2014

ISSN : 0974 - 7435 Volume 10 Issue 21

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(21), 2014 [13399-13404]

Application of risk analysis in the selection of road construction route scheme

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ABSTRACT

Risk analysis plays an important role in many application systems. The current researches prefer to use fuzzy set theory and AHP (Analytic Hierarchy Process) for risk analysis. This paper introduces a comprehensive evaluation method which applies risk analysis to AHP (Analytic Hierarchy Process). With specific cases and examples, this paper introduces how to apply this method to evaluate and select the optimal scheme of the road construction route in detail.

KEYWORDS

Comprehensive evaluation; Risk analysis; Road construction.

INTRODUCTION

With the rapid development of the road construction in China, especially the implement of many freeway programs, how to deepen and standardize feasibility study is of great significance to the modernization of road construction. And the comparison and selection of highway route scheme is an important preliminary work in road construction programs, which has direct influence on whether the expected goals can be achieved and the application effects after programs are put into operation. A comprehensive evaluation method based on fuzzy mathematics combined with AHP is commonly used when comparing and selecting route scheme. However, the construction of all programs are accompanied by lots of risk factors, whose influences on programs are uncertain. Thus, the comprehensive evaluation combined with risk index and index of precision is all-rounded. This paper will introduce such fuzzy comprehensive evaluation method combined with risk analysis.

A THEORETICAL MODEL USING RISK DEGREE TO REPRESENT INDEX MEMBERSHIP DEGREE

The nature of the risk is uncertainty, and the introduction of probability into risk makes the quantitative analysis of the risk possible. According to the B.S.4778(BSI, 1991), risk refers to an incident that can happen during the life span of the program, which may cause potential damages to people and destructive consequences to properties and environment. Based on this definition, risk can be described by the following equation:

$$R(x) = P(x) \times C_r(x) \quad \textbf{(1)}$$

where R refers to risk, P refers to the probability of the risk and C refers to the consequences of the risk.

If the consequences of the risk are divided into fuzzy evaluations in different levels, we can find the probability distribution and calculate the function curve of the Cr (x). Then according to different schemes, we can utilize brainstorming and experts' experience to get their own membership degrees, put the calculated membership degrees into probability functions to get the probability of the risk, and finally use equation (1) to get the risk measures of different schemes.

Introducing this theory to programs’ comprehensive evaluation which is based on AHP, we can combine index of precision with risk index, and further calculate the overall membership of each scheme, and finally get the optimal scheme. The following case will be used to described the calculation process in detail.

The goal-programming model

In the goal-programming model, the decision variable is x_ (0 or 1). The objective function, given byEq. (2), seeks to minimize deviation from desired targets for limited resources (costs, available management hours, and available employee hours)

$$Min\ Z = P_c(d_c^-, d_c^+) + P_b(d_b^-, d_b^+) + P_e(d_e^-, d_e^+) \quad \textbf{(2)}$$

The goal constraints in Eqs. (3), (4) and (5) represent the availabilityof limited resources. The right-hand side of each equation re#ects the targeted or desired level of the resource utilization,where C denotes cost, B available management hours, and E available employee hours. We could also express these limitations of available resources as system constraintsa byremoving the deviation variables from the constraints and the objective function and bychanging the equality signs of the constraints to less than or equal signs. For convenience,this will be done through the combined model:

$$\sum_{i=1}^{m} a_{ci}x_i + d_c^- - d_c^+ = C \quad \textbf{(3)}$$

$$\sum_{i=1}^{m} a_{bi}x_i + d_b^- - d_b^+ = B \quad \textbf{(4)}$$

$$\sum_{i=1}^{m} a_{ei}x_i + d_e^- - d_e^+ = E \quad \textbf{(5)}$$

The ordering of these goal constraints depends on the nature of the problem situation. Either preemptive or non-preemptive goals could be used depending on the order of importance, if any, of the goals.

There are several studies that used the AHP methodologyin combination with goal programming. In the combined model, the objective function also includes deviation variables associated with the qualitymeasure goals. It will seek to minimize such deviations from desired levels. The revised objective function is given in Eq. (6). Moreover, a set of constraints, as shown in Eq.(7), will be added to re#ect the qualitytarget of Q_ in each of the `goal constraintsa. An equation associated with the AHP weights for the quality control instruments will be added to re#ect the preferences for the di!erent instruments. This is given in Eq. (8):

$$Min\ Z = [\sum_{k=1}^{K} P_k\,(w_k d_k^-, w_k d_k^+)] + P_a(d_a^-, d_a^+) + P_c(d_c^-, d_c^+) + P_b(d_b^-, d_b^+) + P_e(d_e^-, d_e^+) \quad \textbf{(6)}$$

$$\sum_{i=1}^{m} a_{ki} x_i + d_k^- - d_k^+ = Q_k \quad (for\ k = 1,2,\dots,k) \quad \textbf{(7)}$$

$$\sum_{i=1}^{m} w_i x_i + d_a^- - d_a^+ = 1 \quad \textbf{(8)}$$

APPLIED CASE

Engineering company M have contracted to build a freeway invested by the government. It starts from city A, and ends in city B. The total budget expense is 1.42 billion yuan and its scheduled construction period is 2.5 year. After experts' field exploration, three routes（s_1, s_2 , s_3）have been selected as alternatives. And optimal scheme can be selected using comprehensive evaluation method to evaluate these three schemes.

The selection of comprehensive evaluation index and the establishment of Fuzzy Hierarchical Mode

Based on quantities of references and historical experience, a comprehensive evaluation index of this road project is decided, which have a total number of 7 indexes of two parts. According to the affiliation of each evaluation index, the following AHP modal was built.(See Figure.1.)

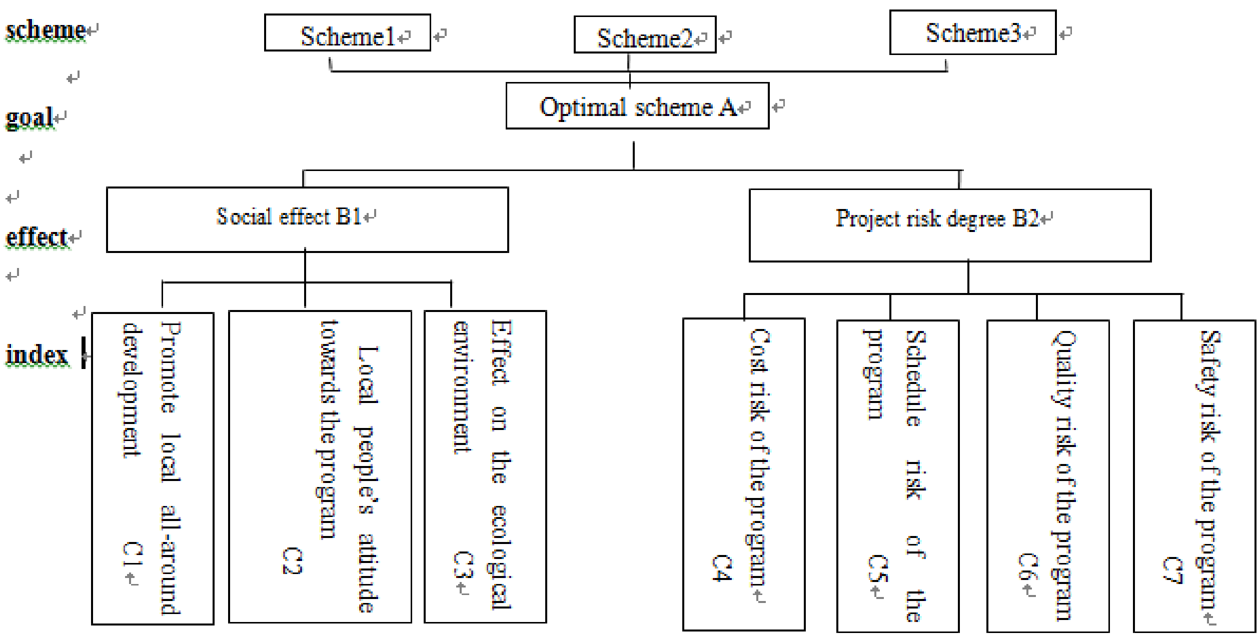

Figure 1 : Fuzzy Hierarchical model of route scheme

The establishment of FAH comprehensive evaluation mathematics modal

The comprehensive evaluation of freeway project adopts the following mathematics modal:

$$B = A \bullet R = \begin{pmatrix} a_1 & a_2 & \cdots & a_n \end{pmatrix} \bullet \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mm} \end{bmatrix} \quad \textbf{(9)}$$

$$= \begin{pmatrix} b_1 & b_2 & \cdots & b_m \end{pmatrix}$$

where A--weight vector, A = (a1, a2,......, an);

a_i -the overall weight gained by the i-th evaluation index in scheme optimization's general objective（i=1,2,3,···, n）, $a_i \in [0,1]$, and $\sum_{i=1}^{n} a_i = 1$;

R-the general evaluation index matrix formed by n evaluation index, R=（r_{ij}）n×m ;
r_{ij}-the membership degree of the j-th scheme's i-th index
B-comprehensive evaluation index matrix
b_j-the comprehensive evaluation index of the j-th scheme, the bigger the value of b_j, the better. The maximum b_j corresponds the relative optimal scheme, and

$$b_j = \sum_{i=1}^{n} a_i r_{ij} \quad (j=1, 2, \cdots, m).$$

In this case, there are 3 schemes, each has 7 evaluation indexes, thus in specific application, n=7, m=3

Derivation of the single factor of total weight value

The paper will mainly use the Fuzzy Analytic Hierarchy Process (FAHP), which is to hire a group of experts to grade, and amass their scores and opinions as the basis of determining the weight. Because determining the total wight value is not the key point of the paper, the specific procedures will not be introduced in detail. And please refer to document[1] for details. According to this method, we can get the relative weight among each index. The summary is as follows :

A= (a_1, a_2,......, a_n) = （0.100, 0.190, 0.132, 0.202, 0.111, 0.186, 0.139）

Determine the membership degree of each single factors

In this case, the indexes are divided into two types: index of precision and risk index.
B1 belongs to index of precision, and B2 belongs to risk index.

Method of membership degree of index of precision

(i) Determine the membership degree of "Promote regional comprehensive development". Firstly determine the set of comments V and the set of Standard membership degree U:

V＝{V1(very good), V2(good), V3(general), V4(poor), V5(very poor)}

U＝{1.0 (very good), 0.8 (good), 0.5 (general), 0.2 (poor), 0.0 (very poor)}

Invite 20 experts to investigate the program, collect data, and grade the 3 schemes. Then the scores are gathered and averaged out as the membership degree. The results are: r_{11}=0.322, r_{12}=0.539, r_{13}=0.611

(ii) Determine the membership degree of "local people's attitudes towards the program". Sample survey is adopted, and the proportion of people who hold positive attitude to the total number of respondents is taken as the membership degree. This method is relatively effective when the sample space is large. The results are: r_{21}=0.860, r_{22}=0.901, r_{23}=0.842

(iii) Determine the membership degree of "the effect on ecological environment". The program of freeway construction must take the potential effect on ecological environment into consideration. Firstly, determine remark set V and standard membership member set U:

V＝{V1(very great effect), V2(quite great effect), V3(general effect), V4(less great effect), V5(no effect)}

U＝{0.0(very great effect), 0.2(quite great effect), 0.5(general effect), 0.8(less great effect), 1.0(no effect)}

Similarly, invite 20 experts to investigate the program, collect data, and grade the 3 schemes. Then the scores are gathered and averaged out as the membership degree. The results are: r_{31}=0.811, r_{32}=0.756, r_{33}=0.547

Method of risk index membership

Method of risky index membership degree is the key point of this paper. This paper attempts to take risk degree as membership degree, because of the mutual independence and similar method of the four risk indexes. The detailed calculation procedure will be introduced using the method of program's cost risky index membership degree as an example:

(i) Collect historical data: Because Co.M contracts to build the program, the construction performance and capability of enduring risk is the key point to be investigated and thus the risk of corporation M equals to the risk of the whole project. The statistics of the cost of fifty programs completed by corporation M in the last five years are collected as TABLE 1:

(ii) Determine remark set V and standard membership degree set U of cost risk consequence in accordance with trade characteristics and expert experience as TABLE 2:

TABLE 1 : Historical statistics of the programs cost of Co. M (unit:ten thousand)

Program number	**1**	**2**	**3**	**4**	**5**	**6**	**…n**
Program budget	85000	12000	105000	56000	46000	97500	…
Total cost	86150.56	12066.33	104947.7	55876.47	46086.58	97820.30	…
Program deficit	1150.56	66.33	-52.30	-123.53	286.58	320.30	…
Deficit rate	1.35%	0.55%	-0.05%	-0.22%	0.62%	0.33%	…

TABLE 2 : Remark set of program's cost risk consequence

Deficit interval	**[10, 5%]**	**[5%,2 %]**	**[2%, 1%]**	**[1%,0. 5%]**	**[0.5%, 0%]**	**[-0.5%,0 %]**	**[-1%,-0.5%]**	**[-2%, -1%]**	**[-5%, -2%]**	**[-10%,-5%]**
V	Very high risk loss	High risk loss	Average risk loss	Low risk loss	Very low risk loss	Very low risk profit	Low risk profit	Average risk profit	High risk profit	Very high risk profit
U	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0

(iii) Collect the probability distribution of Co. M's cost risk consequence membership degree: use original data in TABLE 1 in accordance with the deficit intervals in TABLE 2 to collect the programs number N in each interval and use N/50 to indicate the probability P and draw the conclusion as TABLE 3:

TABLE 3 : Statistical table of membership degree probability

Deficit interval	[10%,5 %]	[5%,2 %]	[2%,1 %]	[1%,0.5 %]	[0.5%,0 %]	[-0.5%,0%]	[-1%-0.5%]	[-2%,-1%]	[-5%-2%]	[-10%,-5%]
U	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0
N	1	0	1	0	2	16	14	10	4	2
P	0.02	0	0.02	0	0.04	0.32	0.28	0.2	0.08	0.04

(iv)If we keep narrowing the interval of the deficit and the corresponding membership degree, the probability distribution of the membership degree of the cost risk consequence will approximate to a smooth curve when the interval is narrowed to a point. We can have the following distribution figure by using statistical software:

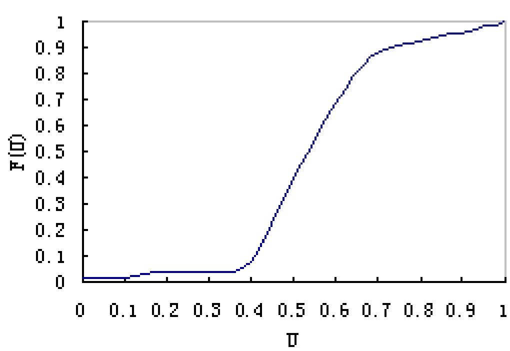

Figure 2 : The probability distribution of membership degree of the cost risk consequence

Since the figure above is the result of counting the historical data of Co.M, it is the reflection of the company's capability on the control of construction cost. Programs in the future will generally obey this distribution on the cost risk control.

The risk degree of the other three risk indexes can be calculated with the same method. When the risk degree of all the indexes are calculated, by replacing the corresponding membership with the risk degree, the total evaluation index matrix R can be calculated:

$$R = \begin{bmatrix} 0.322 & 0.539 & 0.611 \\ 0.860 & 0.901 & 0.842 \\ 0.811 & 0.756 & 0.547 \\ 0.0137 & 0.2077 & 0.164 \\ 0.322 & 0.524 & 0.456 \\ 0.213 & 0.350 & 0.374 \\ 0.232 & 0.105 & 0.208 \end{bmatrix} \quad \textbf{(10)}$$

Calculation and results of the comprehensive evaluation index

Put equation (3) and the total evaluation index matrix R into equation (9):

result: B=A·R=(0.652, 0.726, 0.480)

From the result above we can know that the comprehensive evaluation index of the three schemes s1, s2, s3 respectively are: 0.652, 0.726, 0.480. From the perspective of comprehensive evaluation, the superiority and inferiority order is S_2,S_1,S_3 which can be taken as the reference of construction schemes strategy.

CONCLUSION

The comprehensive evaluation of road construction schemes selection we have discussed in the paper introduces the risk index based on the AHP and gives the general calculation of risk index membership degree. Since a large number of data is needed as basis, there will be unavoidable mistake in the calculation. What's more, the calculation which replace the membership degree with the risk degree is cruder. Therefore, there is a lot to be improved and here we are throwing a sprat expecting to get a whale.

ACKNOWLEDGMENT

This research was supported by "the Fundamental Research Funds for the Central Universities". The authors want to thank the work to this paper by all anonymous reviewers.

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