# Applying Fuzzy Linguistic Preferences to Kansei Evaluation

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**Abstract:** Kansei engineering has been developed as an effective methodology to deal with customers' feeling and demands and further translate them into the design elements of a product. It is very important to determine and substantiate the measure of Kansei preferences before its utilization and performance. Kansei evaluation plays a vital role in the implementation of Kansei engineering; however, it is difficult to quantitatively evaluate customers' preferences on Kansei attributes of products as such preferences involve the human perceptual interpretation with certain subjectivity, uncertainty, and imprecision. This study presents a fuzzy linguistic preference approach for Kansei evaluation. The proposed approach is based on fuzzy linguistic variables associated with the fuzzy weighted average techniques for aggregating Kansei preference information. A case study was conducted to illustrate the implementation of the proposed approach.

**Keywords:** Kansei Evaluation, Fuzzy Linguistic Variables, Kansei Preferences, Aggregation, Fuzzy Weighted Average.

## 1. INTRODUCTION

In today's highly competitive and uncertain market environment with short product life cycles, companies have to develop every aspect of the quality of products to satisfy customers' requirements as well as to guarantee their market success. Kansei engineering has been developed as a consumer-oriented technology to deal with customers' emotional responses and further translate them into the design elements of a product (Nagamachi, 2002). It has been widely employed in various design fields during the past few decades (Fukushima et al., 1995; Jindo & Hirasago, 1997; Nakada, 1997; Tanoue et al., 1997; Chang et al., 2006; Huang et al., 2011). Kansei evaluation is an important process to determine and substantiate the measure of customer preferences prior to the utilization and performance of Kansei engineering. Many studies have conducted Kansei evaluation (KE) in the literature in which statistical analysis associated with semantic differential (SD) method is widely employed to quantify human perception for an understanding of Kansei preferences (e.g., Hsu et al., 2000; Mondragón et al., 2005; Llinares & Page, 2007; Smith & Fu, 2011; Lin et al., 2012). Conventional statistical analysis methods suppose that customers' preferences increase or decrease linearly as Kansei attributes improve or get worse. However, in many cases these attributes can be a non-linear pattern with imprecision and vagueness of meanings, where the attributes perceived as satisfactory are not the same as those perceived as dissatisfactory. This non-linear behavior requires special analytical techniques to identify the different effects which variations in Kansei attributes may have on the customers' preferences. To deal with the quantitative measures of perceptual information, a number of non-linear inference techniques have been developed and used for modeling KE systems, including neural networks (Ishihara et al., 1997; Lai et al., 2006), fuzzy logic (Fukushima et al., 1995; Shimizu & Jindo, 1995; Tsai & Hsiao, 2004; Lin et al., 2007; Yan et al., 2008; Huang et al., 2011), and genetic algorithm (Tsuchiya et al., 1996; Hsiao & Tsai, 2005; Hsiao et al., 2010).

Kansei evaluation (KE) is a systematic determination of significance of customers' preferences using criteria against a set of Kansei attributes. A basic principle in KE is that valid results depend on establishing priorities for the Kansei attributes and priorities for the preferences with respect to each attribute, and synthesizing the priorities for the evaluated alternatives. Kansei attributes refer to a bipolar pair of Kansei words expressed with adjectives of emotional connotations such as beautiful, romantic, fantastic, comfortable, etc. The semantic differential (SD) method is often used as a measure to quantify Kansei attributes. In KE studies, respondents are customarily asked in a questionnaire to indicate their perceptual scales from a set of adjective descriptors. Such responses are fuzzy because the preference options often cannot be objectively and uniformly differentiated by all the respondents (Das, 2002). Many researchers consider the psychometric labeled scales as ordered-categorical data rather than interval-level data since one cannot assume that respondents perceive all pairs of adjacent levels as equidistant. However, often the wording of response levels clearly implies a symmetry of response levels about a middle category; at the very least, such a scale would fall between ordinal-level and interval-level measurement. Information efficacy may be lost when Kansei preferences are merely treated as ordinal data. Kansei preference data can be regarded as integer-level scales which have an ordered set of responses that are whole numbers. The respondent magnitude of “very comfortable”, for example, is more than that of “comfortable” but by how much is not known. Kansei preference data are thus better treated as semantic variables for measuring human perceptual interpretations.

Kansei preferences refer to a non-quantifiable, subjective, and affect-based process and involve the human perceptual interpretation with some uncertainty and imprecision. Previous research indicated that the main problem in constructing customer preference models with a good predictive performance is how to deal with nonlinear correlations between product attributes (Shimizu & Jindo, 1995; Park & Han, 2004). Fuzzy set theory offers a powerful tool for dealing with concepts and rules with uncertainty and non-linearity, especially in real-life situations where absolute precision has little relevance and a robust representation of relative trends is valuable. It launched a scientific revolution based on the premise that the key points in human thinking are not numbers, but linguistic terms (Bellman & Zadeh, 1970). The linguistic approach is an approximate technique which represents qualitative preferences as linguistic values by means of linguistic variables (Zadeh, 1975, 1976; Herrera & Herrera-Viedma, 2000). For KE situations in which the customer preferences cannot be assessed precisely in a quantitative manner but may be in a qualitative one, the use of linguistic evaluation is very appropriate (Delgado et al., 1992; Ruan & Zeng, 2004; Martínez, 2007;

Zeng et al., 2008; Yan et al., 2008; Huang et al., 2011). Accordingly, the present paper offers a Kansei evaluation approach based on fuzzy linguistic preference techniques. The aims of this study are (1) to model Kansei preferences based on fuzzy numbers for the priority analysis; and (2) to aggregate priority information and rank the order of decision alternatives by means of the fuzzy weighted average operation. An empirical study is presented to illustrate the implementation of the proposed approach. Concluding remarks are also drawn in the last section.

## 2. KANSEI PREFERENCE MODELING BASED ON FUZZY NUMBERS

The use of fuzzy sets is central to computing with words or labels as they provide a means of modeling vagueness underlying most natural linguistic terms (Zadeh, 1996; Lawry, 2001). A Kansei word is an adjective of emotional connotations describing customers' feelings towards a product. It can be regarded as a fuzzy set *A* defined by its membership function, $\mu_A$, in a universal set *X*, which is expressed as $\mu_A: X \to [0,1]$, where [0,1] denotes the interval of real number from 0 to 1, inclusive.

Kansei preferences are defined as customers' preferences on a specific Kansei attribute of a product. As shown in Figure 1, a Kansei preference *K* in the semantic space *S* is characterized by a triangular membership function that associates each semantic element *s* of *S* with a real number, $\mu_K(s)$, in the interval [0,1]. It can be thought of as containing the real numbers within some interval to varying degrees, and is expressed as $K = \{s, \mu_K(s) | s \in S\}$, where

$$\mu_K(s) = \begin{cases} \dfrac{s-a}{b-a}, a \leq s \leq b \\ \dfrac{s-c}{b-c}, b \leq s \leq c \\ 0, otherwise \end{cases}$$

The value of membership grade, $\mu_K(s)$, indicates the degree of the customer preferences close to the Kansei attribute. The Kansei preference *K* can be classified as a fuzzy number as it is a convex and normalized fuzzy set whose membership function is piecewise continuous defined on $\mathcal{R}$.

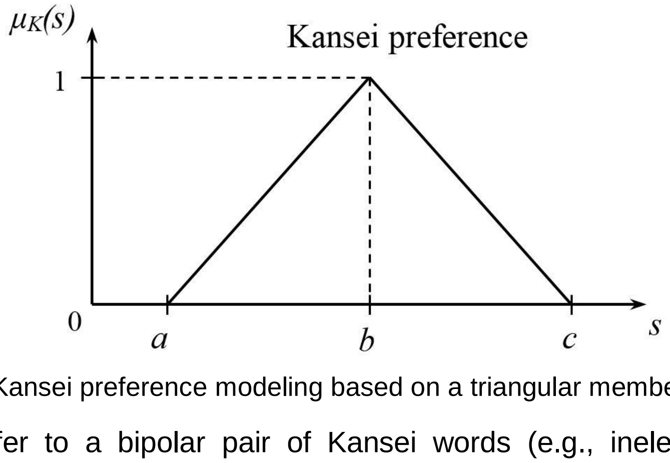



**Figure 1:** Kansei preference modeling based on a triangular membership function

Kansei attributes refer to a bipolar pair of Kansei words (e.g., inelegant/negative feelings–elegant/positive feelings) which involve different levels of adverb intensity descriptors for quantifying customers' preferences (e.g., very inelegant, inelegant, medium, elegant, and very elegant). Since triangular membership functions are a uniformly distributed ordered set of Kansei preferences in a semantic space, they provide a relatively simple way to capture the vagueness of Kansei information. Each Kansei attribute can be defined by piecewise continuous membership functions and comprises 7 semantic sets as shown in Table 1 and Figure 2. These semantic sets are allowable to describe with customers' Kansei preferences and can be quantified with corresponding triangular fuzzy numbers.

**Table 1:** Semantic sets of Kansei attributes

| Semantic label | Semantic element (Perceived intensity/Perceived importance) | Fuzzy number | Crisp number |
|---|---|---|---|
| *VL* | Very low Kansei preference<br>Very low importance | [0, 0.167] | 0 |
| *L* | Low Kansei preference<br>Low importance | [0, 0.333] | 0.167 |
| *ML* | Medium low Kansei preference<br>Medium low importance | [0.167, 0.5] | 0.333 |
| *M* | Medium Kansei preference<br>Medium importance | [0.333, 0.667] | 0.5 |
| *MH* | Medium high Kansei preference<br>Medium high importance | [0.5, 0.833] | 0.667 |
| *H* | High Kansei preference<br>High importance | [0.667, 1] | 0.833 |
| *VH* | Very high Kansei preference<br>Very high importance | [0.833, 1] | 1 |

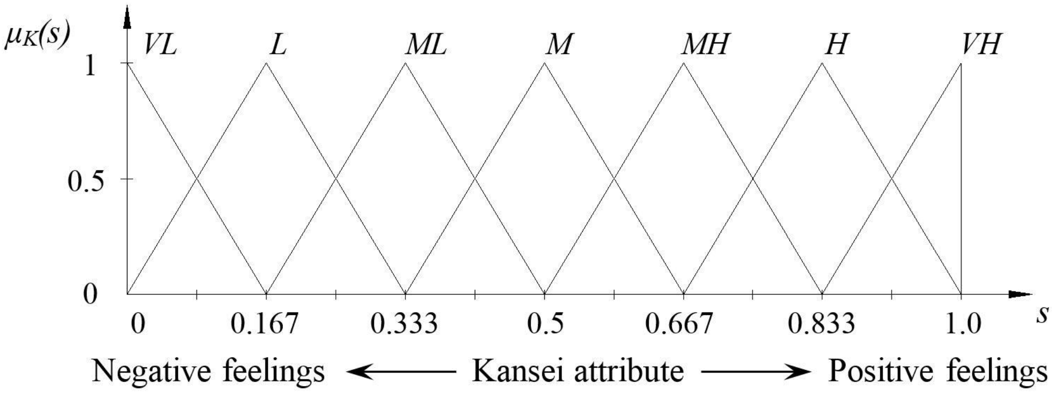



**Figure 2:** Triangular membership functions of Kansei attributes

The concept of α-cut is a means to convert a fuzzy set into a crisp set, which is very significant in the relationship between fuzzy sets and crisp sets and is also useful for defining the arithmetic operations on fuzzy numbers. The α-cut of Kansei preference *K* is a crisp set $K_\propto$ that contains all the elements of the semantic space *S* that have a membership grade in Kansei preference *K* greater than or equal to the specified value of α ($0 \leq \propto \leq 1$). The Kansei preference *K* can be a crisp number at $\propto = 1$. In establishing priorities of preference relations, fuzzy numbers are used as interval type-2 fuzzy numbers for aggregation operations that allow the incorporation of uncertainty on the Kansei evaluation.

## 3. AGGREGATION OPERATION ON FUZZY NUMBERS

Aggregation operations on fuzzy numbers are operations by which several fuzzy numbers are combined to produce a single fuzzy number (Klir & Folger, 1988). The fuzzy weighted average (FWA) is an aggregation operator used in situations where the arguments are inexact numerical variables (Dong & Wong, 1987; Kao & Liu, 2001). More specifically, it is a combination of extended algebraic operations to be used in the Kansei evaluation of alternatives when their corresponding ratings (Kansei preferences) and weights (importance) of criteria (Kansei attributes) are represented by fuzzy numbers. The operation of FWA is formularized as follows (Vanegas & Labib, 2001):

$$D_j = \frac{\sum_{k=1}^{m} w_k \cdot r_{jk}}{\sum_{k=1}^{m} w_k} \tag{1}$$

where
$D_j$ represents the overall desirability of alternative *j*;
$r_{jk}$ represents the preference of the $k^{th}$ attribute of alternative *j*; and,
$w_k$ represents the importance (weight) of the $k^{th}$ attribute.

Variables $D_j$, $r_{jk}$, and $w_k$ are fuzzy numbers. Based on the extension principle, the fuzzy arithmetic operations have been defined to manipulate fuzzy numbers (Zadeh, 1975, 1976). Any fuzzy number can be completely defined by its family of α-cuts, while extended algebraic operations can be defined based on arithmetic operations in intervals assuming that fuzzy numbers are represented by continuous membership functions. According to Klir and Yuan (1995), an arithmetic operation on fuzzy numbers A and B on $\mathcal{R}$ can be reduced to operations on intervals $A_\alpha = [a, b]$ and $B_\alpha = [c, d]$, respectively. The four arithmetic operations on closed intervals are defined below:

Addition:

$$(A + B)_\alpha = A_\alpha + B_\alpha = [a, b] + [c, d] = [a + c, b + d] \tag{2}$$

Subtraction:

$$(A - B)_\alpha = A_\alpha - B_\alpha = [a, b] - [c, d] = [a - d, b - c] \tag{3}$$

Multiplication:

$$(A \times B)_\alpha = A_\alpha \cdot B_\alpha = [a, b] \cdot [c, d] = \left[min[ac, ad, bc, bd], max[ac, ad, bc, bd]\right] \tag{4}$$

Division (provided that $0 \notin B_\alpha$ for all $\alpha \in (0,1]$):

$$(A \div B)_\alpha = \frac{A_\alpha}{B_\alpha} = \frac{[a, b]}{[c, d]} = [a, b] \cdot \left[\frac{1}{d}, \frac{1}{c}\right] = \left[min\left[\frac{a}{c}, \frac{a}{d}, \frac{b}{c}, \frac{b}{d}\right], max\left[\frac{a}{c}, \frac{a}{d}, \frac{b}{c}, \frac{b}{d}\right]\right] \tag{5}$$

The result of the four arithmetic operations is a crisp set (interval) that represents the α-cut of the fuzzy set obtained by operating on fuzzy numbers *A* and *B*. Through the arithmetic operations, the family of α-cuts defined as the resultant membership function of the evaluated alternative can be presented as a membership function curve and classified as a fuzzy number. In order to obtain a quantitative value of the resultant membership function, the center-of-gravity (COG) defuzzification method is used in this study. The formula of the COG method is expressed in Eq. (6). The higher the $\bar{s}$ value, the better is the evaluated alternative.

$$\bar{s} = \frac{\int_u^v m(s) \cdot s ds}{\int_u^v m(s) ds}$$

(6)

where

$m(s)$ represents the resultant membership function of the evaluated alternative;

$u$ and $v$ are the respective lower and upper limits of the support of the fuzzy number.

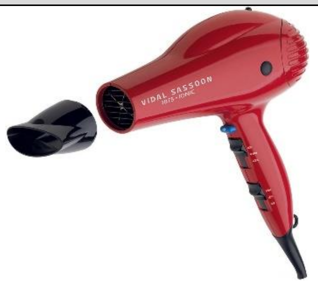
## 4. AN ILLUSTRATIVE CASE

This section conducts an empirical study to illustrate the implementation of the proposed approach. The aim of the case study is to assess the most desirable alternatives from a set of selected products in terms of customers' Kansei preferences.

### 4.1. Selecting a set of product alternatives for evaluation

A hair dryer is an electromechanical device designed to blow cool or hot air over wet or damp hair, in order to dry the hair by speeding up the evaporation of water from the hair's surface. Six branded hair dryers were selected as product alternatives to conduct the Kansei evaluation. The specifications of the product alternatives are listed in Table 2.

**Table 2:** Product alternatives for Kansei evaluation

| Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|
|   <br>Brand: VIDAL SASSOON<br>Model No.: VS547 | <br>Brand: Conair<br>Model No.: YB075W | <br>Brand: Panasonic<br>Model No.: EH-NE11-V |
| **Specifications:**<br>Dimensions: 27.9 x 10.2 x 22.9 cm<br>Weight: 0.636 kg<br>Wattage: 1875 Watts<br>Color: Red | **Specifications:**<br>Dimensions: 22.9 x 8.9 x 20.8 cm<br>Weight: 0.908 kg<br>Wattage: 1875 Watts<br>Color: Yellow | **Specifications:**<br>Dimensions: 17.2 x 7.3 x 21.8 cm<br>Weight: 0.45 kg<br>Wattage: 1200 Watts<br>Color: White/Purple |
| **Alternative 4** | **Alternative 5** | **Alternative 6** |
| <br>Brand: PHILIPS<br>Model No.: HP8213 |   <br>Brand: REVLON<br>Model No.: RVDR5092 | <br>Brand: JOHN FRIEDA<br>Model No.: JF1 |
| **Specifications:**<br>Dimensions: 16 x 9.3 x 28 cm<br>Weight: 0.636 kg<br>Wattage: 1500 Watts<br>Color: White/Purple | **Specifications:**<br>Dimensions: 25.4 x 10.5 x 27.9 cm<br>Weight: 0.908 kg<br>Wattage: 1875 Watts<br>Color: Pink/Black | **Specifications:**<br>Dimensions: 21.6 x 9.8 x 29.2 cm<br>Weight: 0.545 kg<br>Wattage: 1875 Watts<br>Color: Silver |

## 4.2. Collecting a set of Kansei adjectives as semantic elements for Kansei evaluation

The trend of product development is moving towards incorporating customers' affective needs into design elements that deliver customers' Kansei preferences. In establishing a product's attractiveness, the use of perceptual scales can provide a qualified approach for evaluation purposes. The question for measuring customers' perceptual scales is "What kind of feelings do you stress when purchasing a hair dryer". There were 7 pairs of adjectives selected as the Kansei attributes for evaluating hair dryers. According to the Kansei preference modeling given in section 2, the perceived intensity and perceived importance of these Kansei attributes are listed in Table 3.

**Table 3:** Perceived intensity and perceived importance of the Kansei attributes (KAs)

| **Semantic label** | | ***VH*** | ***H*** | ***MH*** | ***M*** | ***ML*** | ***L*** | ***VL*** | |
|---|---|---|---|---|---|---|---|---|---|
| **Fuzzy number** | | **[0.833, 1]** | **[0.667, 1]** | **[0.5, 0.833]** | **[0.333, 0.667]** | **[0.167, 0.5]** | **[0, 0.333]** | **[0, 0.167]** | |
| | Positive feelings | ⟵ | | | | | | ⟶ | Negative feelings |
| $KA_1$ | Handy | □ | □ | □ | □ | □ | □ | □ | Awkward |
| $KA_2$ | Elegant | □ | □ | □ | □ | □ | □ | □ | Inelegant |
| $KA_3$ | Stylish | □ | □ | □ | □ | □ | □ | □ | Styleless |
| $KA_4$ | Fashionable | □ | □ | □ | □ | □ | □ | □ | Unfashionable |
| $KA_5$ | Simplificative | □ | □ | □ | □ | □ | □ | □ | Complicated |
| $KA_6$ | Convenient | □ | □ | □ | □ | □ | □ | □ | Inconvenient |
| $KA_7$ | Novel | □ | □ | □ | □ | □ | □ | □ | Ordinary |
| Weight | Important | □ | □ | □ | □ | □ | □ | □ | Unimportant |

## 4.3. Establishing priorities for obtaining Kansei preference variables

According to the Kansei attributes, evaluators establish priorities for the Kansei attributes and priorities for the Kansei preferences corresponding to each product alternative. The evaluation scales are semantic labels of fuzzy numbers shown in Table 3. After completing the priority analysis, two sets of Kansei preference variables are obtained as follows.

$$R = [r_{jk}] = \begin{bmatrix} ML & L & M & L & H & M & L \\ L & L & MH & M & H & ML & MH \\ H & M & H & MH & M & H & H \\ VH & M & H & H & MH & H & H \\ M & MH & H & H & MH & MH & M \\ MH & M & MH & MH & H & MH & M \end{bmatrix}$$

$$= \begin{bmatrix} [0.167, 0.5] & [0, 0.333] & [0.333, 0.667] & [0, 0.333] & [0.667, 1] & [0.333, 0.667] & [0, 0.333] \\ [0, 0.333] & [0, 0.333] & [0.5, 0.833] & [0.333, 0.667] & [0.667, 1] & [0.167, 0.5] & [0.5, 0.833] \\ [0.667, 1] & [0.333, 0.667] & [0.667, 1] & [0.5, 0.833] & [0.333, 0.667] & [0.667, 1] & [0.667, 1] \\ [0.833, 1] & [0.333, 0.667] & [0.667, 1] & [0.667, 1] & [0.5, 0.833] & [0.667, 1] & [0.667, 1] \\ [0.333, 0.667] & [0.5, 0.833] & [0.667, 1] & [0.667, 1] & [0.5, 0.833] & [0.5, 0.833] & [0.333, 0.667] \\ [0.5, 0.833] & [0.333, 0.667] & [0.5, 0.833] & [0.5, 0.833] & [0.667, 1] & [0.5, 0.833] & [0.333, 0.667] \end{bmatrix} \quad (7)$$

$$W = [w_k] = [VH \quad H \quad MH \quad H \quad H \quad MH \quad H]$$

$$= \left[ [0.833, 1] \quad [0.667, 1] \quad [0.5, 0.833] \quad [0.667, 1] \quad [0.667, 1] \quad [0.5, 0.833] \quad [0.667, 1] \right] \quad (8)$$

## 4.4. Aggregating the priority information and rank the alternative products

Substituting the above two sets of Kansei preference variables into Eq. (1) to perform the FWA operation, the resultant membership functions of the evaluated alternatives can be derived which are presented in membership function curves as shown in Figure 3.

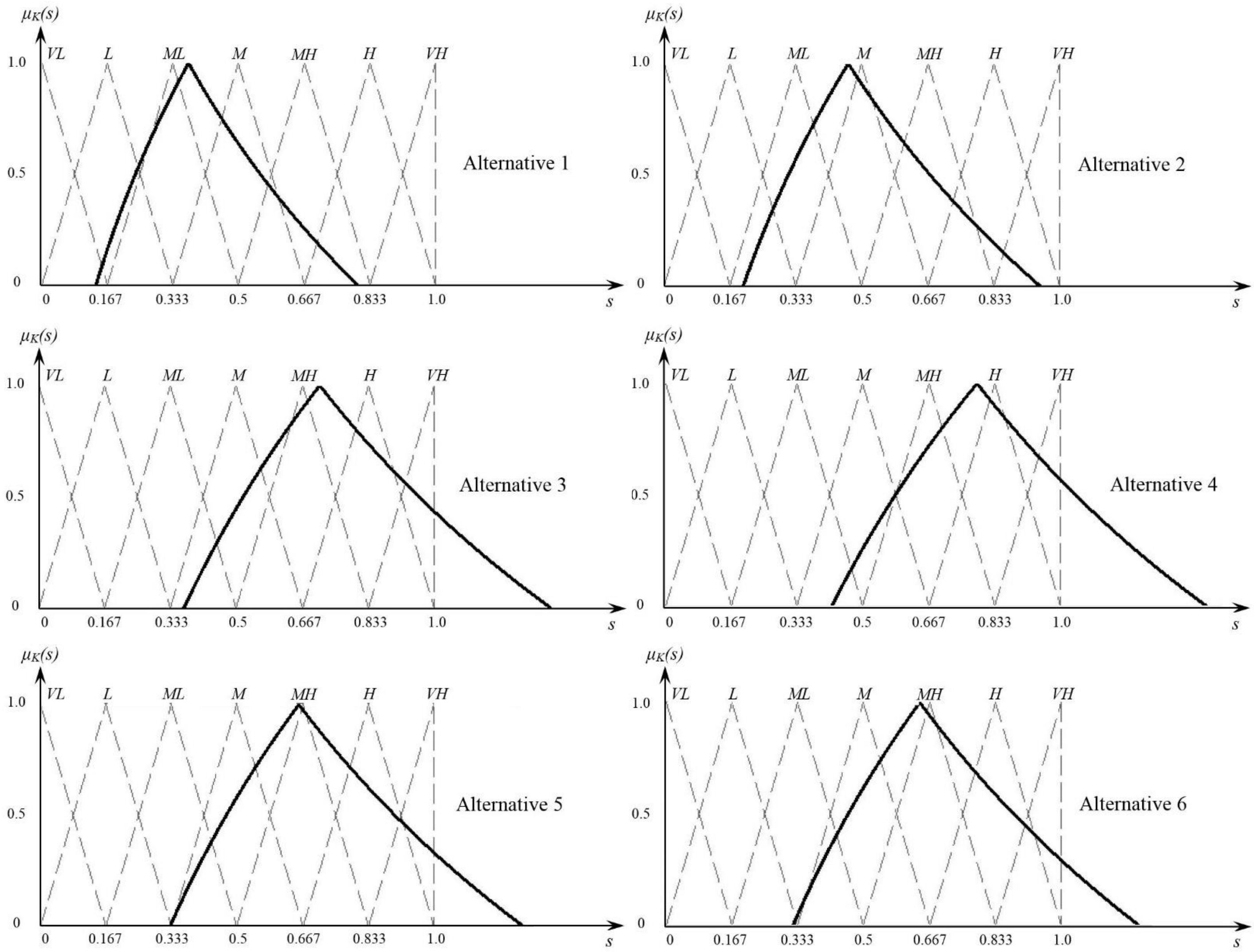


**Figure 3:** Resultant membership function curves of the evaluated alternatives

By using Eq. (6), we can defuzzificate these fuzzy numbers and consequently rank the alternative products by the quantitative values. The final results are listed in Table 4. According to the Kansei evaluation results, the best product is Alternative 4 while the worst is Alternative 1.

**Table 4:** Final results of the Kansei evaluation

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 | Alternative 5 | Alternative 6 |
|---|---|---|---|---|---|---|
| Quantitative values | 0.421 | 0.521 | 0.77 | 0.839 | 0.718 | 0.7 |
| Rank | 6 | 5 | 2 | 1 | 3 | 4 |

## 5. CONCLUDING REMARKS

Kansei evaluation (KE) plays a vital role in the implementation of Kansei engineering; however, it is difficult to quantitatively evaluate customers' preferences on Kansei attributes of products as such preferences involve the human perceptual interpretation with certain subjectivity, uncertainty, and imprecision. This paper presents a Kansei evaluation approach based on fuzzy linguistic preference techniques. Fuzzy linguistic approach deals with Kansei preferences and attributes through natural language instead of numbers. It emulates human cognitive processes to improve solving processes of problems dealing with uncertainty, imprecision, and subjective vagueness.

In the proposed approach, Kansei preferences are modeled by using fuzzy numbers to establish priorities for the Kansei attributes and priorities for the customer preferences with respect to each attribute. Since fuzzy numbers are interval scales derived from the evaluators' linguistic judgments, evaluators feel more confident about giving their perceptual interpretations in the form of semantic sets. Moreover, the preference variables are aggregated by means of the FWA method. The use of FWA allows the evaluators to incorporate unquantifiable information, incomplete information, non-obtainable information, and partially ignorant facts into a decision model; hence, this approach is capable of capturing evaluators' appraisals of ambiguity and is valid for dealing with Kansei evaluation problems. Kansei clustering is an important step to justify that a set of much fewer selected Kansei adjectives can be used to represent the whole meaning of all the Kansei adjectives collected from the customers. Based on the proposed approach, further research could focus on developing a cluster analysis method for classifying Kansei attributes.

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