HIGHWAY ENGINEERING QUALITY ASSESSMENT BASED ON GREY SYSTEM THEORY

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abstract: In view of the problems existing in the current method of highway quality grading, this paper, in combining practical experience with objective data, is to propose, on the basis of weighted calculation by way of grey relationship analysing, a new method of grey clustering evaluation with determined weight by various indices, thus promoting the work of assessment to a higher scientific level.

1. INTRODUCTION

In China at present, highway construction is proceeding at a tremendous speed and supervision system is correspondingly adopted to ensure engineering quality. One of the important tasks in highway supervision and regular management is how to grade engineering quality on scientific basis. The current assessment divides the quality into three grades, viz. grade A ("excellent", over 85 marks), grade B (up to standard, 70—85 marks) and grade C(not up to standard, below 70 marks) . In actual evaluating, the results are given to separate items, projects, construction units and so on respectively(1): in synthetical assessing, different weight values of the general projects and principal projects are taken into consideration(the value of the former being "1"; the value of the latter, "2") . However, owing to such a rough grading, the current assessment cannot sufficiently express the opinions of experts, thus giving rise to the following problems: ① unable to reflect comprehensively and embody objectively the technological level and labour fruit of construction units; ②difficult to feed back effectively the relevant quality information so as to get a comprehensive optimization in highway design, construction, management, maintenance and repair(especially in the use, management and maintenance of built highways). Obviously, too rough a grading makes it difficult to lay down a concrete programme in management and maintenance, as well as to make a reasonable allotment of labour power, material resources and funds for construction and routine maintenance.

In accordance with the grey character in highway engineering quality grades, this paper, making use of grey-relationship analysing, has obtained the relational degrees between the experts' comments and the marks given to various engineering items; and, after normalizing these degrees, obtained the weight coefficients of such items, by means of which the determined weightclustering evaluation can be carried out, and hence, a better result.

2. GREY CHARACTER IN EVALUATING HIGHWAY ENGINEERING QUALITY

Because of its long-lined and wide-ranged worksite, there are numerous factors involved in the evaluation of highway engineering quality. In general, design and construction are two important ones; the latter often refers to five items: personnel, material, machines and tools, technology and environment (4M1E). In spite of these various factors, some people often think that, when some quality indices are quantified after surveying (for example, values of pavement deflection and evenness, frictional coefficient, material strength, sizes of various structures and so on), it is easy, as it were, to get a proper result in quality grading, although not comprehensively or precisely. However, in actual evaluating, lots of factors cannot be surveyed, or tested or quantified; moreover, the fact that, to what extent those quantified quality indices can be evaluated as having made a contribution to the integral quality is still decidedly unknown. All such problems fall under the category of grey system study(2); that is to say, with the current evaluating method, some information is available, and some, unavailable (the extension of it is clear, but its intension, very vague) . Hence the grey character is in engineering-quality evaluating. It is only when some other relevant information is added in that a better result can be obtained.

3. TO DETERMINE WEIGHT COEFFICIENTS

To determine weight coefficients is an important task in grey clustering evaluation with determined weight by various indices. With the view of getting the weight coefficients of each separate project, the first thing to do is to get the relational degree between the separate project and the corresponding surveyed grade, which can be done by means of grey-relationship analysis(3), that is to say, to put the separate projects into a sequence according to the degree whereby each project exercises its influence upon the integral quality. Of course, such grey analysis can only reflect the primary influence or the secondary, not in the least the actual effect, big or small, of the separate project. But, in practice, to use such degrees as weight is feasible, provided that they have been put through the treatment of normalization.

3.1 Grey Relationship Analysis

Suppose x is the factor set of grey relationship, $x_0 \in x$ is the reference sequence, $x_i \in x$ is the comparative sequence, and $x_0(k)$ and $x_i(k)$ are the numbers of x_0 and x_i at point k. If $\gamma[x_0(k), x_i(k)]$ be real numbers, then the relational degree can be found in the following expression:

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n}\gamma[x_0(k), x_i(k)] \tag{1}$$

the relational coefficient can be expressed as follows:

$$\gamma[x_0(k), x_i(k)] = \frac{\min_{J\in I}\min_{K}|x_0(k) - x_j(k)| + \zeta \max_{J\in I}\max_{K}|x_0(k) - x_j(k)|}{|x_0(k) - x_i(k)| + \zeta \max_{J\in I}\max_{K}|x_0(k) - x_i(k)|} \tag{2}$$

where $\zeta \in (0,1)$ is of the distinguished coefficent.

In the study of highway-engineering-grade evaluating, the evaluated grades are taken as major factors(put into one group) , the marks given to separate projects, as minor factors(N−1) , and the number of sections is stipulated as M. Thus, the matrix obtained from these initial data is as follows:

$$x_0 = \begin{bmatrix} x_{11}^{(0)} & x_{12}^{(0)} & \cdots & x_{1M}^{(0)} \\ x_{21}^{(0)} & x_{22}^{(0)} & \cdots & x_{2M}^{(0)} \\ \vdots & \vdots & \vdots & \vdots \\ x_{N1}^{(0)} & x_{N2}^{(0)} & \cdots & x_{NM}^{(0)} \end{bmatrix} \tag{3}$$

On the basis of

$$x_{ij}^{(1)} = \frac{x_{ij}^{(0)}}{x_{(1j)}^{(0)}}$$

we can put the primary data into initial values, and thus get the differential sequence $\delta_{ij}(k)$ in the following expression:

$$\delta_{ij}(k) = |x_{1j}(k) - x_{ij}(k)| \tag{4}$$

the extreme values are:

$$\left.\begin{aligned} MAX &= \max_{j \in I}\max_{K} |x_{1j}(k) - x_{ij}(k)| \\ MIN &= \min_{j \in I}\min_{K} |x_{1j}(k) - x_{ij}(k)| \end{aligned}\right\} \tag{5}$$

Put (5) into(2) , and we can get the relational coefficient; and then proceed from (1)to get relational degrees,which, when arranged in number order, will constitute the relational sequence, thus indicating the surveyed degrees to show how much contribution each separate project has made toward the integral quality in final grading.

3. 2Weight Calculating

From the above relational degree and sequence,the weight set can be given as follows:

$$W = \{W_1, W_2, \cdots, W_{n-1}\} \tag{6}$$

Wherein the W_i can be calculated with the following expression:

$$W_i = r(x_1, x_i) / \sum_{i=1}^{n-1} r(x_1, x_i) \tag{7}$$

here,obviously,

$$\sum_{i=1}^{n-1} W_i = 1.0$$

In actuality, to obtain the weight value, we just first survey and examine the separate items of certain highway sections of various quality grades,the results of which are to be set down in a form(in the hundred-mark system). Then the corresponding quality is to be graded by experts group after an on-the-spot inspection.

Table 1 is the evaluated results of a superhighway of a certain province,the items in which from ①to ⑨stand for the subgrade earthwork 、drainage works 、small bridges, culverts and passages 、retaining works 、base course 、subbase course 、pavement 、protection work and traffic engineering . The length of each section is 1km. It is more reasonable to include the proportion of investment in each item,for the amount of investment can reflect the relative importance of each item.

Experts´comments are an organic result of integrating the objective marks and the subjective ideas(experts´experience) , reflecting the quantitative indices and those indices which cannot be quantified. They also reflect the relative importance of the separate work items.

Put the data in table 1 into grey-relationship caculating,and we get the weight coefficients (after normalizing treatment) as follows:

Table 1 The results of quality grading in terms of subjective and objective evaluation

section number	marks given to each work item									comments of experts
	①	②	③	④	⑤	⑥	⑦	⑧	⑨	
1	88	83	81	86	92	87	88	80	82	5(excellent)
2	89	84	82	88	90	91	89	86	80	
3	90	83	85	89	91	92	91	85	87	
4	84	85	86	82	89	89	87	84	83	
5	82	83	82	80	85	86	85	83	81	4(good)
6	81	81	83	81	86	85	85	81	82	
7	80	80	80	80	87	86	86	80	79	
8	81	80	80	83	86	86	84	81	80	
9	79	79	80	76	84	80	81	80	79	3(up to standard)
10	80	78	77	79	84	82	82	79	78	
11	78	80	78	75	82	81	80	78	77	
12	78	77	79	79	83	82	81	80	78	
13	72	70	75	69	78	73	76	71	70	2(not up to standard)
14	68	72	71	65	76	71	77	70	71	
15	73	74	72	72	69	72	75	72	69	
16	76	65	68	70	73	74	74	69	68	

$$W = \{0.12, 0.11, 0.10, 0.11, 0.12, 0.10, 0.13, 0.10, 0.11\}$$

Given weight coefficient, it is possible to carry out grey clustering evaluation with determined weight. (4)(5)(6)

4. GREY CLUSTERING EVALUATION WITH DETERMINED WEIGHT

When dealing with grey clustering, first consider the clustering index $i, i \in I(i = 1, 2, \cdots, m)$; then the clusterings to be evaluated $j, j \in J(j = 1, 2, \cdots, p)$; and, lastly, the clustering factor $k, k \in K(k = 1, 2, \cdots, n)$. the sample matrix of clustering evalution is:

$$d = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{bmatrix} \qquad (8)$$

The highway engineering quality is classified into `excellent`, `good`, `qualified` and `unqualified` four grey clusterings; the forms of the whitening weight function of a certain grey clustering derived from separate project are as follows:

in the highest category:

$$\begin{cases} f_k(d_{ij}) = 1 & d_{ij} \in [x_2, \infty] \\ f_k(d_{ij}) = \dfrac{x_2 - d_{ij}}{x_2 - x_1} & d_{ij} \in [x_1, x_2] \end{cases} \tag{9}$$

in the mid-category:

$$\begin{cases} f_k(d_{ij}) = \dfrac{d_{ij} - x_i}{x_2 - x_1} & d_{ij} \in [x_1, x_2] \\ f_k(d_{ij}) = 1 & d_{ij} = x_2 \\ f_k(d_{ij}) = \dfrac{x_3 - d_{ij}}{x_3 - x_2} & d_{ij} \in [x_2, x_3] \\ f_k(d_{ij}) = 0 & d_{ij} \overline{\in} [x_1, x_3] \end{cases} \tag{10}$$

in the lowest cotegory:

$$\begin{cases} f_k(d_{ij}) = \dfrac{d_{ij} - x_1}{x_2 - x_1} & d_{ij} \in [x_1, x_2] \\ f_k(d_{ij}) = 1 & d_{ij} \in [0, x_1] \end{cases} \tag{11}$$

In the sample matrix, d_{ij} refers to the sample of the jth index of the ith clustering object; f_{jk}, to the whitening weight function of the k clustering of the jth index. If the weight η_{jk} of the jth index concerning k clustering has no relation to k, then this weight can be set down as $\eta_j (j = 1,2,\cdots m)$, and

$$\sigma_{jk} = \sum_{j=1}^{m} f_{jk}(d_{ij})\eta_j \tag{12}$$

can be regarded as clustering coefficient with determined weight of certain index of i object belonging to k clustering. If $\sigma_{ik}^{*} = \max_{1 \le k \le s}\{\sigma_{ik}\}$, then the i object can be regarded as belonging to k^{*} clustering.

Take the items in table 1 for an example: clustered indices with determined weight are nine separate projects, such as subgrade earthwork, drainage works and so on; grey clusterings are classified into "excellent" (5 marks), "good" (4 marks), "qualified" (3 marks) and "unqualitied" (2 marks). Clustered indices are the marks given to the quality of nine separate projects (such as subgrade earthwork, drainage works and so on); the threshold values of various clusterings are 85, 80, 70; and sample $d_{ij} \in (0, 100)$.

For another example, Table 2 shows the marks given to separate project items of a certain superhighway when completed:

According to the theory of grey clustering evaluation with determined weight by various indices, from the sample matrix d derived from Table 2, we can get the matrix of clustered coefficients as follows:

Table 2 Marks given to separate items of the sections of a highway to be evaluated

section number	Marks given to separate project items								
	①	②	③	④	⑤	⑥	⑦	⑧	⑨
1	86	87	86	85	81	85	91	82	79
2	82	83	78	82	84	83	80	78	80
3	77	83	78	79	80	80	79	82	81

$$\sigma_k = \begin{bmatrix} 0.7340 & 0.3240 & 0.0220 & 0.0000 \\ 0.3140 & 0.6060 & 0.1240 & 0.0000 \\ 0.1280 & 0.7120 & 0.2040 & 0.0000 \end{bmatrix}$$

It thus can be known that section 1 belongs to 'excellent', and the other two sections, to 'good'. Without regard to 'weight', the average marks, of section 1 are 84.7; it can only be graded as 'good' by the standard of the current assessment. This is obviously unreasonable and the same problem also exists in the case of section 3.

5. CONCLUSION

The intrinsic shortcomings in the current grading system can be overcome by the use of the grey clustering assessment with determined weight by various indices. The strong point of the latter lies in the fact that, by analysing the relational degrees between the marks given to separate items and the comments of experts, and by calculating the weight coefficients through normalizing these degrees, we can combine the subjective factors with the objective data, thus considerably giving expression to the relative importance of the separate work items to the synthetical grading of the integral quality of highway enginering. The examples show that this assessment is scientifical and practical, worthy to be recommended in general use.

REFERENCES

1. **Specifications of Quality Inspection for Highway**(1995), the Ministry of Communication, P.R. China.

2. Deng Julong (1989). Introduction to Grey System Theory, **The Journal of Grey System**, Vol. 1 No. 1, Sci—Tech Information Services and China Petroleum Industry

Press, Beijing PP. 1—24.

3. Hu Changshun and Wang Binggang (1992). A Grey Correlative Analysing of the Factors Influencing the Bending Strength of Concrete. **Huadong Highway**, Vol. 1 No. 1 PP. 4—11.

4. Hu Changshun and Wang Binggang (1993). Grey Asessment of Highway Network Pavement Performance. **The Journal of Grey System**, Vol. 5 No. 2, Sci—Tech Information Servicces and China Petroleum Industry Press, Beijing PP. 123—135.

5. Hu Changshun and Wang Binggang (1992). Grey Clustering Evaluation of Asphalt Pavement Performance. **The Journal of ChongQing Communication College**, No. 4, 1992.

6. Hu Changshun and Wang Binggang (1992). The Assessment of Highway Network Pavement Performance. **The Journal of China Highway**, No. 4, 1992