

Group Decision-Making Method in the Field of Coal Mine Safety Management Based on AHP with Clustering

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ABSTRACT

The complex and changeable system of coal mine increases the difficulty and importance of its decision-making. Individual decisions sometimes can not bring satisfactory outcomes since the decision need broad knowledge and experience which is not in single field but related to many domains of economics, sociology, logic, etc. To improve the validity and objectivity of decision-making, the group decision-making method is feasible and necessary since it can collect more intelligence to choose and judge together. This paper synthetically analyzes the content and characteristic of decision-making in the field of coal mine safety. A methodology for group decision-making using analytic hierarchy process (AHP) with cluster analysis is proposed accordingly. Then a case study using the method indicates that it is effective and helpful to improve the level of decision-making in the field of coal mine safety management in China.

Keywords

Coal mine, safety management, group decision-making, analytic hierarchy process (AHP), cluster analysis

INTRODUCTION

The current situation for coal mine safety in China is not satisfied and the incidence rate of coal mine accidents is extremely high. In 2006, the death rate reached 2.041 per million tons of coal mines in China, which was 4 times of that in India, South Africa and Poland and 50 times of that in the US and Australia.

Many attempts have been made to reduce the rate of accidents. Despite lacking in systems analysis, some researchers have begun to give their attention to decision-making study since it makes up crucial aspect in the changeable and complex coal mine system. This paper focuses on group decision-making in the field of coal mine safety management. The brain storm method herein is used to collect group intelligence and present potential schemes. And the methodology of AHP with clustering is applied to evaluate the schemes in order to choose the final one.

Brain storm is a well-known method. Its advantages in ensuring experts fully express their idea and bringing innovative schemes have been widely proved. Analytic Hierarchy Process approach was proposed in early 1970s by Thomas L. Saaty then continues to be highly regarded and widely used in many fields. Designed to reflect the way people actually thinking, AHP reduces complex issues to a series of one-on-one comparisons. Then analyzer can analyze the originally complex problem in a simpler level and see the problem more clearly. The AHP is applied to this study mainly because of its inherent ability to handle complex and unstructured problem with multiple attributes. Furthermore, its strongpoint of objectivity and comprehensiveness is absolutely necessary to solve problem in coal mine safety.

How to gather individual judgment of expert to form final opinion is both challenge and significance when apply AHP to the field of group decision-making. This paper use the method presented by Wu Yunyan, Hua Zhongsheng, Zha Yong(2003) for reference. The experts in the group decision are classified into several groups by clustering method and the weight of every expert is given. Based on the consistency among matrixes, the weight of every matrix is given too. Then combined with the two weights, final weight-value for every potential scheme can be gained accordingly.

DECISION-MAKING ANALYSIS IN COAL MINE SAFETY MANAGEMENT

Decision-making in the field of coal mine management aim to reduce or avoid the happening of mine disasters. And the coal mine accidents can be defined to crisis events which brought by natural disasters or anthropic factors. Fig1 describes the relation between potential threat and crisis in cheese systems or organizations. Every cheese presents some correlatively subsystem and department of whole system or organization. The cheese has some holes in it and the holes are easy to be attacked. If the potential threat hits some or all holes in these cheeses, situation will be worse and crisis will happen. Base on the cheese model, facing a threat is the task of whole coal mine system not only these subsystems and departments which are suffering from the attack. So the decision which aims to defend attacks and avoid the crisis should be made by a group of people coming from different subsystems and departments. It is a group decision-making problem.

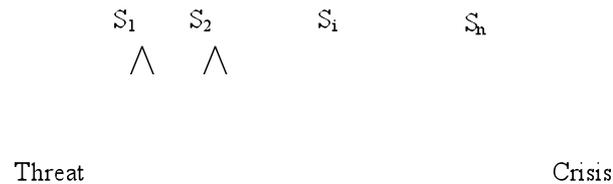


Figure 1. Relation between Threat and Crisis by Cheese System

Meanwhile, decision-making in coal mine safety management deal with abroad issue, which include: (1) macroscopical decision-making of safety management concerning the important problem about policy, guideline, programming, governance structure, inspecting system of coal mine management, etc; (2) decision-making with regard to the fields of coal mine enterprise that covers safety management in any phases of Planning, Organizing, Leading, Harmonizing and Controlling; (3) decision-making for the safety management of engineering project in coal mine, such as build or rebuild a mine; (4) the decision-making of preventing, response and dealing with a coal mine accident. These decisions are serious-minded and significantly meaningful since they cover many fields of coal mine system and refer to most members in coal mine organization. The strongpoint of group decision-making in acceptability and steady-quality is absolutely necessary herein.

Then, the issues in coal mine safe management are complex and most of them are non-structured or semi-structured. The making of these decisions will be a gradual procedure, which requires a lot of information and knowledge referring to the domains of economy, society, technology, etc. As we know, one person can not have so broad knowledge and experience, so the decision-making in the field should be carried by experts group who have necessary experience as well as knowledge. The making of these decisions should be a process of Group Decision-making.

In addition, the using of Group Decision-making strategy in coal mine safety management also have following advantages:(1)Compared with individual decisions, experts with different background can give birth to more idea and put forward more solutions. This supply more opportunity to acquire good measure to solve problem availably. (2)Group Decision-making has high quality and veracity in average. The selected solution from expert group integrates abundant intelligence and experience, and it is considered more comprehensively and adequately. This will improve the level of decision-making and avoid shriveling, losing good opportunity or deciding in a hurry. (3)Decisions made by group encourage decision-makers to have more responsibilities and confidence for the solution. This makes the decision more acceptable and will be helpful to its implement.

GROUP DECISION-MAKING METHOD OF COAL MINE SAFETY MANAGEMENT

Compared with Individual Decision-making, Group Decision-making still has its own shortcoming in despite of many advantage such as time-consuming, adventure, and easy to be influenced by social factors, etc. To lessen or avoid these disadvantages and improve its efficiency in the greatest extent, appropriate method of group decision-making should be advanced and applied to the field of coal mine safety management. A method according to general theory of decision-making herein is proposed to lessen or avoid inherent disadvantage of group decision-making mentioned above and ensure its validity. It can be described as: detects hidden dangers and troubles in coal mine production by opportunity-identification and problem-diagnosis firstly, then collect information widely and present potential schemes using the method of brains storm, and evaluate these schemes

based on AHP with clustering analysis. Further more, the implemental process and effect of selected scheme should be controlled and evaluated.

The Main Steps of AHP with Clustering

Suppose m experts evaluate n solutions. Describe experts group as $E = \{E_1, E_2, \dots, E_m\}$, describe solutions needed to evaluate as $S = \{S_1, S_2, \dots, S_n\}$. Suppose $A^k = (a_{ij}^{(k)})_{n \times n}$ is the evaluation judgment matrix of expert E_k , $k = 1, 2, \dots, m$, $i, j = 1, 2, \dots, n$. $W^{(k)} = (w_1^{(k)}, w_2^{(k)}, \dots, w_n^{(k)})^T$ are weight vectors from $A^{(k)}$, then:

$$w_i^{(k)} > 0, \sum_{i=1}^n w_i^{(k)} = 1 (i, j = 1, 2, \dots, n) \quad (1)$$

Matrix $B^{(k)} = (b_{ij}^{(k)})_{n \times n}$

$$b_{ij}^{(k)} = \frac{a_{ij}^{(k)}}{\sum_{i=1}^n a_{ij}^{(k)}}, i, j = 1, 2, \dots, n \quad (2)$$

Obviously, $b_j^{(k)} = (b_{1j}^{(k)}, b_{2j}^{(k)}, \dots, b_{nj}^{(k)})^T$ is a normalized vector of $a_j^{(k)} = (a_{1j}^{(k)}, a_{2j}^{(k)}, \dots, a_{nj}^{(k)})^T$, then:

$$\bar{b}^{(k)} = (\bar{b}_i^{(k)})_{n \times 1} = \frac{1}{n} \sum_{j=1}^n b_j^{(k)} \quad (3)$$

The method of system cluster is applied to classify experts. Distances between vectors are calculated by the following formula:

$$d_{ij} = \cos \theta_{ij} = \frac{\bar{b}^{(i)} \cdot \bar{b}^{(j)}}{|\bar{b}^{(i)}| \cdot |\bar{b}^{(j)}|} = \frac{\sum_{k=1}^n \bar{b}_k^{(i)} \bar{b}_k^{(j)}}{[(\sum_{k=1}^n (\bar{b}_k^{(i)})^2)(\sum_{k=1}^n (\bar{b}_k^{(j)})^2)]^{1/2}} \quad (4)$$

If the value of d_{ij} is larger, expert i and expert j will be more similar. When the degree of similarity reaches some value, the two experts can be classified into the same classification. According to this idea, cluster analysis about experts can be described as below:

Step 1: Suppose every expert is a classification at the beginning, i.e. $G_1 = \{E_1\}, G_2 = \{E_2\}, \dots, G_m = \{E_m\}$. There will be m classifications initially, at the same time, suppose $q = m$;

Step 2: Calculate d_{ij} according to formula (4);

Step 3: Select the maximum in d_{ij} as d_{xy} and combine the corresponding classifications G_x and G_y into a new classification $G_{q+1}, G_{q+1} = \{G_x, G_y\}$;

Step 4: If there is $q = 2(m-1)$, then turn to Step 7; or else, turn to Step 5;

Step 5: Add the new classification G_{q+1} in classification-set and get rid of G_x and G_y ;

Step 6: Calculate the new d_{ij} in new classification-set.

$$d_{i, Q+1} = \max\{d_{ix}, d_{iy}\}, i \neq x, y, i = 1, 2, \dots, m$$

At the same time, $q = q + 1$, then turn to Step 3 to continue to combine the rest classifications;

Step 7: Draw clustering hierarchical diagram and decide the count and contents of classifications according to the chart.

Calculation Weight-value of Experts

The m experts have been classified into l classifications ($l \leq m$). Experts in the same classification can be considered to have same weight-value since the classified standard is the similarity of experts. For different classifications, if a classification includes more experts, it will express more advices. So according to the

principle of larger count, the experts should have larger weight-value when he or she is in a classification including more experts.

Suppose the expert's count of the classification which contains expert k is ψ_k , and a_k is the weight-value of expert k. According to the above principle, a_k will be positive related with ψ_k , so

$$a_k = a \cdot \psi_k, k = 1, 2, \dots, m \tag{5}$$

Because $\sum_{k=1}^m a_k = 1$, there will be:

$$a_1 : a_2 : \dots : a_m = \psi_1 : \psi_2 : \dots : \psi_m \tag{6}$$

Solve equal group formed by formula (5) and (6), formula (7) can be got to define weight-value of expert k.

$$a_k = \frac{\psi_k}{\sum_{i=1}^m \psi_i} \tag{7}$$

Calculation of Credit Degree of Judgment Matrix

To get more reasonable judging result, consistency should be tested firstly. Generally, Consistent Ratio (CR) can be calculated to indicate the consistency of weight matrixes. If $CR < 0.1$, the consistency of weight matrix is in tolerance, otherwise it should be adjusted.

$$CR = \frac{CI}{RI} \tag{8}$$

Here, $CI = \frac{\lambda_{max} - n}{n - 1}$ and λ_{max} is the biggest value of weight matrix. Random Index (RI) can be found in Table 1.

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

Table 1. The Corresponding Relation between RI and n

Suppose $\bar{A}^{(k)}$ is consistent enough, and its weight-vector is $\bar{W}^{(k)} = (\bar{w}_1^{(k)}, \bar{w}_2^{(k)}, \dots, \bar{w}_n^{(k)})^T$.

Take t_{ij} as the consistent degree between $\bar{A}^{(i)}$ and $\bar{A}^{(j)}$.

$$t_{ij} = \cos \theta_{ij} = \frac{\bar{w}^{(i)} \cdot \bar{w}^{(j)}}{|\bar{w}^{(i)}| \cdot |\bar{w}^{(j)}|} \tag{9}$$

Take t_i as the average consistent degree of judgment matrix $\bar{A}^{(i)}$, and it can be calculated with formula (10).

$$t_i = \frac{1}{m-1} \cdot \sum_{\substack{j=1 \\ j \neq i}}^m a_j \cdot t_{ij} \tag{10}$$

Then normalize t_i to t_i^* , consistent degree of every judgment matrix can be indicated by β_i . And β_i can be defined to the credit degree of Judgment Matrix.

$$\beta_i = t_i^* = \frac{a_i \cdot t_i}{\sum_{j=1}^m a_j \cdot t_j} \tag{11}$$

Finally, according to the principle of keeping order, weight-plus average method is used to finish the combination of judgment matrix and the formula is as following:

$$\bar{w}_i = \prod_{k=1}^m [\bar{w}_i^{(k)}]^{1/m}, i = 1, 2, \dots, n \quad (12)$$

After normalization, w_i^* is weight-value of the solution i .

$$w_i^* = \frac{w_i}{\sum_{j=1}^n w_j} \quad (13)$$

AN EXAMPLE OF GROUP DECISION-MAKING IN COAL MINE SAFETY MANAGEMENT

A certain coal mine use the method proposed in this paper to make decision for its safety management. The process is as following.

The Problem for Decision-making

After identifying opportunities and diagnosing problem synthetically, the coal mine decide to make investments in the following five years to improve its safety level. It wants to determine its main aspects of investments this year.

The Group of Decision-makers

A local officer who is familiar with the situation of the coal mine and an expert with abundant experience in the field of coal mine safety management are invited to form an expert group combined with a governor and a technician of this coal mine.

Four Alternative Solutions

Experts synthetically analyze the relative information and propose four solutions by using the method of brainstorm, which are (1) invest in education and training and set up safety fund; (2) develop pre-warning information system of coal mine safety; (3) improve working conditions; (4) update production equipment and safety device.

Data Processing

Apply the method of AHP with clustering to evaluate above solutions. The following four matrixes are given to reflect t expert's opinions.

$$A^{(1)} = \begin{bmatrix} 1 & 2 & 3 & 3 \\ 1/2 & 1 & 2 & 2 \\ 1/3 & 1/2 & 1 & 1 \\ 1/3 & 1/2 & 2 & 1 \end{bmatrix}, A^{(2)} = \begin{bmatrix} 1 & 3 & 3 & 2 \\ 1/3 & 1 & 1 & 1/2 \\ 1/3 & 1 & 1 & 1/3 \\ 1/2 & 2 & 3 & 1 \end{bmatrix}$$

$$A^{(3)} = \begin{bmatrix} 1 & 2 & 2 & 1 \\ 1/2 & 1 & 2 & 2 \\ 1/2 & 1/2 & 1 & 1 \\ 1 & 1/2 & 1 & 1 \end{bmatrix}, A^{(4)} = \begin{bmatrix} 1 & 2 & 1/2 & 1/2 \\ 1/2 & 1 & 1/2 & 1/4 \\ 2 & 2 & 1 & 2 \\ 2 & 4 & 1/2 & 1 \end{bmatrix}$$

The consistent rates (CR) of the above four matrixes are all lower than 0.1, so they are in consistency and need not to be rebuilt.

$$CR_{(1)} = 0.0921, CR_{(2)} = 0.0172, CR_{(3)} = 0.0695, CR_{(4)} = 0.0695$$

Firstly, calculate the weight-value of experts.

Calculate $\bar{b}^{(k)}$ according to formula (2) and (3).

$$\bar{b}^{(1)} = (0.4413, 0.2541, 0.1367, 0.1679)^T, \bar{b}^{(2)} = (0.4467, 0.1380, 0.1272, 0.2881)^T$$

$$\bar{b}^{(3)} = (0.3417, 0.2875, 0.1646, 0.2062)^T, \bar{b}^{(4)} = (0.1843, 0.1172, 0.3798, 0.3187)^T$$

According to formula (4), the similarity-degree for each two experts is:

$$d_{12} = 0.9552, d_{13} = 0.9790, d_{14} = 0.7223, d_{23} = 0.9325, d_{24} = 0.7814, d_{34} = 0.8004$$

According to clustering principle based on max-distance, we can get clustering hierarchical diagram as Fig.2.

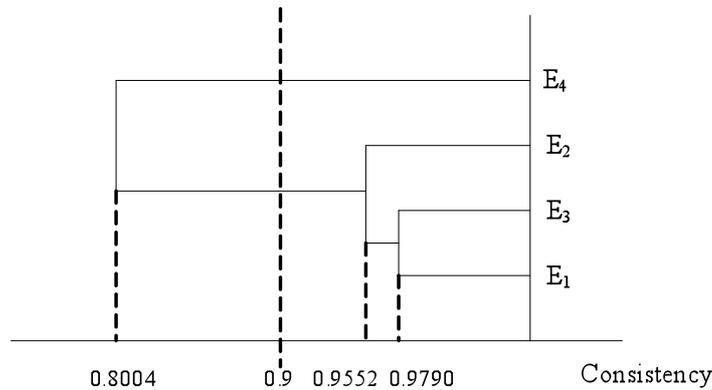


Figure 2. Clustering Hierarchical Diagram

According to above clustering hierarchical diagram, four experts can be classified into two classifications at point of 0.9, i.e. $G_1 = \{E_1, E_2, E_3\}, G_2 = \{E_4\}$. The weight-value (a_k) of four experts according to formula (7) are:

$$a_1 = a_2 = a_3 = \frac{3}{3 + 3 + 3 + 1} = 0.3, a_4 = \frac{1}{3 + 3 + 3 + 1} = 0.1$$

Then, calculate the credit degree of Judgment Matrix. There will be $A^{(k)} = \bar{A}^{(k)}$ and $W^{(k)} = \bar{W}^{(k)}$ since the matrix $A^{(k)}$ is consistency.

$$\begin{aligned} W^{(1)} = \bar{W}^{(1)} &= (0.4394, 0.2556, 0.1364, 0.1686)^T, W^{(2)} = \bar{W}^{(2)} = (0.4486, 0.1377, 0.1258, 0.2879)^T \\ W^{(3)} = \bar{W}^{(3)} &= (0.3462, 0.2855, 0.1635, 0.2048)^T, W^{(4)} = \bar{W}^{(4)} = (0.3462, 0.2855, 0.1635, 0.2048)^T \end{aligned}$$

According to formula (9) and formula (10), the average consistent degrees of judgment matrix $\bar{A}^{(i)}$ are:

$$t_1 = 0.2175, t_2 = 0.2147, t_3 = 0.2180, t_4 = 0.2281.$$

After normalization, we can get the credit degree of Judgment Matrix.

$$\beta_1 = t_1^* = 0.2995, \beta_2 = t_2^* = 0.2956, \beta_3 = t_3^* = 0.3002, \beta_4 = t_4^* = 0.1047$$

Finally, the four experts' comprehensive suggestion about the four solutions can be given according to formula (12) and formula (13).

$$w_1^* = 0.3917, w_2^* = 0.2111, w_3^* = 0.1636, w_4^* = 0.2335$$

Final Decision

From the above calculations, the first solution is the best one based on above calculate result, then the fourth one, the second one, and the third one.

Based on above selection, the coal mine decide to invite in training and education and set aside a sum of money to award people who contribute to improving the safety level of the coal mine.

CONCLUSIONS

The method of group decision-making proposed herein based on AHP with clustering proved to be an effective approach to make decisions in the field of coal mine safety management. The method with its inherent objectivity and applicability enable experts and officers to broadly take part in the process of decision-making. The using of brain-storm method makes information be shared among experts, and experts group can express their idea freely and to be understood favorably. The example using group decision-making method based on AHP with clustering advanced in this paper indicates that it is an efficient and satisfied approach of to avoid experimentalism and improve the veracity of decision-making of coal mine safety management in china.

Also, this paper studies the content of decision-making in the field of coal mine safety management. It makes people widely understand the decision-making in coal mine safety and contribute to the further research in this field. But, because of the complexity and variety of this field, the in-depth study is absolutely necessary to describe its content in detail.

The weight matrixes in the example were satisfied enough and they needn't be rebuilt. But there may be inconsistent weight matrixes in performing a decision-making with AHP method. How to adjust these matrixes is an open issue herein, and more study should be carried out in this area.

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