Paper No. 108

ISMS 2016

# Use of the Analytic Hierarchy Process in safety control of rescue equipment

Zhang Yinghua, Sun Qian, Huang Zhian*, Gao Yukun

State Key Laboratory of High-Efficient Mining and Safety of Metal Mines (University of Science and Technology Beijing), Ministry of Education, Beijing, China, 100083

ABSTRACT
Ground maneuver rescue equipment is complex, therefore, systematic analysis and risk assessment of the rescue equipment needs to be carried out. This evaluation method provides positive guidance and reference for the management and maintenance of the equipment system.
At present, many countries adopt the risk matrix method to assist in decision-making about the safety control of important systems. There is a relationship between the possibility and importance of the factors that influence the development of the transaction. The risk matrix method can be used to find this relationship and to stratify the data. It also has a good effect on systems in which objective judgment is weak. The present study refers to the mature evaluation system in the field of abroad car production, combines the actual rescue situation of Fengfeng District in Jizhong Energy Group, and aims to establish a subjective evaluation system with special characteristics for underground emergency refuge systems. This evaluation system uses the method of scoring combing weight combined with the analytic hierarchy process. It provides a scientific basis and effective reference for daily use and maintenance of the entire system.
KEYWORDS: analytic hierarchy process; ground maneuver rescue equipment system

## 1. INTRODUCTION

Ground maneuver rescue equipment which supports the emergency refuge system is complex. During routine maintenance and rescue drills, it requires not only that the relative rules must be executed in installation and operation, but also that the unit of high weights in the system are controlled (Gao and Mu, 2000).

At present, many developed countries use the risk-matrix method for decision-making on major affairs and safety control of important systems. When processing systems with large amounts of data, this method does not have high reliability and accuracy. When using the risk-matrix method, the consistency of the risk matrix should be tested (Sun and Liu, 1999). If it cannot pass the test, it should be checked and adjusted until it has passed the test. On one hand, this method is time-consuming and laborious; on the other hand, the consistency of the evaluation matrix is low, due to differences in experience and understanding of evaluation personnel (Hartman, 2002).

To solve these problems, this study refers to the mature evaluation system of the field of abroad car production, combines the actual rescue situation of Fengfeng District in Jizhong Energy Group, and attempts to establish a subjective evaluation system with consideration for the special characteristics of underground emergency refuge systems. This evaluation system uses the method of scoring combing weight combined with the analytic hierarchy process. Through the evaluation of personnel subjective scores on the factors that influence the criterion layer, the weight of the safety control index and the total score are concluded (Zhang, 2000). Lastly, the validity and necessity of AHP application will be proven through the computer consistency test and adjustment. This evaluation system assesses the safety status of maneuver rescue equipment systems objectively, and identifies risks and vulnerabilities. It can reduce the difference of consistency between the evaluation matrixes and thought of judges, propose the orientation of the safety control, and provide a scientific basis and effective reference for daily use and maintenance of the entire system. This method can evaluate the protection focus of maneuver rescue equipment systems effectively, and have a positive effect on safety management of the entire system.

## 2. ANALYTIC HIERARCHY PROCESS

The analytic hierarchy process divides all kinds of factors which affect the decision-making objectives into target layer, criterion layer, and scheme layer. Through the interaction between the levels, the weight of each factor to the target level can be determined qualitatively and quantitatively, in order to help the decision makers to make the appropriate decision (Chen and Crolla, 1996).

*Corresponding author – email : huang_za@qq.com

First, the AHP lists the factors that affect the target, and sets them into different levels according to the logic of the relationship between them. Second, it builds a hierarchical model according to the degree of membership between different levels. Then it determines the ranking from the bottom layer combing the subjective judgment and the mathematical method of the evaluation personnel. Finally, according to the calculated weight factor, it determines the impact of the target level and can assist decision makers to judge the planning (Jing et al., 2006).

After the establishment of the matrix, it should be judged by a consistency test to determine whether it is reasonable or not. If it passes the verification, the evaluation system meets the requirements. If it did not pass the verification, the judgment factor should be checked and adjusted, so that it can be in accordance with the logical relationship of the mathematical judgment. After the consistency test of the criteria layer, the consistency between the levels of the hierarchical model is tested (Guo et al., 2008a).

## 3. ESTABLISHMENT OF FUZZY EVALUATION INDEX SYSTEM FOR RESCUE EQUIPMENT SYSTEMS

### *3.1 Hierarchical structure model*

The influence factors on the safety and stability of the ground maneuver rescue equipment system are many, so it is necessary to take comprehensive consideration, combine the evaluation of individual performance index, and make a reasonable summary before establishing the AHP hierarchy model (Guo et al., 2008b). Referring to the mature evaluation system in the field of abroad car production (Xu et al., 2009), and combining the actual rescue situation of Fengfeng District in Jizhong Energy Group, a hierarchical structure model was established, as shown in Figure 1.

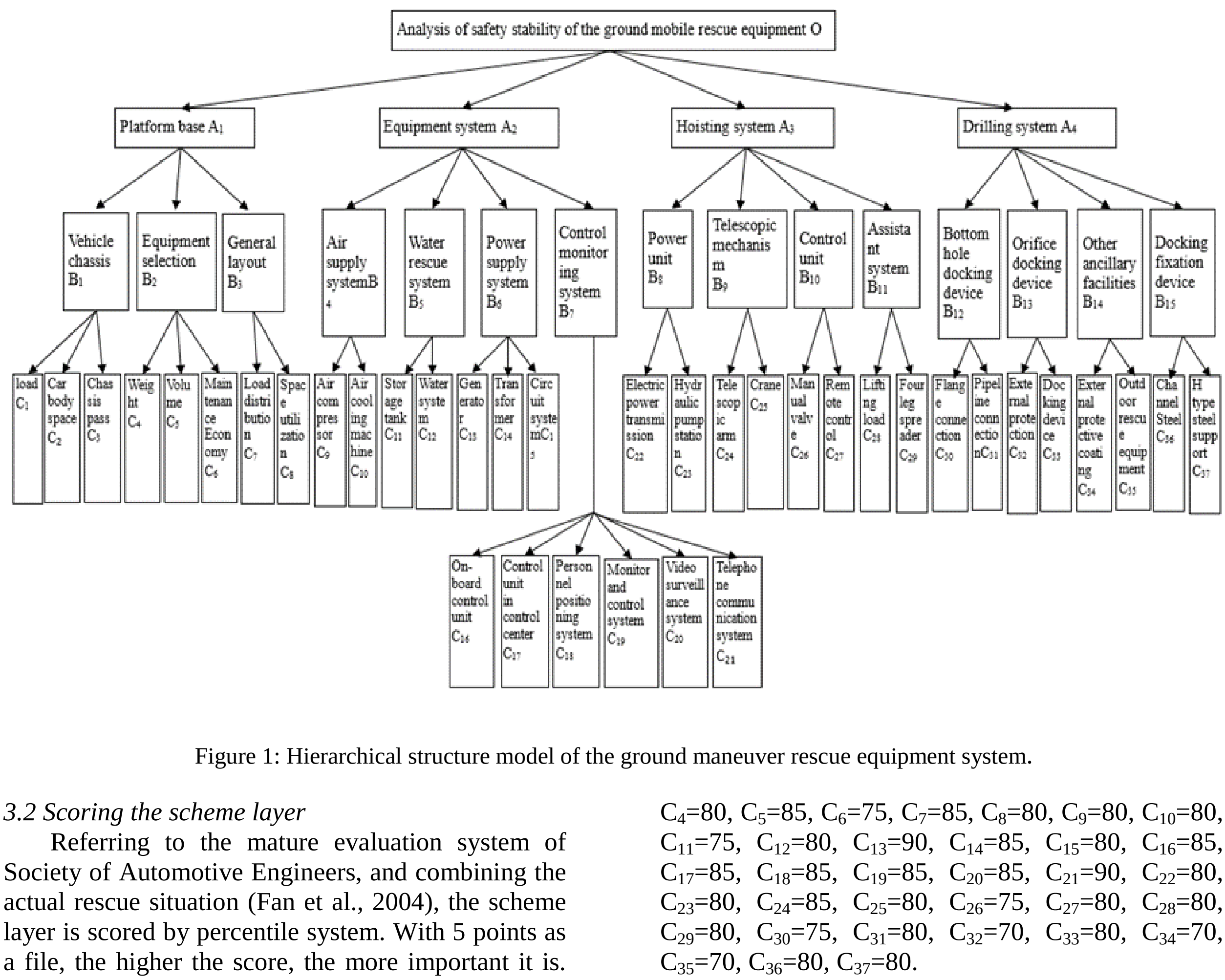


Figure 1: Hierarchical structure model of the ground maneuver rescue equipment system.

### *3.2 Scoring the scheme layer*

Referring to the mature evaluation system of Society of Automotive Engineers, and combining the actual rescue situation (Fan et al., 2004), the scheme layer is scored by percentile system. With 5 points as a file, the higher the score, the more important it is. Specific scoring is as follows: $C_1$=70, $C_2$=75, $C_3$=75, $C_4$=80, $C_5$=85, $C_6$=75, $C_7$=85, $C_8$=80, $C_9$=80, $C_{10}$=80, $C_{11}$=75, $C_{12}$=80, $C_{13}$=90, $C_{14}$=85, $C_{15}$=80, $C_{16}$=85, $C_{17}$=85, $C_{18}$=85, $C_{19}$=85, $C_{20}$=85, $C_{21}$=90, $C_{22}$=80, $C_{23}$=80, $C_{24}$=85, $C_{25}$=80, $C_{26}$=75, $C_{27}$=80, $C_{28}$=80, $C_{29}$=80, $C_{30}$=75, $C_{31}$=80, $C_{32}$=70, $C_{33}$=80, $C_{34}$=70, $C_{35}$=70, $C_{36}$=80, $C_{37}$=80.

### *3.3 Establishing judgment matrix*

According to the above data, five evaluation personnel establish the pairwise comparison matrix, the comparison matrix values are as follows.

Safety stability:

$A_1/A_2=1/4$, $A_1/A_3=1/3$, $A_1/A_4=2$, $A_2/A_3=1$, $A_2/A_4=3$, $A_3/A_4=3$;

Platform base:

$B_2/B_3=1/2$, $B_2/B_1=1/2$, $B_3/B_1=2$;

Equipment system:

$B_5/B_6=1/4$, $B_5/B_4=1/3$, $B_5/B_7=2$, $B_6/B_4=1$, $B_6/B_7=3$, $B_4/B_7=3$;

Hoisting system:

$B_{10}/B_{11}=3$, $B_{10}/B_9=1/2$, $B_{10}/B_8=1/2$, $B_{11}/B_9=1/3$, $B_{11}/B_8=1/3$, $B_9/B_8=3$;

Drilling system:

$B_{13}/B_{12}=2$, $B_{13}/B_{15}=3$, $B_{13}/B_{14}=4$, $B_{12}/B_{15}=3$, $B_{12}/B_{14}=2$, $B_{15}/B_{14}=2$;

Vehicle chassis: $C_1/C_2=1/2$, $C_2/C_3=3$;

Equipment selection:

$C_4/C_6=2$, $C_4/C_5=1$, $C_6/C_5=1/2$;

Air supply system: $C_9/C_{10}=3$;

Water rescue system: $C_{11}/C_{12}=1/2$;

Power supply system:

$C_{14}/C_{13}=1$, $C_{14}/C_{15}=1/2$, $C_{13}/C_{15}=1/2$;

Control monitoring system:

$C_{19}/C_{18}=1$, $C_{19}/C_{20}=1/2$, $C_{19}/C_{17}=2$, $C_{19}/C_{16}=2$, $C_{19}/C_{21}=1/2$, $C_{18}/C_{20}=1/2$, $C_{18}/C_{17}=1/2$, $C_{18}/C_{16}=1/2$, $C_{18}/C_{21}=1/2$, $C_{20}/C_{17}=1$, $C_{20}/C_{16}=1/2$, $C_{20}/C_{21}=1/3$, $C_{17}/C_{16}=1/2$, $C_{17}/C_{21}=1/2$, $C_{16}/C_{21}=1/2$;

Power unit: $C_{22}/C_{23}=1$;

Telescopic mechanism: $C_{25}/C_{24}=1/3$;

Control unit: $C_{27}/C_{26}=1$;

Assistant system: $C_{29}/C_{28}=2$;

Bottom hole docking device:

$C_{31}/C_{30}=2$;

Orifice docking device: $C_{32}/C_{33}=1/2$;

Other ancillary facilities: $C_{34}/C_{35}=2$;

Docking fixation device: $C_{37}/C_{36}=2$.

## 4. SYSTEM APPLICATION BASED ON THE ANALYTIC HIERARCHY PROCESS

First, the hierarchical structure is drawn as shown in Figure 1.

Secondly, the judgment matrix of all levels should be assigned with values, and the consistency should be tested to ensure that the calculated value of the judgment matrix is less than 0.1. The consistency of the combination weight vector is also tested to ensure the level of comparative judgment.. When the judgment matrix is not consistent, it is reasonable to carry out inspection and make adjustments.

Software can sort the weight of the scheme layer and other layers quickly and facilitate the follow-up studies. The weight value of each factor is as follows:

$C_1=0.0101$, $C_2=0.0232$, $C_3=0.0088$, $C_4=0.0106$, $C_5=0.0106$, $C_6=0.0053$, $C_7=0.0501$, $C_8=0.0167$, $C_9=0.0549$, $C_{10}=0.0198$, $C_{11}=0.0169$, $C_{12}=0.0337$, $C_{13}=0.0111$, $C_{14}=0.0111$, $C_{15}=0.0223$, $C_{16}=0.0387$, $C_{17}=0.0274$, $C_{18}=0.0217$, $C_{19}=0.0345$, $C_{20}=0.0322$, $C_{21}=0.0657$, $C_{22}=0.0473$, $C_{23}=0.0473$, $C_{24}=0.1228$, $C_{25}=0.0409$, $C_{26}=0.0370$, $C_{27}=0.0370$, $C_{28}=0.0116$, $C_{29}=0.0232$, $C_{30}=0.0096$, $C_{31}=0.0192$, $C_{32}=0.0161$, $C_{33}=0.0322$, $C_{34}=0.0073$, $C_{35}=0.0036$, $C_{36}=0.0100$, $C_{37}=0.0050$.

## 5. ANALYZING RESULTS OF THE ANALYTIC HIERARCHY PROCESS

### *5.1 Analyzing the scheme layer*

By comparing the above results, it can be found that the weight value has the following rules:

$C_{24}>C_{21}>C_9>C_7>C_{22}>C_{23}>C_{25}>C_{16}>C_{26}>C_{27}>C_{19}>C_{12}>C_{20}>C_{33}>C_{17}>C_2>C_{29}>C_{15}>C_{18}>C_{10}>C_{31}>C_{11}>C_8>C_{32}>C_{28}>C_{13}>C_{14}>C_4>C_5>C_1>C_{36}>C_{30}>C_3>C_{34}$.

It can be concluded that the telescopic arm, telephone communication system, air compressor, load distribution, and power transmission have more influence on security and stability of the system. Therefore, they should be a main focus of the design, use, and maintenance process. When analyzing the factors with higher weights, it can be found that these factors will directly affect the security and stability of the whole system.

### *5.2 Analyzing the criterion layer*

The score of each criterion layer can be calculated by combining with the index weight coefficient of the target layer and the subjective evaluation of each criterion. For example, factors of the criterion layer related to platform base $A_1$ are load $C_1$, car body space $C_2$, chassis pass $C_3$, weight $C_4$, volume $C_5$, maintenance economy $C_6$, load distribution $C_7$, space utilization $C_8$. The weight coefficient of each index is 0.0101, 0.0232, 0.0088, 0.0106, 0.0106, 0.0053, 0.0501, 0.0167. Then the score of platform based $A_1$ is: $0.0101 \times 70 + 0.0232 \times 75 + 0.0088 \times 75 + 0.0106 \times 80 + 0.0106 \times 85 + 0.0053 \times 75 + 0.0501 \times 85 + 0.0167 \times 80 = 10.848$.

In the same way, the total score of other indicators can be calculated, as shown in Table 1.

Table 1: The score of criterion layer.

| criterion layer | score |
|---|---|
| Platform base $A_1$ | 10.848 |
| Equipment system $A_2$ | 33.072 |
| Hoisting system $A_3$ | 29,797 |
| Drilling system $A_4$ | 7.922 |

From Table 1, it can be seen that the equipment system A2 and the hoisting system A3 are more important for the safety and stability of the whole system. The influence factors are two times more than the influence of the platform base A1 and drilling system A4.

The score of equipment system A2 is slightly higher than the score of hoisting system A3. It is necessary to strengthen the daily safety management and control of the equipment system and hoisting system. Although the score of platform base A1 and drilling system A4 is not high, the key factors affecting the system also need to strengthen their safety management and control.

## 6. CONCLUSIONS

At present, there is no specific evaluation system for ground maneuver rescue equipment. Referring to the mature evaluation system of the field of abroad car production combined with the actual rescue situation of Fengfeng District in Jizhong Energy Group, this study established a subjective evaluation system with consideration for the special characteristics of underground emergency refuge systems.

In order to minimize the subjective uncertainty, this evaluation used the method of scoring combing weight combined with analytic hierarchy process. Through the evaluation of personnel subjective score on the factors that influence the criterion layer, the weight of the safety control index and the total score were found.

The validity and necessity of AHP application will be proven through a consistency test of computer and adjustment. This evaluation system objectively assesses the safety status of maneuver rescue equipment systems and identifies risks and vulnerabilities. It can reduce inconsistencies between the evaluation matrixes and thought of judges.

Through comprehensive consideration of the results of the evaluation test results and the weight coefficient of the ground mobile rescue equipment system, this study proposes the orientation of the safety control, and provides a scientific basis and effective reference for daily use and maintenance of the entire system.

## 7. ACKNOWLEDGEMENT

It is with great pleasure that we acknowledge the generous financial support of National Natural Science Foundation of China (project number: 51474017) and Natural Science Foundation of Xinjiang Uygur Autonomous Region of China (2014211B013).

## 8. REFERENCES

Chen, D.C. and Crolla D A.A. (1996) Comprehensive study of subjective and objective vehicle handling behavior. Vehicle System Dynamics. Volume 25, No. 1, pp. 66-68.

Fan, X.Y., Qiao, J.P. and Chen, Y.B. (2004) Application of analytic hierarchy process in assessment of typical landslide danger degree. Journal of Natural Disasters. Volume 13, No. 1, pp. 72-76.

Gao, Y. and Mu, D.Y. (2000) AHP method in assessment of airline safety. China Safety Science Journal. Volume 10, No. 3, pp. 38-41.

Guo, J.Y., Zhang, Z.B. and Sun, Q.Y. (2008) Study and applications of analytic hierarchy process. China Safety Science Journal. Volume 18, No. 5, pp. 147-153.

Guo, J.Y., Zhang, Z.B., Sun, Q.Y. (2008) Applications of AHP method in safety science. Journal of Safety Science and Technology. Volume 4, No. 15, pp. 69-73.

Hartman D. (2002) Application of the analytic hierarchy process to select characterization and risk-based decision-making and management methods for hazardous waste sites. Environmental Engineering and Policy. Volume 3, No. 1-2, pp. 1-7.

Jing, Q.Z., Jiang, X.H., Yang, J.S. and Zhou, Y.F. (2006) Study on index system of capability of production safety in coal mine based on AHP. China Safety Science Journal. Volume 16, No. 9, pp. 74-79.

Sun, R.S. and Liu, H.H. (1999) Assessment theory and practice for airline safety. China Safety Science Journal. Volume 9, No. 3, pp. 69-74.

Xu, Y., Zhou, Y., Sun, X. and Yu, Y. (2009) Synthesized assessment method for coal mine safety based on fuzzy analytic hierarchy process. China Safety Science Journal. Volume 19, No. 5, pp. 147-152.

Zhang, J.J. (2000) Fuzzy analytical hierarchy process. Fuzzy System and Mathematics. Volume 14, No. 2, pp. 80-88.