A Research of Key Indicators of Highway Construction for Public Supervision Based on Cloud Model

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***Abstract*—In order to solve the problem that the number of detecting indicators of constructing highway is too great, and key indicators are not clear, questionnaire survey is used to obtain the raw data of the quantitative evaluation of detection indicators by expert. After analyzing the reliability credibility of questionnaire survey result, an indicator feature cloud model that used to characterize the quantitative evaluation with feature of randomness, fuzziness and subjectivity, and a standard qualitative evaluation cloud model that used to qualitatively characterize an indicator is critical or not are presented. By comparing the approximation of indicator feature cloud model and standard qualitative evaluation cloud model, the conversion model between raw data and qualitative result is deduced to extract the key indicators that can reflect the safety, durability and reliability of highway project. The research is also helpful for reduce the anthropogenic factors, such as randomness, fuzziness and subjectivity in evaluation.**

***Index Terms*—traffic project, quality management, highway construction, cloud model, key indicator**

I. Introduction

With the rapid development of transport, logistics and auto industries in China, the highway construction has made great achievements. For the foreseeable future, the highway construction will also keep rapid development [1]. Meanwhile, the rapid development of traffic highway construction puts forward a giant challenge to the quality management of highway project [2], [3]. For the current quality management of highway construction in China, the quality management system is supervised by the government, who has the important responsibilities to ensure the construction quality. Currently, however, the number of detecting indicators of constructing highway is too great during the government supervision of construction quality and the key indicators system is not prominent, which restricts the further improvement of quality management level of projects.

For the supervision and administration of quality of highway project, the supervisory authorities shall focus on the key indicators influencing traffic project. Besides, there is correlation among detecting indicators for the quality of highway project [4]. From a lot of daily detecting indicators, we can sort out key ones reflecting the safety, durability and reliability of highway project. And focusing on priorities is one of effective ways to improve the quality management level of highway project.

The evaluation of criticality of detecting indicators for the quality of highway project is influenced by the knowledge of experts and is of certain randomness, fuzziness and subjectivity, which brings difficulties to qualitatively judge if the indicator is key or not. The research of sorting out the key indicators system of the quality of highway project from a lot of daily detecting indicators, essentially, is the issue of equivalent conversion model between the quantitative evaluation data of randomness, fuzziness and subjectivity and the objective qualitative judgment. The cloud model proposed by Academician Li Deyi based on the probability theory of fuzzy theory, provides an effective tool to describe the randomness, fuzziness and subjectivity of evaluation of key indicators [5]. The cloud model has been widely applied in the field of traffic construction project. [6] proposes the comprehensive evaluation method of operation safety of highway tunnels by integrating the cloud model and matter element analysis theory. [7] adopts the cloud model to analyze the whole safety level of highway. For the fuzziness and randomness during the evaluation of rockburst intensity, [8] establishes the comprehensive judging model based on the Delphi method and normal cloud model. The application of cloud model in the field of traffic project, currently, is mostly applied for the mathematical description tools with physical concepts of randomness and uncertainty. However, further research is required for

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the equivalent conversion model between the subjective quantitative data and objective qualitative judgment among key indicators for supervision of the quality of highway construction.

Taking the quantitative evaluations for criticality of detecting indicators for the quality of highway project from experts by the means of questionnaire survey, the paper conducts the reliability analysis for such questionnaire survey. On the condition that the raw data is reliable, this paper, based on the theory of normal cloud model, proposes the concept of key indicator feature cloud model corresponding to the quantitative evaluation data of experts and the calculating method of qualitative judging the digital features of corresponding standard qualitative evaluation cloud model, as well as the calculating method for the approximation of indicator feature cloud model. Based on the comparison of approximation between the key indicator feature cloud model and standard key indicator feature cloud model, the paper proposes the logical equivalence between the quantitative data and objective qualitative judgment, and verifies the effectiveness of the method proposed through the application experiment for key indicators of quality management of highway.

II. Quantitative Evaluation for Quality Indicators

The Quality Inspection and Evaluation Standards for Highway Engineering (JTG F80-2012) published by the Ministry of Transport of the PRC [9] is the main technical regulation for the quality inspection of highway construction, and the main basis for traffic project construction, inspection and supervision departments to inspect and evaluate the quality of highway. The Standard specifies clear upper and lower bounds of intervals for project quality parameters regarding to the civil and electromechanical works of highway construction, and proposes clear instructional requirements for the measurement method of project quality parameters.

The Standard is guiding principles for comprehensively evaluate the quality of highway project and the rules for the daily management of project quality. There are 95 items regarding to details of quality inspection and evaluation for highway civil works, and the number of specific inspection indicators is 969. Besides, there are numerous quality control indicators specified in the Standard, part indicators are of correlation and focus of project management is not prominent, which are not helpful for highlighting the management.

Using the investigation of questionnaire survey, the paper invites experts to make quantitative evaluation for the criticality of quality detecting indicators for highway project in the range of 0-3 points, and conduct the research on key indicators for quality management of highway construction by taking the evaluation as raw data.

III. Reliability Analysis for Questionnaire

The reliability of quantitative rating for criticality of quality detecting indicators for highway project, is an important indicator for raw data being of consistency and stability, and the important basis for questionnaire survey reflecting the real situation or not. Currently, common calculating and analysis indicators for reliability include: binary reliability, *Kuder* & *Richardson* and *Cronbach*'s alpha coefficient. As the quantitative rating, rather than the binary-fraction quantitative evaluation, the *Cronbach*'s alpha coefficient is suitable for analysis [11]. The calculating method for *Cronbach*'s alpha coefficient is shown in (1) [10] .

$$\alpha = \frac{k}{k-1}\left(1-\frac{\sum S_i^2}{S_X^2}\right) \tag{1}$$

Wherein, k is the item number of the questionnaire, S_i^2 is the score variance of the i th questionnaire item; S_X^2 is the total variance of the questionnaire.

The relationship between the value of *Cronbach*'s alpha coefficient and the reliability of questionnaire result is shown as follows [10].

$$\begin{cases} \alpha < 0.3 & \text{unreliable} \\ 0.3 < \alpha < 0.4 & \text{reluctantly reliable} \\ 0.4 < \alpha < 0.5 & \text{slightly reliable} \\ 0.5 < \alpha < 0.7 & \text{reliable} \\ 0.7 < \alpha < 0.9 & \text{really reliable} \\ 0.9 < \alpha & \text{very reliable} \end{cases}$$

IV. Analysis of Questionnaire Results

For questionnaire results of key highway indicators of reliability, to further research the conversion model between the quantitative data of randomness, fuzziness and subjectivity and objective qualitative judgment is the main content for research on key indicators for government quality management of highway construction. The normal cloud model is an effective tool for the mathematical description of these issues. Based on the theory of normal cloud model, this paper, by introducing concepts of indicator feature cloud model and standard qualitative evaluation cloud model and calculating the approximation of clouds, aims to solve the description issue of quantizing rating data and the issue of objective qualitative evaluation of experts in questionnaire for key indicators.

A. Indicator Feature Cloud Model

The normal cloud model is a special form of cloud models and jointly expresses the digital feature of a concept with a set of parameters mutually independent based on the normal distribution and membership functions so as to reflect the uncertainty, fuzziness and randomness of such concept. The set of parameters adopt the following three digital features – expectation E_x , entropy E_n and hyper entropy H_g for representation [11]:

Expectation E_x : the point that can represent the qualitative concept most in the domain space, which is the most typical sample point of the quantification.

Entropy E_n : measurable particle size represents a qualitative concept. Generally, the greater the entropy, the more macroscopic the concept is. Besides, the entropy also reflects the uncertainty of qualitative concept, representing the value range of domain space that can be accepted by the qualitative concept - ambiguity, which is the measurement of double-sided property for the qualitative concept.

Hyper entropy H_g : the measurement for the uncertainty of entropy, which reflects the randomness of sample representing the value of qualitative concept and reveals the correlation between the fuzziness and randomness.

This paper, based on the normal cloud model, proposes the concept of indicator feature cloud model. And the definition of indicator feature cloud model is as follows.

Definition 1. Set $X=\{x_1,x_2,...,x_n\}$ as the domain of reason. The domain X corresponds to the concept of indicator feature A. For any numerical element x_i in the domain, there always be a random number $\mu_i(x_i)$ of stabilization bias - degree of certainty for the concept of indicator feature A and the distribution of x on X is called the indicator feature cloud model.

The domain of indicator feature cloud model defined in this paper corresponds to the raw rating data x_i quantified by experts for quality indicators of certain highway project. The concept A corresponds to the feature of an indicator, and the $\mu_i(x_i)$ is the certainty of raw rating data x_i corresponding to the concept of indicator feature A. $\mu_i(x_i)\in[0,1]$. The closer that the value is to 1, it indicates that the rating of experts is more inclined to the concept of indicator feature A.

B. Standard Qualitative Evaluation Cloud Model

The standard qualitative evaluation cloud model collection is the critical degree based on the quality indicators of highway project, and a set of a series of standard qualitative evaluation cloud models preset. Each standard qualitative evaluation cloud model is determined by the clear qualitative concept and indicates the objective qualitative evaluation results of corresponding key indicators. The definition of standard qualitative evaluation cloud model is as follows:

Definition 2. Corresponding values of qualitative rating evaluation degree for all key indicators are in the interval of $[0,R]$. Divide the interval into M subintervals $[R_i^{\min},R_i^{\max}]$; $R_i^{\min}$ and $R_i^{\max}$ are separately the upper and lower bounds of the $i-th$ subintervals, $i=1,2,...,M$. And each subinterval corresponds to a clear qualitative concept.

In the standard qualitative evaluation cloud model collection, the algorithms for expectation E_{xi} , entropy E_{ni} , hyper entropy H_{ei} of the $i-th$ standard qualitative evaluation cloud model are as follows:

Algorithm 1. Determining method for feature parameters of standard qualitative evaluation

1. The expectation E_{xi} of the $i-th$ standard qualitative evaluation cloud submodel:

$$E_{xi}=\begin{cases}R_i^{\min} & i=1\\ \dfrac{R_i^{\min}+R_i^{\max}}{2} & 1<i<M\\ R_i^{\max} & i=M\end{cases}\qquad(2)$$

2. The entropy E_{ni} of the $i-th$ standard qualitative evaluation cloud submodel:

$$E_{ni}=\frac{R_i^{\min}+R_i^{\max}}{3}\qquad(3)$$

3. The entropy H_{ei} of the $i-th$ standard qualitative evaluation cloud submodel:

H_{ei} reflects the degree of uncertainty for the concept of standard qualitative evaluation, the greater the value, the greater the error of E_{xi} and the greater randomness of indicator significance. Therefore, the results of features of standard qualitative evaluation (H_{ei}) are hard to determine.

C. Qualitative Evaluation Method for Indicators

As shown in Fig. 1 Model Structure for Qualitative Evaluation of Indicators Based on the Cloud Model, there are four steps for the calculation: (1) generate the indicator feature cloud model based on the raw rating data for indicators quantified by experts; (2) by dividing the standard qualitative evaluation, generate various standard qualitative evaluation cloud models so as to constitute the standard qualitative evaluation cloud model collection; (3) conduct the similarity calculation of indicator feature cloud model and standard qualitative evaluation cloud submodel; (4) obtain the equivalent conversion results between the indicator rating of expert quantification and standard qualitative evaluation.

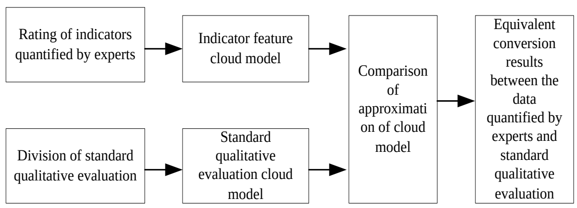

Figure 1. Model structure for qualitative evaluation of indicators based on the cloud model

As the raw rating data for quality indicators of highway project quantified by experts is of randomness, fuzziness and subjectivity and the samples are of limited number, it is hard to describe the corresponding concept of indicator feature. Based on the raw rating data for indicators ($X_k = \{x_{k1}, x_{k2}, ..., x_{kn}\}$), therefore, we shall firstly calculate the digital features (expectation E_{xk} , entropy E_{nk} and hyper entropy H_{ek}) with the reverse normal cloud generator. And the calculating methods are as follows.

$$E_{xk} = \frac{1}{n}\sum_{i=1}^{n} x_{ki} \quad (4)$$

$$S_k^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_{ki} - E_{xk})^2 \quad (5)$$

$$E_{nk} = \sqrt{\frac{\pi}{2}} \cdot \frac{1}{n}\sum_{i=1}^{n} | x_{ki} - E_{kx} | \quad (6)$$

$$H_{ek} = \sqrt{S_k^2 - E_{kn}^2} \quad (7)$$

Wherein $k = 1,2,...,K$, and K is the total number of project quality indicators quantified by experts.

Based on the digital features of indicator feature cloud model for standard rating data samples, generate the indicator feature cloud constituted of N cloud droplets with the positive normal cloud generator. And the algorithm steps for the generation of indicator feature cloud are as follows:

Algorithm 2. Cloud generation algorithm of indicator features.

① Set E_{nk} as expectation and H_{ek}^2 is a variance. Randomly generate a normal distribution number E_{xki} and indicate it as $E_{xki} = Norm(E_{nk}, H_{ek}^2)$;

② Set E_{xk} as expectation and E_{xki}^2 is a variance. Randomly generate a normal distribution number x_{ki} and indicate it as $x_{ki} = Norm(E_{xk}, E_{nki}^2)$

③ Calculate $\mu_{ki} = e^{-\frac{(x_k - E_x)^2}{2E_{nk}^2}}$;

④ Generate a cloud droplet (x_{ki}, μ_{ki}) ;

⑤ Repeat steps ①-④ until N cloud droplets meeting requirements are generated.

⑥ Repeat steps ①-⑤ until the indicator feature cloud model for K standard rating data samples is generated, which is indicated as $IC_1, IC_2, ..., IC_K$, wherein $IC_k = \{(x_{k1}, \mu_{k1}), (x_{k2}, \mu_{k2}), ..., (x_{kN}, \mu_{kN})\}$, $k = 1,2,...,K$.

(2) Generate the standard qualitative evaluation cloud model collection.

Based on the criticality level and raw data features for quality indicators of highway project, the *Algorithm 1* is adopted to determine the digital features of standard qualitative evaluation cloud models in the standard qualitative evaluation cloud model collection. With the *Algorithm 2* adopted, besides, generate M standard qualitative evaluation cloud models based on the digital feature parameters of standard qualitative evaluation cloud model so as to constitute the standard qualitative evaluation cloud model collection. Indicate it as $SIC = \{SIC_1, SIC_2, ..., SIC_M\}$, wherein $SIC_m = \{(x_{m1}, \mu_{m1}), (x_{m2}, \mu_{m2}), ..., (x_{mN}, \mu_{mN})\}$ and $m = 1,2,...,M$.

(3) Calculation for similarity of cloud model

In order to evaluate the correlation between the indicator features and standard qualitative evaluation cloud model, this paper proposes an algorithm to describe the similarity among cloud models. And the calculating method for the similarity ξ among cloud models is as follows:

Algorithm 3: algorithm for similarity of cloud model

With the positive cloud generator, the standard feature cloud model $IC_1(E_{x1}, E_{n1}, H_{e1})$ and standard qualitative evaluation cloud model $SIC_2(E_{x2}, E_{n2}, H_{e2})$ generate the cloud droplets - (x_{1i}, μ_{1i}) and (x_{2i}, μ_{2i}) , wherein $i = 1,2,...,N$.

① In N cloud droplets of IC_1 , retain the cloud droplets of x_{1i} in the range of [$E_{x1} - 3E_{n1}$, $E_{x1} + 3E_{n1}$] and save to the set $D = \{d_1, d_2, ..., d_{N1}\}$. In N cloud droplets of SIC_2 KIC2, ratain the cloud droplets of x_{2i} in the range of [$E_{x2} - 3E_{n2}$, $E_{x2} + 3E_{n2}$] and save to the set $E = \{e_1, e_2, ..., e_{N2}\}$.

② If $N1 > N2$ and $N3 = N2$, randomly delete $N1 - N3$ elements from the set D , and the number of elements in the set E remains unchanged. And the sets D and E being re-ordered will then constitute the new sets $D' = \{d_1', d_2', ..., d_{N3}'\}$ and $E' = \{e_1', e_2', ..., e_{N3}'\}$ from the small to large. Otherwise, if $N1 < N2$ and $N3 = N1$, randomly delete $N2 - N3$ elements from the set E , and the number of elements in the set D remains unchanged. And the sets D and E being re-ordered will then constitute the new sets $D' = \{d_1', d_2', ..., d_{N3}'\}$ and $E' = \{e_1', e_2', ..., e_{N3}'\}$ from the small to large.

③ The similarity value ξ of cloud model is calculated as follows:

$$\xi(IC_1, SIC_2) = \frac{\sum_{j=1}^{N3} d_j' \cap e_j}{\sum_{j=1}^{N3} d_j' \cup e_j'} \quad (8)$$

Wherein, $\cap$ and $\cup$ are *Zadeh* operators. $\cap$ and $\cup$ represent to take the minimum and mumimum values separately for values, $0 \le \xi(IC_1, SIC_2) \le 1$.

(4) Equivalent conversion model

Definition 2. The condition for the equivalence between $IC_1(E_{x1}, E_{n1}, H_{e1})$ and the $p-th$ standard qualitative evaluation cloud model collection is that:

$$\xi(IC_1, SIC_p) \ge \xi(IC_1, SIC_m)(m = 1,2,...,M)$$

Based on the definition 2, the corresponding qualitative evaluation concept of the $p-th$ standard qualitative evaluation cloud model of the greatest similarity is adopted as the qualitative evaluation results for quality indicators of the highway project.

V. Analysis of Results

In order to sort out indicators that can reflect the safety, durability and reliability of highway project from the above detecting indicator data, this paper, by combining the actual geography of highway construction in Anhui, conducts the quantitative evaluation for quality indicators of the following highway civil works by taking roadbed and road surface, bridges and tunneling as examples in the Standard.

(1) Roadbed and road surface

① Common roadbed: compactness, deflection, vertical-section elevation, flatness and width;

② Special roadbed: stability of high slope, settlement observation of soft foundation, vertical-section elevation, compactness of stone roadbed and compactness of earth-rock mixture;

③ Base course of pavement: compactness, thickness and strength;

④ Asphalt pavement: mixing temperature of asphalt, asphalt-aggregate ratio of asphalt mixture, paving temperature, thickness, compactness and deflection.

(2) Bridge works

① Pile foundation: concrete strength, bearing capacity, pore-forming quality and quality evaluation of piles;

② Pile caps & pier studs: thickness of the protective layer, concrete strength and top elevation;

③ Beam and slab: prestress & tensioning stress value, thickness of the protective layer, concrete strength and geometric dimensions;

(3) Tunneling works

① General: clear height of tunnel;

② Open cut tunnel: concrete strength and thickness;

③ Tunnel cutting: bolt grouting plumpness and back break;

④ Shotcrete support: concrete strength, shotcrete thickness and detection of empty barrels;

⑤ Barrel lining: thickness of secondary lining and lining concrete strength.

Send questionnaires for quality supervision units, supervising units and construction units of 38 sites under construction in the whole province. Request experts from each unit to quantify and rate detecting indicators in three types of projects (rating for criticality within the range of 0-3) so as to obtain the raw data for research on the quality supervision key indicators for highway construction.

A. Analysis of Reliability for Questionnaire Results

By formula (1), calculate the *Cronbach'* s alpha coefficient of questionnaires for roadbed and road surface, bridge and tunneling projects. And the analysis results of consistent reliability are obtained then, as shown in Table I.

As shown in Table I, we can conclude that the questionnaire survey for key indicators of highway is of consistent reliability. Therefore, we can further conduct the qualitative analysis for results.

TABLE I. RELIABILITY FOR QUESTIONNAIRE SURVEY

	Road works	Bridge works	Tunneling works
Cronbach's alpha coefficient	0.714	0.668	0.578
Consistent reliability	Really reliable	Reliable	Reliable

B. Qualitative Analysis of Questionnaire Results

Taking the compactness and width of common roadbed in questionnaire results as examples, analyze the questionnaire results. Based on the compactness and width of common roadbed for highway project quantified by experts, rate the original data size. And the digital features of indicator cloud model generated by formulas (4) - (7) and Algorithm 2 are shown in Table II.

TABLE II: DIGITAL FEATURES OF INDICATOR FEATURE CLOUD MODEL OF COMPACTNESS AND WIDTH OF ROADBED

Parameters Selected	Ex	En	He
Compactness of Roadbed	2.92	0.18	0.21
Width of Roadbed	2.01	0.19	0.36

According to the rating standard of questionnaires, we select three qualitative concepts of “very critical”, “generally critical” and “non-critical”. Divide in the interval of [0, 3], and the value-taking intervals selected for three qualitative concepts and digital features for corresponding standard qualitative evaluation cloud model are shown in Table III.

TABLE III: DIGITAL FEATURES FOR STANDARD QUALITATIVE EVALUATION CLOUD MODEL

Qualitative Evaluation	Value-taking Interval	Ex	En	He
Very critical	[2,3]	3	0.33	0.2
Generally critical	[1,2]	1.5	0.33	0.2
Non-critical	[0,1]	0	0.33	0.2

For the indicator feature cloud model of compactness and width for roadbed, three standard qualitative evaluation cloud models of “very critical”, “generally critical” and “non-critical” are shown in Fig. 2. Then the *Algorithm 2* is adopted to calculate the similarity between the indicator feature cloud model and standard qualitative evaluation cloud model, which is shown in Table IV.

TABLE IV: CALCULATION RESULTS FOR SIMILARITY BETWEEN THE INDICATOR FEATURE CLOUD MODEL AND STANDARD QUALITATIVE EVALUATION CLOUD MODEL

	Very critical	Generally critical	Non-critical
Compactness of Roadbed	0.96	0.51	0.02
Width of Roadbed	0.66	0.75	0.05

We can see from Fig. 2 that, the corresponding indicator feature cloud model of roadbed compactness and corresponding standard qualitative evaluation cloud model of qualitative concept of “very critical” almost overlap with each other. And there is more overlap between the corresponding indicator feature cloud model of roadbed width and corresponding standard qualitative evaluation cloud model of qualitative concept of “generally critical”. As shown in Table IV, the similarity between the indicator feature cloud model of roadbed compactness and standard qualitative evaluation cloud model of qualitative concept of “very critical” is the maximum. Moreover, the similarity between the indicator feature cloud model of roadbed width and standard qualitative evaluation cloud model of qualitative concept of “generally critical” is the maximum. We can conclude that, therefore, the qualitative evaluation for indicator rating of roadbed compactness of highway project quality quantified by experts is “very critical”; while the corresponding qualitative evaluation for roadbed width is “generally critical”.

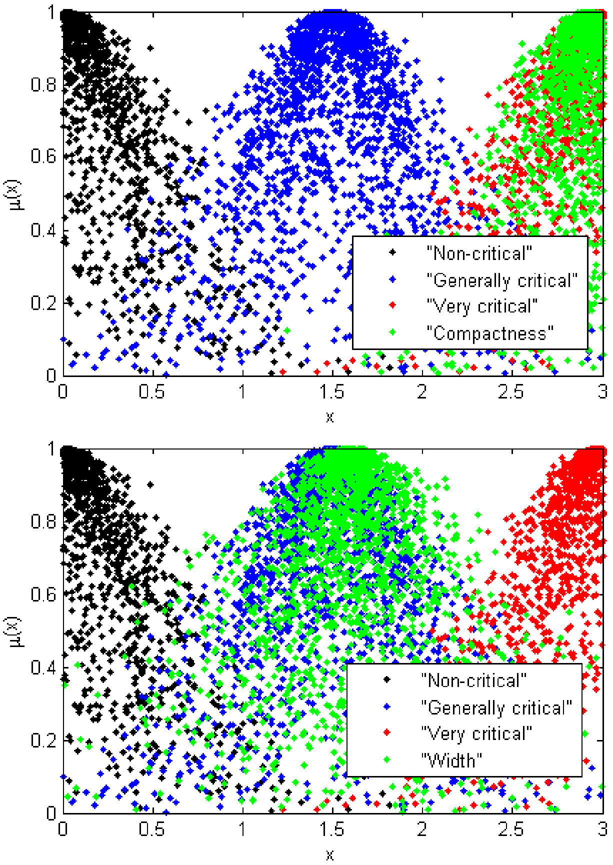

Figure 2. Comparison diagram between the roadbed compactness and standard qualitative evaluation cloud model

With the method proposed in this paper adopted, the qualitative evaluation results for indicators in roadbed and road surface, bridge and tunneling projects among quality indicators of highway civil works are that: indicators of being “very critical” include: common roadbed: compactness and deflection; special roadbed: stability of high slope and settlement observation of soft foundation; Asphalt pavement: mixing temperature of asphalt, asphalt-aggregate ratio of asphalt mixture, paving temperature, thickness, compactness, deflection and cornering ratio; Bridge pile foundation: concrete strength, bearing capacity and pore-forming quality; pile caps & pier studs: thickness of the protective layer and concrete strength; beam and slab: prestress & tensioning stress value, thickness of the protective layer and concrete strength; tunneling: clearance of tunnel, shotcrete strength, thickness of secondary lining and concrete strength of secondary lining.

VI. CONCLUSIONS

In order to further improve the quality management of highway project, from a lot of daily detecting indicators, we can sort out key ones reflecting the safety, durability and reliability of highway project so as to highlight the management focus. Based on the evaluation analysis, this paper attributes the essence of research on key indicators for highway quality management to solve the issue of equivalent conversion model between the quantitative data of randomness, fuzziness and subjectivity and the objective qualitative judgment.

For these scientific theory issues, this paper firstly adopts the form of questionnaire to collect the raw data for the quantitative evaluation of criticality for quality detecting indicators of highway project. Beside, this paper also adopts the *Cronbach*’s alpha coefficient to conduct the reliability analysis of quantitative evaluation data. Secondly, on the condition that the raw data is credible and available, this paper, based on the theory of normal cloud model, proposes the concept of key indicator feature cloud model and the conversion method between the quantitative evaluation raw data and the key indicator feature cloud model. Moreover, this paper also develops the calculating method for qualitatively judging the digital features of corresponding key indicator feature cloud model. At last, this paper proposes a calculating method for similarity between the key indicator feature cloud model and standard key indicator feature cloud model, and the equivalent conversion logic from the quantitative data to the objective qualitative judgment. Taking the Anhui highway project as an object, this paper conducts the application practice for the methods proposed and provides qualitative evaluation results for quality indicators of highway civil works.

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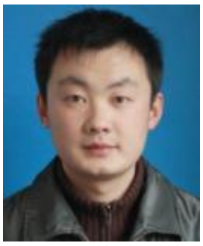

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