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Decision making with extended fuzzy linguistic computing, with applications to new product development and survey analysis

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ABSTRACT

Fuzzy set theory, with its ability to capture and process uncertainties and vagueness inherent in subjective human reasoning, has been under continuous development since its introduction in the 1960s. Recently, the 2-tuple fuzzy linguistic computing has been proposed as a methodology to aggregate fuzzy opinions (Herrera & Martinez, 2000a, 2000b), for example, in the evaluation of new product development performance (Wang, 2009) and in customer satisfactory level survey analysis (Lin & Lee, 2009). The 2-tuple fuzzy linguistic approach has the advantage of avoiding information loss that can potentially occur when combining opinions of experts. Given the fuzzy ratings of the evaluators, the computation procedure used in both Wang (2009) and Lin and Lee (2009) returned a single crisp value as an output, representing the average judgment of those evaluators. In this article, we take an alternative view that the result of aggregating fuzzy ratings should be fuzzy itself, and therefore we further develop the 2-tuple fuzzy linguistic methodology so that its output is a fuzzy number describing the aggregation of opinions. We demonstrate the utility of the extended fuzzy linguistic computing methodology by applying it to two data sets: (i) the evaluation of a new product idea in a Taiwanese electronics manufacturing firm and (ii) the evaluation of the investment benefit of a proposed facility site.

1. Introduction

The strength of fuzzy set theory, which was first proposed by Zadeh (1965), lies in its ability to represent and process both uncertainties in measurements and vagueness in concepts expressed in the natural language. Unlike the classical set theory in which an element must either belong or not belong to a set of interest, an object in the universe of discourse can instead be a member of a fuzzy set to some degree. This added flexibility allows mathematical representation of non-precise human concepts and enables a proliferation of fuzzy set theory applications in a broad range of industrial engineering and electronics areas today.

The pervasiveness of applications of fuzzy set theory in industrial engineering research can in fact be found in the recent issues of Expert Systems with Applications (Chuang, Lin, Kung, & Lin, 2010; Dursun & Karsak, 2010; Galetakis & Vasiliou, 2010; Lin, 2010; Pan, 2010; Sen & Baraçlı, 2010): for example, it was used in aggregating evaluators' opinions in new product development (Wang, 2009) and in survey analysis (Lin & Lee, 2009). As the capability to introduce marketable new products is essential in maintaining and advancing the competitiveness of a firm relative to its rivals, accurate decision making in the domain of new product development becomes increasingly important, and thus the evaluations of new product ideas nowadays are usually carried out by a committee of experts. As pointed out in Hwang and Yoon (1981) and Wang (2009), a great deal of fuzziness and inhomogeneity can occur across the experts' subjective perceptions and cognitions, and as a results, the subsequent information integration could lead to evaluation results being incompatible with the experts' expectations. Hence, Wang (2009) proposed using a 2-tuple fuzzy linguistic approach for new product development evaluation that can avoid information loss inherent in other fuzzy approaches (Herrera-Viedma, Herrera, Martinez, Herrera, & Lopez, 2004). Similarly, Lin and Lee (2009) applied fuzzy linguistic computing to analyze customer satisfactory level survey data. Vague concepts like *strongly unsatisfactory*, *unsatisfactory*, *average*, *satisfactory* and *strongly satisfactory* were represented by fuzzy linguistic terms. In the methodologies of both Lin and Lee (2009) and Wang (2009), the evaluators were required not only to rate the sufficiency of a product idea/service under consideration with respect to various pre-determined criteria and sub-criteria, but also to rate the importance of the criteria and sub-criteria themselves, in determining the overall viability of a new product idea or satisfaction level of a service. This double rating helped capture more fully the experiential cognition of the evaluators.

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The computation procedure used in the above mentioned papers took the fuzzy ratings given by the individual evaluators as inputs and returned a single crisp value describing the average judgment of the evaluators. In this article, we propose to expand the methodology by outputting not a crisp value, but a fuzzy number to represent the aggregation of opinions. This makes logical sense in that one would expect the result of aggregating fuzzy ratings to be fuzzy itself. Furthermore, the resulting fuzzy number can be viewed as a fuzzy set theory analog of the statistical interval used in classical statistics. For example, in the case of customer satisfactory level analysis, a service under consideration might get an overall average crisp rating of "satisfactory." The fuzzy number that will be obtained with the proposed methodology represents how confident we are that the service is indeed "satisfactory," reflected by how much of the support of the associated membership function is contained within the support of the linguistic term "satisfactory." A procedure to formulate and compute statistical confidence intervals for fuzzy data has actually been proposed recently in Wu (2009). It involved the use of α-cut (denoted as h-level set in that paper) and the extension principles in Zadeh (1975a, 1975b, 1975c), leading to an interesting but mathematically non-trivial optimization problem. In this article, we propose to use an alternative formulation based on sampling distribution, giving an efficient and simple procedure for calculating the fuzzy number.

The article is organized as follows: In Section 2, the basic format of the survey questionnaires used in eliciting evaluators' opinions and the 2-tuple fuzzy linguistic approach for aggregating the opinions used in Lin and Lee (2009) and Wang (2009) will be reviewed. After that, we will describe a computationally efficient framework for calculating a fuzzy number representing the aggregation of opinions. In Section 3, we will apply the proposed methodology on evaluating new product development ideas and on survey analysis. A brief summary will be given in Section 4.

2. Background and methodology

2.1. Format of the survey questionnaires

The questionnaires used in Lin and Lee (2009) and Wang (2009) have the following common format: A typical questionnaire, for instance to evaluate a new product idea, consists of several main criteria, such as the research and development capability of the firm in producing a prototype, the organizational capacity in manufacturing the proposed product, and the marketability of the product. Associated with each of these main criteria are several sub-criteria. Under the marketability heading, these sub-criteria could be (i) the present market share of related products, (ii) the potential number of major customers, and so on. As discussed in the Introduction, an individual decision maker will rate the product idea with respect to each sub-criterion, for example, giving an "excellent" rating for the product idea regarding item (i) and an "average" rating regarding item (ii), the ratings being chosen from a list of linguistic terms *very poor*, *poor*, *average*, *good*, and *excellent*. This yields a first set of ratings. In addition, each decision maker will rate the criteria and each of the associated sub-criteria themselves in order to express his/her opinion about the relative importance of the criteria and sub-criteria in determining the overall viability of a product idea. For example, he/she could give an "important" rating for item (i) and a "very important" rating for item (ii), selected from a list of linguistic terms *negligible*, *not important*, *average*, *important*, and *very important*. This produces a second set of ratings. In a later sub-section, we will review how the two sets of ratings are combined to form the decision makers' aggregate opinion on the overall prospect of success of a new product idea.

2.2. Fuzzy linguistic computing approach

Details of the fuzzy linguistic formulation and representation of imprecise data can be found in Herrera and Martinez (2000a, 2000b), Zimmermann (1991) and the references therein. We summarize the core ideas here for completeness. A triangular fuzzy number L with parameters (p, q, r) can be described by a membership function

$$f_L(x) = \begin{cases} (x-p)/(q-p) & \text{when } p \leqslant x \leqslant q \\ (x-r)/(q-r) & \text{when } q \leqslant x \leqslant r \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where x is a real number. Such a fuzzy number is graphically depicted in Fig. 1. Thus, if x represents the height of an individual, and L represents a particular person's (denoted as person A) concept (termed a *fuzzy concept*) of an average-height individual, then a given individual with an associated height will be considered by person A as having "average height" to a degree determined by the membership function. For example, an individual with height $x = q$ is definitely a member of the concept "average-height individual" according to A (for $f_L(q) = 1.0$), while an individual taller than r is definitely not (for $f_L(x) = 0$ for any $x \geqslant r$). For the scenarios considered in this article, a fuzzy concept can be described by a fuzzy number. Furthermore, the membership function of a fuzzy number does not need to be constrained in the triangular form – other shapes such as the parabola or trapezoid could also be used. However, the triangular form can capture fuzziness in human concepts with good approximation and is employed extensively in this article.

A fuzzy linguistic variable is a variable whose domain is a collection of pre-specified fuzzy concepts. For example, a fuzzy linguistic variable can be used to represent the rating of a particular object given by an evaluator in a survey questionnaire. In this case, the domain of the variable consists of the fuzzy concepts (also denoted as the *fuzzy linguistic terms*) *very poor*, *poor*, *average*, *good* and *excellent*. These fuzzy linguistic terms correspond to the five membership functions illustrated in Fig. 2a. Referring to the figure, to represent the crisp value $x = 0.4$ within the fuzzy linguistic framework, a 2-tuple (*average*, -0.1) is used. That is, $x = 0.4$ is expressed as the sum of the "q" value of the fuzzy linguistic term *average* ($q_{average} = 0.5$) and the offset of x from the "q" position (-0.1). Therefore, we can translate between a crisp value and its 2-tuple fuzzy linguistic form using the formulas

$$\Delta(x) = (S^i, \alpha) \quad (2)$$

and

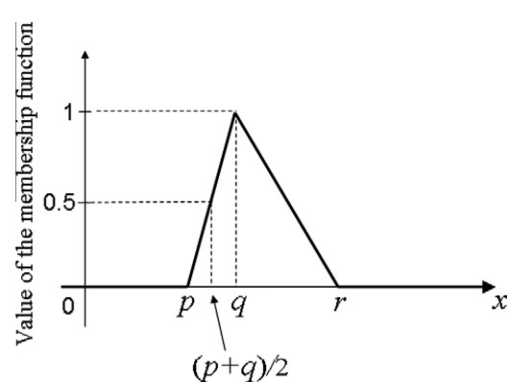

Fig. 1. A triangular fuzzy number L with parameters (p, q, r) representing person A's fuzzy concept of an "average-height individual." When $x = q$, the value of the membership function is 1. When $x = (p + q)/2$, the value is 0.5.