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Research on the Model of Public Project Performance Evaluation–A Case Study of Water Environment Project

Hongbo Xu
School of Economics and Management, Nanjing Institute of Industry Technology. Nanjing 210000, China.
xuhongbo2011@163.com

In order to improve urban water environment project investment benefit, it is necessary to evaluate the performance of the project systematically and comprehensively. The paper takes advantage of Dempster-Shafer (D-S) evidential theory and triangle whitening function in data processing and data integration to construct the evaluation model. Firstly, the triangular fuzzy number is used to determine the indicator weight. Then the grey clustering matrix is constructed to determine the level of each criterion of the urban water environment project. Finally, the paper identifies the grey class of project performance evaluation based on D-S evidence theory and determines the integrated performance level of project.

1. Introduction

Quite a number of pollutants have been discharged into water bodies and have accumulated in company with economic growth in recent years in China(Miao and Fan,2012). As a result, most waters in China are suffering different degrees of pollution. From a national perspective, the pollution is extending from the tributaries to the master streams, spreading from urban areas to rural areas, permeating from earth surface to underground layers, and diffusing from areas to basins Wu,2010;Lv , et al.,2014).. Water environment has turned into one of the key bottle necks to the economic and social development in China.

Water environment has turned into one of the key bottle necks that severely restrict the economic and social development in China. In order to control urban water pollution, improve the urban sewage treatment capacity, and assure drinking water security, the governments at all levels made heavy investment in engineering construction, and the number and size of urban water environment improvement projects are growing. However, project performance assessment is still a difficulty. With this fact as a starting point, this paper probes into the method for urban water environment improvement project performance evaluation.

In order to control urban water pollution and improve the urban sewage treatment capacity to protect the security of drinking water, the Chinese government have made heavy investment in water environment improvement project since 2005. In this background, the project performance assessment is necessary and has been researched by many scholars : Ma and Weng(2011)constructed a performance evaluation index system of urban water environment treatment including function, benefit and potential indexes. Zhang (2006) established an index system for urban water environment improvement performance evaluation using analytic hierarchy process and presented the fuzzy comprehensive evaluation method based on indicators. Bai and Wang (2010) established the fuzzy synthetic evaluating model for assessing pollution control performance. Xu and Song (2005) brought forward the concept of "guarantee rate" for quantitative assessment of water environment for urban environmental & hydraulic works and the hydraulic calculation method based on the predictive evaluation and mathematical statistics theory of water environment.

The present studies have focused on the indexes of the performance evaluation of urban water environment project from different perspectives. As the information of the project is always little and ambiguity in the performance evaluation, the paper tries to takes advantage of Dempster-Shafer (D-S) evidential theory and triangle whitening function in data processing and data integration to construct the evaluation model. The reminder of this paper is organized as follows. In Section 2, the general knowledge for the methodology is described. In Section 3, the improved performance evaluation model for urban water environment project is described in detail. Finally, some concluding remarks are drawn in Section 5.

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2. Establishment of Urban Water Environment Improvement Project Performance Evaluation Index System.

Urban water environment improvement project performance evaluation index system is essential for project performance evaluation; scientific and rational index system enables evaluators to get the whole picture of the performance and existing problems of urban water environment improvement project, thus being a means necessary for performance evaluation. An evaluation index system is developed in this paper to objectively reveal the level of consistency of project with national policy and physical needs, rationally determine the project implementing efficiency, accurately reflect the project effectiveness, completely indicate the project sustainability, while assuring the independence between indicators.

The urban water environment improvement project performance evaluation index system developed in this paper consists of three layers, i.e. the objective layer, the criteria layer, and the indicator layer, as shown in table 1.

Table 1: Urban water environment improvement project performance evaluation index system

Objective layer	Criteria layer	Indicator layer
Urban water environment improvement project performance evaluation	Level of consistency x_1	Degree of correlation of project with development strategy x_{11}
		Degree of agreement of project with physical need x_{12}
	Process efficiency x_2	Level of consistency of practical and expected cycles x_{21}
		Degree of agreement of the use of fund with budget x_{22}
		Sewage treatment plant project completion ratio x_{23}
		Sewage interception project completion ratio x_{24}
	Output effect x_3	Ratio of new sewage treatment capacity x_{31}
		New sewage treatment rate x_{32}
		New sewage household connection rate x_{33}
		BOD reduction x_{34}
		COD reduction x_{35}
		Beneficiaries' satisfaction x_{36}
	Sustainability x_4	Soundness of operating equipment x_{41}
		Degree of the adequacy of funds x_{42}

The first layer is objective layer, namely the urban water environment improvement project performance evaluation.

The second layer is criteria layer, which defines the perspective and content of urban water environment improvement project performance evaluation. Based on the distinctive features of urban water environment improvement project and its performance evaluation, as well as the existing research findings of urban water environment improvement project performance evaluation, this paper ascertains four evaluation criteria, i.e. the level of consistency, the process efficiency, the output effect, and the sustainability. The level of consistency refers to the degree of conformity of urban water environment improvement project with national, regional and industrial policies and physical local needs; process efficiency means the economic efficiency of the conversion from input into output; output effect indicates the immediate effect and social impact of urban water environment improvement project; sustainability refers to the possibility of project outputs to operate sustainably and generate benefits upon the completion of project.

The third layer is indicator layer; in response to the four criteria of criteria layer, this paper sets up the urban water environment improvement project performance evaluation indicator layer composed of 14 indicators using literature review method and frequency statistics method by taking into account the distinctive features of urban water environment improvement project and its performance evaluation.

3. Dempster–Shafer theory and triangular fuzzy number

Some scholars have link grey system theory up with D-S evidence theory; for example, Wang Yuhong and Dang Yaoguo carried out studies on comprehensive evaluation method for project through the combination of grey fixed weight grey clustering evaluation model and D-S evidence theory. An evaluation model is built in this paper based on grey system theory and D-S evidence theory by taking into account the complexity of urban water environment improvement project and the considerable difficulties in data collection for performance evaluation. The polar triangle whitening weight function-based grey evaluation method and D-S evidence theory are combined for rational, comprehensive and systematic evaluation of urban water environment improvement project by borrowing the domestic and foreign experience in urban water environment improvement project performance evaluation and making use of the more objective selection of extreme point by polar triangle whitening weight function based on the objective, function and characteristics of urban water environment improvement project performance evaluation on the basis of the predecessors' research findings regarding the method for combining grey theory and D-S evidence theory.

D-S evidence theory-based development of urban water environment improvement project performance evaluation model is realized in the following four steps: (1) The collection and processing of basic data through desk research, face-to-face interview, expert consulting, panel discussion, and field research; (2) The determination of indicator weight by triangular fuzzy number method; (3) Identify evaluation grey class, compute grey integrated clustering matrix, and determine each criterion level; (4) Identify the grey class of project performance evaluation using D-S evidence theory, and determine the integrated performance level of project.

Dempster–Shafer theory is a generalization of the Bayesian approach. The Dempster–Shafer theory was first developed by Dempsterin the 1960s. His work was later extended and refined by Shafer in the 1970s. This theory can deal with incomplete data by managing ignorance (Shafer, 1976). It is based on Dempster's works on the lower and upper limits of probabilities.

Definition 1. Let m (A) denote the basic probability assignment (BPA) to the subset A, which measures the extent to which the evidence supports A. The BPA is a function.

Definition 2. The function $Bel: 2^{\Theta} \to [0,1]$ is the belief function should satisfy the following:

1) $Bel(\varnothing)=0$,

2) $Bel(\Theta)=1$,

3) $\forall A_1, A_2, \cdots, A_N \subseteq \Theta$, $Bel(\bigcup_{i=1}^{N} A_i) \geq \sum_{i=1}^{N} Bel(A_i) - \sum_{i<j} Bel(A_i \cap A_j) + \cdots + (-1)^{N+1} Bel(\bigcap_{i=1}^{N} A_i)$.

Definition 3. Assume that a= (al, am, au) is a triangular fuzzy number, the membership function is $\mu_{a(x)}$: *R [0, 1],* so we can get,

$$\mu_{a(x)} = \begin{cases} 0, & x < a^l \\ \dfrac{x-a^l}{a^m-a^l}, & a^l \leq x \leq a^m \\ \dfrac{x-a^m}{a^m-a^u}, & a^m \leq x \leq a^u \\ 0, & x \geq a^u \end{cases} \tag{1}$$

Where x∈R, a^l, a^u stands for the lower bound and the upper bound of the triangular fuzzy number.

Definition 4. Assume that a= (a^l, am, au) and b= (b^l, bm, bu) are two triangular fuzzy numbers, we can obtain the possibility degree of a≥b through:

$$p(a \geq b) = \lambda \frac{min(a^m-a^l+b^m-b^l, max(a^m-b^l,0))}{a^m-a^l+b^m-b^l} + (1-\lambda) \frac{max(a^u-a^m+b^u-b^m, max(a^u-b^m,0))}{a^u-a^m+b^u-b^m} \tag{2}$$

The value of λ depends on the decision maker's attitude towards risk. When λ>0.5, the decision-maker is willing to take risks. When λ=0.5, decision-maker is risk neutral. When λ<0.5, the decision-maker is averse to risk.

4. The model

The evaluation model for the performance of urban water environment improvement project is realized in the following three steps. Firstly, determine the indicator weight by triangular fuzzy number. Secondly, identify evaluation grey class to determine each criterion level based on gray system theory. At last, identify the grey class of project performance evaluation using D-S evidence theory and determine the integrated performance level of project.

4.1 Determine the indicator weight.

The evaluators build a judgment matrix that determines the importance of urban water environment improvement project performance indicators through triangular fuzzy number. Based on (1)and (2) , we can get the weights of evaluation indicators.

4.2 Determine the criterion level through the grey clustering evaluation

In the principle of "maximum clustering factor", grey integrated clustering matrix can help to identify the grey class of each criterion at criteria layer in urban water environment improvement project index system and obtain the performance evaluation result for each criterion at criteria layer. Based on gray system theory, the calculation for each grey integrated clustering matrix is realized in the following three steps:

(1) Determine the evaluation grey class

According to the requirements on urban water environment improvement project evaluation, we need to cluster the value range of each indicator *j* into *s* grey classes. Suppose that x_{ij} is the observed value of object *j* with respect to indicator *s* , and that the value range is $[a_{ij}^1, a_{ij}^{s+1}]$, it could be defined as follows:

$$a_{ij}^1 \le x_{ij}^1 < a_{ij}^2, a_{ij}^2 \le x_{ij}^2 < a_{ij}^3, \cdots, a_{ij}^s \le x_{ij}^s \le a_{ij}^{s+1} \tag{3}$$

Where a_{ij}^k,*i=1,2,…,n, j=1,2,…,m, k=1,2,…,s+1*. The value of a_{ij}^k is determined based on the practical situation of the indicators for urban water environment improvement project.

(2) Calculate the degree of grey class membership

According to gray system theory, we suppose that the whitening weight function value of the k grey class is 1, connect (λ_{ij}^k,1), the starting point ($a_{1\,ij}^{k-}$,0) of the *k*-1 grey class and the ending point ($a_{1\,ij}^{k+2-}$,0) of the *k*+1 grey class to achieve the triangle whitening weight function $f_{ij}^k(\cdot)$.

Where $\lambda_{ij}^k=(a_{ij}^k+a_{ij}^{k+1})/2$, *i=1,2,…,m, k=1,2,…,s.*

For indicator x_{ij}, we can get its the degree of grey class membership $f_{ij}^k(x_{ij})$ according to the following equation:

$$f_{ij}^k = \begin{cases} 0, & x \notin [a_{ij}^{k-1}, a_{ij}^{k+2}]\ ; \\ \dfrac{x_{ij}-a_{ij}^{k-1}}{\lambda_{ij}^k - a_{ij}^{k-1}}, & x \in [a_{ij}^{k-1}, \lambda_{ij}^k]; \\ \dfrac{a_{ij}^{k+2}-x_{ij}}{a_{ij}^{k+2}-\lambda_{ij}^k}, & x \in (\lambda_{ij}^k, a_{ij}^{k+2}]. \end{cases} \tag{4}$$

(3) Calculate the whitening weight synthetic clustering factor matrix of each indicator

Based on equation $\sigma_i^k = \sum_{j=1}^m f_j^k\left(x_{ij}\right)\eta_j$, we can get the synthetic clustering factor σ_i^k of object *i* in relation to grey class *k*. Where η_j, *j=1,2,…,m* is the indicator weight determined with triangular fuzzy number method.

Based on the above steps, we can obtain the whitening weight synthetic clustering factor of each affecting factor for urban water environment improvement project performance evaluation. The clustering factor matrix can be composed as the following:

$$\Sigma=(\sigma_i^k)=\begin{bmatrix} \sigma_1^1 & \sigma_1^2 & \cdots & \sigma_1^s \\ \sigma_2^1 & \sigma_2^2 & \cdots & \sigma_2^s \\ \vdots & \vdots & \cdots & \vdots \\ \sigma_n^s & \sigma_n^s & \cdots & \sigma_n^s \end{bmatrix} \tag{5}$$

The grey class of each indicator at criteria layer is identified in the principle of "maximum clustering factor". Since $\max\limits_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^{k^*}$, the object i should be of grey class *k**. If there are many objects belong to grey class *k**, they could be sorted by synthetic clustering factor, and thereby determine the advantages and disadvantages of each object of grey class *k**.

4.3 Determine the integrated performance level of the urban environment project

(1) Determine the assigned value of basic probability

Assume that Θ is the identification framework, and that A_i is the single-point set in Θ ; make

$$m_i(A_k) = \frac{\sigma_i^k}{\sum_{k=1}^{s} \sigma_i^k} \tag{6}$$

Where *i=1,2,…,n, k=1,2,…,s*. Suppose that as a minimum, there should be an i_0 that makes $\sigma_{i_0}^k \neq 0$ for any *k,k=1,2,…,s*.

Matrix M_1 is obtained through computation based on the $n \times s$ basic credit assignment functions in the same identification framework Θ :

$$M_1 = \begin{bmatrix} m_1(A_1) & m_2(A_1) & \cdots & m_n(A_1) \\ m_1(A_2) & m_2(A_2) & \cdots & m_n(A_2) \\ \vdots & \vdots & \cdots & \vdots \\ m_1(A_s) & m_2(A_s) & \cdots & m_n(A_s) \end{bmatrix} \tag{7}$$

(2) Make belief function by Dempster rule

1) Make belief function for the first time

Assuming that m_1, m_2,…,m_n are n basic credit assignment functions on the same identification framework Θ ,and the focal elements are $A_i(i = 1, 2, \cdots, s)$. According to the D-S composition rule (Jia , et al., 2013):

$$m(A_i) = (m_1 \oplus m_2 \oplus m_3 \oplus m_4)(A_i) = \begin{cases} \dfrac{\sum_{A_1 \cap \cdots \cap A_n = A} \prod_{i=1}^{n} m_i(A_i)}{1-K}, & A \neq \varnothing \\ 0 \, , & A = \varnothing \end{cases} \tag{8}$$

Where, $K = \sum_{A_1 \cap \cdots \cap A_n = \varnothing} \prod_{i=1}^{n} m_i(A_i)$ reflects the degree of conflict between evidences. $A_i \cap B_j = \varnothing$ means that the two evidences assign the credibility respectively to two antagonistic propositions. The bigger the *K* value, the more intensive is the conflict.

Make belief function according tothe Dempster rule, we can obtain $(m^1(A_1), m^1(A_2), \cdots, m^1(A_s))$ based on Equation (8).

2) Make belief function for the second time

If $m_{j_0}(A_{i_0}) = 0,\ i_0, j_0 \in \{1, 2, \cdots, n\}$, $m_{j_0}(A_{i_0}) = \frac{1}{10}\min\{m_j(A_i)\}$, the value could be obtained by splitting from basic belief assignment value $\max\{m_{j_0}(A_{i_0})\}$. Where $\frac{1}{10}\min\{m_j(A_i)\}$ is called the permissible minimum set function value(Shafer,1976) .

The following equation is obtained through the appropriate adjustment of values assigned to the set functions with a basic belief assignment value of 0 in M_1:

$$M_2 = \begin{bmatrix} m_1(A_1) & m_2(A_1) & \cdots & m_n(A_1) \\ m_1(A_2) & m_2(A_2) & \cdots & m_n(A_2) \\ \vdots & \vdots & \cdots & \vdots \\ m_1(A_s) & m_2(A_s) & \cdots & m_n(A_s) \end{bmatrix} \tag{9}$$

Make belief function following the Dempster rule to obtain $(m^*(A_1), m^*(A_2), \cdots, m^*(A_s))$.

3) Determine the result of performance evaluation in the principle of maximum informatively.
Determine the urban water environment improvement project performance evaluation result using the grey class that corresponds to the maximum focal element of belief function in the principle of "maximum informatively". Then check whether the result from the first belief function is consistent with that from the second belief function. If the result is consistent, the performance can be evaluated the good.

5. Conclusions

In this paper, the performance evaluation model for urban water environmental project based on D-S theory and gray clustering. In the model, the triangular fuzzy number is used to determine the indicator weight and the clustering factor matrix is transformed based on the obtained grey clustering factor of evaluation object to determine the level of each criterion. The combination of grey system theory and D-S evidence theory for handling the uncertainties in the performance evaluation model for urban water environmental project is practically feasible.

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