 Coal mine safety evaluation based on the reliability of expert decision

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Abstract

As a specific systematic assessment, many effect factors of coal mine safety evaluation cannot be directly quantified because of their complexities and uncertainties. Generally, a large number of experts are needed for making auxiliary decisions. To a great extent, the dependability of the evaluation results heavily depends on the reliability of the expert decisions. The present paper, based on the similarity and difference of expert decisions, established an expert reliability model. The expert reliability obtained from this model is a kind of objective and dynamic weight which can properly overcome the pitfalls of the static weighting in the traditional method.

Keywords: expert reliability; uncertain AHP; coal mine safety evaluation, dynamic weight

1. Introduction

The coal production system is a special and complicated man-machine-environment system. In this system, there are many factors affecting the coal mine safety, and the relationships of these factors are complex. Additionally, it is very difficult to study most of these factors by using quantitative method directly, which often requires a large number of experts to make auxiliary decisions. As a result, the reliability of expert decision which should be evaluated by a series of scientific standards, will directly affect the accuracy of the final coal mine safety evaluation. However, literatures concerning the reliability of the decision made by experts in coal mine safety evaluation or the expert reliability are still very limited up to now and all methods available for determining expert reliability (weighting) are subjective and static[1-4]. This kind of weight determining process is strong in subjectivity and casualness, but lack of normalization.

Consequently, current study establishes an uncertain AHP model based on the reliability of expert decision in terms of solving the following two aspects: (1) expert reliability. The expert weight obtained by this model is dynamic and objective, vary with the different evaluation information given by the experts, i.e. the expert reliability is determined by its understanding and controlling degree of factors. (2) Index weight. This model replaces the traditional AHP and centralization statistical method with uncertain AHP method. It does not only overcome the ambiguousness and uncertainty of knowledge, but also solves the multifactor sequencing problem[5-7].

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This paper is divided into five parts. The first part is the introduction, which analyzes the application background of the uncertain AHP model based on expert decision reliability in coal mine safety evaluation. The second part illustrates the principle of expert decision reliability. The third part makes an empirical study with examples of coal mine safety evaluation. The fourth part is the discussion and analysis on the results. The fifth part is conclusions.

2. Principles of expert decision reliability

The reliability of expert panel decision in coal mine safety evaluation study is generally determined by the prestige and reputation of the experts. This weighting method, to some extent, is static and subjective as well as can not reflect the experts’ understanding level about the decision problem completely and objectively. While the expert’s dynamic weight is determined by connecting the expert with his decision’s status in the panel decision which means that the expert reliability is determined by his own decision reliability. Both the overall similarity and local difference of expert decisions should be taken into consideration when investigating the expert decision reliability[8-9].

In order to analyze the similarity and difference of expert decisions, we proposed some definitions as follows:

Definition 1: The expert decision in this context particularly refers to the uncertain AHP judgment matrix presented by the experts. “vec” represents vector operation of matrix. Then the \( 1 \times 2n^2 \) Vector

\[
vec(A) = (a_{11},...,a_{n1},a_{12},...,a_{n2},...,a_{nn},a_{11}^u,a_{12}^u,...,a_{nn}^u)
\]

denotes the derivation vector of uncertain Matrix A.

2.1. Similarity of uncertain judgment matrices in group decision

Assuming that there are \( q \) experts involved in a decision making, denoted as \( E_1,E_2,...,E_q \), respectively. The \( n \times n \) matrices proposed by them are defined as \( A_l (l=1,2,...,q) \). It could be concluded, among all \( q \) matrices, that more reliability of \( A_l \) will be if higher similarity exists between \( A_l \) and other uncertain judgment matrices, i.e. \( A_l \) will play a larger role in group decision.

The derivation vectors of \( A_l \) and \( A_k \) are represented by \( vec(A_l) \) and \( vec(A_k) \) respectively. The angle between \( vec(A_l) \) and \( vec(A_k) \) is \( \alpha_{lk} \) and \( \gamma_{lk} = \cos \alpha_{lk} \). Then:

\[
\gamma_{lk} = \frac{\langle vec(A_l), vec(A_k) \rangle}{\|vec(A_l)\|\|vec(A_k)\|} \quad (1)
\]

Obviously, \( 0 \leq \gamma_{lk} \leq 1 \), and equals 1 only when \( vec(A_l) = vec(A_k) \). \( \gamma_{lk} \) reflects the similarity between \( vec(A_l) \) and \( vec(A_k) \) as well as the similarity between \( A_l \) and \( A_k \). If \( \gamma_k = \sum_{l=1,l\neq k}^q \gamma_{lk} \), then \( \gamma_k \) reflects the sum of similarities between \( A_k \) and other judgment matrices. Clearly, the larger \( \gamma_k \) means the more reliable of \( A_k \). The similarity (denoted as \( \lambda_k \)) between the evaluation of No. \( k \) expert and other experts can be obtained by normalizing \( \gamma_k \) which can be expressed by:
\[ \lambda_k = \gamma_k / \sum_{k=1}^{q} \gamma_k \]  

(2)

2.2. Difference of uncertain judgment matrices in group decision

Assuming \( \text{vec}(A_k) \) is the vector derivated from the \( n \times n \) uncertain AHP judgment matrix that proposed by the No. \( q \) expert.

\[
\sigma_k = \sum_{j=1}^{2n^2} a_{sj} - \frac{1}{q} \sum_{j=1}^{q} a_{sj}, \quad (k = 1, 2, ..., q)
\]  

(3)

\( \sigma_k \) refers to the sum of the values of difference between the evaluations of No. \( q \) expert and that of other expert. The difference degree \( \delta_k \) between the evaluation of No. \( k \) expert and other expert can be achieved by normalizing \( \sigma_k \). That is:

\[
\delta_k = \sigma_k / \sum_{k=1}^{q} \sigma_k, \quad (k = 1, 2, ..., q)
\]  

(4)

Supposing the similarity and difference among uncertain judgment matrices are two variables in assessing expert decision reliability and the expert reliability is denoted by decision reliability. Then, the obtained expert weight is dynamic and its reliability varies with the judgment matrix. The corresponding formula is:

\[
r_k = \begin{cases} 
\lambda_k & \sum_{i=1}^{q} \lambda_i \delta_i = 1 \\
\lambda_k (1 - \delta_k) / (1 - \sum_{i=1}^{q} \lambda_i \delta_i) & \sum_{i=1}^{q} \lambda_i \delta_i \neq 1 
\end{cases} \quad (k = 1, 2, ..., q)
\]  

(5)

2.3. Calculation of uncertain AHP model based on expert decision reliability

(1) Invite relevant experts to score the uncertain AHP judgment matrices, i.e. construct the uncertain AHP judgment matrices.
(2) Evaluate the reliability of expert decision.

Based on the above theory of similarity and difference among uncertain AHP judgment matrices, the following items can be calculated:

- Similarity of uncertain judgment matrices (eq. 1.2).
- Difference of uncertain judgment matrices (eq. 3.4).
- Expert decision reliability, i.e. expert reliability.

(3) Calculate the weight ordering interval of uncertain judgment matrices.

Presently, there are many literatures concerning the weight sequence of uncertain AHP. Some weight calculation methods for optimal ordering have been proposed continuously and, up to now, there are above 10 different methods. After a comprehensive comparison of various methods, according to Fan and Pan (1996)[10], the uncertain AHP weight can be calculated by employing the following steps:
3. Empirical study of safety index in coal production system

3.1. Determination of the index system

The selection of index system is the foundation and key point in the coal mine safety evaluation. Although many researchers as well as literatures focus on this area, there seems to be no consistent solution for this issue so far[11-12]. On the one hand, it is difficult to unify the index system due to the great difference among various mines. On
the other hand, it is also difficult to unify the quantitative standard of indexes even if they have the same system as
the influence degree varies in different mines. Thus, the current investigation about safety index system and weight
(security risk value) is based on the national average level. In spite of each coal mine may have its own index system
and weight, the methodology proposed here can be used in global scale.

Based on the investigation and analysis of safety accidents within national coal production system, together with
opinions from relevant experts and conclusions from previous researchers, the main safety accident indexes to assess
coal production system can be divided into 8 categories in terms of accidents influencing coal mine safety. They are
roof accidents, gas accidents, water accidents, fire accidents, dust accidents, blasting accidents, transportation & lift
accidents, and electromechanical accidents as is shown in Fig. 1

![Assessment Index System of Safety Accidents in Coal Production System]

Fig. 1. Evaluation index system of safety accidents in coal production system

3.2. Determination of expert decision reliability and weight index

Five experts were engaged in current coal mine safety research to construct their own uncertain AHP judgment
matrix (See Table 1). The experts must be familiar with the laws, regulations and relevant technical standards of
coop mine safety production and involved in this field for at least 10 years. Two supplementary explanations should
be point out: (1) only five experts were invited to make decisions in this empirical research and this may affect the
accuracy of final evaluation results to some extent. But this study aims at introducing a new evaluation method for
coal production system. In practical application, more experts can be invited to improve the reliability of group
decision according to the actual situation. (2) Out of the full data-sets only one decision matrix are presented for
illustrative purposes as well as because of the limited space. Table 2 shows the results, by using computer program,
derived from calculation processes in Section 2.3.

Table 1. Expert decision matrix of safety accidents in coal production system

<table>
<thead>
<tr>
<th>Expert A</th>
<th>Roof accidents</th>
<th>Gas accidents</th>
<th>Water accidents</th>
<th>Fire accidents</th>
<th>Dust accidents</th>
<th>Blasting accidents</th>
<th>Transportation accidents</th>
<th>Electromechanical accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof accidents</td>
<td>1-1</td>
<td>1/3-1</td>
<td>1-3</td>
<td>3-5</td>
<td>4-6</td>
<td>6-7</td>
<td>6-7</td>
<td>6-7</td>
</tr>
<tr>
<td>Gas accidents</td>
<td>1-3</td>
<td>1-1</td>
<td>5-6</td>
<td>5-7</td>
<td>7-8</td>
<td>7-8</td>
<td>7-8</td>
<td>7-8</td>
</tr>
<tr>
<td>Water accidents</td>
<td>1/3-1</td>
<td>1/6-1/5</td>
<td>1-1</td>
<td>2-3</td>
<td>3-5</td>
<td>2-4</td>
<td>2-4</td>
<td>2-4</td>
</tr>
<tr>
<td>Fire accidents</td>
<td>1/5-1/3</td>
<td>1/7-1/5</td>
<td>1/3-1/2</td>
<td>1-1</td>
<td>3-5</td>
<td>3-5</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Dust accidents</td>
<td>1/6-1/4</td>
<td>1/8-1/7</td>
<td>1/5-1/3</td>
<td>1/5-1/3</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>Blasting accidents</td>
<td>1/7-1/6</td>
<td>1/8-1/7</td>
<td>1/4-1/2</td>
<td>1/5-1/3</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>Transportation accidents</td>
<td>1/7-1/6</td>
<td>1/8-1/7</td>
<td>1/4-1/2</td>
<td>1/4-1/3</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
</tr>
<tr>
<td>Electro-mechanical accidents</td>
<td>1/7-1/6</td>
<td>1/8-1/7</td>
<td>1/4-1/2</td>
<td>1/4-1/3</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
<td>1-1</td>
</tr>
</tbody>
</table>
Table 2. Expert Decision Reliability and Index Weight

<table>
<thead>
<tr>
<th>Expert</th>
<th>Expert decision reliability</th>
<th>Index</th>
<th>Weight</th>
<th>Index</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert A</td>
<td>0.215</td>
<td>Roof accidents</td>
<td>0.307</td>
<td>Blasting accidents</td>
<td>0.029</td>
</tr>
<tr>
<td>Expert B</td>
<td>0.207</td>
<td>Gas accidents</td>
<td>0.353</td>
<td>Transportation accidents</td>
<td>0.076</td>
</tr>
<tr>
<td>Expert C</td>
<td>0.195</td>
<td>Water accidents</td>
<td>0.093</td>
<td>Electromechanical accidents</td>
<td>0.028</td>
</tr>
<tr>
<td>Expert D</td>
<td>0.186</td>
<td>Fire accidents</td>
<td>0.050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expert E</td>
<td>0.197</td>
<td>Dust accidents</td>
<td>0.064</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Discussion

It can be seen from Table 2 that (1) the values of decision reliability of all experts are in the range from 0.186 to 0.215. The expert reliability is no longer the traditional static weighting which is dynamic and determined by its decision matrix, namely decision reliability; and (2) the gas accident accounting for 35.3% of all coal mine accidents is the main risk and brings the most potential hazard to coal mine safety. In addition, the roof accidents and water accidents account for 30.7% and 9.3% of all accidents. Finally, fire, dust, blasting, transportation and electromechanical accidents account for 5%, 6.4%, 2.9%, 7.6% and 2.8% of all accidents, respectively.

In order to assess the reliability of evaluation results, a comparison was performed between the results and the total death toll in coal mine accidents from 2001-2006, see Table 3. Death toll is the most important index to evaluate the risk loss of coal mine safety and can reflect the risk of accidents.

As shown in Fig. 2 that (1) two curves almost coverage with each other and this partly confirms the reliability of evaluation results; and (2) two curves don’t completely coincide with each other which may be caused by the following two reasons: First of all, their statistical data calibers are different. Death toll is from the accident loss while the risk value in system evaluation is from the double viewpoints of risk loss and probability. Secondly, only 5 experts participated in current investigation and this may, more or less, affect the accuracy of final evaluation results.

Table 3. Death toll in various coal mine accidents from 2001-2006*

<table>
<thead>
<tr>
<th>Type of accidents</th>
<th>Death toll</th>
<th>Percentage (%)</th>
<th>Type of accidents</th>
<th>Death toll</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas accidents</td>
<td>13255</td>
<td>38.50</td>
<td>Blasting accidents</td>
<td>525</td>
<td>1.60</td>
</tr>
<tr>
<td>Roof accidents</td>
<td>11668</td>
<td>33.90</td>
<td>Transportation accidents</td>
<td>3057</td>
<td>8.80</td>
</tr>
<tr>
<td>Water accidents</td>
<td>2671</td>
<td>7.80</td>
<td>Electromechanical accidents</td>
<td>598</td>
<td>1.70</td>
</tr>
<tr>
<td>Fire accidents</td>
<td>483</td>
<td>1.40</td>
<td>Other accidents</td>
<td>2177</td>
<td>6.30</td>
</tr>
</tbody>
</table>

*Data Source: China Industrial Statistical Yearbook 2001 - 2007

5. Conclusion and outlook

The expert reliability model in this paper, which is based on the similarity and variation of expert decisions not only embodies the dynamic characteristic of expert weight, but also makes the weight determining more scientific and objective. It is helpful to perfect the existing assessment methods for coal mine safety system and improve the reliability of assessment results by introducing the model into coal mine safety assessment. The empirical research shows that the model can solve the problem of expert decision reliability more objectively and scientifically, and thus improves the accuracy and reliability of assessment results. Certainly, there are some deficiencies in the research. For instance, only five experts were invited to make decisions in this empirical research. The number may be too small and will affect the accuracy of final assessment results to some extent. In practical application, more experts can be invited to make the assessment results more objective and scientifically according to the actual situation.
Fig. 2. Comparison graph of risk weight between death toll proportion and system evaluation

References


