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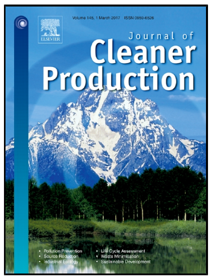

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A Research on the Application of Fuzzy Iteration Clustering in the Water Conservancy Project

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Abstract: Water conservancy project bidding involves many aspects including nature, society, economy, and environment. In water conservancy project bidding evaluation, both quantitative and qualitative indexes are involved; moreover, different targets are often incommensurable and compete with each other. Scientific decision-making in bidding evaluation is key to linking the stages of project bidding; selecting an appropriate contractor is not only conducive to improving the project quality, but also helpful to achieve the goal of saving on investments. This paper intends to study the problem of multi-target group decision-making in project bidding processes via the use of the mathematical method of fuzzy clustering. Bidder 3 is finally chosen as the most suitable contractor for the construction of this project by determining the score matrix and index weight vector of the four bidders concerned. Results have indicated that the aforementioned method is more reasonable and reliable; thus, the bidding evaluation decision is more scientific.

Key words: fuzzy clustering; fuzzy mode recognition; iteration; project bidding; bidding evaluation

1.Introduction

In 1965, Professor Zadeh at the University of California published the famous paper, ‘Fuzzy Sets’ in which the theory of a multi-valued set was formally proposed (L. A. Zadeh,1965). This theory had broken through the classical set theory by Descartes at the end of the 19th century, laying the foundation for the fuzzy theory. With the publication of a research report on fuzzy logic by Barclay and Marinos in 1966 (Barclay, 1966), and another research report on fuzzy reasoning by Zadeh in 1975 (L. A. Zadeh, 1975), fuzzy theory has become a hot subject. Zadeh was mainly accredited with the unification of fuzziness and mathematics. Fuzzy mathematics seeks to deal with fuzzy things previously deemed indescribable in mathematics with precise mathematical methods, because absolute precision is almost impossible in the real world, and what is possible is only to reduce the so-called inaccuracy to an insignificant level. According to Zadeh, it is not the job of mathematics to accommodate for fuzziness at the expense of rigorousness, but rather to penetrate mathematical methods into the “forbidden zones” of the fuzzy phenomenon, i.e. to let mathematics draw from the advantage of human brains in the recognition and judgment of fuzzy phenomenon instead (Zhang, 1991). This will then open a new path for computers to imitate the characteristics of human brain thinking. At present, fuzzy mathematics is advancing towards two directions: theoretical research and applied research.

Clustering refers to the process in which things are distinguished and classified according to certain requirements and rules (Chen, 1995; Li Liu et al, 2010). It falls into the category of unsupervised classification in that there is not any prior knowledge with respect to the classification, only relying on the similarity between things as the criteria for classification. Through clustering, it is possible to recognize dense and sparse areas and find an interesting interrelationship between the global distribution patterns and data attributes. In data mining, clustering analysis can be used as a stand-alone tool for acquiring information about data distribution, observing the characteristics of each cluster, and, if necessary, making further analysis on certain specific clusters (Libor and Petr Cintul, 2005; Ting et al, 2014). In addition, clustering analysis can also be used as a preprocessing step towards other algorithms (e.g., characteristics and classification, etc.) which can then be processed accordingly to the clusters generated. Clustering originates from many research fields, including data mining, statistics, machine learning, spatial database, biology and marketing, etc. Due to the large amount of data gathered in the database, clustering analysis has become an exceptionally active research subject in data mining.

The traditional clustering analysis is a hard classification, in which the objects to be identified are strictly divided into different classes. It is “either one or the other” in nature, and the boundaries in this category-based classification are distinct (Libor and Petr, 2006). In fact, most of the objects have no such strictly-defined attributes and are characterized by intermediacy in terms of status and category, which are either one or the other in nature, and are therefore more suitable in the category of soft classification. The proposition of fuzzy set theory has provided a powerful analyzing tool for soft classification (Liu et al, 2012). Dealing with clustering problems with fuzzy methods is precisely the purpose of fuzzy clustering analysis (Seok-Beom et al, 2014). Fuzzy clustering theory has been widely applied in many areas, and has achieved satisfactory effects and objective benefits. The foray of the fuzzy clustering theory into multiple target domains has prompted new developments in multi-target decisions. Chen (2001), on the basis of the traditional concept of membership degree, proposed the concept of relative membership degree, and further suggested the theoretical models involving fuzzy optimization in multi-stage, multi-target decision-making systems. This model has been extensively used in water resources. Taking the minimization of the inconsistencies between the results from the weighting method and preference sets of the decision-maker through the selection of weight vector as the objective function, Wencong et al. (2014) have established the multi-target decision-making method for finite schemes which is based on the weighted method and linear distribution method. Keming and Fengming (2012) put forward the conflicting multi-target negotiation model. Terry and Thomas (2013), according to the characteristics of timing sequence in economic development and planning, established the theoretical model of timing sequence multi-target fuzzy optimization. Chen Shouyu (2004) studied solutions for the fuzzy optimization converse proposition, and put forward two weight calculation methods consistent with the intention of the decision-maker by applying the solutions to the decision-making in flood control scheduling. Nadizadeh et al (2014) not only applied the fuzzy set theory to the complicated water resource system management, but also studied the fuzzy recognition model with regards to water quality, the fuzzy optimization model for the evaluation of susceptibility of water-bearing stratum to contamination, the multi-level and multi-target fuzzy optimization model for decision-making in water system management, as well as the democratic method and fuzzy optimization model for decision-making in water system management. Chen (2001) studied the multi-target fuzzy optimization model for river water quality management. Georg et al. (2013), based on the mutation theory, studied the methods for fuzzy decision-making, evaluation, and prediction as well as the decomposition of application objectives in multi-level water resource systems with regards to the evaluation of environmental impacts on hydropower stations. He performed quantitative recursive computation on the system as a result of the initial fuzzy membership function and unifying formula so as to obtain the total mutations membership function value of different proposed schemes in terms of environmental impact. Then, according to the order of the total mutations membership function value of different schemes, construction schemes can be optimized from the perspective of the environmental impact assessment.

Water conservancy project bidding involves many aspects such as nature, society, economy, and environment. In water conservancy project bidding evaluation, both quantitative and qualitative indexes are involved (Georg et al, 2013); moreover, different targets are often incommensurable and compete with each other (Yihua, 2011). Wherein, project bidding is the early stage of water conservancy project implementation, which has a direct bearing on the success of the engineering project, while the core issue with the theory of water conservancy still lies in decision-making. Decision-making in bidding evaluation is a key link at the stage of project bidding; hence selecting an appropriate contractor is not only conducive to improving the project quality, but also helps to achieve the goal of saving on the investment. Decision makers will need to rely on their own experience to carry out a series of analyses, reasoning and judgment on the fuzzy concepts and select the water conservancy project contractor through comprehensive evaluation. The traditional scheme optimization method includes “language-oriented evaluation method” using linguistic comparative degree for qualitative evaluation, "direct scoring method" by means of quantitative scoring; "sectional scoring system” based on membership frequency statistics; “option-based scoring method” based on predesigned score sections; and “hierarchy-based analysis method” based on binary comparison sequencing and layer-by-layer evaluation, and other bidding evaluation methods, all of which cannot optimize the multi-target group decision-making involved in project bidding. In this paper, it is intended to optimize and evaluate the multi-target group decision-making issues with the objects at the bidding evaluation stage of the project construction, and, according to the nature of the objects, make the decisions for bidding evaluation more scientific.

2. Principle of Fuzzy Clustering Iteration

Suppose a sample set is

$X=\{x_1,x_2,...,x_n\},n$ as the sample size. Each sample x has m indexes expressed in the following matrix:

$$X_{m\times n}=\begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}=f_{ij} \tag{1}$$

X_{ij} the characteristic value of index i in sample j, in which i=1, 2,... m, j=1,2...n.

The basic idea of the fuzzy clustering iteration method is to choose a reasonable number of classifications according to the maximal matrix element principle for a classified sample (bidder) X, and adjust constantly according to the number of bidders and the theoretical model of evaluation element until the optimal classification is achieved.

2.1 Establish a fuzzy similar matrix for project bidding to determine the reasonable number of classification (Francisco et al,2013)

As a means to achieve the optimal classification, it is necessary to determine a reasonable number of classification c. The maximal matrix element principle of fuzzy clustering is adopted in this paper to determine the number of classification. First, establish the fuzzy similar matrix whose elements can be calculated by the subordinate dot product formula： $\bar{x}_{ki}=x_{ki}/S_{k2}$.

$$t_{ij}=\sum_{k=1}^{m}\bar{x}_{ki}\bar{x}_{kj}/\max_{i\neq j}\sum_{k=1}^{m}\bar{x}_{ki}\bar{x}_{kj}\left(i,j=1,2,...,n\right) \tag{2}$$

The maximal matrix element at any row of the fuzzy similar matrix is equal to cut set level λ (except for the leading diagonal). Replace λ with the maximal matrix element, and rank its values from big to small, so as to classify sample subsets with similar values as a group. Set the jumping zone of λ as group c as the initial number of classification in fuzzy clustering iteration method, and get the optimal classification according to this method.

2.2 Normalized Treatment to Index Value in Project Bidding

Fuzzy evaluation for project bidding requires applying normalized treatment in original data (number of bidders and evaluation elements). For m evaluation elements and c bidders, suppose $S_{m\times c}=(S_{ik})_{m\times c}$.

The following formula is applied for higher value in bidding evaluation and a smaller chance of winning the bidding:

$$s_{ik} = (S_{ic} - S_{ik}) / (S_{ic} - S_{il}) \tag{3}$$

$$f_{ij} = \begin{Bmatrix} 1 & x_{ij} \le S_{il} \\ (S_{ic} - x_{ij}) / (S_{ic} - S_{il}) & S_{il} < x_{ij} < S_{ic} \\ 0 & x_{ij} \ge S_{ic} \end{Bmatrix} \tag{4}$$

The following formula is applied for a higher value in bidding evaluation and a higher chance of winning the bidding: $s_{ik} = (S_{ik} - S_{ic}) / (S_{il} - S_{ic})$

$$f_{ij} = \begin{Bmatrix} 1 & x_{ij} \ge S_{il} \\ (S_{ij} - x_{ic}) / (S_{il} - S_{ic}) & S_{ic} < x_{ij} < S_{il} \\ 0 & x_{ij} < S_{ic} \end{Bmatrix} \tag{5}$$

$$(i = 1, 2, ..., m; k = 1, 2, ..., c; j = 1, 2, ..., n)$$

To make all index data comparative, it is necessary to conduct a dimensionless treatment and set certain weights based on their effect (Francisco et al, 2010). Due to different dimensions for m physical quantities of index characteristic value, Chen (2009) indicates that the influence of dimensions should be eliminated during recognition, so as to normalize the index characteristics value, namely to change its matrix into a relative membership matrix:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} = f_{ij} \tag{6}$$

In this formula, f_{ij} is the normalized number or relative membership of index characteristic value, and $0 \le f_{ij} \le 1$. Although this reduces data precision, each index factor is changed to a non-dimensional quantity of the same order of magnitude.

2.3 Determining the Weight of Index Value for Each Factor in Project Bidding

G. Gan (2008) and F.M. (2000) conduct data treatment in statistical indexes at each representative point, of which mainly makes index data more comparative, then conduct non-dimensional treatment whilst setting a certain weight to the effect of the index data. Although the data precision is reduced, each index factor is changed to a non-dimensional quantity of the same order of magnitude. Calculate out the optimal fuzzy division matrix by using fuzzy division theory.

Target function in fuzzy division is:

$$\min\left\{F=\sum_{j=1}^{N}\sum_{h=1}^{2}u_{hj}^{2}\left[\sum_{t=1}^{M}(w_{oi}(r_{tj}-s_{rh}))^{p}\right]^{2/p}\right\} \tag{7}$$

In this function, w_{Oi} is the weight for each bidder, and $w_{oi}=\frac{1}{M},(i=1,2,...,M)$ m $r_{ij}=f_{ji}$; u_{hj} is the membership of the sample to type h, and satisfies the following constraint condition:

$$1^{\circ}\ 0\le u_{hj}\le 1,\ 2^{\circ}\sum_{h=1}^{2}u_{hj}=1,\ 3^{\circ}\sum_{j=1}^{N}u_{hj}>0 \tag{8}$$

$$(h=1,2;\ j=1,2,...N)$$

The iterative formula to calculate the optimal fuzzy division matrix U^*:

$$s_{ih}=\frac{\sum_{j=1}^{N}u_{hj}^{2}w_{im}^{2}r_{ij}}{\sum_{j=1}^{N}u_{hj}^{2}w_{oi}^{2}} \tag{9}$$

Set p = 2.

$$u_{kj}=1/\sum_{k=1}^{2}\left[\frac{\sum_{i=1}^{M}(w_{iM}(r_{ij}-s_{ih}))^{2}}{\sum_{i=1}^{M}(w_{oi}(r_{ij}-s_{ik}))^{2}}\right] \tag{10}$$

The first line of $U^*=(u_{hj}^*)$, which is the membership of each evaluation factor to the bidder, namely the weight of each index, can be normalized.

2.4 Determining the Optimal Bidder Grading Matrix

Suppose the membership of sample to level h, then matrix $D_{c\times n}=(d_{hj})_{c\times n}$ satisfies the following constraint condition:

$$1^{\circ}\ d_{kj}\ge 0,\ 2^{\circ}\sum_{h=1}^{c}d_{hj}=1,\ 3^{\circ}\sum_{j=1}^{n}d_{hj}>0 \tag{11}$$

$$(i=1,2,...,n;\ h=1,2,...,c)$$

The principle of the optimal grading principle to win the bidding is: the quadratic sum of the total evaluation elements, and the weighted generalized distance of the bidder is minimal. Namely, the target function is as follows:

$$\min\left\{F=\sum_{j=1}^{n}\sum_{h=1}^{c}d_{hj}^{2}\left[\sum_{i=1}^{m}(w_i(r_{ij}-s_{ih}))^{p}\right]^{2/p}\right\} \tag{12}$$

Chen (2009) takes weighted generalized European weight distance , p =1, and the iteration formula for grading matrix D of optimal bidding-winner as:

$$d_{hj}=1/\sum_{k=1}^{c}\left(\frac{\sum_{i=1}^{m}(w_i(f_{ij}-s_{ih}))^{p}}{\sum_{i=1}^{m}(w_i(f_{ij}-s_{ik}))^{p}}\right)^{2/P} \tag{13}$$

$$(j=1,2,\ldots,n;h=1,2,\ldots,c;p=1)$$

Among that, w_i is the weight of each index. Conduct normalization to the first line of U^* to get:

$$w_i=1/\sum_{k=1}^{m}\left(\frac{\sum_{j=1}^{n}\sum_{h=1}^{c}(\mu_{hj}(f_{ij}-s_{ih}))^{2}}{\sum_{j=1}^{n}\sum_{h=1}^{c}(\mu_{hj}(f_{ij}-s_{kh}))^{2}}\right) \tag{14}$$

According to the principle of maximal membership, the maximal element in each column of matrix D should be set as 1, and the rest as 0, as a means to get a $Boole$ matrix D°. Conduct grading accordingly.

3. Method to Determine the Index Weight Vector

In many cases, pattern recognition and the determination of index weight in a complex system requires knowledge and experience by decision makers, Carlos W.D. de Almeida (2013) concluded that decision makers often have difficulty in giving out the quantized value of index weight [], therefore, there is a need for the application of a weighting method with an integration of cross iteration and experience knowledge under such a method. First, set c=2, and apply fuzzy pattern recognition to cross iterate pattern formula (14) and (10) and determine the index weight vector (called initial index weight vector value). Then apply the second weighting method according to the decision-maker's experience and knowledge to adjust the index weight vector. Hesam (2015) applied the fuzzy pattern recognition model (10) where c>2 to calculate the relative membership of all levels. Experience of evaluators is also very important in project practice.

Therefore, this weighting method can better determine the index weight vector.

4. Case Analysis

There are four qualified water conservancy design and construction enterprises bidding for the construction of a hydropower station in Zhejiang: (1) is a small-sized construction enterprise, (2) is a medium-sized construction enterprise, (3) is a large-scale construction enterprise, and (4) is a super-large construction enterprise. Tadanobu (2013) and Jiuping (2012) adopt indexes to evaluate the four bidders.

(1) Technical assurance measures: evaluate the rationality of the construction plan, foundation excavation, construction material plan, concrete plan and grout construction plan, etc.

(2) Quality of the project manager: verify if the person bears over 10 years of experience in hydropower civil engineering and the level of their certificate, etc.

(3) Quality of the person in charge of technology: examine if the person bears over 10 years of experience in hydropower civil engineering and the level of the certificate for the person in charge of project technology, etc.

(4) Construction organization design: evaluate the on-site construction organization, mechanics, and management, technical staff, management technology and civilized production, etc.

(5) Progress assurance measures: evaluate the construction progress target and network control.

(6) Construction safety assurance measures: evaluate safety targets, prevent physical injuries, equipment and project accidents with safety technology organization measures, etc.

(7) Enterprise qualification: evaluate enterprise qualification as level A or B.

(8) Construction team performance: evaluate the maturity, stability and related previous projects of constructors.

(9) Financial credit: investigate the enterprise's line of credit and assets and liabilities.

X matrix is transformed into an R matrix by directly introducing the method in the literature found in this paper.

$$R=\begin{bmatrix} 0.96 & 0.92 & 0.86 & 0.70 \\ 0.72 & 0.78 & 0.86 & 0.95 \\ 0.34 & 0.50 & 0.66 & 0.78 \\ 0.26 & 0.58 & 0.82 & 1 \\ 0.87 & 0.73 & 0.59 & 0.22 \\ 0.84 & 0.68 & 0.56 & 0.36 \\ 0.83 & 0.66 & 0.34 & 0.18 \\ 1 & 1 & 0.97 & 0.20 \\ 0 & 0 & 0.26 & 0.38 \end{bmatrix}=(f_{ij})$$

4.1 Determining the Index Weight Vector by the Iteration and Experience Combination Weighting Method

This method considers not only iteration precision, but also the effect of experience in project bidding. Set c =2, iteration precision $\varepsilon_1=\varepsilon_2=10^{-4}$, and the initial weight vector is:

$$w^0=\left[\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9},\frac{1}{9}\right]$$

Iterations in formula (13) and (14) are convergent, and the required initial value of index weight vector is calculated as:

During bidding evaluating

${}_0w=\left(0.378,0.252,0.051,0.056,0.058,0.066,0.039,0.085,0.015\right)$, experts regard the initial weight, 0.051, of the qualification index (3) for person in charge of technology as smaller and, consequently, an adjustment is necessary. Therefore, it is necessary to use the initial weight vector ${}_0w$ to divide the biggest element 0.378 to get a non-normalized initial weight vector:

$${}_0w^{'}=(1,0.667,0.135,0.148,0.153,0.175,0.103,0.225,0.040)$$

In addition, experts regard that index (1) in technology assurance measure is more important than the qualification index (3), so the latter is adjusted from 0.135 to 0.667. After getting the adjusted expert knowledge and experience, the non-normalized weight vector is:

$$w^{'}=(1,0.667,0.667,0.148,0.153,0.175,0.103,0.225,0.040)$$

w normalized weight vector is achieved through iteration and experience.

$$w = (0.315, 0.210, 0.210, 0.046, 0.048, 0.055, 0.032, 0.071, 0.013)$$

4.2 Selection Optimization of the Water Conservancy Project Bidding Plan

During the classification of the plans, we grouped them into five levels namely I, II, III, IV and V. Set c=5 and determine the value according to the 5 levels of selection optimization plans. I is 1, II is 0.8, III is 0.6, IV is 0.3 and V is 0.5. Therefore, the relative membership vector is:

$$\begin{aligned} s_i &= (s_{i1}, s_{i2}, s_{i3}, s_{i4}, s_{i5}) \\ &= (1, 0.8, 0.6, 0.3, 0) \end{aligned}$$

According to the membership of bidders, namely index weight, input related data from R, w and s_i into formula (10) to get the relative membership matrix of 4 plans for 5 levels is as follows:

$$U = \begin{bmatrix} 0.207 & 0.197 & 0.149 & 0.154 \\ 0.384 & 0.499 & 0.683 & 0.480 \\ 0.280 & 0.227 & 0.132 & 0.283 \\ 0.090 & 0.055 & 0.026 & 0.060 \\ 0.039 & 0.022 & 0.010 & 0.023 \end{bmatrix} = (u_{hj})$$

$$h = 1, 2, ..., 5;\ j = 1, 2, 3, 4.$$

Chen (1995) put forward a comprehensive recognition and evaluation formula of grade characteristic value, and conducted a comprehensive evaluation of the result of multi-level fuzzy pattern recognition belonging to level H_j:

$$H = (1, 2, 3, 4, 5) * (u_{hj}) = (2.370, 2.206, 2.065, 2.318)$$

The smaller $\min H_j$ is, the better. Value in the third plan is 2.065, which is the smallest. Thus plan 3 is the optimal plan, and the optimal construction enterprise is therefore selected out.

5. Conclusion

Fuzzy clustering method is widely applied in water resources planning, and has achieved good effects. This thesis employs "fuzzy iteration" method to estimate the evaluation, ranking and optimization selection of the water conservancy project constructers. The weighted iteration calculation takes advantage of the decision-making intention implied in the recommended scheme to work out the weight determination prescription in multi-objective decision-making, and overcome the human traces in confirmation of real right, making it more objective in reflecting the weight of all objects in the scheme. This right confirmation method is virtually within the category of objective weighting method. The result shows that fuzzy clustering iteration theory can not only classify indexes in evaluation, but also conduct unit sequencing in bidding, which can explicitly reflect the advantages and disadvantages of each of the bidders, and support decision-making in the selection of a bidding plan. By fuzzy clustering technology, plan 3 is evaluated to be reasonable and reliable, and is thus the optimal plan.

6. Conflicts of Interest

There are no conflicts of interest involved in this work.

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