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Evaluating Brownfield Redevelopment using an Modified Multilevel Grey Method - A Case Study of Xi'an

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ABSTRACT

A novel multiple criteria decision analysis (MCDA) method is designed for comparing and ranking resolution solutions to a brownfield redevelopment project. In particular, an MCDA technique called the modified multilevel grey evaluation method is developed using concepts from grey systems theory, entropy and the analytical hierarchical process (AHP). To obtain weights for the range of criteria and sub-criteria used to assess and compare the resolution solutions, results obtained using AHP and an entropy technique are combined. In order to reflect uncertainty in the evaluation scores of the resolutions according to the sub-criteria, a grey systems class is employed to appropriately transform the scores. Subsequently, the evaluation method for the resolutions along with the combined weights is used to rank the resolutions. To demonstrate how this new methodology can be conveniently used in practice and provide valuable insights for aiding decision making, it is applied to a brownfield site in Xi'an, China, created by a former chemical factory.

Keywords: brownfield redevelopment, modified multilevel grey evaluation, grey class, combined weight

INTRODUCTION

In April 2016, with the widely report of CCTV and many other media on the Changzhou "poison" incident in China, the region's students health injury has become the focus of public attention, which would gradually be concerned about redevelopment of polluted land in city. Brownfield, the opposite of greenfield, refers to a developed property that is abandoned or underutilized. Brownfields usually occur when an industrialized region evolves into a more service-oriented economy. In the United States, the Environmental Protection Agency (US EPA) (2005) defines brownfield sites as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, or contaminant". Brownfields are of widespread concern because they pose serious environmental and public health risks, limit economic development opportunities and restrict urban revitalization. There exists a large number of brownfields in industrialized countries around the world. For example, the USA has between half a million and one million brownfields while Germany is believed to contain about 362,000 sites (Bush, 2002, NRTEE, 2003).

The brownfield redevelopment process consists of re-mediating a given site by treating, removing or isolating the pollutants and subsequently developing the location for useful purposes, such as constructing an office building or creating a new park (G. Atkinson et al.,2014). This procedure usually involves negotiations among a range of stakeholders who attempt to meet, as much as possible, their particular objectives. Brownfield redevelopment has become an important issue in developed countries and benefits society in many ways. It revitalizes urban communities and improves environmental quality. Moreover, a 2003 survey by the US Conference of Mayors demonstrated that brownfield redevelopment in 148 cities could generate 576,373 new jobs and as much as $1.9 billion annually in additional tax revenues (US Conference of Mayors, 2003). Brownfield redevelopment also indirectly preserves up to 4.5 hectares of green space for every hectare redeveloped, largely through reduced requirements for new infrastructure and denser site plans, as reported in a George Washington University study (Deason et al., 2011; Mathey et al.,2015).

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Contribution of this paper to the literature

- The buildup index system for brownfield redevelopment is obtained from six dimensions: environmental and health, financial and accounting, characteristics of the brownfield, social stability, policy and technology criteria, and performance criteria (Zhu & Guo, 2014).
- The weights can not only balance the roles of the subjective and objective weighting methods, but also almost overcome the one-sidedness of only using one of the two methods (Liang, 2014). Therefore, the weights of the combination weighting method can reflect both the decision makers' subjective intentions and the objective reality, and make our synthetic evaluation results match the actual situation better (Fu & Zou, 2007).
- The case study indicates that can provide a useful tool for the complicated multiple objective decision-making in order to obtain scientific and reasonable results for decision makers (Zhang & Nie, 2012).

Thus, brownfields have recently received significant attention from governments, communities, environmental advocates, scientists, and researchers around the world. Considerable research has focused on various brownfield redevelopment topics including development of remediation technologies, environmental evaluation, risk assessment and management, financial arrangements, and public involvement (Li & Chao, 2007). Many methodologies from fields such as economics, systems engineering and management science have been applied to challenging environmental management problems. Among these methodologies, project evaluation methods can be especially valuable to decision makers and stakeholders. For example, a number of optimization models have been developed for evaluating resolutions to environmental problems, such as a linear programming (Lynn et al., 1962), dynamic programming (Evenson et al., 1969; Chia & Defilippi, 2009), nonlinear programming and conflict resolution models (Rossman, 1980; Hipel & Bernath, 2011). However, the inherent uncertainty and complexity of selecting the optimal resolution were rarely taken into account.

Grey systems theory developed by Deng (1982) has been widely applied to a range of problems arising in different fields (Lin et al., 2006). It has been shown to be effective for dealing with unquantifiable information, non-obtainable information, incomplete information and partial ignorance (Xia et al.,2015). The grey evaluation method (GEM) is a part of grey systems theory, which is useful for solving problems with complicated interrelationships between multiple factors and variables in the face of high uncertainty. The Analytic Hierarchy Process (AHP) is a multiple objective decision-making method, proposed by the famous American researcher Saaty (1980). AHP serves as a systematic, transparent, and reproducible method for formally modeling and analyzing complex decisions (Chang & Wang, 2016). The integration of AHP and GEM can be used to solve inexact problems containing multiple criteria and uncertainty in typical decision-making processes. However, only a few studies regarding this integration have been reported in the literature. For example, Chen & Li (2006) designed a model using AHP and GEM to evaluate the risk of enterprise technological innovation. Wang & Li (2008) analyzed the choice of third party logistics service agents using a mufti-hierarchical grey evaluation approach. The Modified grey evaluation method proposed by Zhang & Nie (2012) has been successfully applied to the selection of cooperative partners for virtual enterprises. Because of the mufti-objective and uncertain properties in selecting an optimal brownfield redevelopment resolution, the authors of this paper intend to develop a new modified grey evaluation method for facilitating the decision-making process (Tian et al., 2012; Hsin & Chen, 2015). The modified approach possesses the advantages of both AHP and GEM, and it is applied to an actual brownfield redevelopment project for verification and demonstration.

THE EVALUATING CRITERION SYSTEM OF BROWNFIELD REDEVELOPMENT

Evaluation work normally starts with the establishment of evaluation index system. Creation of a criterion system for the evaluation of a brownfield redevelopment project is an important task of the project evaluation-based research framework (Zhu, 2008; Hsueh & Su, 2016). Brownfield literature provides numerous studies regarding the reduction of pollution and financial supports, a few of them aimed at setting up an evaluating criterion system for brownfield redevelopment projects. For example, Syms (1999) has proposed six groups of decision-making factors relevant to the redevelopment of brownfields; De Sousa (2000) has developed an index system based on the three aspects of environmental benefits, social benefits and economic benefits; Lange & McNeil (2004a, b) have conducted significant research into both the attributes of successful brownfield redevelopments and possible predictors of successful projects; Bacot & O'Dell (2006) have also suggested practical, valid criteria to measure the viability of governmental brownfield programs in terms of environmental and economic concerns; and Wedding (2007) has proposed an index system to assess the success of redevelopments according to sustainability goals, including multi-stakeholder perspectives, green building elements, and site-level details.

Taking the characteristics of the brownfields of China (Zhu, 2014; Liang, 2014) and the requirements of sustainable development into account, 500 questionnaires were sent to major stakeholders of brownfield

Table 1. The index system of brownfield redevelopment projects

Main criteria	Sub-criteria
Environmental and health benefits Criteria B_1	1) Improvement of the quality of underground water B_{11} 2) Improvement of soil quality B_{12} 3) Improvement of air quality B_{13} 4) Lowering the health risks of local residents B_{14} 5) Increase of green cover percentage B_{15} 6) Improvement of remediation technologies B_{16}
Financial criteria B_2	1) Payback period B_{21} 2) Return on investment B_{22} 3) Total cost of brownfield redevelopment B_{23} 4) Ratio of remediation cost to total cost B_{24} 5) Net present value B_{25}
Brownfield site criteria B_3	1) Location of brownfield B_{31} 2) Status of infrastructure facilities of area B_{32} 3) Transportation convenience of brownfield area B_{33} 4) Size of brownfield B_{34}
Societal stability criteria B_4	1) Increase local tax base B_{41} 2) Increase local employment rate B_{42} 3) Improvement of local security status B_{43}
Policy and technical criteria B_5	1) Protecting and recycling the land/soil resourceB_{51} 2) Influence from other contamination hazards nearby B_{52} 3) Difficulty and cycle of remediation B_{53}
Performance criteria B_6	1) Matchup with city planning B_{61} 2) Increase land value of neighborhood B_{62} 3) Improvement of image of local community and government B_{63}

redevelopment, which included relevant government divisions, brownfield owners, brownfield developers, the financial sector, public representatives and some other stakeholders. The data collected from the questionnaires are analyzed with the help of factor analysis. Criteria for the brownfield index system are based on the six dimensions (Zhu & Guo, 2014) given below:

(1) Environmental and health, which focus on the environmental improvement of the area and the health improvement of the communities, mainly from the perspective of soil quality, air quality, groundwater, green ratio, remediation technologies and lowering health risks;

(2) Financial and accounting, which concentrate on the cash flow, development potential and profitability of the brownfield redevelopment project, mainly from the perspective of net present value, rate of return, investment return period, and total cost of the remediation and construction of the brownfield project;

(3) Characteristics of the brownfield, which center on the geographical position of the brownfield, mainly from the perspective of infrastructure facilities, transportation convenience and size of the brownfield;

(4) Social stability, which focuses on enhancing the government's image and the social benefits of redevelopment, mainly from the perspective of increasing local employment rate, increasing local tax base and local security status;

(5) Policy and technology criteria, which concentrate on difficulties in the treatment and the policy support of the redevelopment, mainly from the perspective of protecting and recycling land resources, influences from other nearby contamination hazards, and difficulty and cycle of remediation;

(6) Performance criteria, which focus on the actual practical impacts of brownfield redevelopment, mainly from the perspective of city planning, increasing the land value of the neighborhood, and improving of the image of the local community and government.

A total of 24 criteria are selected for building up the index system from the above-mentioned six dimensions. The evaluating criteria system is shown in **Table 1**.

MODIFIED GREY EVALUATION METHOD

The AHP organizes the decision-making problem as a hierarchical structure containing several levels. The main criteria define the main goal of the decision problem, and the sub-criteria usually describe the decision resolutions. In order to take into account the uncertainty in brownfield redevelopment and relevant criteria for assessing alternative solutions using AHP (National Research Council, 2005), a modified multilevel grey evaluation approach combining AHP and the grey system method is proposed.

A three-level hierarchy that represents a standard decision problem with a finite set of resolutions may be considered: B denotes overall objection, $B_i(i = 1,2,\cdots,m)$ denotes main criterion, $B_{ij}(j = 1,2,\cdots,n_i)$ denotes sub-criterion, n_i denotes the number of sub-criteria corresponding to B_i, $k(k = 1,2,\ldots,q)$denotes the serial number of resolutions, U^k denotes the comprehensive evaluating value of the k th resolution.

Constructing the Judgment Matrix Using the Marking Scores

Index of evaluation is uniformly divided into the following five-scale standard: 5-Excellent, 4-Very Good, 3-Fair, 2-Poor, 1-Very Poor. In addition, any level in between two adjacent grades will be awarded the corresponding point scores of 4.5, 3.5, 2.5 and 1.5.

The identification label for an expert is written as h $(h = 1,2,\cdots p)$, for which there is a total of p experts. These experts will evaluate or mark resolutions according to the data of criterion B_{ij}.

According to the B_{ij} mark of the k th resolution given by the h th expert, the judgment matrix D_k is obtained:

$$D_k = \begin{bmatrix} d_{11}^1 & d_{11}^2 & \cdots & d_{11}^h & \cdots & d_{11}^p \\ d_{12}^1 & d_{12}^2 & \cdots & d_{12}^h & \cdots & d_{12}^p \\ & & \vdots & & & \\ d_{ij}^1 & d_{ij}^2 & \cdots & d_{ij}^h & \cdots & d_{ij}^p \\ & & \vdots & & & \\ d_{mn_m}^1 & d_{mn_m}^2 & \cdots & d_{mn_m}^h & \cdots & d_{mn_m}^p \end{bmatrix},$$

d_{ij}^h denotes the mark of the h th expert with respect to criterion B_{ij}.

Combined Weighting Method

The weights of evaluating criteria have deep effects on the results during the process of quantitative project assessment. If the subjective weighting method is used, the results are often subjective though they can reflect the intentions of decision makers. On the contrary, if only the objective weighting method is used, the results cannot reflect the experience and judgment of decision makers, but may involve a quagmire of mechanical materialism as they have a strong mathematical theory basis. Hence, integrating the two methods may be considered so that the results are more scientific and rational. The combined weighting method used in this paper integrates the AHP, which stands for the subjective weighting method, and the entropy method, which stands for the objective weighting method, in order to evaluate the brownfield redevelopment project (Fu & Zou, 2007). The steps of the combined weighting method in determining the weights are as follows:

AHP

The Analytic Hierarchy Process (AHP) is a powerful tool for the analysis of complex decision-making problems. The decision maker expresses his/her preferences by comparing the importance of the elements of the given level with respect to an element of the preceding level. A matrix according to the expert scoring method can be considered and the consistency test be carried out.

The weights of vector α may be given as vector$\alpha = (\alpha_{11}, \alpha_{12}, \ldots, \alpha_{ij}, \ldots, \alpha_{mn_m})$. The steps of AHP are unnecessary to describe because it is widely used.

Entropy method

The entropy method is a weight determining method that uses the original data of the criteria of resolutions. The entropy value reflects the degree of disorder in information theory, and can be used to measure the amount of information. The entropy method procedures used to determine the weights are presented as follows:

1) Normalization of the original evaluating matrix

The k th resolution can be expressed as $M^i = \left[x_{ij}^k\right]_{n_i \times q}$. Normalization of this matrix produces $Y = (y_{ij}^k)_{n_i \times q}$, where y_{ij}^c is the data of the k th evaluating object on the criterion B_{ij}. For the criteria for which a larger amount of data is preferred, the function is as follows:

$$y_{ij}^k = \frac{x_{ij}^k}{\sum_{k=1}^q x_{ij}^k} \tag{1}$$

For the criteria for which fewer data are preferred, the function is as follows:

$$y_{ij}^{k}=\frac{1/x_{ij}^{k}}{\sum_{k=1}^{q}(1/x_{ij}^{k})} \tag{2}$$

2) Definition of the entropy

$$e_{ij}=-\lambda\sum_{c=1}^{q}y_{ij}^{c}lny_{ij}^{c} \tag{3}$$

$\lambda = 1/\ln q$, and when$y_{ij}^{k}=0$,$y_{ij}^{k}\ln y_{ij}^{k}=0$is supposed.

3) Definition of the weight of entropy

The weight vector of criterion B_{ij} is $\beta=(\beta_{11},\beta_{12},\dots,\beta_{ij},\dots,\beta_{mn_m})$. The weight value of criterion B_{ij} could be defined as:

$$\beta_{ij}=\frac{1-u_{ij}}{\sum_{j=1}^{n_i}(1-u_{ij})} \tag{4}$$

Combined weighting method

The combined weighting method is a weight determining method that integrates the subjective and objective weighting methods and reflects information in both methods. So, on the basis of comprehensive analysis of the AHP and the entropy method, the analytic results of the two methods can be combined. The multiplication integration method is used to determine the combined weight ω_{ij} and can obtain $\omega_i=(\omega_{i1},\omega_{i2},\dots,\omega_{in_i})$.

Multiplication integration method:

$$\omega_{ij}=\frac{\alpha_{ij}\times\beta_{ij}}{\sum_{j=1}^{n_i}\alpha_{ij}\times\beta_{ij}} \tag{5}$$

As described above, the combined weight ω_i of criterion B_i is similarly calculated and is obtained as: $\omega=(\omega_1,\omega_2,\dots,\omega_m)$.

Determination of Evaluation Whitenization Weight Function

Determining the evaluation **whitenization weight function** means determining the differentiation vector of the grey evaluation class, grey number and grey whiteness function. According to the index set and the marking criteria for assessing the potential resolutions, five evaluation grey classes are used in this case, for which the grey class serial numbers $e, e=1,2,3,4,5$. The numbers denote greatly contribute, comparatively contribute, slightly contribute, no effect and hinder, respectively (Tao & Song, 2010). The grey class and the corresponding grey whiteness function are as follows:

The first grey class: greatly contribute($e=1$), grey number $\otimes_1\in[5,\infty]$, the corresponding grey whiteness function f_1 is:

$$f_1=\left.\begin{cases} d_{ij}^{h}/5 & d_{ij}^{h}\in[0,5] \\ 1 & d_{ij}^{h}\in[5,\infty] \\ 0 & d_{ij}^{h}\notin[0,\infty] \end{cases}\right]$$

The second grey class: comparatively contribute($e=2$), grey number$\otimes_2\in[0,4,8]$, the corresponding grey whiteness function f_2 is:

$$f_2=\left.\begin{cases} d_{ij}^{h}/4 & d_{ij}^{h}\in[0,4] \\ \dfrac{8-d_{ij}^{h}}{4} & d_{ij}^{h}\in[4,8] \\ 0 & d_{ij}^{h}\notin[0,8] \end{cases}\right]$$

The third grey class: slightly contribute($e=3$), grey number$\otimes_3\in[0,3,6]$, the corresponding grey whiteness function f_3 is:

$$f_3=\left.\begin{cases} d_{ij}^{h}/3 & d_{ij}^{h}\in[0,3] \\ \dfrac{6-d_{ij}^{h}}{3} & d_{ij}^{h}\in[3,6] \\ 0 & d_{ij}^{h}\notin[0,6] \end{cases}\right]$$

The fourth grey class: no effect ($e=4$), grey number$\otimes_4\in[0,2,4]$, the corresponding grey whiteness function f_4 is:

$$f_4 = \begin{cases} d_{ij}^h/2 & d_{ij}^h \in [0,2] \\ \dfrac{4-d_{ij}^h}{2} & d_{ij}^h \in [2,4] \\ 0 & d_{ij}^h \notin [0,4] \end{cases}$$

The fifth grey class: hinder ($e = 5$), grey number $\otimes_5 \in [0,1,2]$, the corresponding grey whiteness function f_5 is:

$$f_5 = \begin{cases} 1 & d_{ij}^h \in [0,1] \\ 2 - d_{ij}^h & d_{ij}^h \in [1,2] \\ 0 & d_{ij}^h \notin [0,2] \end{cases}$$

Calculating Grey Evaluation Coefficient and Evaluation Matrix

For evaluation criterion B_{ij}, the grey evaluation coefficient of the k th resolution that belongs to the e th grey class is written asx_{ije}^k, the calculating formulae are:

$$x_{ije}^k = \sum_{h=1}^{e} f_e(d_{ij}^h) \qquad x_{ij}^k = \sum_{e=1}^{5} x_{ije}^k$$

For evaluation of criterion B_{ij}, the eth grey evaluation weight of the k th resolution is written as r_{ije}^k, the calculating formula is $r_{ije}^k = \frac{x_{ije}^k}{x_{ij}^k}$

The number of grey evaluation class is 5, the grey evaluation weight vector of criterion B_{ij} for the k th resolution is written as r_{ij}^k, $r_{ij}^k = (r_{ij1}^k, r_{ij2}^k, r_{ij3}^k, r_{ij4}^k, r_{ij5}^k)$

According to the grey evaluation weight vector of criterion B_{ij}, the grey evaluation matrix $R_i^k$of criterion B_i for the k th resolution is obtained as:

$$r_i^k = \begin{bmatrix} r_{i1}^k \\ r_{i2}^k \\ \vdots \\ r_{ij}^k \end{bmatrix} = \begin{bmatrix} r_{i11}^k & r_{i12}^k & r_{i13}^k & r_{i14}^k & r_{i15}^k \\ r_{i21}^k & r_{i22}^k & r_{i23}^k & r_{i24}^k & r_{i25}^k \\ \vdots & & \cdots & & \vdots \\ r_{in_i1}^k & r_{in_i2}^k & r_{in_i3}^k & r_{in_i4}^k & r_{in_i5}^k \end{bmatrix}$$

The Comprehensive Evaluation of Criterion B_i

Assuming the comprehensive evaluation value of criterion B_i for the k th resolution is A_i^k,

$$A_i^k = \omega R_i^k = \left(a_{11}^k, a_{12}^k, a_{13}^k, a_{14}^k, a_{15}^k\right),$$

$$A^K = \begin{bmatrix} A_1^k \\ A_2^k \\ \vdots \\ A_m^k \end{bmatrix} = \begin{bmatrix} a_{11}^k & a_{12}^k & a_{13}^k & a_{14}^k & a_{15}^k \\ a_{21}^k & a_{22}^k & a_{23}^k & a_{24}^k & a_{25}^k \\ \vdots & & \cdots & & \vdots \\ a_{m1}^k & a_{m2}^k & a_{m3}^k & a_{m4}^k & a_{m5}^k \end{bmatrix}$$

The Comprehensive Evaluation of Resolutions

The grey comprehensive evaluation value of the k th resolution is written as E^k: $E^k = \omega A^k$

According to the differentiation value vector of grey class number $C = (100,80,60,40,20)$, the comprehensive evaluation value of the k th resolution is written as U^k: $U^k = E^k C^T$.

Supposing $U^k = \max[U^1, U^2, \cdots, U^q]$, the k th resolution is the best resolution for the brownfield redevelopment project.

CASE STUDY

This paper regards the reformation project of an abandoned chemical plant in Xi'an, China as a case study. The abandoned chemical plant is a contaminated brownfield. With the purpose of promoting economical growth at the brownfield site, the government plans to undertake measures to remedy and redevelop it. There are three redevelopment resolutions for this brownfield: shopping center 1, industrial plant 2, and residential building 3. Five experts are invited to mark the resolutions according to the marking scheme. The original scores of resolutions

Table 2. Criteria scores of resolutions by experts

$D_1 =$					$D_2 =$					$D_3 =$				
3.7	3.9	4.0	3.6	3.8	3.5	3.2	3.1	3.6	3.5	3.8	3.9	4.0	4.1	4.2
3.5	3.7	3.7	3.8	3.8	3.1	3.4	3.7	3.8	3.5	4.1	4.2	4.3	4.3	4.6
3.0	4.0	4.2	4.3	3.9	3.4	3.3	3.9	3.2	3.7	3.7	3.5	4.1	3.7	4.0
3.3	3.3	3.1	3.3	3.5	2.8	3.0	3.1	3.1	3.0	3.6	3.4	3.7	3.8	3.5
3.2	3.2	3.0	3.2	3.4	2.9	2.8	3.0	3.2	3.1	3.0	3.2	3.4	3.6	3.3
3.4	3.6	3.5	3.8	3.7	3.5	3.8	4.1	3.6	4.0	3.8	4.0	4.1	3.9	4.2
3.6	3.9	3.9	3.4	3.7	3.4	3.2	3.7	3.6	3.5	4.1	3.7	3.6	4.1	4.0
3.8	4.3	4.0	4.0	4.2	3.6	3.0	3.8	3.7	4.0	4.3	3.8	4.4	3.8	3.7
3.4	3.9	3.9	4.0	3.9	3.6	4.0	3.3	3.7	3.9	3.3	3.2	3.7	3.6	3.7
3.7	3.5	3.7	3.8	3.8	3.8	3.1	3.3	3.5	3.2	3.4	3.7	3.1	3.5	3.3
3.5	3.7	3.9	3.6	3.8	3.0	3.2	3.5	3.4	3.6	3.8	4.0	4.2	4.1	3.9
4.0	4.5	4.1	4.2	4.2	3.6	3.4	3.8	3.9	3.8	4.6	4.7	4.5	4.2	4.0
3.9	3.9	4.3	4.1	4.3	3.7	3.8	4.2	4.0	4.3	4.4	4.5	4.3	4.6	4.7
3.8	4.0	4.0	3.9	4.3	3.7	3.8	4.0	4.1	3.9	3.9	3.8	4.2	4.6	4.5
3.4	3.6	3.8	3.9	3.8	3.6	3.7	3.5	3.3	3.4	4.0	4.0	4.1	4.4	4.0
3.6	3.5	3.8	4.0	4.1	4.0	4.5	4.4	4.1	4.5	3.5	3.9	4.0	4.2	4.4
4.0	3.9	3.8	4.2	4.1	4.0	4.4	4.2	4.0	4.2	3.6	3.7	3.8	3.5	3.4
3.0	3.2	3.3	3.4	3.1	3.3	3.8	3.9	3.4	3.6	4.2	4.3	4.0	4.3	4.2
3.4	3.6	3.7	3.8	4.0	3.4	3.5	3.7	3.3	3.6	3.7	3.8	3.9	4.0	4.1
3.3	3.4	3.5	3.6	3.7	3.6	3.4	3.7	3.6	3.7	2.7	3.0	2.9	3.2	3.2
3.3	3.1	3.2	3.4	3.5	3.0	3.3	3.4	3.5	3.8	2.9	3.1	3.0	3.2	3.3
3.5	3.7	3.6	3.5	3.7	2.9	3.0	3.1	3.2	3.3	3.5	3.6	3.8	3.8	3.3
4.1	4.3	4.3	4.0	4.3	3.5	3.6	3.7	3.5	3.2	3.7	3.5	3.8	3.9	3.6
3.8	4.0	4.2	4.3	3.7	3.5	4.0	3.9	3.5	3.6	4.0	4.1	4.2	4.3	4.4

given by the experts are shown in **Table 2**. Because some qualitative criteria are difficult to quantify, the average scores of criterion given by the experts are treated as the original objective data of resolutions.

The AHP approach is used to determine the subjective weights of different factors in this case. We take into account the experience and wisdom of experts through implementation of the expert scoring method, judgment matrix, sub-level sequencing and consistency test. The subjective weight of criterion B_{ij} is obtained:

$$\alpha_1 = [0.207, 0.33.0.083, 0.235, 0.066, 0.079], \alpha_2 = [0.165, 0.193, 0.099, 0.132, 0.411],$$
$$\alpha_3 = [0.397, 0.199, 0.072, 0.331], \alpha_4 = [0.138, 0.195, 0.667], \alpha_5 = [0.203, 0.644, 0.153],$$
$$\alpha_6 = [0.357, 0.442, 0.201]$$

The objective weights obtained from Eq. (1) to Eq. (4) of the entropy method are as follows:

$$\beta_1 = [0.07, 0.07, 0.08, 0.04, 0, 39.0.35], \beta_2 = [0.17, 0.29, 0.24, 0.15.0.15], \beta_3 = [0.14, 0.26, 0.46, 0.14],$$
$$\beta_4 = [0.69, 0.23, 0.08], \beta_5 = [0.67, 0.06, 0.27], \beta_6 = [0.22, 0.07, 0.71]$$

The subjective weights and the objective weights are combined to obtain the combined weights from Eq. (5). The results are as follows:

$$\omega_1 = [0.135, 0.216, 0.062, 0.088, 0.242, 0.257], \omega_2 = [0.148, 0.296, 0.125, 0.105, 0.326]$$
$$\omega_3 = [0.297, 0.277, 0.178, 0.248], \omega_4 = [0.493, 0.232, 0.276], \omega_5 = [0.63, 0.179, 0.191]$$
$$\omega_6 = [0.312, 0.123, 0.566]$$

ω is obtained in a similar manner: $\omega = [0.277, 0.177, 0.143, 0.064, 0.096, 0.243]$.

According to Sections 3.6 to 3.8, the grey evaluating matrix is obtained as follows:

$$R_1^1 = \begin{bmatrix} 0.299 & 0.373 & 0.288 & 0.0390 \\ 0.286 & 0.358 & 0.297 & 0.0580 \\ 0.309 & 0.366 & 0.281 & 0.0430 \\ 0.241 & 0.302 & 0.329 & 0.1280 \\ 0.231 & 0.288 & 0.337 & 0.1440 \\ 0.275 & 0.343 & 0.305 & 0.0760 \end{bmatrix},$$

$$R_2^1 = \begin{bmatrix} 0.286 & 0.358 & 0.296 & 0.058 & 0 \\ 0.332 & 0.394 & 0.264 & 0.008 & 0 \\ 0.301 & 0.377 & 0.286 & 0.035 & 0 \\ 0.286 & 0.358 & 0.296 & 0.058 & 0 \\ 0.286 & 0.358 & 0.296 & 0.058 & 0 \end{bmatrix},$$

$$R_3^1 = \begin{bmatrix} 0.351 & 0.397 & 0.251 & 0 & 0 \\ 0.337 & 0.393 & 0.261 & 0.008 & 0 \\ 0.324 & 0.393 & 0.270 & 0.012 & 0 \\ 0.286 & 0.358 & 0.296 & 0.058 & 0 \end{bmatrix},$$

$$R_4^1 = \begin{bmatrix} 0.298 & 0.369 & 0.288 & 0.043 & 0 \\ 0.324 & 0.393 & 0.270 & 0.012 & 0 \\ 0.230 & 0.288 & 0.336 & 0.144 & 0 \end{bmatrix},$$

$$R_5^1 = \begin{bmatrix} 0.286 & 0.358 & 0.296 & 0.058 & 0 \\ 0.263 & 0.329 & 0.313 & 0.094 & 0 \\ 0.241 & 0.301 & 0.329 & 0.127 & 0 \end{bmatrix},$$

$$R_6^1 = \begin{bmatrix} 0.274 & 0.343 & 0.305 & 0.076 & 0 \\ 0.351 & 0.397 & 0.251 & 0 & 0 \\ 0.324 & 0.385 & 0.270 & 0.020 & 0 \end{bmatrix},$$

$$A_1 = \begin{bmatrix} \omega_1 \times R_1^1 \\ \omega_2 \times R_2^1 \\ \omega_3 \times R_3^1 \\ \omega_4 \times R_4^1 \\ \omega_5 \times R_5^1 \\ \omega_6 \times R_6^1 \end{bmatrix} = \begin{bmatrix} 0.269 & 0.335 & 0.309 & 0.086 & 0 \\ 0.302 & 0.371 & 0.286 & 0.041 & 0 \\ 0.327 & 0.386 & 0.269 & 0.019 & 0 \\ 0.286 & 0.353 & 0.297 & 0.064 & 0 \\ 0.274 & 0.342 & 0.306 & 0.078 & 0 \\ 0.312 & 0.374 & 0.279 & 0.035 & 0 \end{bmatrix}$$

The evaluating results of index criteria can be yielded as follows:

$$E^1 = \omega \times A^1 = [0.295\ 0.360\ 0.291\ 0.054\ 0]$$

Hence the comprehensive evaluating result of the 1st resolution is yielded as follows:

$$U^1 = E^1 C^T = 77.931$$

Similarly, the comprehensive evaluating result of the other resolutions is yielded as follows:

$$U^2 = 75.714, U^3 = 79.898$$

According to the evaluation results, $U^3 = \max[U^1, U^2, U^3]$=79.898, the 3rd is the best resolution for the brownfield redevelopment project.

CONCLUSIONS

The buildup of the evaluation index system of the brownfield redevelopment project is based on the current situation of brownfields in China and the requirements of sustainable development, and adopts the modified grey evaluation method to prioritize the resolutions for the brownfield redevelopment project. The conclusions and innovations are as follows: 1) Brownfield redevelopment plays a very important role in improving environmental quality and promoting economic growth of the brownfield site. In this paper, the buildup index system for brownfield redevelopment is obtained from six dimensions: environmental and health, financial and accounting, characteristics of the brownfield, social stability, policy and technology criteria, and performance criteria (Zhu & Guo, 2014); 2) The weights of the combination weighting method obtained from the multiplication integration method are between the values of the AHP and the entropy method. The weights can not only balance the roles of the subjective and objective weighting methods, but also almost overcome the one-sidedness of only using one of the two methods (Liang, 2014). Therefore, the weights of the combination weighting method can reflect both the decision makers' subjective intentions and the objective reality, and make our synthetic evaluation results match the actual situation better (Fu & Zou, 2007).

Compared to other evaluating techniques, the modified grey evaluation method makes the most use of evaluating information and it avoids yielding invalid evaluating results. The case study indicates that such an approach can provide a useful tool for the complicated multiple objective decision-making in order to obtain scientific and reasonable results for decision makers (Zhang & Nie, 2012). The disadvantages of this method are that the evaluating matrix is established by the original data of resolutions, and the minor difficulties encountered in obtaining accurate original data of evaluating criteria in application.

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