Research on Operation Reliability for Refuge Capsule Oxygen Supply System Based on HEART

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Abstract. This paper applies the HEART to decompose the task classification and error producing condition of refuge capsule oxygen supply system, which can improve the applicability of the method in manual control system operation in the field of reliability analysis. It cannot only be used in quantitative analysis of probability of human error and human operating reliability in refuge capsule oxygen supply system operation, but also be used in finding error producing conditions which influences human operating reliability. The results provide theoretical basis for refuge capsule management unit of formulate management measures and training program.

1. Introduction
Refuge capsule is an important part of coal mine emergency system, playing a significant role in coal mine safety production and avoid dangerous. As one of the main function systems, oxygen supply system's reliability mainly composed of equipment reliability and operational reliability, in which equipment reliability has been greatly improved with the improving of the technical level, however human reliability problems are more prominent. Therefore, it is necessary to analysis and assessment the refuge capsule oxygen supply system's operating reliability.

At present, technique for human error rate prediction (THERP) and cognitive reliability and error analysis method (CREAM) are commonly used in human reliability analysis in domestic and foreign. Gao Yang studied human error probability on flight conflict deployment by controllers in human error assessment and reduction technique (HEART), and discovered the relationship between error-producing conditions (EPC) and human error probability. But its analysis did not further deduce human reliability factors. HEART method can identify the type of tasks and error-induced conditions by analyzing the influence of human-machine tasks and environment to operator's experience, and further assess human error probability, analysis operational reliability. The result can provide decisions for refuge capsule unit to formulate related management system and training program.

2. HEART method fundamentals
HEART method was first proposed in 1986 by the Williams, J. C. the core idea is to analysis EPC, and reduce HEP levels and improve human reliability levels by develop limit EPC measures. The method mainly consists of task classification, EPC and calculation method.

2.1. Task classification
HEART method makes all the tasks inductive into nine kinds of common task types, then give nominal human error probability (NHEP) for each task type, meanwhile all tasks are math to the nine mission
2.2. Error-producing conditions
EPC is defined as environmental and ergonomics factors to adjust the human error probability (HEP) in HEART method, such as experience, time pressure and external conditions. In addition, HEART method also gives the weights $\omega$ for each EPC, to reflect the greatest impact of each EPC.

2.3. Calculation method
The calculation basis of HEART method is to determine the influence value of EPC based on the difference of the influence value of different EPC on human error, and to determine the error probability by using the influence value of different EPC and the product of NHEP.

3. HEART Modeling
HEART modeling process can be summarized into four steps, specific modeling process is as follows:

- It determines the actual impact values of EPC. For a specific task, each EPC is different in the degree of influence, it is difficult to get actual impact value of EPA by statistical analysis, therefore, this paper uses expert scoring method to determine it.
- It can adjust the weight value of EPC. To calculate simpler, weight value of EPC are normalized in this paper, all weight value are mapped to $[1\sim 100]$, and EPC weight value $\omega_{EPC_i}$ are adjusted by formula (1).

$$\omega_{EPC_i} = \left( \frac{100 \cdot \omega_{EPC_i} - \omega_{EPC_i,min}}{\omega_{EPC_i,max} - \omega_{EPC_i,min}} - 1 \right) \cdot AIV_{EPC_i} + 1$$

Wherein: $\omega_{EPC_i}$ is the i-th EPC weight value given by experts; $\omega_{EPC_i,min}$ is the i-th EPC minimum weights; $\omega_{EPC_i,max}$ is the i-th EPC maximum weights; $AIV_{EPC_i}$ is the actual impact values of the i-th EPC.
- The calculation of Human errors probability (HEP) can be calculate by formula (2).

$$HEP = NHEP \cdot \prod_{i} \omega_{EPC_i}$$

- The calculation of Human operating realibility (RM). RM can be calculate by formula (3)

$$R_M = 1 - HEP = 1 - NHEP \cdot \prod_{i} \omega_{EPC_i}$$

4. Analysis process
Rescue capsule Oxygen system is made up of air (pressure wind and oxygen bottles), air filter device, air flow pressure sensor, flow accumulation device and the decompression device, its structure diagram shown in Figure 1.
4.1. Refuge capsule oxygen system operation tasks classification

According to refuge capsule oxygen system operating procedures, the operational tasks (Figure 2) can be divided into: open air switch; open air filtration devices; observe whether the air current pressure sensor data is normal; open the cylinder switch and open wind control.

Figure 2 rescue capsule Oxygen System Operation Task Model

Manual control system nominal operating task's NHEP is determined in HEART method, as shown in table 1. In addition, refuge capsule oxygen supply system's operating task steps corresponding task classification, as shown in table 2.

Table 1 Manual control system nominal operating task's NHEP

| Task classification                                      | NHEP    |
|----------------------------------------------------------|---------|
| (A) Select from only the reference numerals similar operator | 0.003   |
| (B) Select from the functional classification of the operator | 0.001   |
| (C) Operating table operator selection                   | 0.0006  |
| (D) The correct direction of rotation                    | 0.0006  |
| (E) Rotating in the wrong direction                      | 0.05    |
| (F) Rotating in the wrong direction under high stress    | 0.01    |
Table 2 Oxygen supply system's operating task steps corresponding task classification

| Serial number | Task Steps                                           | Task classification |
|---------------|------------------------------------------------------|---------------------|
| 1             | a. open air switch                                   | D                   |
| 2             | b. open air filtration devices                        | A                   |
| 3             | c. observe whether the air current pressure sensor data is normal | B                   |
| 4             | d. open wind control                                 | D                   |
| 5             | e. open the cylinder switch                          | C                   |

4.2. Oxygen supply system's operating EPC

Refuge chamber oxygen supply system's EPC is analyzed from the human-machine environment and cognition In this paper. To determine the actual impact value (AIV) of EPC, 10 experts are invited to score each EPC between 0 to 10 at first, and higher scores indicates the greater degree of influence. Then the means of each EPC influence level determined by the impact values experts identified, finally, the impact values of EPC are normalized, all impact values are mapped to [0~1], so the AIV is getting. The results are shown in Table 3.

Table 3 Refuge capsule oxygen system EPC analysis table

| Task Steps                                           | EPC                        | AIV | Weights $\omega'$ |
|------------------------------------------------------|----------------------------|-----|-------------------|
| Harsh environment underground                        | 0.40                       | 3.43|                   |
| Operator tense                                       | 0.26                       | 1.45|                   |
| Pressure wind switch is damaged                      | 0.34                       | 1.67|                   |
| Operator tense                                       | 0.31                       | 1.08|                   |
| Air filtering device damaged                         | 0.69                       | 5.50|                   |
| Operator is not familiar with sensor                 | 0.76                       | 9.87|                   |
| Sensor is unreliable                                 | 0.24                       | 1.32|                   |
| Operator is tense                                    | 0.50                       | 4.35|                   |
| Cylinder switch is damaged                           | 0.50                       | 4.35|                   |
| Operator is not familiar with flow meter             | 0.16                       | 1.01|                   |
| Flow meter is damage                                 | 0.84                       | 11.21|                  |

4.3. Refuge capsule oxygen supply system's HEP

As shown in Tables 1 and 2, open air switch tasks classified as D, which corresponds to a value of 0.0006 NHEP, combined with the data in Table 3, using the formula (2) calculate the open air switch probability of human errors:

$$HEP = NHEP \times \prod_{j} \omega'_{\text{EPC}_j} = 0.0006 \times 3.43 \times 1.45 \times 1.67$$

$$= 0.0050$$

HEP of other operational tasks steps are shown in table 4.

4.4. Human operating reliability

According to human error probability data corresponded to each task step of refuge capsule oxygen supply system, combining formula (3), determine the human operating reliability as shown in table 4.
| Serial number | Task steps | HEP   | human operating reliability |
|--------------|------------|-------|-----------------------------|
| 1            | a          | 0.0050| 0.9950                      |
| 2            | b          | 0.0178| 0.9822                      |
| 3            | c          | 0.0130| 0.9870                      |
| 4            | d          | 0.0114| 0.9886                      |
| 5            | e          | 0.0068| 0.9932                      |

4.5. Analysis and Discussion

By the analysis of HEP and human operating for each task step of refuge capsule oxygen system, EPC, AIV and its weight is the 3 factors that affect human operating reliability, in which AIV plays a crucial role. When AIV is similar, human operating reliability mainly affected by the number of EPC. Equipment unreliable and damaged can be solution by choose a higher reliability equipment and strengthen maintenance, and facts comes to operator tense or not familiar with the system, usually we need to strengthen education and training and psychological counseling ways to solve them.

5. Conclusion

The HEART method applied by this article is used to analysis operational tasks, error-producing conditions of refuge capsule oxygen supply system, quantitative calculate HEP and human operating reliability of refuge capsule oxygen supply system. The results showed that: HEART reliability analysis method has good adaptability in the rescue cabin oxygen system, the resulting EPC and its impact can be as a basis for refuge cabin management unit develop management measures and training programs.

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