect to the goal. 30 experts in textile engineering were interviewed to compare the importance and the wearing characteristics. In this process, the experience and knowledge was applied and simulated.

After the calculation, the weights for the obtained wearing characteristics are in Table 3.

| Wearing Characteristics | Weight |
|-------------------------|--------|
| C1                      | 23.9   |
| C2                      | 18.3   |
| C3                      | 27.6   |
| C4                      | 16.5   |
| C5                      | 13.7   |

Then the model for the selection is established.

5.5. Experiment II (Fabric selection for the garment design aiming at physically disabled people)

Here an experimental design case discussed using the proposed model. The design case is to design a summer dress for physically disabled people. Based on the request, five ideal fabrics are preselected by the designers. Then, 10 experienced designers are invited to carry out the sensory evaluation experiment. Then the wearing characteristics are compared to have a ranking. Different scores corresponding to different wearing characteristics are given from 1-5. At last, the weights of the characteristics are calculated with the sensory evaluation scores. The best fabric is then selected.

6. Conclusions

In this study, the analytic hierarchy process and fuzzy sets theories have been applied to establish a dynamic material selection model. The requirements of the customers can be fully considered and analyzed. A list of wearing characteristics and their corresponding weights can be obtained using the proposed model based on the customer’s requirements. Then, sensory evaluation experiment of preselected fabric permits to a quick and effective fabric selection based on the wearing characteristics. The analytic hierarchy process and fuzzy sets theories have been applied to mindshare the diverse requirements from the customer and inherent interaction/interdependencies among these requirements. Sensory evaluation ensures a quick and effective selection without complex laboratory test such as KES and FAST, using the professional knowledge of the designers. A real empirical application for the physically disabled people is carried out to demonstrate the proposed method. Both the theoretical and practical background of this paper have indicated the fuzzy analytical network process can capture expert’s knowledge existing in the form of incomplete, ambiguous and vague information for the mutual influence on attribute and criteria of the material selection.

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