Fifth IFSA World Congress (1993), 1163-1166

A Method in Evaluating Mechanical Design Plans With Fuzzy Theory

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Abstract This paper studies the evaluation of mechanical design plans through fuzzy cluster. Plans are classified into two sets, 'good' and bad'. The membership of a plan to the 'good' set is numerically equal to the distance to the 'bad' set. The central parameter of the 'good' set is defined as '1', and that of the 'bad' set '0'. This will greatly simplify calculations.

The result of the calculating example proves the method available.

1. Introduction

Plan evaluations is a reasonable judgement of various candidate plans from a comprehensive point of view, to provide for decision making and to be carried out. Both evaluation and decision making are made when the prospect is still not clear. It is with some risks. The problem of evaluation and decision making for plan has drawn the attention of many people. (See articles [1]–[7].)

Decision making follows evaluation. Evaluation is the key of decision making. When the problem of evaluation is solved, decision making will be no longer difficult. The evaluation and decision making of mechanical design plans are fuzzy. Not only because the meaning of designing requirements is fuzzy, such as 'convienient to maintain', 'compact in structure', etc, but also the satisfaction of various candidate plans to the designing requirements is fuzzy. In order to evaluate designing plans, article [4] uses a method of grading. Article [5] puts forward concepts such as 'the subjective evaluating proboble reliability of plan adaptability', 'effectiveness' and so on .Apparently, these concepts are fuzzy just like some concepts in the fuzzy sets theory. Both of them have not distinctly put forward concepts. They are lack of systematic theory and perfect methematical methods. They can not universally in getting an expression in number. Fuzzy sets is a methematical tool to study and deal with these problems. This paper uses the fuzzy cluster analysis to study the problem of fuzzy evaluation of mechanical design plans

2. Fuzzy Evaltion of Designing Plan

From the view of systematic theory, the general function of a product can be divided into several branch functions. Each branch function can also be further divided into several subfunctions.i.e. the function of a mechanical product has a levels structure. On the sme level, a function and its carrier have relative independence. According to the known conditions (function requirements, working surroundings, working objects, financial conditions and other requirements), the designer can use form matrix or other methods to seek and synthesize into some feasible plans. The aim of evaluation is to select some feasible plans for decision making in order to realize the best one.

According to fuzzy cluster analysis[8], we get the evaluating matrix R, which the candidate plans $X_1, X_2, \ldots, X_j, \ldots, X_n$, are relative to the evaluating factors sets $p = (p_1, p_2, \ldots, p_i, \ldots, p_m)$.

$$R = \begin{array}{c} \begin{matrix} X_1 & X_2 \cdots & X_j \cdots & X_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} \cdots & x_{13} \cdots & x_{1n} \\ x_{21} & & & x_{2n} \\ \cdots & & & \cdots \\ x_{i1} & x_{i2} \cdots & x_{ij} \cdots & x_{in} \\ \cdots & & & \cdots \\ x_{m1} & x_{m2} \cdots & x_{mj} \cdots & x_{mn} \end{bmatrix} \end{array} \quad (1)$$

where

$$x_{ij} \in [0,1] \qquad i = 1,2,\ldots,m \qquad j = 1,2,\ldots n$$

X_{ij} is the membership of plan X_j relative to the evaluating factor P_i.

According to the importnat degree of evaluating factors, we get the weight victor of evaluating factors:

$$W = (w_1, w_2, \ldots, w_i, \ldots, w_m) \quad (2)$$

If plans are classified into c sets, and the characteristic parameter of the center of each set is V_{ih} (i = 1,...,m; h = 1,...,c), then the classifying matrix is:

$$\begin{array}{c} \begin{matrix} V_1 & V_2 \cdots & V_h \cdots & V_c \end{matrix} \\ \begin{bmatrix} v_{11} & v_{12} \cdots & v_{1h} \cdots & v_{1c} \\ v_{21} & & & v_{2c} \\ \cdots & & & \cdots \\ v_{i1} & v_{i2} \cdots & v_{ih} \cdots & v_{ic} \\ \cdots & & & \cdots \\ v_{m1} & v_{m2} \cdots & v_{mh} \cdots & v_{mc} \end{bmatrix} \end{array} \quad (3)$$

Where V_{ih} is the membership of the set V_h relative to factor P_i

where.

$$v_{ih} \in [0,1]$$

$$\sum_{i=1}^{m} v_{ih} = 1$$

The Euler distance of plan X_j to set V_h is :

$$\|X_j - V_h\| = \sqrt{\sum_{i=1}^{m} (x_{ij} - v_{ih})^2}$$

Considering factor weight, the Euler distance of plan X_j to set V_h is :

$$D_{hj} = \|w(X_j - V_h)\|$$

$$= \sqrt{\sum_{i=1}^{m} w_i (x_{ij} - v_{ih})^2} \quad (4)$$

$$h = 1,\ldots,c \qquad j = 1,\ldots,n$$

Based on fuzzy classification, plan X_j belongs to the '1' set with its membership u_{1j}. At the same time, it belongs to the 'h' set (h = 2,3,4,...c) with membership u_{hj}. Then the membership matrix of the plan relative to the sets is represented as:

$$\begin{array}{c} \begin{matrix} X_1 & X_2 \cdots & X_j \cdots & X_n \end{matrix} \\ \begin{bmatrix} u_{11} & u_{12} \cdots & u_{1j} \cdots & u_{1n} \\ u_{21} & & & u_{2n} \\ \cdots & & & \cdots \\ u_{h1} & u_{h2} \cdots & u_{hj} \cdots & u_{hn} \\ \cdots & & & \cdots \\ u_{c1} & u_{c2} \cdots & u_{cj} \cdots & u_{cn} \end{bmatrix} \end{array} \quad (5)$$

where:

$$\begin{cases} 0 \leqslant u_{hj} \leqslant 1 \\ \sum_{h=1}^{c} u_{hj} = 1 \end{cases} \quad (6)$$

We can regard membership u_{hj} as weight value, thus the weight distance of plan X_j to set V_h is $u_{hj}^m D_{hj}$.

The total weight distances of plan X_j to center of each set is :

$$\sum_{h=1}^{c} u_{hj}^m D_{hj} \tag{7}$$

The total weight distances of all plans to center of each set is :

$$\sum_{j=1}^{n} \sum_{h=1}^{c} u_{hj}^m D_{hj} \tag{8}$$

J.C.Bezdek pointed out that the index m in formula (8) is better to be 2. So, formula (8) should be written as:

$$\sum_{j=1}^{n} \sum_{h=1}^{c} u_{hj}^2 D_{hj} \tag{9}$$

However, from the practical point of view in evaluation of engineering design, it is not necessary to calcultate the membership of all plans to each set. Instead ,It is enough to arrange them in order. Thus, if defining c = 2, we classify plans into 2 sets, 'good' and 'bad'. After having got the membership of each plan to the 'good' set, we can arrange them in order.

According to formula(7), the total weight distance of plan X_1 to the 'good' and 'bad' sets is :

$$\sum_{h=1}^{2} u_{h1}^2 D_{h1} = u_{11}^2 D_{11} + u_{21}^2 D_{21} \tag{10}$$

For plan X_1,here is relation:

$$D_{11} + D_{21} = 1 \tag{11}$$

Put formula (6) and (11) into (10), we get:

$$\begin{aligned} & u_{11}^2 D_{11} + u_{21}^2 (1 - D_{11}) \\ &= D_{11}(u_{11} + u_{21})(u_{11} - u_{21}) + u_{21}^2 \\ &= u_{21}^2 - 2u_{21} D_{11} + D_{11} \end{aligned} \tag{12}$$

Using the same method, we get the total weight distance of plan $X_2, \ldots X_j \ldots X_m$:

$$\begin{cases} u_{22}^2 - 2u_{22} D_{12} + D_{12} \\ u_{23}^2 - 2u_{23} D_{13} + D_{13} \\ \ldots \\ u_{2j}^2 - 2u_{2j} D_{1j} + D_{1j} \\ \ldots \\ u_{2n}^2 - 2u_{2n} D_{1n} + D_{1n} \end{cases} \tag{13}$$

Add the distance of each plan to both sets, we get:

$$\sum_{j=1}^{n} \sum_{h=1}^{2} u_{hj}^2 D_{hj} = \sum_{j=1}^{n} (u_{2j}^2 - 2u_{2j} D_{1j} + D_{1j})$$

According to cluster judgement, we difine the smallest function of the total weight distance of all plans to center of each set to be its 'cluster principle'. Thus, the above formula is :

$$\begin{aligned} J_m &= min \sum_{j=1}^{n} (u_{2j}^2 - 2u_{2j} D_{1j} + D_{1j}) \\ &= \sum_{j=1}^{n} min(u_{2j}^2 - 2u_{2j} D_{1j} + D_{1j}) \end{aligned} \tag{14}$$

To figure out membership u_{2j}, we differentiate the curves in formula (14) by u_{2j},then let it is to be '0'.

$$\frac{d(u_{2j}^2 - 2u_{2j} D_{1j} + D_{1j})}{du_{2j}} = 2u_{2j} - 2D_{1j} = 0$$

$$\therefore \quad u_{2j} = D_{1j} \tag{15}$$

The same:

$$u_{1j} = D_{2j}$$

To a system whose set number is 2, the farther the distance to the 'bad' set, the nearer the distance to the 'good' set. Formula (15) shows that the membership of plan X_j to the 'good' set is equal to its Euler distance to the 'bad' set in number. If we further define all the parameters of the 'good' center to be '1', and that of the 'bad' to be '0' (This is ideal 'good' and 'bad'), we can get from formula (4) and (15) the following:

$$u_{1j} = D_{2j} = \sqrt{\sum_{i=1}^{m} w_i x_{ij}} \qquad (16)$$

Formula (16) enables us to figure out the membership of plan X_j to the 'good' set very easily.

3. Calculating Example (omit)

4. Summary

This paper uses the fuzzy cluster analysis method to study the evaluating problem of mechanical design plans. It classifies all plans into two sets ('good' and 'bad'). From relation $\sum_{h=1}^{2} u_{hj} = 1$, we can figure out the membership u_{1j} of a plan to the 'good' set from its membership u_{2j} to the 'bad' set. Further study shows, in a two-set system, membership of plan to the 'good' can be represented by its weight distance to the 'bad'. Let all the parameters of the 'good' center is to be '1', and that of the 'bad' is to be '0', we can greatly simplify the calculation of principle equation.

The result of the calculating example shows the principles and methods of this paper sensible. The principles and methods put forword in this paper also fit the evaluation problems in other scientific fields.

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