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# Study on Fuzzy Comprehensive Evaluation Model for the Safety of Mine Belt Conveyor

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**Abstract.** To improve the situation of the frequent failures of mine belt conveyor during operation, a model was used to evaluate the safety of mine belt conveyor. Based on the foundation of collecting and analyzing a large quantity of fault information of belt conveyor in the nationwide coal mine, the fault tree model of belt conveyor has been built, then the safety evaluation index system was established by analyzing and removing some secondary indicators. Furthermore, the weighted value of safety evaluation indexs was determined by analytic hierarchy process(AHP), and the single factor fuzzy evaluation matrix was constructed by experts grading method. Additionally, the model was applied in evaluating the security of belt conveyor in Nanliang coal mine. The results shows the security level is recognized to the "general", which means that this model can be adopted widely in evaluating the safety of mine belt conveyor.

## 1 Introduction

As a widely used and efficient transportation equipment, the stable operation of belt conveyor is very important to ensure the production safety of coal mine[1,2]. At present, most coal mine takes regular maintenance on the belt conveyor, but this method is unable to eliminate the hidden danger timely, which leads to frequent failures of conveyor and causes heavy casualties and damage to severe economic property[3]. There are increasing researchers initiate the study of monitoring system to improve the safety and reliability of conveyor, such as Li H J[4] who designs a slipping-belt protecting and monitoring system based on CAN and WSNs to real-time monitor the operating parameters to reduce the occurrence of slipping faults; Wang C[5] who devises a belt conveyor monitoring system based on PLC to master the running state of conveyor in real time, which ensures the safe and reliable operation of conveyor. However, the field investigation indicates that some hidden dangers still exist. To avoid the happening of conveyor accidents, a reasonable and effective safety evaluation method was created. For the types of conveyor faults and the uncertainty of relationship among them, AHP and expert scoring method were used to establish the fuzzy evaluation model of belt conveyor, which can quantify the evaluation indicators, and improve the accuracy of the evaluation results. Moreover, this model was be used in Nanliang coal mine, with the safety analysising of belt conveyor, we can find out the defections and come up with the corresponding countermeasures to improve the safe operation of conveyor.

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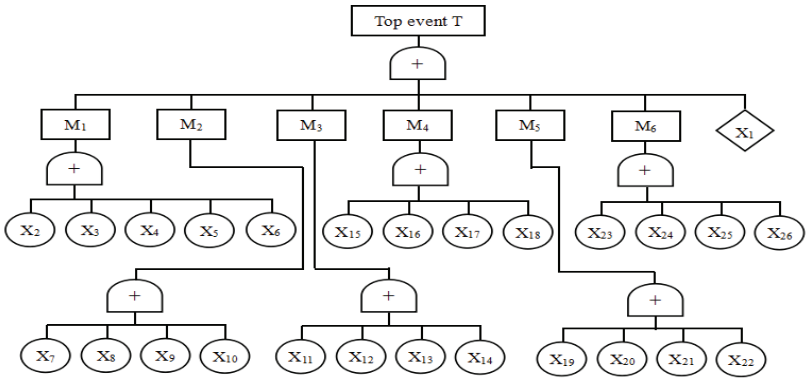
## 2 The establishment of the fault tree model

Based on the understanding of working principles and structure characteristics of belt conveyor, this paper extracts the main types of safety hazard of belt conveyor and confirms the logical relationship among faults, then two-level fault tree model of belt conveyor is established, which lays the foundation of the safety evaluation of belt conveyor. The fault tree model is shown in figure1.




T: safety hazard of belt conveyor
$M_1$: slipping fault
$M_2$: tearing fault
$M_3$: smoking fault
$M_4$: material scattering failure
$M_5$: deviation fault
$M_6$: motor fault
$X_1$: the lack of tension belt
$X_2$: driving drum worn seriously
$X_3$: belt appeared thin and narrow
$X_4$: roller damaged
$X_5$: the belt is overload
$X_6$: belt damaged
$X_7$: foreign bodies stuck in belt
$X_8$: joint damaged and folding
$X_9$: the belt was broken for overload
$X_{10}$: drum smoke for wear seriously
$X_{11}$: belt smoke for wear
$X_{12}$: the temperature of roller is rise
$X_{13}$: electrical short circuit lead to fire
$X_{14}$: the scattered of coal
$X_{15}$: floating coal is too much
$X_{16}$: guide groove damaged
$X_{17}$: the belt is suspended
$X_{18}$: the belt center line is deviate
$X_{19}$: aging belt appeared S
$X_{20}$: the nose is uneven force
$X_{21}$: loading position is wrong
$X_{22}$: shell lost heat is not enough
$X_{23}$: motor fan damaged
$X_{24}$: fastening bolts are loose
$X_{25}$: long time overload operation, motor heating lead to short circuit

Figure1. Fault tree model of belt conveyor

## 3 The establishment of fuzzy comprehensive evaluation model

### 3.1 The determination of the safety evaluation index system

Based on the fault tree model of belt conveyor, some secondary indicators which combined with survey data of conveyor was deleted to determine the safety evaluation index of belt conveyor. Then, the factor set of evaluation target is U={U1, U2, U3, U4, U5, U6}; sub factor set Ui={Ui1, Ui2, ...Uin} (i=1,2, 6); The safety evaluation index system of belt conveyor is shown in figure2.

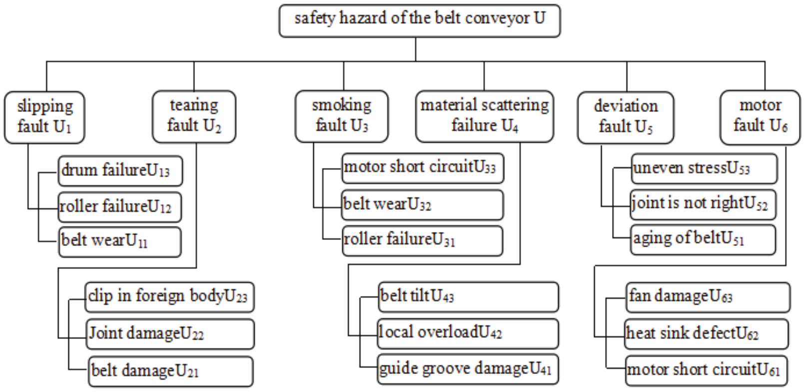



Figure2. safety evaluation index system of belt conveyor

### 3.2 The construction of the evaluation set

Through the statistical analysis of the number of failures and the causes of conveyor in the field investigation, the belt conveyor experts evaluate the safety level of belt conveyor according to the possibilities and severities of the accident occurrence. In this paper, the safety status of belt conveyor is divided into 5 grades, which is written as V={V1, V2, V3, V4, V5}={safe, relatively safe, general, relatively dangerous, dangerous}={>0.95, 0.95-0.90 0.90-0.85, 0.85-0.80, <0.80}.

### 3.3 The determination of the weight of factors based on AHP

#### *3.3.1 Constructing pairwise comparison matrices*

According to the Saaty 1~9[6]scale method(as shown in table1), the pairwise comparison matrix was constructed by comparing every two fuzzy factors of evaluation index system, through normalization, we got the weight vector Zi=(Zi1, Zi2,⋯,Zin), and $\sum_{j=1}^{n} z_{ij} = 1$

**Table1.** The 1~9 scale table

| scale | definition | meaning |
|---|---|---|
| 1 | equally important | same contribution to target |
| 3 | slightly important | slightly different |
| 5 | suitable importance | different |
| 7 | really important | obvious difference |
| 9 | absolutely important | obvious importance |
| 2,4,6,8 | intermediate to two degrees | need to compromise |
| The reciprocal | If the element i compares element j that obtained the resulting bij, then the resulting of the elements j compares element i that is 1/bij | |

#### *3.3.2 Calculating the weight vector and checking the consistency*

The maximum eigenvalue and the corresponding eigenvector were obtained according to the pairwise comparison matrix, then calculated the deviation consistency index CI ,which compared with average random consistency index RI[7], If the consistency check passed, the weight vector of evaluation factors set can be obtained by normalizing the eigenvector of evaluation matrix. Otherwise, we need to reconstruct the pairwise comparison matrix.

1 Calculate the maximum eigenvalue of the evaluation matrix

$$AW = \lambda_{\max} W \tag{1}$$

In the formula (1), $\lambda_{\max}$ is the largest eigenvalue of a matrix A, W is the eigenvector corresponding to the largest eigenvalue of matrix A.

2 Consistency check

The formula for calculating deviation consistency index:

$$CI = (\lambda_{\max} - n)/(n-1) \tag{2}$$

Average random consistency index: RI can be found from table 2.

The formula for calculating consistency:

$$CR = CI / RI \tag{3}$$

If CR<0.1,which indicates that the evaluation matrix passed the consistency test; otherwise, the contrast matrix ought to be reconstructed.

**Table2.** The standard value of average random consistency index RI

| Matrix order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI standard value | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 |

### 3.4 The establishment of a single factor matrix

Combined with their own experience and the influence degree of each index of belt conveyor, the experts and specified technicians were invited to vote according to the scoring criteria, then the single factor matrix was founded based on the principles of maximum subordinate.

$$R_i = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

The formula of first level fuzzy comprehensive evaluation:

$$V_i = Z_i \bullet R_i = (b_{i1},\ b_{i2},\cdots,\ n_{im}) \tag{4}$$

In the Chad operator algorithm, the" $\wedge$ "symbol refers to take small operations, the" $\vee$ "symbol refers to take big operations, and for example:

$$b_j = \bigvee_{i=1}^{n} (z_i \wedge r_{ij}) \tag{5}$$

The formula of second level fuzzy comprehensive evaluation:

$$V = Z \bullet R = Z \bullet (V_1 \quad V_2 \quad \ldots \quad V_{\mathrm{n}})^T \tag{6}$$

## 4 The safety evaluation of belt conveyor in Nanliang coal mine

### 4.1 The calculation of weight vector

Based on the experience of the coal mine belt conveyor and some other criteria, relevant experts and field technicians construct pairwise comparison matrix by using the 1~9 scale method to calculate the weight vectors of the belt conveyor. Take the first weight vector as an example, the calculation is shown in table 3.

**Table3.** The calculation of the first weight vector.

| U | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ | $U_6$ | $K_i$ | weight vector $Z_i$ | Consistency check |
|---|---|---|---|---|---|---|---|---|---|
| $U_1$ | 1 | 3 | 4 | 5 | 1/3 | 6 | 19.33 | 0.302 | |
| $U_2$ | 1/3 | 1 | 3 | 2 | 1/5 | 2 | 8.53 | 0.133 | |
| $U_3$ | 1/4 | 1/3 | 1 | 2 | 1/5 | 2 | 5.78 | 0.090 | $\lambda_{\max} = 6.41$ |
| $U_4$ | 1/5 | 1/2 | 1/2 | 1 | 1/3 | 2 | 4.53 | 0.071 | $CR = CI/RI =$ |
| $U_5$ | 3 | 5 | 5 | 3 | 1 | 6 | 23.00 | 0.360 | [(6.41-6)/5]/1.26=0.07 |
| $U_6$ | 1/6 | 1/2 | 1/2 | 1/2 | 1/6 | 1 | 2.83 | 0.044 | qualified |
| | | | | | | | $Z_i = k_i / \sum k_i$ , | $\sum Z_i = 1$ | |

From table3, we got $CR = 0.07 < 0.1$, which means the first weight vector passes the consistency test, and the first weight vector can be written as Z=(0.302 0.133 0.090 0.071 0.360 0.044).

As well, the establishment of pairwise comparison matrix of the second level evaluation and the judgment matrices are shown in table 4.

**Table4.** Matrices of the the second level

| $U_1$ | $U_{11}$ | $U_{12}$ | $U_{13}$ | $U_2$ | $U_{21}$ | $U_{22}$ | $U_{23}$ | $U_3$ | $U_{31}$ | $U_{32}$ | $U_{33}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_{11}$ | 1 | 2 | 3 | $U_{21}$ | 1 | 3 | 5 | $U_{31}$ | 1 | 1/3 | 2 |
| $U_{12}$ | 1/2 | 1 | 3 | $U_{22}$ | 1/3 | 1 | 3 | $U_{32}$ | 3 | 1 | 3 |
| $U_{13}$ | 1/3 | 1/3 | 1 | $U_{23}$ | 1/5 | 1/3 | 1 | $U_{33}$ | 1/2 | 1/3 | 1 |
| $U_4$ | $U_{41}$ | $U_{42}$ | $U_{43}$ | $U_5$ | $U_{51}$ | $U_{52}$ | $U_{53}$ | $U_6$ | $U_{61}$ | $U_{62}$ | $U_{63}$ |
| $U_{41}$ | 1 | 2 | 3 | $U_{51}$ | 1 | 1/3 | 2 | $U_{61}$ | 1 | 3 | 5 |
| $U_{42}$ | 1/2 | 1 | 3 | $U_{52}$ | 3 | 1 | 3 | $U_{62}$ | 1/3 | 1 | 3 |
| $U_{43}$ | 1/3 | 1/3 | 1 | $U_{53}$ | 1/2 | 1/3 | 1 | $U_{63}$ | 1/5 | 1/3 | 1 |

Through calculation, the consistency of the two level weight vector is qualified, and the judgment matrix can be used. According to table4, the weight vectors of the two level are Z1=(0.575 0.311 0.114), Z2=(0.603 0.290 0.107), Z3=(0.274 0.575 0.151), Z4=(0.575 0.311 0.114), Z5=(0.274 0.575 0.151), Z6=(0.603 0.290 0.107).

## 4.2 Determination of single factor evaluation matrix

Based on the operation of the conveyor and experience, the experts and the field technicians' voting are accomplished by means of scoring, then the single factor matrix is established, and the fuzzy evaluation matrixes are obtained after normalization processing.

$$R_1=\begin{bmatrix}0.1&0.2&0.4&0.2&0.1\\0.2&0.3&0.2&0.2&0.1\\0.5&0.1&0.2&0.1&0.1\end{bmatrix}\quad R_2=\begin{bmatrix}0.1&0.2&0.4&0.2&0.1\\0.1&0.2&0.3&0.3&0.1\\0.4&0.2&0.2&0.1&0.1\end{bmatrix}\quad R_3=\begin{bmatrix}0.4&0.2&0.2&0.1&0.1\\0.1&0.2&0.3&0.3&0.1\\0.4&0.3&0.2&0.1&0\end{bmatrix}$$

$$R_4=\begin{bmatrix}0.1&0.2&0.3&0.3&0.1\\0.4&0.2&0.2&0.1&0.1\\0.2&0.3&0.2&0.2&0.1\end{bmatrix}\quad R_5=\begin{bmatrix}0.1&0.2&0.3&0.3&0.1\\0.2&0.2&0.4&0.1&0.1\\0.3&0.3&0.2&0.1&0.1\end{bmatrix}\quad R_6=\begin{bmatrix}0.1&0.2&0.3&0.3&0.1\\0.4&0.2&0.2&0.1&0.1\\0.3&0.3&0.2&0.2&0\end{bmatrix}$$

## 4.3 Calculation and evaluation the safety of conveyor

Based on the operation of the conveyor and experience, the experts and the field technicians' voting are accomplished by means of scoring, then the single factor matrix is established, and the fuzzy evaluation matrixes are obtained after normalization processing.

### *4.3.1 The first comprehensive evaluation*

Under the condition that the single factor fuzzy evaluation matrix and the weight vector value are determined, we can calculate according to formula3.

$$V_1=Z_1\bullet R_1=(0.575\quad 0.311\quad 0.114)\times\begin{bmatrix}0.1&0.2&0.4&0.2&0.1\\0.2&0.3&0.2&0.2&0.1\\0.5&0.1&0.2&0.1&0.1\end{bmatrix}.$$

According to the rule of Chad operator, we can got $V_1$=(0.200 0.300 0.400 0.200 0.100), similarly, $V_2$=(0.107 0.200 0.400 0.290 0.100), $V_3$=(0.274 0.200 0.300 0.300 0.100), $V_4$=(0.311 0.200 0.300 0.300 0.100), $V_5$=(0.200 0.200 0.400 0.274 0.100), $V_6$=(0.290 0.200 0.300 0.300 0.100).

### *4.3.2 The second comprehensive evaluation*

The evaluation vector obtained from the first level evaluation is combined into the evaluation matrix of the second level evaluation R. The second comprehensive evaluation is following:

$$V=Z\bullet R=(0.302\quad 0.133\quad 0.090\quad 0.011\quad 0.360\quad 0.044)\times\begin{bmatrix}0.200&0.300&0.400&0.200&0.100\\0.107&0.200&0.400&0.290&0.100\\0.274&0.200&0.300&0.300&0.100\\0.311&0.200&0.300&0.300&0.100\\0.200&0.200&0.400&0.274&0.100\\0.290&0.200&0.300&0.300&0.100\end{bmatrix}$$

$$=\left(0.200\quad 0.300\quad 0.360\quad 0.274\quad 0.100\right)$$

After normalization, we got the V=(0.162 0.243 0.292 0.222 0.081), according to the principle of maximum membership degree, the corresponding level of the largest number in the fuzzy evaluation set V is the level of the evaluation. The results show that the safety level of the belt conveyor is grade 3,which means the safety of belt conveyor is "general", and its safety needs to be improved.

From the table 3 we can see, the weight value of slip fault and deviation fault up to 0.302 and 0.360 ,which indicates the failure is relatively large for slip fault and deviation. The slip fault belt is prone to wear, it is mainly because that the conveyor belt has to carry large amounts of coal and the edge of coal is not even, the belt will often be worn. In order to prevent slipping failures, relevant measures should be taken to resolve the problem. Such as checking the conveyor belt is clean or not, checking the belt condition of deformation and aging problems regularly, cleaning or replacing the conveyor belt timely, reducing the quantity of conveyor transportation and so on. The deviation fault is likely to be caused by the wrong joint of belt, which can be found by checking whether the belt joint appears skin cracks and the edge burr, therefore we can readjust or remake joint according to requirements, and clean air conveying section which ensure the clean of roller surface to reduce the occurrence of accidents.

## 5 Conclusion

Aiming at the situation that frequent failures appear on the belt conveyor, a fuzzy comprehensive evaluation model of belt conveyor safety is established. In this paper, we use AHP to determine the weight of each index value and the expert scoring method to build up single factor fuzzy evaluation matrix, which combines the qualitative analysis and quantitative evaluation to reflect the safety degree of belt conveyor objectively. A case study of Nanliang coal mine was conducted based on this model, the results show that its security level is "general", and the slipping fault and deviation fault are the main factors that influence the safety of mine belt conveyor, we can put forward the corresponding countermeasures to improve the safety operation of conveyor. In addition, the model can be combined with the actual operation of the conveyor to build the corresponding evaluation matrix for specific coal mines. Thus this model has practical application values in improving the safety of mine belt conveyor.

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