

## Risk Evaluation and Application on Fuzzy-FMECA Method Using Cloud Model

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### Abstract

*In order to safeguard the safety of passengers and reduce maintenance costs, it is necessary to analyze and evaluate the security risk of the Railway Signal System. However, the conventional Fuzzy Analytical Hierarchy Process (FAHP) can not describe the fuzziness and randomness of the judgment, accurately, and once the fuzzy sets are described using subsection degree function, the concept of fuzziness will be no longer fuzzy. Thus Fuzzy-FMECA method based on cloud model is put forward. Failure Modes Effects and Criticality Analysis (FMECA) method is used to identify the risk and FAHP based on cloud model is used for determining the subsection degree function in fuzzy method, finally the group decision can be gained with the synthetically aggregated cloud model, the method's feasibility and effectiveness are shown in the practical examples. Finally Fuzzy-FMECA based on cloud model and the conventional FAHP are used to assess the risk respectively, evaluation results show that the cloud model which is introduced into the risk assessment of Railway Signal System can realize the transition between precise value and quality value by combining the fuzziness and randomness and provide more abundant information than subsection degree function of the conventional FAHP.*

**Keywords:** risk evaluation, cloud model, Fuzzy-FMECA method, risk rating

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### 1. Introduction

With the high speed railway speed increasing and driving distance shortening in China, the demand for security of railway signal system is becoming more and more severe. After the "7.23" Yongwen particularly important railway line accident, Railway Ministry stressed to strict with the security access of the equipments for high speed railway. For this reason, professional testing for high speed railway equipments and risk assessment are carried out. Since China does not have the comprehensive security certificate. In order to perfect the security certificate, it is urgent to study the risk assessment methods for equipments of high speed railway. The train control center is the core equipment of train operation control system, which is widely used in line for passenger transportation and plays a crucial role in protecting the safety of the train. To conduct the risk assessment of the train control center can improve the system security and safety certification work for China's railway signal equipment.

In the research field of risk assessment for Railway Signal System, it is very difficult to effectively quantify the risk with only collecting and counting data that are full of different kinds of fuzziness and randomness. At present, many methods, such as Fault Tree Analysis (FTA) [1], Analytical Hierarchy Process (AHP) [2] and Fuzzy Analytical Hierarchy Process (FAHP) [3] are adopted to assess the risk of Railway Signal System. But these methods usually ignore the randomness presented in the assessment processes, meanwhile, they lack of an effective and simple transition model between quality and quantity. The different risk factors reflect different status and importance, which make different contributions to the failure, so each factor in the index system has its own weight and risk degree.

AHP is used by researchers to investigate the weight of index [4]. But there are disagreements between the language description and the numeric relation of scale division. The qualitative linguistic scale division is not scientific and it is hard to ensure the consistency in AHP and group decision. As a main tool to deal with the fuzzy problem, fuzzy mathematical evaluation method has great advantage in post-processing fuzzy problem [5]. However, once

the fuzzy sets are described by a subjection degree function, which curves the fuzzy things' uncertainty by the degree of membership.

The Cloud model [6] which is put forward by Academician Deyi Li is a method which can combine fuzziness and randomness. It can realize the transition between precise value and quality value by combining the fuzziness and randomness. So, cloud model can be introduced to present the fuzziness and randomness of the judgment more obviously and to reduce the subjectivity of the judgment more effectively. For the problem of interval multi-attribute group decision-making in AHP and fuzzy method, the risk values and the preference importance are expressed and calculated in the form of cloud model.

In this paper, Fuzzy-FMECA method based on cloud model is put forward to analyze and judge the risk of Centralized Traffic Control (CTC) interface module for the train control center. FMECA is firstly employed to summarize the potential failure modes of the function. And then based on the expert scoring for each failure mode, fuzzy comprehensive evaluation method based on the cloud model is applied to map the investigation data to the corresponding fuzzy matrixes described by the cloud model of each failure mode, it also gets the weight distribution of every failure mode by using analytic hierarchy process method based on the cloud model. By comparing the evaluation results of the proposed algorithm with the evaluation results of the conventional FAHP, Fuzzy-FMECA method based on cloud model can reflect the data distribution characteristics more obviously and more objectively, which is feasible and effective in the practice of the risk assessment for the railway signal equipment.

## 2. Cloud and Cloud Model

It is always difficult to distinct randomness and fuzziness in objective world and subjective reasoning process, especially in the natural language. On the foundation of fuzzy theory and statistic theory, cloud model is a kind of model which can transit the uncertainty between qualitative concept described by lingual values and its numerical values expression.

### 2.1. Concept of Cloud

Definition 1, Cloud and Cloud drops [6]. Assume that  $U$  is a quantitative numerical universe of discourse and  $C$  is a qualitative concept in  $U$ . If  $x \in U$  is a random realization of concept  $C$ , and  $\mu(x) \in [0, 1]$ , standing for confirmation degree for which  $x$  belongs to  $C$  ( $\mu(x)$  standing for Membership Degree of concept  $C$  as in fuzzy sets theory), is a random variable with stable tendency. A membership cloud is a mapping from the universe of discourse  $U$  to the unit interval  $[0, 1]$ . That is,  $\mu: U \rightarrow [0, 1], \forall x \in U, x \rightarrow \mu(x)$ .  $x$ 's distribution in universe of discourse  $U$  is called cloud and expressed by  $C(X)$  and each  $x$  is called a cloud drop.

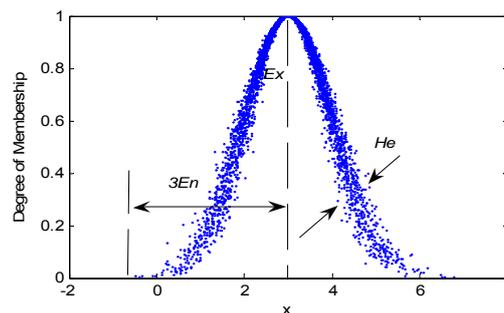


Figure 1. The Normal Cloud and Digital Characters

The cloud overall characteristic can be reflected by the number of features of the cloud: respectively is Expected value  $Ex$ , Entropy  $En$  and Hyper Entropy  $He$ , marked  $C(Ex, En, He)$ . Expected value  $Ex$  is the representative value of the qualitative concept. Entropy  $En$  is the measuring of the fuzziness of qualitative concept, reflects the numerical range which can be

accepted by this concept in the theory field. Hype Entropy  $He$  reflects the dispersion of the cloud drops.

## 2.2. Cloud Model

The normal cloud is the most basic tool to express the language value, and can be generated by the cloud's digital character  $(Ex, En, He)$ , and its Mathematic Expectation Curve (MEC) is:

$$MEC_A(x) = \exp[-(x - Ex)^2 / (2En^2)] \quad (1)$$

The generating algorithm of the normal Cloud [6] is that:

(1)  $x_i = G(Ex, En)e^{i\theta}$ , generating a normal random number  $x_i$ , whose expected value is  $Ex$  and standard deviation is  $En$ ;

(2)  $E_{ni}' = G(Ex, En)$ , generating a normal random number  $x_i$ , whose expectation value is  $En$  and standard deviation is  $He$ ;

(3) Compute  $\mu_i = \exp[-\frac{(x_i - Ex)^2}{2E_{ni}'^2}]$ ,  $(x_i, \mu_i)$  is a cloud drop.

(4) Repeat the step 1 to step 4, until the cloud drops were generated enough.

Cloud-generating algorithm can be conducted by software, and also be solidified by hardware to achieve, called Cloud Generator (CG). According to the numerical characteristics of cloud, cloud drops can be generated, and namely the transition from the qualitative to the quantitative can be achieved, which is called forward normal cloud generator, as shown in Figure 2. The above-mentioned cloud-generating algorithm namely is forward cloud generator algorithm.

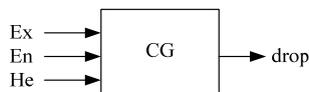


Figure 2. Forward Normal Cloud Generator

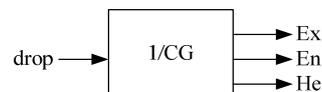


Figure 3. Backward cloud generator

Given a set of cloud drops accorded with some normal cloud distributing rule for sample  $(x_i, \mu_i)$ , we can generate the three numerical characteristics of the qualitative concept described by cloud,  $(Ex, En, He)$ . That is the transition from the quantitative to the qualitative and its achieving software or hardware is called Backward Cloud Generator ( $CG^{-1}$ ), as shown in Figure 3. Combining forward normal cloud generator and backward cloud generator together, we can achieve the transition between the qualitative and the quantitative at any moment.

Backward normal cloud generator is based on statistic theory. There are two kinds of basic algorithm: one uses certain degree information, the other does not need certain degree information [7]. This paper took the backward cloud algorithm that does not need certain degree information, as shown below:

Input: sample point  $x_i$ , where  $i = 1, 2, \dots, n$ .

Output: characteristics reflecting the qualitative concept,  $(Ex, En, He)$ . Arithmetic steps:

(1) According to  $x_i$ , compute sample average of this set of data  $\bar{X} = \frac{1}{n} \sum_{i=1}^n x_i$ ;

(2) Sample's first order absolute central moment  $\frac{1}{n} \sum_{i=1}^n |x_i - \bar{X}|$ ;

(3) Sample's variance  $S^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{X})^2$ ;

(4)  $Ex = \bar{X}$ ;

$$(5) \quad En = \sqrt{\frac{\pi}{2}} \times \frac{1}{n} \sum_{i=1}^n |x_i - Ex|;$$

$$(6) \quad He = \sqrt{S^2 - En^2}.$$

The above-mentioned backward cloud generator algorithm is statistic method, and its numerical characteristic is a kind of estimation value. When cloud drops are few, error perhaps is large; with the increase of cloud drop number, error will decrease.

**2.3. Operation Rules of Cloud**

Given two clouds  $C_1$  and  $C_2$ , their digital characters are respective  $C_1(Ex_1, En_1, He_1)$  and  $C_2(Ex_2, En_2, He_2)$ . The arithmetic operation [8] result of  $C_1$  and  $C_2$  and the power operation result of  $C_1$  is  $C$  and its digital characters is  $C(Ex, En, He)$ . Define the operation rules as follows in Table 1.

Table 1. The Algorithm of Cloud

Operator	$Ex$	$En$	$He$
+	$Ex_1 + Ex_2$	$\sqrt{En_1^2 + En_2^2}$	$\sqrt{He_1^2 + He_2^2}$
-	$Ex_1 - Ex_2$	$\sqrt{En_1^2 + En_2^2}$	$\sqrt{He_1^2 + He_2^2}$
×	$Ex_1 \times Ex_2$	$ Ex_1 Ex_2  \sqrt{\left(\frac{En_1}{Ex_1}\right)^2 + \left(\frac{En_2}{Ex_2}\right)^2}$	$ Ex_1 Ex_2  \sqrt{\left(\frac{He_1}{Ex_1}\right)^2 + \left(\frac{He_2}{Ex_2}\right)^2}$
÷	$Ex_1 \div Ex_2$	$\left  \frac{Ex_1}{Ex_2} \right  \sqrt{\left(\frac{En_1}{Ex_1}\right)^2 + \left(\frac{En_2}{Ex_2}\right)^2}$	$\left  \frac{Ex_1}{Ex_2} \right  \sqrt{\left(\frac{He_1}{Ex_1}\right)^2 + \left(\frac{He_2}{Ex_2}\right)^2}$

The concept of  $C_1$  and  $C_2$  must be in the same universe of discourse so that the cloud operation involved in the algorithm above has its meaning. The cloud algebraic operation is simplified as the algorithm between cloud and precise value when any one of the cloud's  $En$  and  $He$  both be zero.

**3. Fuzzy-FMECA Method Based on Cloud Model**

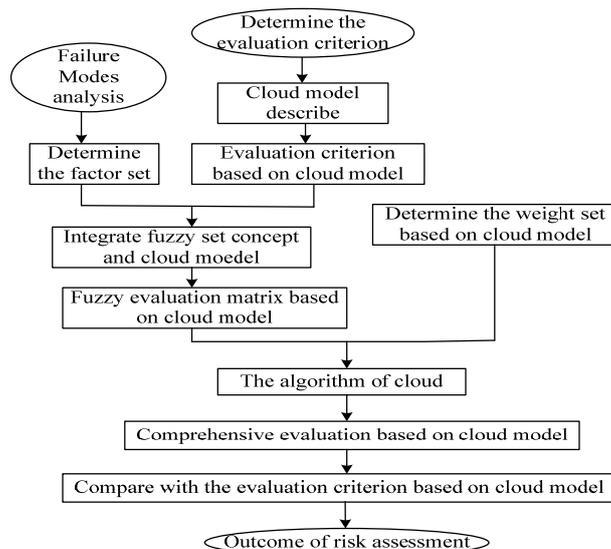


Figure 4. The Procedure of Fuzzy-FMECA Method Based on Cloud Model

The Fuzzy-FMECA based on the cloud model is proposed, and the cloud model was also used to determine the subjection degree function in the risk assessment of CTC interface module for the train control center, finally the group decision can be made with the improved algorithm that integrated methods of AHP and fuzzy with cloud model. Figure 4 describes the flows of risk assessment by combining the Fuzzy-FMECA method with the cloud model.

The Fuzzy-FMECA method based on the cloud model refers to selecting the failure modes, and then the cloud model combining the fuzziness and randomness is applied to improve the fuzzy evaluation matrix and weight matrix of fuzzy comprehensive evaluation method to assess the risk of the failure modes. There are three key factors of this method: factor set ( $U$ ), weight set ( $W$ ) and evaluation set ( $V$ ).

### 3.1. Determining the Factor Set

$U = \{u_1, u_2, \dots, u_m\}$  is the evaluation factor set, that is the evaluation index system ( $u_i, (i=1, 2, \dots, m)$  shows the  $i$ th factor which is influential to evaluation objects). The establishment of index system must follow the principles: systematic, scientific comparability and feasibility. After Delphi questionnaires repeatedly surveys, index system is divided into a number of levels according to their attributes. In general, the levels can be classified into three categories.

### 3.2. Determining the Weight Set

The weight set is based on the expert investigation, all of the weight subsets are expressed using qualitative language, which are transformed into normal cloud. The degree of the importance can be expressed using different normal cloud digital characters. The weight set can be expressed as  $W = \{w_1, w_2, \dots, w_m\}$ . Normally, the grade of the weight factor subsets is not less than 3, and not more than 9.

### 3.3. Establishment of Evaluation Criterion Based on Cloud Model

In this study, we establish the membership clouds of the standard risk states in stead of the membership curves in the conventional fuzzy method [9]. The qualitative remarks of factors have bilateral constraints. The factor remark has bilateral constraint  $[C_{\min}, C_{\max}]$ , its cloud processing can use  $Ex$  as the intermediate value of constraints to approximate the remark, and then we can use (2) to calculate the eigenvalues of the cloud [10].

$$\begin{cases} Ex = (C_{\min} + C_{\max}) / 2 \\ En = (C_{\max} - C_{\min}) / 6 \\ He = i \end{cases} \quad (2)$$

Where  $k$  is a constant number, which can be modified according to the fuzzy threshold degree of the variable.

The evaluation set of risk is  $V = \{V_1, V_2, \dots, V_m\}$ . If we assume that there are  $k$  experts to judge the importance of each factor in the AHP index system, there will be  $k$  remarks for each factor. Then  $V_i = \{C_i^1, C_i^2, \dots, C_i^k\}$  can be used to describe the assessment set of factor  $i$ , among which  $C_i^j$  is the cloud model of the factor  $i$  with the remarks of expert  $j$  ( $i = 1, 2, 3, \dots, m; j = 1, 2, 3, \dots, k$ ).

To the comments which are one side restrain  $C_{\min}$  or  $C_{\max}$ , we can confirm the missing expectation firstly, then compute cloud's parameters according to formula (2), and descript it by semi-up and down.

### 3.4. Cloud Model Based on Comprehensive Evaluation

Supposing that the evaluation factor set  $C = (c_1, c_2, \dots, c_q)$  is a set of  $m$  factors for evaluation unit, the weight set is  $A = [a_1, a_2, \dots, a_q]$ , comprehensive evaluation matrix of each evaluation unit is  $R = [r_1, r_2, \dots, r_q]^T$ . Cloud model is used to calculate the weights and evaluation matrix instead of constructing the subjection degree function. As for weight calculation, this can

be calculated in a statistical form, based on the collation of the questionnaires, experts are found to score the weight of the evaluation factors. Scoring results can be a fraction. Then the parameters ( $Ex, En, He$ ) can be obtained using backward cloud generator to calculate the statistical samples [11].

The weight set described by the model cloud of evaluation factors is:

$$A = [a_1, a_2, \dots, a_q] = \begin{bmatrix} Ex_{a_1} & En_{a_1} & He_{a_1} \\ Ex_{a_2} & En_{a_2} & He_{a_2} \\ \vdots & \vdots & \vdots \\ Ex_{a_q} & En_{a_q} & He_{a_q} \end{bmatrix}^T \tag{3}$$

The fuzzy comprehensive evaluation matrix based on the cloud model is:

$$R = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_q \end{bmatrix} = \begin{bmatrix} Ex_1 & En_1 & He_1 \\ Ex_2 & En_2 & He_2 \\ \vdots & \vdots & \vdots \\ Ex_q & En_q & He_q \end{bmatrix} \tag{4}$$

For the factor set is  $C = (c_1, c_2, \dots, c_q)$ , the weight coefficient based on the cloud model  $a_i(Ex_{a_i}, En_{a_i}, He_{a_i})$  can be understood as each weight coefficient has certain fuzziness and randomness. The evaluation factor can be calculated as  $Ex_{a_i}$ , the evaluation results of different people are defined in the scope of  $[Ex_{a_i} - 3En_{a_i}, Ex_{a_i} + 3En_{a_i}]$  [12].  $He_{a_i}$  further reflects the randomness of subjective evaluation. Comprehensive evaluation matrixes based on the cloud model has the same mathematical meaning.

Then the fuzzy synthesis operator is used to calculate comprehensive evaluation result (synthetically computing operator, which uses weighted average based such as  $M(\bullet, \oplus)$ ), as shown (5).

$$B = A \circ R = \begin{bmatrix} Ex_{a_1} & En_{a_1} & He_{a_1} \\ Ex_{a_2} & En_{a_2} & He_{a_2} \\ \vdots & \vdots & \vdots \\ Ex_{a_q} & En_{a_q} & He_{a_q} \end{bmatrix}^T \circ \begin{bmatrix} Ex_1 & En_1 & He_1 \\ Ex_2 & En_2 & He_2 \\ \vdots & \vdots & \vdots \\ Ex_q & En_q & He_q \end{bmatrix} \tag{4}$$

$$= \begin{bmatrix} \frac{Ex_{a_1} \times Ex_1 + Ex_{a_2} \times Ex_2 + \dots + Ex_{a_q} \times Ex_q}{\sqrt{\left(Ex_{a_1} Ex_1 \sqrt{\left(\frac{En_{a_1}}{Ex_{a_1}}\right)^2 + \left(\frac{En_1}{Ex_1}\right)^2}\right)^2 + \left(Ex_{a_2} Ex_2 \sqrt{\left(\frac{En_{a_2}}{Ex_{a_2}}\right)^2 + \left(\frac{En_2}{Ex_2}\right)^2}\right)^2 + \dots + \left(Ex_{a_q} Ex_q \sqrt{\left(\frac{En_{a_q}}{Ex_{a_q}}\right)^2 + \left(\frac{En_q}{Ex_q}\right)^2}\right)^2}}{\sqrt{\left(Ex_{a_1} Ex_1 \sqrt{\left(\frac{He_{a_1}}{Ex_{a_1}}\right)^2 + \left(\frac{He_1}{Ex_1}\right)^2}\right)^2 + \left(Ex_{a_2} Ex_2 \sqrt{\left(\frac{He_{a_2}}{Ex_{a_2}}\right)^2 + \left(\frac{He_2}{Ex_2}\right)^2}\right)^2 + \dots + \left(Ex_{a_q} Ex_q \sqrt{\left(\frac{He_{a_q}}{Ex_{a_q}}\right)^2 + \left(\frac{He_q}{Ex_q}\right)^2}\right)^2}} \end{bmatrix} \tag{4}$$

$= (Ex, En, He)$

The type used in computing to the cloud computing, corresponding rules can be seen in Table 2.

$B = A \circ R = (Ex, En, He)$  is the characteristic value of comprehensive evaluation, which is an evaluation of cloud model.  $Ex$  is compared with reviews various expectations of cloud model, the closest evaluation is the evaluation result. Evaluation criterion based on cloud model and evaluation model are simulated using MATLAB, respectively, and the nearest evaluation criterion based on cloud model had the greatest influence on evaluation of cloud model, which is the final risk rating. The risk assessment results can be assessed and shown with the MATLAB tools.

## 4. Example Analysis

### 4.1. Cloud Model Application

FMECA method is used to identify the risk of CTC interface module, based on the characteristics of signal transmission between the functions and the knowledge and expertise of the expert, the failure modes of CTC interface module are summarized as five types, the first one is that the system can't receive information from the CTC interface module, the second one is that the system receives incorrect information from the CTC interface module, the third one is that the system can't send information to the CTC interface module, the fourth one is that the system sends incorrect information to the CTC interface module, the fifth one is that the information communicated with CTC interface module is always the same.

The basic idea of security risk classification is based on the theory of risk of mathematical relationship, risk = risk probability × risk severity degree. The risk rating can be obtained according to the degree of risk levels. In the process of the risk assessment of failure modes for CTC interface module, expert assignment or index can be used to express the likelihood and the severity of the accident. Risk matrix rating table is presented in Table 2.

Table 2. Risk Matrix Rating Table

Risk severity degree Risk probability	Risk rating				
	V (Negligible)	IV (Mild)	III (Moderate)	II (Serious)	I (Disaster)
Frequent	6	6	7	8	8
Sometimes	4	5	6	7	8
Occasional	2	4	5	7	7
Rare	1	2	4	6	7
Remote	1	1	3	5	6

The evaluation criterion can be defined as four levels in this paper, acceptable, conditional acceptable, don't want to, unacceptable, the value range of these four levels are defined as, [0, 3), (3, 5), (5, 7) and (7, 8], use these evaluation criteria to describe the evaluation results. According to the formula (2), these evaluation criteria can be transformed into normal cloud. Evaluation criterion based on cloud model is presented in the Table 3.

Table 3. Evaluation Criterion Based on Cloud Model

Risk level	Acceptable	Conditional acceptable	Don't want to	Unacceptable
Evaluation indicators	(1.5,0.5,0.1)	(4,0.33,0.1)	(6,0.33,0.1)	(7.5,0.167,0.1)

20 experts are selected to assess the risk of failure modes of CTC interface module, according to (4), the expectations, entropy and hyper entropy of each failure mode can be calculated using backward normal cloud generator, the fuzzy comprehensive evaluation matrix based on the cloud model is obtained as:

$$R = \begin{bmatrix} (2.000, 0.8773, 0.1812) \\ (6.9500, 0.8335, 0.1143) \\ (7.000, 0.7520, 0.2571) \\ (4.6500, 1.2345, 0.4816) \\ (4.8000, 1.0779, 0.2144) \end{bmatrix}$$

Also 20 experts are selected to assess the relative importance ratings of these five failure modes for CTC interface module, based on the corresponding comparison matrix, the weights of each factor in the AHP index system can be calculated in the weight calculation, the corresponding weight coefficient matrix based on cloud model is obtained as:

$$A = \begin{bmatrix} (0.0383, 0.0093, 0.0045) \\ (0.4136, 0.0150, 0.0053) \\ (0.4136, 0.0150, 0.0053) \\ (0.0728, 0.0252, 0.0128) \\ (0.0616, 0.0198, 0.0075) \end{bmatrix}^T$$

Then according to (5), the fuzzy comprehensive evaluation based on cloud model can be obtained by  $B = A \circ R = (6.4369, 0.5191, 0.1403)$ .

Finally, we can obtain the cloud of risk assessment result for the CTC interface module, and the MATLAB tool can be used to visually display the results, as shown in Figure 5.

MATLAB is used to represent the evaluation criterion based on cloud model and evaluation results, from Figure 5, it is shown the cloud of assessment results is close to the second cloud of the four ranks of the evaluation criterion based on cloud model, which can be directly found that the evaluation result of cloud model suited in the middle of the cloud of conditional acceptable and the cloud of don't want to, and the evaluation result more close to the cloud of conditional acceptance, also the evaluation result is affected by the conditional acceptable cloud model is bigger, so we can easily and visually determine that the potential failure risk of the CTC interface module tends to be conditional acceptable.

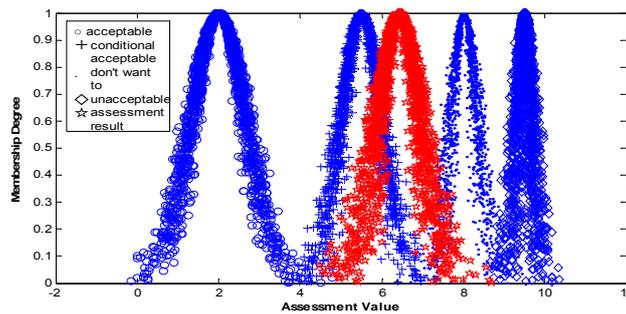


Figure 5. Risk Assessment Results of CTC Interface Module

**4.2. Conventional FAHP Method Application**

Based on the recycling of 20 experts' questionnaire, the number of occurrences for each comment can be counted, fuzzy comprehensive evaluation matrix can be get by:

$$R = \begin{bmatrix} 0.65 & 0 & 0 & 0.35 \\ 0 & 0.65 & 0.35 & 0 \\ 0 & 0.7 & 0.3 & 0 \\ 0 & 0 & 0.55 & 0.45 \\ 0 & 0 & 0.65 & 0.35 \end{bmatrix}$$

At the same time the relative weight of the five failure modes for CTC interface module can be calculated as  $W = (0.0383, 0.4139, 0.4139, 0.0728, 0.0616)$ .

Fuzzy comprehensive evaluation matrix can be described by:

$$B = W \circ R \tag{6}$$

Where“ $\circ$ ” is synthetically computing operator, which uses weighted average model such as  $M(\bullet, \oplus)$ . Fuzzy mathematics has four models such as  $M(\wedge, \vee)$ ,  $M(\bullet, \vee)$ ,  $M(\wedge, \oplus)$  and  $M(\bullet, \oplus)$  for membership degree conversion, long-term results show  $M(\bullet, \oplus)$  that is widely accepted [13].

The fuzzy comprehensive evaluation can be get by:

$$B = W \circ R = (0.0250, 0.5587, 0.2689, 0.1474)$$

According to the results of the fuzzy comprehensive evaluation, we can get the conclusions. The comprehensive evaluation results of the CTC interface module is taken into account, based on the calculation, the risk ratio are calculated as follows: 2.5%, 55.87%, 26.89%, and 14.74%. According to the maximum membership principle, the risk rating for the

failure modes of the CTC interface module is conditional acceptable, and the distribution situation of evaluation criterion for risk rating of the CTC interface module is shown as in Figure 6.

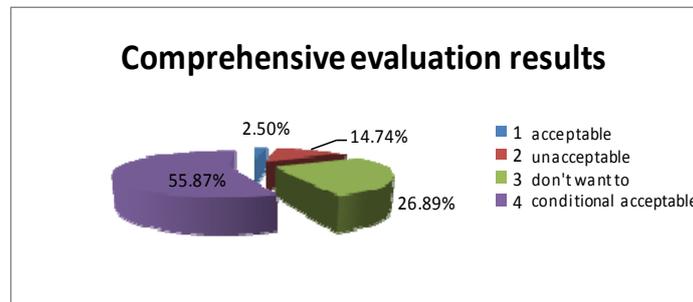


Figure 6. Comprehensive Evaluation Results of the CTC Interface Module

### 4.3. Results Analysis

Comparing the risk results of Fuzzy-FMECA based on cloud model with the risk results of conventional FAHP method, risk assessment results of the two methods are consistent: the risk rating for the failure modes of the CTC interface module is conditional acceptable. But the conventional FAHP method has the following defects:

(1) Seen from the comprehensive assessment results, the results of conventional FAHP method largely depend on the expert's subjective judgment, is not objective, subjection degree function is also given on the basis of experience, and according to maximum membership principle, the results of conventional FAHP method lack volatility and randomness.

(2) For simplicity to get the assessment results, the final evaluation result of conventional FAHP is transformed into a fractional simply, so conventional FAHP method is difficult to embody the essence of fuzzy. And cloud model not only can rate the evaluation results, but also the internal fuzzy characteristics of evaluation objects can be analyzed, thus providing more abundant information than subjection degree function of the conventional FAHP.

(3) The results will lose precision because the fuzzy value is transformed into the accurate value, so the conventional FAHP is not suitable for the raw data which is accurate. And the Fuzzy-FMECA method based on cloud model is suitable for the unitary data ( $x$ ) (accurate or fuzzy value) or the binary data  $\{x, y\}$  (accurate or fuzzy value). So the Fuzzy-FMECA method based on cloud model is more widely applicable.

## 5. Conclusion

By comparing the results of the two methods of evaluation, the Fuzzy-FMECA method based on cloud model can effectively make comprehensive decision on group evaluation of the risk of CTC interface module for train control center, which reduces the influence subjective of experts' factors on the evaluation results, using the normal cloud model to construct the subjection degree function can fully characterize the risk degree of fuzziness and randomness of the risk factor for the CTC interface module and realize the transformation between qualitative and quantitative evaluation, so that the Fuzzy-FMECA method based on cloud model can be more objective and accurate.

Constructing subjection degree functions is considered as a key question to assess the risk of the CTC interface module for the train control center, in view of the shortcomings and the insufficiency of the conventional FAHP, draw lessons from the characteristics and advantages of cloud model, and cloud model is applied to improve the conventional FAHP, cloud model is used to construct the subjection degree function and the group judgment to make use of gathering clouds gather, thus the degree of each failure mode for the CTC interface module can be more accurate and reasonable. The introduction of the cloud model should be able to develop and improve the risk assessment method.

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