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A fuzzy ordinary regression method for modeling customer preference in tea maker design

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ABSTRACT

Faced with fierce competition in marketplaces, manufacturers need to determine the appropriate settings of engineering characteristics of the new products so that the best customer preferences of the products can be obtained. To achieve this, functional models relating customer preferences to engineering characteristics need to be developed. As information regarding functional relationships between customer preferences are generally subjective or heuristic in nature, development of the customer preference models involve two uncertainties, namely fuzziness and randomness. Existing approaches use only fuzzy-based technologies to address the uncertainty caused by fuzziness. They are not designed to address the randomness of the observed data which is caused by a limited knowledge of the variability of influences between customer preferences and engineering characteristics. In this article, a fuzzy ordinary regression method is proposed to develop the customer preference models which are capable of addressing the two uncertainties of crispness and fuzziness of the customer preferences. A case study of a tea maker design which involves both uncertainties is used to demonstrate the effectiveness of the proposed method.

1. Introduction

Nowadays, global competition and the development of novel manufacturing technologies have dramatically changed the operating environment of commercial industries [18]. Vigorous challenges have transformed many manufacturers from production-centralized to customer-driven ones. If manufacturers were able to develop new products which satisfy customer preferences, this would give them a competitive advantage. New product planning is a complex process involving different perspectives including identifying customers and markets to be targeted, defining products to be developed and determining settings of engineering characteristics of the products [23]. This paper aims at presenting a methodology to address the third issue which is to determine the optimal engineering characteristics of the products. It is the key to satisfying the customer preferences before manufacturing the products; this increases the probability of success for the new product in the marketplace [2].

To determine the optimal engineering characteristics of new products, quality function deployment (QFD) [10] has commonly been used. The QFD utilizes a matrix, namely houses of quality (HOQ), to relate customer preferences to engineering characteristics. Target values of engineering characteristics, normally housed at the bottom of a HOQ, provide definitive and quantitative technical specifications for new products. However, determining the HOQ associated with engineering characteristics is a complex decision-making process with multiple variables, and also it is normally accomplished in a subjective or heuristic manner; therefore, there is no guarantee that optimal engineering characteristics can be achieved.

Alternatively, we can develop a customer preference model which illustrates the relationship between customer preferences and engineering characteristics. Based on the customer preference model, optimal engineering characteristics of new products can be determined with respect to the specified customer preferences. This customer preference model is developed using numerical experimental data or customer survey data which investigates various customer preferences with respect to engineering characteristics (Chan et al. 2013). As the customer preferences are subjective and heuristic measures, fuzzy based modeling methodologies are commonly used. A fuzzy neural network model has been developed based on customers' survey data with different age groups, in order to study the customer preferences of the

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affective design of chair products [19,13]. A similar approach based on a fuzzy neural network model has been developed in order to generate an image of a new product described with the corresponding engineering characteristics when particular customer preferences are given. A fuzzy inference system has been developed to represent the customer preference models for the affective design of mobile phones, where better modeling results can be obtained compared with the more complicated neural networks approach [15]. Also, a fuzzy logic model has been proposed by integrating the customer preferences when using e-commerce into a single fuzzy quantity, in order to evaluate the overall customer satisfaction [16]. However, these methods can generate only implicit customer satisfaction models, which give no explicit information. These methods are not widely utilized by engineers as no analytical information such as their significance for engineering characteristics can be indicated by the implicit customer satisfaction models. They reveal no explicit reasons for the design. Also, neural networks have the similar limitation that they cannot generate explicit information for new product development. Apart from these fuzzy modeling methods, statistical multivariate analysis techniques and genetic programming have been used to explain the relationship between the engineering characteristics of new products and customer preferences [3,7–9,24]. However, these techniques have limitations due to their inability to capture the fuzziness of consumer requirements.

To address both the fuzziness and the explicitness of the customer preference models, a linear fuzzy regression has been applied, whereby the fuzzy coefficients are used to represent the uncertainty of customer preferences [14]. The significance and fuzziness of each engineering characteristic is indicated by the fuzzy regression formulations. However, the fuzzy coefficients generated by the approach are in symmetric triangular form which is likely to create unnecessary outliers. Hence, it is not effective as a means of satisfying all features for customer preferences. Another approach of fuzzy regression integrated with asymmetric triangular fuzzy coefficients is applied to develop a functional model in QFD in order to represent the relationship between customer preferences and engineering characteristics ([4,5,6]. This approach is intended to increase the flexibility of the fuzzy regression in satisfying all customer preference data by the asymmetric triangular fuzzy coefficients. However, they are not designed to address the randomness of the observed data which is a result of the limited knowledge of variability of the amount of influence between customer preferences and engineering characteristics.

In this article, a fuzzy ordinary regression method, namely FORM, is proposed to model both crispness and fuzziness of the experimental data [14], in order to address both the fuzziness and randomness of the customer preference models. The FORM is applied to the designing of a tea maker, as the experimental data used for investigating tea maker design contains the uncertainties associated with both randomness and fuzziness. Fuzzy regression is used to deal with uncertainty due to fuzziness and ordinary regression deals with uncertainty as random residuals. The FORM overcomes the limitation of fuzzy regression that only address uncertainty due to fuzziness and it overcomes the limitation of ordinary statistical regression that only address uncertainty due to randomness. The effectiveness of the FORM is evaluated through the design. Section 2 presents the customer preferences and the engineering characteristics when designing the tea makers. Section 3 demonstrates how the FORM can be formulated to develop the customer preference models for the tea makers. Section IV presents the experimental data used when investigating the customer preferences of the tea makers, and it also demonstrates the effectiveness of the FORM when designing the tea makers compared with other commonly-used fuzzy regression methods. A conclusion is given in Section 5.

2. Customer preference models for tea maker design

In tea maker design, manufacturers generally aim to optimize two customer preferences when making tea, namely catechin content and tea concentration. Catechin content is a type of antioxidant found in great abundance in the leaves of the tea plant. Its health benefits have been under close examination, due to tea consumption being associated with health and longevity in many ancient cultures. Tea concentration elicits three affective streams from tea drinkers namely the rating of tea in terms of aroma, texture and overall taste tea. These two customer preferences indicate the preferences of the tea drinkers. Here the catechin content and the tea concentration are denoted as y_1 and y_2 respectively.

For brewing tea, the manufacturing company supporting this research implemented the following five steps as the mechanisms for the tea maker, an illustration of which is provided in Fig. A1 in the Appendix. Based on the company supporting this research, five engineering characteristics namely x_1, x_2, x_3, x_4 and x_5 which are correlated to y_1 and y_2 are identified and discussed in the following.

Step 1: Heating the fresh water
Two and half litres of fresh water are poured into container II of the tea maker, and are heated to 98 °C.

Step 2: Placing the tea and reheating the water
Seventy grams of tea leaves are poured into the tea infuser which is then placed into container I of the tea maker. As the original temperature of the water decreases due to the heat lost by immersing the cold tea infuser, the water needs to be reheated in order to keep the temperature at a certain level. The reheat temperature is identified as the first engineering characteristic x_1.

Step 3: First brewing cycle
After the water is reheated, the tea is brewed through the first brewing cycle. The tea infuser is dropped into the water a certain number of times in order to release chemical contents. For each drop, the tea infuser is immersed in the water for 10 s and then 10 s elapse before the next drop. The number of drops is identified as the second engineering characteristic x_2.

Step 4: Tea dipping
The tea brewed through cycle one is immersed in the water in order to release the chemical contents. The amount of immersion time is identified as the third engineering characteristic x_3.

Step 5: Second brewing cycle
The second brewing cycle is intended to release more chemical contents into the water. Similar to the first brewing cycle, the tea infuser is immersed into the water with for a certain drops. At each drop, the tea infuser is immersed in the water for a certain amount of time and then 10 s elapse before the next drop. The number of drops the tea infuser is immersed into the water and the immersion time are identified as the fourth engineering characteristic x_4 and the fifth engineering characteristic x_5 respectively.

Therefore, the five engineering characteristics which are significant to the customer preferences of the tea makers are identified as: reheating temperature (x_1), number of drops in the first brewing cycle (x_2), dipping time (x_3), number of drops in the second brewing cycle (x_4), and immersion time in the second brewing cycle (x_5).

A key feature of tea maker design is to develop the functional relationships, namely customer preference models, in order to correlate the specified customer preferences with the identified engineering characteristics. The customer preference models are