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# A decision support system for engineering design based on an enhanced fuzzy MCDM approach

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ABSTRACT

Design concept is an important wealth-creating activity in companies and infrastructure. However, the process of designing is very complex. Besides, the information required during the conceptual stage is incomplete, imprecise, and fuzzy. Hence, fuzzy set theory should be used to handle linguistic problem at this stage. This paper presents a fuzzy integrated approach to assess the performance of design concepts. And those criteria rating, relative weights and performance levels are captured by fuzzy numbers, and the overall performance of each alternative is calculated through an enhanced fuzzy weighted average (FWA) approach. A practical numerical example is provided to demonstrate the usefulness of this study. In addition, this paper, in order to make computing and ranking results easier to increase the recruiting productivity, develops a computer-based decision support system to help make decisions more efficiently.



## 1. Introduction

Conceptual design of mechanical system is the first and key stage of a product lifecycle. Because every stage of product design follows the process of design-evaluation-redesign, the selection and evaluation of the feasible scheme is of great importance. However, the process of designing is very complex and not well understood, and the information managed during the conceptual stage is incomplete, imprecise, and vague. Within this stage, several design solutions have to be generated, correctly evaluated and selected. Therefore, how to select the "best" design concept from a set of concept variants is a multiple criteria decision making problem (Chen & Hwang, 1992; Fodor & Roubens, 1994). Design engineers need to consider not only the required functionality, but also other life-cycle criteria (e.g., manufacturability, reliability, assembability, maintainability, etc.) of a product. Each alternative of design concept has each of the product criteria to meet the required performance. Designers have to take into account all the criteria and their relative weights (relative importance levels) for the expected performance of each alternative. This decision-making process is not straightforward because assigning performance levels and weights is rather difficult, and the information for doing so is usually imprecise. Conventional evaluation design concept methods, such as the weighted objectives method, are not flexible enough to deal with imprecise information; thus, improved evaluation approaches are necessary at this stage from the perspectives of fuzzy set theory (Zadeh, 1965).

An alternative evaluation of mechanical system can be characterized by imprecise or vague requirements. Fuzzy set theory and fuzzy logic have emerged as powerful ways of representing quantitatively and manipulating the imprecision in the selections of schemes (Chen, 2000; Herrera & Herrera-Viedma, 2000). Besides, fuzzy sets or fuzzy numbers can appropriately represent imprecise parameters, manipulated through different operations of fuzzy sets or fuzzy numbers. Since imprecise parameters are treated as imprecise values instead of precise ones, the process will be more powerful and its results are more credible.

Some research works proposed using MCDM in engineering design. Generally, it is usually classified into two approaches: (1) multiple criteria utility analysis (Siddall, 1983; Thurston, 1991; Thurston & Carnahan, 1992), (2) fuzzy set analysis (Carnahan, Thurston, & Liu, 1994; Jothi, Umaretiya, & Jothi, 1991; Knosala & Pedrycz, 1992; Otto & Antonsson, 1991; Wood, Otto, & Antonsson, 1992). Multi-attribute utility analysis has been widely applied in the area of engineering for decision-making (Chen & Hwang, 1992; Hwang & Yoon, 1981). However, utility analysis requires the expected performance of each criterion to be represented by a quantitative form. Therefore, it is not appropriate to be used at the early designing stage, because some design criteria (e.g., the

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market reaction to the product) are hard to quantify precisely (Thurston & Carnahan, 1992). On the contrary, fuzzy set analysis does not need the accurate quantitative inputs from design engineers. It allows designing engineers to describe the performance of each criterion with some linguistic terms (such as "good", "medium", "poor", etc.) or fuzzy numbers. The linguistic terms and fuzzy numbers can be represented and manipulated with fuzzy set theory.

This paper presents an enhanced FWA approach to evaluate five schemes in conceptual design for overall performance of a mechanical system. Besides, the rating for each scheme under different criteria and their relative weight is represented, assessed and computed by standard fuzzy arithmetic. A three-level fuzzy comprehensive evaluation model is extracted and characterized by multiple criteria (factors), multiple hierarchy features, multiple experts involved, and various constituent schemes. In addition, the scheme's comprehensive rating value can be obtained by ranking the fuzzy numbers, and its essence is to map fuzzy numbers onto the real-number axis and then rank them through proper transformation by ranking method.

The remainder of this paper is organized as follows: Section 2 describes the fuzzy set theory. Section 3 discusses the performance of assessed indicators for engineering conceptual design. Section 4 introduces the basic concept of fuzzy weighted average and an enhanced fuzzy integrated approach. Section 5 provides a practice numerical example. In Section 6, a computer based interface of decision support system is developed. Finally, we draw conclusions and make suggestions for future work.

## 2. Fuzzy set theory

In this section, some definitions and properties of fuzzy sets are being discussed. For a further detail of fuzzy sets, the reader can refer to Zimmermann (2001).

### 2.1. Preliminaries

**Definition 1** (*Fuzzy set*). A fuzzy set may be defined as $A = \{(x, \mu_A(x)), x \in U, \mu_A(x) \in [0,1]\}$, where $x \in U$ is the universe of discourse and $\mu_A(x) \in [0,1]$ denotes the membership function or degree of $x$ belonging to $A$.

**Definition 2** (*Fuzzy number*). A fuzzy number (FN) is a fuzzy set defined on the real line $R$ and has the properties of convexity and normality of fuzzy sets. Moreover, a FN can be written as $A = (a^L, a^M, a^R)$, where $a^L$ and $a^R$ denote the left and right bounds, respectively, and $a^M$ represents the mode of A. $(a^L, a^R)$ is called the support of $A$. The special cases of FNs may include the crisp real numbers and intervals of real number. For instance, triangular FNs (TFNs) may be defined by the triangular membership functions

$$\mu_A(x) = \begin{cases} 0, & x < a^L, \\ (x - a^L)/(a^M - a^L), & a^L \leqslant x \leqslant a^M, \\ (a^R - x)/(a^R - a^M), & a^M \leqslant x \leqslant a^R, \\ 0, & x > a^R, \end{cases} \tag{1}$$

and the $\alpha$-cuts are therefore continuous closed intervals.

Furthermore, a fuzzy number (FN) on the real line $\Re$ can be represented by the L-R representation (Dubois & Prade, 1980), e.g., $A = (l_A, m_A, u_A)_{L-R}$, where $l_A$ and $u_A$ denote the *lower* and*upper bounds*, $m_A$ the *mode*, and $L$ and $R$ the *left* and *right membership*(*reference*or *shape*)*functions* of $A$, respectively. The membership function of $A$ which defines the degree of belongingness of elements $x \in \Re$ to $A$, is denoted as $\mu_A(x) \in [0,1]$ and is defined by $L(x)$ and $R(x)$. The $\alpha$-cut, $\alpha \in (0,1]$, of a FN is defined as the ordinary subset $\{x \in \Re \| \mu_A(x) \geqslant \alpha\}$ and written as $(A)_\alpha = [a, b]$, where $a$ and $b$ denote the *left* and *right endpoints* of $(A)_\alpha$, respectively. Thus, a triangular FN (TFN) may be specially denoted as $(l_A, m_A, u_A)_T$ with $\mu_A(x) := L(x) = (x - l_A)/(m_A - l_A)$ for $l_A \leqslant x \leqslant m_A, \mu_A(x) := R(x) = (u_A - x)/(u_A - m_A)$ for $m_A \leqslant x \leqslant u_A, \mu_A(x) := 0$ elsewhere, and $(A)_\alpha = [a, b] = [(m_A - l_A)\alpha + l_A, u_A - (u_A - m_A)\alpha]$. Other definitions of FNs can be found in Dubois & Prade (1980).

**Definition 3** (*The $\alpha$-cuts*). For a fuzzy set A on a universe of discourse$U$ and $\alpha \in (0,1]$, the $\alpha$-cuts denoted as $(A)_\alpha$ of $A$ can be defined.

$$(A)_\alpha = \{x \in U | \mu_A(x) \geqslant \alpha\}. \tag{2}$$

The $\alpha$-cut fuzzy arithmetic is important to the FNs. For instance, for a general function $f(A_1, A_2, \ldots, A_n)$ representing an arithmetic and the $\alpha$-cuts of $A_i, (A_i)_\alpha$, denoted as $[(a_i^L)_\alpha, (a_i^R)_\alpha]$ for $i = 1, \ldots, n$, the $\alpha$-cuts of the fuzzy image $Y$ through the function $f$ from $A_1, A_2, \ldots, A_n$ can be defined as $(Y)_\alpha = [(y^L)_\alpha, (y^R)_\alpha]$ and in a more detailed manner,

$$\begin{aligned}(Y)_\alpha = [(y^L)_\alpha, (y^R)_\alpha] &= f((A_1)_\alpha, \ldots, (A_n)_\alpha) \\ &= f([(a_1^L)_\alpha, (a_1^R)_\alpha], \ldots, [(a_n^L)_\alpha, (a_n^R)_\alpha]).\end{aligned} \tag{3}$$

**Definition 4** (*Arithmetic operations of fuzzy number*). In accordance with the concept of $\alpha$-cuts, the fuzzy arithmetic of FNs can be defined by interval arithmetic on the closed intervals on $R$. For instance, a two fuzzy numbers arithmetic operations is described as follows,

$$\begin{aligned}\text{Addition:}\quad (A_1 + A_2)_\alpha &= (A_1)_\alpha + (A_2)_\alpha \\ &= [(a_1^L)_\alpha + (a_2^L)_\alpha, (a_1^R)_\alpha + (a_2^R)_\alpha],\end{aligned} \tag{4}$$

$$\begin{aligned}\text{Subtraction:}\quad (A_1 - A_2)_\alpha &= (A_1)_\alpha - (A_2)_\alpha \\ &= [(a_1^L)_\alpha - (a_2^R)_\alpha, (a_1^R)_\alpha - (a_2^L)_\alpha],\end{aligned} \tag{5}$$

$$\begin{aligned}\text{Multiplication:}\quad (A_1 \cdot A_2)_\alpha &= (A_1)_\alpha \cdot (A_2)_\alpha \\ &= [\min\{(a_1^L)_\alpha \cdot (a_2^L)_\alpha, (a_1^L)_\alpha \cdot (a_2^R)_\alpha, (a_1^R)_\alpha \\ &\quad \cdot (a_2^L)_\alpha, (a_1^R)_\alpha \cdot (a_2^R)_\alpha\}, \max\{(a_1^L)_\alpha \cdot (a_2^L)_\alpha, (a_1^L)_\alpha \\ &\quad \cdot (a_2^R)_\alpha, (a_1^R)_\alpha \cdot (a_2^L)_\alpha, (a_1^R)_\alpha \cdot (a_2^R)_\alpha\}],\end{aligned} \tag{6}$$

$$\begin{aligned}&\text{Division:}\quad (A_1/A_2)_\alpha = (A_1)_\alpha/(A_2)_\alpha \\ &= [\min\{(a_1^L)_\alpha/(a_2^L)_\alpha, (a_1^L)_\alpha/(a_2^R)_\alpha, (a_1^R)_\alpha/(a_2^L)_\alpha, (a_1^R)_\alpha/(a_2^R)_\alpha\}, \\ &\quad \max\{(a_1^L)_\alpha/(a_2^L)_\alpha, (a_1^L)_\alpha/(a_2^R)_\alpha, (a_1^R)_\alpha/(a_2^L)_\alpha, (a_1^R)_\alpha/(a_2^R)_\alpha\}], \\ &\quad 0 \notin [(a_2^L)_\alpha, (a_2^R)_\alpha],\end{aligned} \tag{7}$$

$\forall \alpha \in [0,1]$. The results of fuzzy arithmetic are obtainable by recomposing the $\alpha$-cuts into the fuzzy numbers.

### 2.2. Linguistic variables and fuzzy numbers

**Definition 5** (*Linguistic variable*). A linguistic variable can also be defined by the fuzzy sets. A linguistic variable refer to the possible states are fuzzy sets or FNs assigned to relevant linguistic terms (e.g., "important", "unimportant", "very good", "good", etc. as used here).

In fuzzy sets theory, conversion scales are applied to transform linguistic terms to fuzzy numbers. Determining the number of conversion scales is generally intuitive. While too few conversion scales reduce analytical discrimination capability, too many conversion scales make the system overly complex and impractical (Chen & Hwang, 1992). Besides, Miller (1956) noted that the scale of "seven plus or minus two" generates the largest amount of