Development and Application of a Human Reliability Assessment Model for Mine Dispatchers in a Romanian Hard Coal Basin

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Abstract: Employees in hazardous industries, such as mining industry, are constantly faced with judging amounts of risk and behaving in accordance with these judged amounts. The importance of human reliability assessment in system safety is considered in this paper. The factors influencing the reliability of the operator's activity are particularly analyzed and their quantification is carried out. The method of experts' reasoning is applied in order to bring together the influences of certain reliability factors. The model developed in the paper is based on expert reasoning method applied in cases where it is not possible to assess risk factors and their characteristics by objective measurements or when initial data are insufficient for statistical processing. The model was applied in a case study conducted for the dispatchers from the coal mines in a Romanian hard coal basin.

Key-Words: risk, human reliability assessment, expert reasoning, coal mine dispatcher

1 Introduction

The unsatisfactory reliability of nearly all-artificial systems in use by man through out history represents one of the main problems of mankind. This is caused not so much by the low reliability and short lifetime of artificial systems themselves, but very often is due to various errors by human operators who deal with such systems. Naturally, the losses caused by artificial system operation faults are proportional to their power, significance and value. In the case of many modern mining and transportation systems (planes, fast trains, large ships, trucks), large power plants, important financial systems, security and defense systems, and also important medical care systems, the losses caused by their malfunction could be extreme high or also of catastrophic character [6].

Therefore, besides the continuing interest in diminishing the probability of technical failures in any artificial system as much as possible (with respect to economically acceptable expenses), considerable interest has also been shown in recent years in the reliability of system operator activity. Many statistics demonstrate that the amount of human error represents a still larger proportion of all the expenses, which are required for the compensation of artificial system malfunctions.

The requirements on a human operator of a working system can be concentrated in the following main categories:

- requirements on attention level and continuity,
- requirements on the speed of operator reaction,

- requirements on the correctness of operator decisions.

Within all three above-mentioned categories of the reliability of human operator - technical system interaction a correlation naturally exists. A straightforward correlation exists between attention level and speed of reaction. Operators functioning at a high level of attention usually also possess very fast reactions. On the other hand cases can appear, when fast, almost impulsive reaction may not be accompanied by very high level of the operator's concentration and attention. Some people can react fast also when their attention is shared by very different objects (they have very fast reflexes) [9].

In addition, a high level of attention in the majority of cases leads to a very high probability of correct decisions and vice versa - if somebody is not concentrating enough, there is a rather low probability that his/her decision will be correct. On the other hand, in the case of very fast reactions accompanied by a very low level of a human operator's attention, the probability of an incorrect decision can increase significantly. This is typical for a so-called surprise reaction, from which a transition to a panic reaction can sometimes be observed.

The main reason for this unfavorable situation can be seen in increasing requirements on an operator's ability, his/her level of continuous and long-time attention, the speed of his/her reactions and monotonous scenes or view which operator must watch.

A drop in the attention level of a particular human operator can be caused by various external or internal reasons; some of them have a general character; the intensity of others depends significantly on the operator's individuality. Among the general conditions causing the decrease in attention are [12]:

- extreme length of a particular operator's service without breaks,
- operator's physical and mental exhaustion,
- monotonous scene which the operator has to observe for a long time,
- extreme temperature in which the operator has to serve (too high or too low),
- extreme humidity in which the operator has to serve (too high or too low),
- extreme air pressure,
- air smell, dust density etc.

Matters leading the operator to concentrate on problems other than his/her main service can likewise cause attention to drop. All these circumstances in combination with a monotonous character of the operator's service, the scenes that are observed by him/her and his/her possible personal indisposition could lead to a micro-sleep.

The assessment of human reliability [2, 8], involves an adequate knowledge of specific probability values which are defining the potential errors for each operation [3, 10]; this, in turn, involves the need of a significant amount of data gathering and interpretation, in order to compute the reliability indexes, by means of statistic data processing [1]. By reason of difficulties connected with data acquisition, the analytical approaches based on probability theory and statistics are, more and more, replaced through other modern approaches [17]. The issue of initial data relevance for human reliability assessment can be solved using the quantitative evaluation on intervals. This procedure, even if does not lead to precise index values, allows to establish a possible interval of values and the interval size depends on the previously imposed level for assessment validation and on the shape of the statistic function imposed for evaluation distribution. The evaluation intervals are expressed as fuzzy-values and fuzzy numbers, so that both probability and fuzzy-sets theories can be employed in the human reliability assessment field [4, 7]. The resort to fuzzy-sets theory is not limited to the thinking process modeling; it can be expanded to other relevant human psycho-physiologic characteristics (learning, working task, global vision, perceived stress, etc.) [5].

2 Approaches for human reliability quantification

In this paragraph we concentrate on methods for assessing the human risk. Many risk analysis methods, especially for semi- or fully automated manufacture lines only consider potential failures caused by machines. Potential failures caused by the line workers are not looked at. As we saw before, making errors is part of the human nature. Humans are indispensable for making machines work, but they are also the weakest link in the work process. We think human factors should be analyzed more carefully in risk assessment processes.

An easy way to assess the human risks of a process is to perform the work situation. For example, the quality of new machines designs - in different areas like medical devices, transportation or manufacturing line - should be estimated regarding consequences of human misuse.

In order to address human factors in workplace safety settings, peoples' capabilities and limitations must first be understood. The modern working environment is very different to the settings that humans have evolved to deal with. The human characteristics that can lead to difficulties interacting with the working environment are including [11]:

- attention - the modern workplace can "overload" human attention with enormous amounts of information, far in excess of that encountered in the natural world. The way in which we learn information can help reduce demands on our attention, but can sometimes create further problems Perception - in order to interact safely with the world, we must correctly perceive it and the dangers it holds. Work environments often challenge human perception systems and information can be misinterpreted.
- memory - our capacity for remembering things and the methods we impose upon ourselves to access information often put undue pressure on us. Increasing knowledge about a subject or process allows us to retain more information relating to it.
- logical reasoning - failures in reasoning and decision making can have severe implications for complex systems such as chemical plants, and for tasks like maintenance and planning.

In human reliability quantification analytical, expert and fuzzy approaches are applied. Analytical approach for reliability quantification is based on the creation of the mathematical dependence $P = f(P_{ik})$, $i = 1,...,m$ (m is the number of operation types), $k = 1,...,l$ (l is the number of elementary probabilities necessary for the reliability assessment of a particular operation type performance). It is assumed that all P_{ik} probabilities are known. Therefore, for human reliability assessment familiarity with quantitative values of all probabilities characterizing possible errors in all operation types is necessary [16].

This points out the need for acquiring a large number of relevant data concerning human errors for the purpose of calculating valid quantification of reliability indices by statistical data processing. It is difficult to acquire the necessary amount of relevant data for the assessment of particular reliability indices due to the following facts:

- lack of awareness about the usefulness of recording and collecting data;
- confidentiality, i.e. readiness not to publish data;
- various causes and mechanisms of an error;
- data outdating with respect to permanent innovation technology and the demands of working place;
- inappropriate generalization of experimental data;
- long time needed for collecting necessary data (which might cause data outdating even in the course of collecting).

As a result of the above mentioned difficulties analytical approach based on the theory of probability and mathematical statistics gradually yields to more modern approaches.

The problem of the initial data relevance for human reliability assessment can be resolved by interval quantitative assessment. This procedure does not yield obtaining the accurate index value, but an interval of possible values the size of which depends on the required assessment validity and on a form of the statistical function of assessments distribution. Interval assessments are expressed by fuzzy-values and fuzzy-numbers so that the theory of possibility and the theory of fuzzy-sets are introduced to the field of human reliability assessment.

The necessity of their application is confirmed by objective complexity of human activities in modern production systems and by the peculiarity of information received by man (which primarily refers to the operator's activity). This is essentially caused by the existence of uncertainties based on the use of information models relatively reflecting reality, on the existence of a large amount of incorrect information as well as on the peculiarity of human reception, processing and interpretation of information. The elements of human thinking are not numbers but objects characterized by continual transition from one class to another. The uncertainty of thinking and the ability to use approximate notions point to the fact that the basis of human intellectual activity is not two-valued or multy-valued logic, but the logic with fuzzy-authenticity, fuzzy-relations and fuzzy-conclusion rules. This explains why to opt for, from the set of pieces of available information, exactly that related to the task being accomplished, interpreted and corresponding by assessed. The application of fuzzy-set theory is not limited only to the process of the modeling of thinking, but is also encountered in other psycho-physiological human properties (learning, sight, strain, load). The approach of expert judgment is applied in cases were the assessment of objects or their characteristics is impossible to be carried out by objective measuring. It is also used in case the amount of initial data is insufficient for statistical processing expert assessment is adopted. It is assumed that the accurate value of unknown quantitative characteristic in this case the corresponding event probability) is within the limits of expert judgment. The unknown quantitative characteristic is considered as an accidental value, the law of distribution which is determined by experts' individual opinions.

The approach of expert judgment is particularly applied to human reliability assessment [6]. The reason is the existing uncertainty peculiar to human behavior, which causes the impossibility of exact quantification of particular parameters (primarily psycho-physiological and professional characteristics) necessary for reliability assessment. The expert method of paired comparison is applied to the operator’s reliability assessment. Application of the method demands classification and quantification of operator’s reliability factors.

Consequently, it is assumed that the precise probability value is comprised within the limits imposed by experts’ reasoning. The unknown quantitative parameter is considered as an accidental value and the considered parameters’ distribution law is determined by means of expert reasoning. This approach can be considered as appropriate for human reliability assessment, if we take into account the particular character of uncertainty of human behavior, which does not allow an accurate specific parameter quantification, mostly in the case of psycho-physiological and occupational characteristics [13].

3 Factors affecting the operator’s reliability

The operator's reliability is influenced by a great many factors. Therefore, it is expressed by a large number of indices. Up to now, there have been no attempts to unify those indices in one unique reliability assessment. This paper gives such an approach by quantification and an assessment of particular factor groups, taking into account the weight of those factors. The reliability factors of a human operator may be divided into the following groups: psycho-psychological characteristics, functional condition, the factors of material environment, working place factors and the complexity of tasks [15].

3.1 Psycho-physiological characteristics

The index of psycho-psychological characteristics of the operator is the velocity of action. The velocity of action, provided that the operator immediately begins to act, is characterized by the time required to fulfill the following task. The velocity of action is often calculated as the sum of typical time periods for particular phases in information processing (reception, analysis, and solution choice). Each particular time period is calculated taking into account that quantity corresponds to the quantity of information processed in particular phases.

Unless the operator acts immediately upon receiving the signal, the sequence of signals is formed and the velocity of action is characterized by the time required for service. The action velocity that the operator should achieve depends on the duration of control cycle.

3.2 Functional condition

In the aspect of working activities and the quality of performed work, functional condition is considered as a sum of features of those functions and qualities which directly or indirectly influences fulfilling the required tasks at reception, processing and transmitting information. Functional condition is described by the functional condition coefficient. This coefficient denotes how much less work an operator can perform in a particular functional condition compared to the quantity of work that the same person may perform under optimal functional condition concerning the targeted activity. The dependence of k_{fc} on time and the calculation formulas my be found in the literature. The values of the coefficient range from 1 to 5. This fact is used for quantification of influences that physiological condition have on reliability of the operator. The values of coefficient are assigned to the particular functional conditions as follows: stable functional condition - 1, monotony - (1-2], fatigue - (2-3], overload - (4-5].

3.3 Factors of material environment

There are five levels of material environment factors. The first level determines optimal values of the operator's work. These values denote the level which does not require strain on the physiological systems of the operator under unlimited exposure. The second level represents the exploitation standards. These values require a certain strain on the physiological systems under limited exposure of the operator. The third level represents bound conditions. Those values are allowed for short exposition to certain influences, provided that performed work type allows temporary weakening of working capabilities. The fourth level defines bound tolerable values. Under these conditions the operator possesses the minimum of working capabilities, but his life is not jeopardized. The fifth level implies exceeding of the bound tolerable values.

3.4 Working place factors

Working place assessment is based on static and dynamic assessment. Static assessment includes the suitability of working place to the operator's anthropological and psycho-physiological characteristics. Dynamic assessment is based on working place dynamics, i.e. the complexity of the operator's task. As the complexity of the operator's task is of exceptional importance for the operator's reliability it will be considered separately.The following working place features should suit the human antropometrical and psycho-physiological requirements [14] dimensions of operator's panel; areas of position layout and control devices; areal position layout of indicators and control devices inside an area; dimensions of indicators; light and technical features of indicators. The fulfillment of the above conditions is assessed ranging from 0 to 5. In the working place assessment, the following principles should be respected: principle of suitability to human psycho-physiological characteristics (human activities at signal processing and control should be maximally respected); principle of optimal information coding (information should be coded in such a way that its processing requires minimal strain of the operator); principle of unique operators activity (constructive solution allowing inappropriate effect or requiring long time for appropriate effect choice, should be avoided).

4 Human error analysis and reduction

Human reliability assessment resulted, primary, from the necessity to reduce the risk of high-technology production systems (nuclear and chemical plants). However, it also contributes to productivity improvement. There is a large number of methods based on expert judgment for the assessment of the operator's activity reliability. The method of expert reasoning is applied in order to form a complex index of the operator's reliability in this paper. This method yields the following: the operator's reliability assessment in given conditions, monitoring changes in the operator's reliability due to working conditions (task complexity, working place characteristics, material environment factors), defining the level of the operator's suitability for the actual tasks and the operator's unreliability assessment, i.e. his hazardous behavior.

A second additional analysis of the results will be possible only with quantification methods which use a structured performance shaping factor (PSF) approach (e.g., SLIM, IDA, HEART, THERP, TESEO). With these approaches it is possible to determine the contributions of individual PSFs to human error goals. For example, the most significant PSF in a particular scenario may be "quality of procedures" and, therefore, error reduction measures aimed at improving the quality of procedures will be most effective at reducing error likelihood. Furthermore, if for example quality of procedures is the most important PSF for a number of human errors, this then suggests that a single global error reduction strategy generally to enhance performance can be specified. This type of investigation of the results will enable the cost effectiveness of potential error reduction strategies to be assed.

Another method for human error analysis is embedded within the systematic Human Error Reduction and Prediction Approach (SHERPA). This human error analysis method consists of a computerized question – answer routine which identifies likely errors for each step in the task analysis. The error models indentified are based on the "skill rule and knowledge" model, and Generic Error Modeling System.

There are five types of human-system interaction which the analyst should consider with respect to an incident scenario:

- maintenance / testing errors affecting safety system availability (latent errors),
- operator errors initiating the incident,
- recovery actions by which operators can terminate the incident,
- errors (e.g., misdiagnosis) by which operators can prolong or even aggravate the incident, and
- actions by which operators can restore initially unavailable equipment and systems.

Consideration of these types of interaction, and discussions with the system risk analyst at the problem definition stage will enhance the smooth integration of the human reliability analysis into the system risk analysis. Once human error probabilities have been quantified, the system risk, can be calculated and compared to an acceptable level to see if improvement is necessary. If human error cannot be reduced to an acceptable level, even with additional hardware recommendations, then significant redesign of the system and/or its operation will be required. Usually however, an effective combination of human and hardware modifications can be found to achieve an acceptable level of risk.

In the case of specific identified critical errors there are several ways of reducing their impact on the system [9]:

- prevention by hardware or software changes: use of interlock devices to prevent error; automate the task etc.
- increase system tolerance: make the system hardware and software more flexible or self-correcting to allow a greater variability in operator inputs which will achieve the intended goal.
- enhance error recovery: enhance detection and correction of errors by means of increased feedback, checking procedures, supervision and automatic monitoring of performance.
- reduction at source: reduction of errors by improved procedures, training, and interface or equipment design.

5 Human Operator Reliability Model Development

The reliability and the effects of potential errors are the basis for the risk assessment of coal mine operator-dispatcher's activity. Therefore, the development of the operator's reliability model is a basic step in operator's activity risk assessment. This model is developed on the basis of expert reasoning and ranking method. The expert reasoning method is applied when it is not possible 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. Analysts are organizing 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. Very often the operator's reliability model can be assumed in the form of a linear additive function of reliability factors [15]:

$$P = \sum_{i=1}^{n} \gamma_i \cdot F_i \qquad (1)$$

where:

F_i is normalized value of the i-th reliability factor;

γi - the 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 - the number of reliability factors.

Most frequently, the reliability factors and their weight coefficients are determined using the expert reasoning method. 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 mostly. In the second part of expert reasoning method, the weight coefficients are determined. Experts are assessing the influence of reliability factors using marks from 1 to 10. The value of the mark corresponds to the level of factor influence. Based on the experts' opinions, the resulting matrix has the following form:

$$A = \left\| f_{ij} \right\|_{n,m} \qquad (2)$$

where:

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

Further, the analyst ranks the reliability factors according to matrix A. The ranking result represents the basis for checking the agreement of the experts' opinion. The concordance coefficient „w" is the measure of the experts' opinion agreement. In the case of strict ranking (each factor has a different rank) the concordance coefficient is:

$$w = \frac{S}{S_m} \qquad (3)$$

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

$$S_m = \frac{1}{12} \cdot m^2 \cdot n \cdot \left(n^2 - 1\right) \qquad (5)$$

where:

w is the concordance coefficient;

r_{ij} - the rank of the i-th reliability factor allotted by the j-th expert.

In the free ranking case, the concordance coefficient is given by:

$$w = \frac{S}{S'_m} \quad (6)$$

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

$$S_j = \sum_{i=1}^{R_j} \left(r_k^3 - r_k\right) \quad (8)$$

where:

p is the number of experts whose ranking contain the identical ranks;

R_j - the number of groups with the identical ranks given by the j-th expert;

r_k - the number of the identical ranks in the k-th group given by the j-th expert.

Experts' agreement is considered satisfactory if w>0.5. The significance of the concordance coefficient can be determined by using the χ2 criterion. The number of freedom degrees can be determined as:

$$\nu = m - 1 \quad (9)$$

The χ^2 criterion is expressed by:

- the strict ranking case:

$$\chi^2 = m(m-1) \cdot w \quad (10)$$

- the free ranking case:

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

For the previously calculated ν and the significance α, the value χ_t^2 is directly read form tables.

If

$$\chi^2 > \chi_t^2 \quad (12)$$

then, the significance of concordance coefficient exists on α level.

If the agreement of the experts' opinions is satisfactory, the 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. The indices of the experts' group opinion are:

- the mean value of the mark of individual reliability factors;
- the weighted coefficients of individual reliability factors.

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

$$M^{(1)} = \frac{1}{m} \cdot A \cdot E_1 = \left\| M_1^{(1)} M_2^{(1)} \ldots M_n^{(1)} \right\|^T \quad (13)$$

$$\gamma^{(1)} = \frac{1}{\sum_{i=1}^{n} M_i^{(1)}} \cdot M^{(1)} = \left\| \gamma_1^{(1)} \gamma_2^{(1)} \ldots \gamma_n^{(1)} \right\|^T \quad (14)$$

where:

$E_1 = \left\| 1\ 1\ \ldots\ 1 \right\|_{n\times 1}^T$

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

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

On condition that: $\sum_{j=1}^{m} k_j^{(2)} = m$, the experts' competence coefficients $k_{ij}^{(2)}$ for each factor can be determined, as well as the resulting competence coefficients of the experts.

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

$$K^{(2)} = \left\| k_{ij}^{(2)} \right\| \quad (17)$$

$$k^{(2)} = \frac{1}{n} \cdot E' \cdot K^{(2)} = \left\| k_1^{(2)} k_2^{(2)} \ldots k_m^{(2)} \right\| \quad (18)$$

where:

$E' = \left\| 1\ 1\ \ldots\ 1 \right\|_{n\times 1}$

The $B^{(2)}$ matrix is formed:

$$B^{(2)} = \left\| k_{ij}^{(2)} \cdot f_{ij} \right\|_{n\times m} \quad (19)$$

and indices of group opinion are determined, based on the relationships below:

$$M^{(2)} = \frac{1}{m} \cdot B^{(2)} \cdot E_1 = \left\| M_1^{(2)} M_2^{(2)} \ldots M_n^{(2)} \right\|^T \quad (20)$$

$$\gamma^{(2)} = \frac{1}{\sum_{i=1}^{n} M_i^{(2)}} \cdot M^{(1)} = \left\| \gamma_1^{(2)} \gamma_2^{(2)} \ldots \gamma_n^{(2)} \right\|^T \quad (21)$$

When the following condition is fulfilled, the iterative procedure comes to end:

$$\left| \gamma_i^{(l)} - \gamma_i^{(l-1)} \right| \le \varphi_i \quad (22)$$

where for φ_i is assigned a value comprized in the interval $\left(\frac{0.01}{n} \le \varphi_i \le \frac{0.1}{n} \right)$.

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

$$\gamma^{(l)} = \left\| \gamma_1^{(l)} \gamma_2^{(l)} \ldots \gamma_n^{(l)} \right\|^T \quad (23)$$

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

6 Human Reliability Assessment Model's Application for Dispatchers in Valea Jiului Collieries

In order to establish the reliability model of the dispatcher in the control centers in the collieries in Valea Jiului coal basin, seven experts (former and present mine safety officers, mine managers, mine research institute members of staff) have estimated the reliability factors. After the first stage, the following influence factors of the dispatcher's reliability were identified and classified:

- 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, color, 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, color, blinking, cursors); coding (color coding, alphanumeric codes, code group); picture presentation (tables, diagrams, histograms);
- microclimate;
- lighting;
- work organization (working hours, breaks, shift work).

The second stage resulted in the list of factors, which influence the dispatchers' reliability most:

- F_1: Manner of information coding;
- F_2: Education/training;
- F_3: Functionality of operator's executive means;
- F_4: Shape and dimensions of control panels.

In the third stage the expert reasoning on the influence of each factor is carried out. The results of the judgement are shown in Table 1. The marks comprised in the Table 1 correspond to the elements of the matrix (2).

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

Table 1. Marks assigned by experts for the reliability factors

Reliability factors	Expert						
	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

Table 2. The reliability factors ranking

Reliability factors	Expert						
	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 equations (6-8) and Table 2 the concordance coefficient of free ranking is determined:

$$S = 157.75; \quad S'_m = 225; \quad w = 0.7$$

It can be seen that w > 0,5, so the concordance of experts' opinions is considered satisfactory. Furthermore, the significance of this coefficient is determined on the basis of the equations (9-12):

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

While $\chi^2 > \chi_t^2$, it comes that the concordance coefficient is relevant. So, the agreement of experts' individual opinions enables the forming of the group opinion, using equations 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 were calculated with eq. (16) and matrices (17, 18 and 19) were formed (not given in this paper). The indices of the expert's group opinion in the second iteration are (eq. 20 and eq. 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 value φ = 0.025 and the calculated values $\gamma_i^{(1)}$ and $\gamma_i^{(2)}$ the fulfillment of the following condition: $\left|\gamma_i^{(2)} - \gamma_i^{(1)}\right| < 0.025$, is valid for any value of „i".

Consequently the iterative procedure comes to end and the equation describing the coal mine dispatcher human reliability model can be written, as it follows:

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

7 Conclusion

At present there exists a general agreement on the limitation of understanding accidents from a merely technical - or human error perspective. The interaction between technical and social aspects within an organization has been given growing attention in efforts to build up a deeper understanding of the causes of accidents. During the past decade such discourses of effective accident prevention have shed a growing emphasis on Safety Management. Safety management is, however, a broad concept, embedding different understandings of prevention strategies.

Clearly, no single individual or managerial group is able to encompass all knowledge on risks, nor to foresee all possible events, which may lead to an accident. Acknowledging this, it is recommended to develop a reporting system on errors, freed of barriers to openness, such as blame and sanctioning. We have found it promising to take the existing safety cultures - and the rationales behind - seriously. And from there, take a learning approach to prevention and culture change.

When the relationship between man and his working environment is studied, one should mention that, regardless of the fact that the implementation of automation has the function of supporting the human operator, it also has a negative influence on the operative activities.

This is conditioned by the greater demands of intellectual nature (observation, attention, awareness, memory, opinion, learning) in accordance with the sensory and mobility abilities of the human operator (sight, hearing, movements of the extremities, etc.), his biological mechanisms of the reciprocal connection (watchfulness, sleepiness, monotony), preventive protection from the homeostatic disorders in human organism (stress, strain, fatigue) and the level of accordance of the signaling and commanding devices with the operators. Because of these demands, the operator has to have high qualifications in organizing and managing informational-managerial systems in automated production, he has to be in optimal psycho-physical condition and endurance, he has to have neural-psychical and intellectual effectiveness, psychosomatic and emotional stability and professional motivation for such a responsible and intellectually hard work.

Researches have shown that in the great number of cases, automated systems prevent the operators from getting complete situation awareness, i.e. from understanding the situation fully and foreseeing future actions. That is why we should pay special attention to the design and implementation of these systems.

Human reliability assessment resulted, primary, from the necessity to reduce the risk of high-technology production systems (nuclear and chemical plants). However, it also contributes to a significant productivity improvement. The human factors and the management of human knowledge are playing an increasingly relevant role in every aspect of the day-to-day risk management processes, because the massive introduction of automation and computational tools requires a human contribution, to productive processes based almost exclusively on knowledge. The human reliability model developed in the paper can be used for the assessment of dispatcher's reliability in control centers from collieries in Valea Jiului coal basin for normal operation regime of the coal mines. If deviations related to transient phenomena are not followed by large quantity of information and high speed of the change of information, the model can also be useful. The linear model of operator's reliability is not applicable on accidental situations. In this case it is necessary further work, aimed at developing a nonlinear model of operator's reliability, by the method of regressive analysis.

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