FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 2, N° 4, 2004, pp. 259 - 265

FORMING OF RELIABILITY MODEL IN ORDER TO EVALUATE THE OPERATOR'S ACTIVITY RISK

UDC 62.51

Suzana Savić, Ljubiša Vučković

Faculty of Occupational Safety, University of Niš

Abstract. *In this paper the expert ranking method has been applied in the process of forming the operator's reliability model in the control centres of the coal mines in Serbia. The expert group determined the important reliability/risk factors and estimated their influence on the operator's reliability. The ranking process and determination of concordance coefficient has confirmed the uniformity of expert group opinions. Weight coefficients of reliability factors have been determined using the iterative procedure, which includes different competencies of experts. On the basis of these results the reliability model of operator-dispatcher has been defined.*

Key Words: *Expert Method, Reliability/risk Factors, Operator's Reliability Model*

INTRODUCTION

Reliability and effects of potential errors are the basis for the risk evaluation of operator's activity. Therefore, forming of operator's reliability model is the very first step in operator's activity risk evaluation. This model is formed in this paper on the basis of expert ranking method.

Expert judgement method is applied when it is impossible to realize assessment of elements or their characteristics by objective measurement as well as when the bulk of the starting data is insufficient for statistical processing [3].

Analysts organize the expertise process, starting with the aim and the task of research and ending with the interpretation and presentation of results.

The expert group consists of competent persons-specialists for the given area of research.

The flow of information from experts to analysts is organized in three stages. The information obtained is processed in order to check the agreement of the experts' opinion and form the group opinion.

Received May 15, 2003

FORMING OF OPERATOR'S RELIABILITY MODEL

Very often the operator's reliability model can be assumed in the form of a linear additive function of reliability factors [5]:

$$P = \sum_{i=1}^{n} \gamma_i F_i \tag{1}$$

where F_i is normalized value of the i-th reliability factor, γ_i is weighted coefficient reflecting the influence of the i- th reliability factor on the operator's reliability and fulfilling the condition $\sum_{i=1}^{n} \gamma_i = 1$, n is number of reliability factors. Most frequently, reliability factors and their weight coefficients are determined using the expert judgement method.

The first part of expert judgement method includes the first two of the above-mentioned stages. The first stage results in the list of reliability factors. The second stage results in the list of factors which influence the operator's reliability most.

In the second part of expert judgement method weight coefficients are determined. Experts assess the influence of reliability factors using the marks from 1 to 10. The value of the mark corresponds to the level of factor influence.

The resulting matrix of expert judgement has the following form:

$$A = \| f_{ij} \|_{n,m} \tag{2}$$

where f_{ij} is the mark of the i-th reliability factor given by the j-th expert (m is a total number of experts).

Expertise analyst rank reliability factors according to matrix A. The ranking result represents the basis for checking the agreement of the experts' opinion.

Concordance coefficient is the measure of the experts' opinion agreement [4]. In the case of strict ranking (each factor has a different rank) the concordance coefficient is:

$$w = \frac{S}{S_m} \tag{3}$$

$$S = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} r_{ij} - \frac{m(n+1)}{2} \right)^2 \tag{4}$$

$$S_m = \frac{1}{12} m^2 n (n^2 - 1) \tag{5}$$

where w is the concordance coefficient, r_{ij} is the rank of the i-th reliability factor allotted by the j-th expert.

In the case of free ranking the concordance coefficient is:

$$w = \frac{S}{S'_m} \tag{6}$$

$$S'_m = \frac{1}{12} m^2 n (n^2 - 1) - \frac{1}{12} (2m - p) \sum_{j=1}^{m} S_j \tag{7}$$

$$S_j = \sum_{i=1}^{R_i} (r_k^3 - r_k) \tag{8}$$

where p is the number of experts whose ranking contain the identical ranks, R_j is the number of groups with the identical ranks given by the j-th expert, r_k is the number of the identical ranks in the k-th group given by the j-th expert.

Experts' agreement is satisfactory if $w > 0.5$. The significance of concordance coefficient can be determined by using χ^2 criterion. The number of degrees of freedom can be determined as:

$$\nu = m - 1 \tag{9}$$

and for strict ranking the value of χ^2 is calculated:

$$\chi^2 = m(m-1)w \tag{10}$$

In the case of free ranking χ^2 is:

$$\chi^2 = \frac{12S}{mn(n+1) - \frac{1}{n-1}\sum_{j=1}^{m} S_j} \tag{11}$$

For the above calculated ν and significance α, the value of χ_t^2 is read form the table. If

$$\chi^2 > \chi_t^2 \tag{12}$$

the significance of concordat coefficient exists on α level.

If the agreement of the experts' opinions is satisfactory, group opinion is established. If not, either the analysis of the reasons for the disagreement is carried out and the experts' opinions reconciled (if possible) or the whole procedure is repeated.

Indices of the experts' group opinion are:

– mean value of the mark of individual reliability factors;

– weight coefficients of individual reliability factors.

The assumption that goes with the iteration is that all experts are equally competent ($k_j^{(1)} = 1,\ j = 1,\dots,m$) and that the indices of the group experts' opinion are determined as follows:

$$M^{(1)} = \frac{1}{m} AE_1 = \| M_1^{(1)}\ M_2^{(1)} \dots M_n^{(1)} \|^T \tag{13}$$

$$\gamma^{(1)} = \frac{1}{\sum_{i=1}^{n} M_i^{(1)}} M^{(1)} = \| \gamma_1^{(1)}\ \gamma_2^{(1)} \dots \gamma_n^{(1)} \|^T \tag{14}$$

where $E_1 = \| 11 \dots 1 \|_{n\times 1}^T$

If we assume different expert competencies (which is more realistic) we define measure of deviation of individual marks of reliability factors from the mean mark value of these factors:

$$\delta_{ij}^{(2)} = | M_i^{(1)} - f_{ij} | \tag{15}$$

On condition that: $\sum_{j=1}^{m} k_j^{(2)} = m$ [1] competence coefficients of experts are calculated for each reliability factor as well as the resulting competence coefficients of the experts:

$$k_{ij}^{(2)} = \frac{m}{\delta_{ij}^{(2)} \sum_{j=1}^{m} \frac{1}{\delta_{ij}^{(2)}}} \tag{16}$$

$$K^{(2)} = \| k_{ij}^{(2)} \| \tag{17}$$

$$k^{(2)} = \frac{1}{n} E' K^{(2)} = \| k_1^{(2)} k_2^{(2)} ... k_m^{(2)} \| \tag{18}$$

where $E' = \| 1 1 ... 1 \|_{n \times 1}$

The matrix is formed:

$$B^{(2)} = \| k_{ij}^{(2)} f_{ij} \|_{n \times m} \tag{19}$$

and indices of group opinion are determined:

$$M^{(2)} = \frac{1}{m} B^{(2)} E_1 = \| M_1^{(2)} \; M_2^{(2)} ... M_n^{(2)} \|^T \tag{20}$$

$$\gamma^{(2)} = \frac{1}{\sum_{i=1}^{n} M_i^{(2)}} M^{(2)} = \| \gamma_1^{(2)} \; \gamma_2^{(2)} ... \gamma_n^{(2)} \|^T \tag{21}$$

The iterative procedure is terminated when the following condition is fulfilled:

$$| \gamma_i^{(l)} - \gamma_i^{(l-1)} | \le \varphi_i \tag{22}$$

where φ_i is assigned value $\left(\frac{0.01}{n} \le \varphi_i \le \frac{0.1}{n} \right)$.

The result of this procedure is the matrix of weight coefficients of reliability factors:

$$\gamma^{(l)} = \| \gamma_1^{(l)} \; \gamma_2^{(l)} ... \gamma_n^{(l)} \|^T \tag{23}$$

After we have determined reliability factors and their weight coefficients, we form reliability model (1).

RELIABILITY MODEL OF OPERATOR-DISPATCHER IN CONTROL CENTERS IN THE COAL MINES

In order to form reliability model of the operator-dispatcher in the control centers in the coal mines in Serbia, seven experts estimated reliability factors.

The first stage results in the list of reliability factors:
- psycho-physiological characteristics (sensitivity, adaptability and selectivity of senses, as well as the characteristics of operation movements);
- education, motivation, training;
- functional state of the operator (monotony, fatigue and stress);
- ergo technical characteristics of the control panel:
  - elements, colour, shape, dimensions of the control panel;
  - functionality, layout, grouping and assigning of indicators and operator's executive means;
- manner of information presentation:
  - clarity (lighting, contrast, light/dark characters, flicker);
  - legibility (size, shape and separation/spacing (of/between) the characters, resolution, colour, blinking, cursors);
  - coding (colour coding, alphanumeric codes, code group);
  - picture presentation (tables, diagrams, histograms);
- microclimate;
- lighting;
- work organization (working hours, breaks, shift work).

The second stage results in the list of factors, which influence the operator-dispatchers' reliability most:
1. Manner of information coding;
2. Education/training;
3. Functionality of operator's executive means;
4. Shape and dimensions of control panels.

In the third stage the expert judgement of influence of these factors is carried out. The results of the judgement are shown in Table 1. The marks in the Table 1 correspond to the elements of the matrix (2).

Table 1. Expert marks of reliability factors

Reliability factors	Experts						
	1	2	3	4	5	6	7
1	8	10	8	9	8	10	10
2	10	9	8	10	8	9	8
3	8	8	10	8	10	5	8
4	7	7	6	6	6	6	6

The result of the reliability factors ranking (on the basis of Table 1) is shown in Table 2.

Table 2. Reliability factors ranking

Reliability factors	Experts						
	1	2	3	4	5	6	7
1	2.5	1	2.5	2	2.5	1	1
2	1	2	2.5	1	2.5	2	2.5
3	2.5	3	1	3	1	4	2.5
4	4	4	4	4	4	3	4

On the basis of the equation (6-8) and Table 2 the concordance coefficient of free ranking is determined:

$$S = 157.75; \quad S_m^{'} = 225; \quad w = 0.7$$

The significance of this coefficient is determined on the basis of the equations (9-12):

$$\chi^2 = 14.34; \qquad \chi_t^2 = 12.592; \text{ (For } \nu = 6 \text{ and } \alpha = 0.05\text{)}$$

The agreement of experts' individual opinions enables the forming of the group opinion (13 and 14):

$$M^{(1)} = \| 9 \quad 8.86 \quad 8.14 \quad 6.28 \|^T$$

$$\gamma^{(1)} = \| 0.279 \quad 0.274 \quad 0.252 \quad 0.195 \|^T$$

The competence coefficients of experts for each reliability factor are calculated (16) and matrices (17, 18 and 19) are formed:

$$K^{(2)} = \begin{Vmatrix} 1.16 & 1.16 & 1.16 & - & 1.16 & 1.16 & 1.16 \\ 0.31 & 2.56 & 0.42 & 0.31 & 0.42 & 2.56 & 0.42 \\ 1.67 & 1.67 & 0.12 & 1.67 & 0.12 & 0.07 & 1.67 \\ 0.47 & 0.47 & 1.21 & 1.21 & 1.21 & 1.21 & 1.21 \end{Vmatrix}$$

$$k^{(2)} = \| 0.90 \quad 1.46 \quad 0.73 \quad 1.06 \quad 0.73 \quad 1.23 \quad 1.12 \|$$

$$B^{(2)} = \begin{Vmatrix} 9.28 & 11.60 & 9.28 & - & 9.28 & 11.60 & 11.60 \\ 3.10 & 23.04 & 3.36 & 3.10 & 3.36 & 23.04 & 3.36 \\ 13.36 & 13.36 & 1.20 & 13.36 & 1.20 & 0.56 & 13.36 \\ 3.29 & 3.29 & 8.47 & 8.47 & 8.47 & 8.47 & 8.47 \end{Vmatrix}$$

From the matrix of competence coefficients it can be seen that the most competent expert is the second expert and the least competents are the third and the fifth experts.

The indices of the expert's group opinion in the second iteration are (20 and 21):

$$M^{(2)} = \| 8.95 \quad 8.91 \quad 8.06 \quad 6.99 \|^T$$

$$\gamma^{(2)} = \| 0.272 \quad 0.271 \quad 0.245 \quad 0.212 \|^T$$

For the chosen values $\varphi_i = 0.025$ and the calculated values $\gamma_i^{(1)}$ and $\gamma_i^{(2)}$, the following calculation can be made:

$$| \gamma_i^{(2)} - \gamma_i^{(1)} | < 0.025 \text{ for all } i.$$

This points to the termination of the iterative procedure. The operator-dispatcher's reliability model is:

$$P = 0.272F_1 + 0.271F_2 + 0.245F_3 + 0.212F_4$$

CONCLUSION

Reliability model which has been formed in this paper can be used for the assessment of operator-dispatcher's reliability in control centers for normal regime of operation of the coal mines. This model is also applicable if deviations are not followed by large quantity of information and high speed of the change of information. The linear model of operator's reliability is not applicable on accidental situations. In this case it is necessary to form nonlinear model of operator's reliability, by the method of regressive analysis [2].

REFERENCES

1. Savić, S.: Analysis of Control Errors and their Influence on Man-Machine System Reliability, Doctorate dissertation, Faculty of Occupational Safety, Nis, 1992.
2. Savić, S., Grozdanović,M.: Formation of Operator's Reliability Model in Yugoslav Railway Control and Management Centers, Proceedings of the Second International Conference ERGON-AXIA 2000, Control Institute for Labour Protection, Warsaw, 2000, pp 215-218.
3. Savić, S., Grozdanović, M.: Operator's Reliability Assessment Using Expert Method of Paired Comparison, Proceedings of the Seventh International Conference on Human Aspects of Advanced Manufacturing: Agility &Hybrid Automation, IEA Press, Krakow, 2000.
4. Savić, S., Grozdanović, M., Application of Expert Ranking Method in the Process of Forming Operator's Reliability Model, Proceedings of the 5th International Conference on Reliability, Maintainability & Safety, ICRMS 2001, China instrument and control society, Dalai, 2001.
5. Vujošević, M.: Operativni menadžment -kvantitativne metode, Društvo operacionih istraživača Jugoslavije, Beograd, 1997.

FORMIRANJE MODELA POUZDANOSTI U CILJU PROCENE RIZIKA OPERATORSKE DELATNOSTI

Suzana Savić, Ljubiša Vučković

U radu je prikazan ekspertni metod rangiranja i njegova primena za formiranje modela pouzdanosti operatora-dispečera u centrima upravljanja u rudnicima uglja. Ekspertna grupa je definisala bitne faktore pouzdanosti, odnosno rizika, i ocenila njihov uticaj na pouzdanost operatora. Postupkom rangiranja i određivanjem koeficijenta konkordacije potvrđena je saglasnost mišljenja eksperata. Iteracionim postupkom koji uključuje različitu kompetentnost eksperata, određeni su težinski koeficijenti faktora pouzdanosti. Na osnovu toga formiran je model pouzdanosti operatora-dispečera.

Ključne reči: *ekspertni metod, faktori pouzdanosti/rizika, model pouzdanosti operatora*