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OPERATOR'S RELIABILITY ASSESSMENT USING EXPERT METHOD OF PAIRED COMPARISON

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Abstract. *The importance of human reliability assessment in production systems is considered in this paper. The approaches for human reliability quantification are also given 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 paired comparison is applied in order to bring together the influences of certain reliability factors. Thus, a complex reliability index is created on the basic of which it is possible to assess the operator's activity reliability.*

1. INTRODUCTION

The attitude that a reliable technical system is the basic of production system reliability has resulted in highly-reliable technical systems and technology. Nevertheless, even highly reliable technical systems and technological processes are subject to failures the initial cause of which does not lie in them. If the causes resulting from the impact of the environment on the considered system are left out, the most frequent factor of the system unreliability is human errors, incorrectly or untimely performed tasks, i.e. unperformed tasks. According to so far performed researches [3], man is the immediate cause of 20% − 90% of all system failures (60% − 70% in land transport, ≅ 75% in air transport, ≅ 70% in industry, in the army from 74% during the period of peace up to 90% during war). This fact has led to a sharp increase of interest in studying human reliability for the purpose of eliminating, i.e. reducing human errors in production systems.

The actualization of system safety and risk problem has extremely intensified the study of human reliability in the sense of creating a uniform methodology for its quantification. The problem of system safety is outstandingly current now a days due to great power capacities of production systems and to the application of now (still insufficiently examined) technologies and materials.

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According to the data [1,3,6], 50% of the most serious accidents in industry and transportation have taken place over the last 20 years of this century and 33% of them happened during the 1980 s. Only a few of them are the following: Sevezo (Italy), Bazel (Switzerland), Three Mile Island (USNRC), Bhopal (India), Chernobyl (Ukraine).

The two greatest world catastrophes (Bhopal - 1984, Chernobyl - 1986) were proved to have been caused not only organization and management, as well as by inadequate safety measures [3,5]. To the immediate consequences reflected in a large number of human victims also enormous material losses due to system ravage, unforeseeable and immeasurable genetically and ecological consequences should be added.

All the above mentioned facts point out the necessity of human reliability assessment as an integral part of system risk assessment. This assessment should include not only operators (immediate executors of particular tasks) but also people involved in system global organization and management.

2. Approaches for Human Reliability Quantification

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. There fore , for human reliability assessment familiarity with quantitative values of all probabilities characterizing possible errors in all operation types is necessary. 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:

– latch 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 human-ability 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. The reason is the existing uncertainty peculiar to human behavior, which causes the impossibility of exact quantification of particular parameters (primarily psicho-phusiological and professional characteristics) necessary for reliability assessment. The expert method of paired comparison is applied of the operator’s reliability assessment. Application of the method demands classification and quantification of operator’s reliability factors.

3. OPERATOR'S RELIABILITY FACTORS

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.

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.

$$\tau = a + bH \qquad (1)$$

where a denotes latent respond time, b is the quantity adversely proportional to the velocity of information processing, and H denotes the quantity of information that human operator has to process.

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 according to equation (1), taking into account that quantity H 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:

$$\tau' = \tau_{wt} + \tau \qquad (2)$$

where τ_{wt} is waiting time for service and τ is responding time. 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 k_{fc}. 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 [7,10]. 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 [7] 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 are assessed ranging from 0 to 5. The unique assessment is derived from following equation:

$$\alpha \equiv \frac{1}{5N}\sum_{i=1}^{5}\sum_{j=1}^{N} A_{ij} \tag{3}$$

where N is the number of experts, A_{ij} is the assessment that the expert "j" assign to the condition i.

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). This assessment is calculated using the following equation:

$$\beta = \frac{1}{3N}\sum_{i=1}^{3}\sum_{j=1}^{N} B_{ij} \tag{4}$$

The values of the assessments α and β may range from 0 to 10. The final static assessment k_{wp} denotes the average of the assessments α and β.

3.5. Working task complexity

One of the approaches to the working task complexity assessment is based on the operational-psychological model of the operator's activity. This model yields analysis of the operator's working results on the level of micro and macro analysis. Macro analysis provides, with certain credibility, comparing of working tasks according to complexity, on the basis of the set aim and the conditions needed for its achievement. More reliable assessment is obtained at micro level, i.e. by decomposing conditions into operations needed for accomplishing the task. However, the number of operations and the methods of performing them are not a sufficient condition for task complexity estimation. An important parameter is also the strain required for accomplishing each of them. Therefore, the operator's professionally important characteristics are defined for each operation. Thus, the working task complexity assessment is based on the operation level, and it is a function of the index of complexity k_{co}, and the index of working strain k_{ws} [4]:

$$k_{op} = k_{co} k_{ws} \tag{5}$$

In order to assess the complexity of operations, they are divided into motor operations, motor / logical operations and logical operations. The complexity of operations increases from motor toward logical, considering the activation of mental processes. This may be represented by ratio 1 : 1.2 : 1.4. The indices of strain may be defined experimentally or by expert assessment of particular, professionally important characteristics of the operator, and they range from 0 to 1. The quantitative assessment of the entire task may be obtained on the basis of the complexity of particular tasks:

$$k_{tc} = \frac{1}{n} \sum_{i=1}^{n} k_{opi} \tag{6}$$

were n denotes the number of operations necessary to accomplish the task. Considering the values of coefficients k_{co} and k_{ws}, the complexity coefficient quantification is obtained as shown in Table 1

4. Operator's Reliability Assessment According Paired Comparison Method

The criteria according to the created order scale of five positions shown in Table 1 are applied in the operator's reliability assessment. On the basis of the value of chosen indices, the position (point score) of particular factors is defined [7,8].

Table 1. Values of indices and assessments

Reliability	Position	τ (τ')	k_{fc}	k_{tc}	k_{ms}	k_{wp}
Optimal	5	T_{opt}	1	< 0.6	Level 1	10
Very good	4	$< T_g$	(1-2]	(0.6-0.8]	Level 2	[9-10)
Good	3	T_g	(2-3]	(0.8-1.0]	Level 3	[7-9)
Critical	2	$> T_g$ in partic time interval	(3-4]	(1.0-1.2]	Level 4	[5-7)
Insufficient	1	$> T_g$	(4-5]	(1.2-1.4]	Level 5	< 5

Expert assessment is applied in order to evaluate the influence level of particular factors. Experts rank factors according to their significance by using paired comparison method. The result of this procedure is a list of factors ranked according to the intensity of influence they have on the operator's reliability. In its final form this list is adopted by assigning the lowest rank to the group of factors bearing the least influence.

The characteristic table is firstly formed to bind the influences of particular factors together and to represent their influence by one index. The table comprises all the criteria and all the positions, as well as the basic and the final assessments. The characteristic table for one criterion is shown in Table 2.

The values of basic assessments are $a_{ij} = j$, (j = 1, ...5), while the values $\varphi(k_i)$ denote the weight of the criterion i (i = 1,...5) and they are given in [2]. The characteristic table may be represented in the matrix form:

$$M = \| a_{ij} \varphi(k_i) \|_{i,j=1,5} \tag{7}$$

The complex index of the operator's reliability is defined by the equation:

$$k = \frac{\sum_{i=1}^{5} a_{ij}\varphi(k_i)}{\sum_{i=1}^{5} a_{i5}\varphi(k_i)} \tag{8}$$

and the limits of its values are:

$$k_{\min} = \frac{\sum_{i=1}^{5} a_{i1}\varphi(k_i)}{\sum_{i=1}^{5} a_{i5}\varphi(k_i)} = 0{,}2\,; \quad k_{\max} = \frac{\sum_{i=1}^{5} a_{i5}\varphi(k_i)}{\sum_{i=1}^{5} a_{i5}\varphi(k_i)} = 1$$

Table 2. Part of characteristic table

Criteria and Position		Assessments	
		Basic	Final
Criterion	k_1		
Positions	P_1	a_{11}	$a_{11}\varphi(k_1)$
	P_2	a_{12}	$a_{12}\varphi(k_1)$
	P_3	a_{13}	$a_{13}\varphi(k_1)$
	P_4	a_{14}	$a_{14}\varphi(k_1)$
	P_5	a_{15}	$a_{15}\varphi(k_1)$

At calculating the values of the complex index k, the actual values of the characteristic matrix elements $m_{ij}= a_{ij}\ \varphi(k_i)$ are chosen on the basis of they assessment of the position "i" and the rank "j". The reliability of the operator's work increases when the value of complex index tends to reach 1.

5. Conclusion

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 paired comparison is applied in order to form a complex index of the operator's reliability in this paper. This index 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.

REFERENCES

1. *Accident management programmes in nuclear power plants*, Vienna, IAEA, 1994.
2. Anđelković, B., *Kompleksna ocena opasnosti u tehnološkim sistemima kao osnova za projektovanje optimalne zaštite radne sredine*, Doktorska disertacija, Fakultet zaštite na radu, Niš, 1990.
3. Белов, П.Т., *Теоретические основы системной инженерии безопасности*, ГНТП "Безопасность", Москва, 1996.
4. Кантылев, Е.Я., *Деятельность инженера-оператора в системе автоматизированного проектирования*, Экономика, Москва, 1985.
5. Kirwan, B., *Human reliability assessment, Evaluation of Human Work*, Edited by John R Wilson and E.Nigel Corlett, Taylor & Francis, 1995.
6. *Reliability data collection and use in risk availability assessment*, Proceedings of the 6th Euredata conference, Italy, 1989.
7. Savić, S., *Analiza grešaka upravljanja i njihov uticaj na pouzdanost sistema "čovek-mašina"*, Doktorska disertacija, Fakulltet zaštite na radu, Niš, 1992.
8. Savić S., Vučković Lj., Anđelković B. - *Human operator as a risk factor in technological system*, Proceedings of III International Conference "Risk in Technological Systems and the Environment", October 30 - 31 th, Faculty of Occupational Safety, Niš, 1997.
9. Зайцев, В.С., *Системный анализ операторской деятельности*, Радио и связь, Москва, 1990.
10. Зараковский, Г.М., Павлов, Б.Б, *Закономерности функционирования эргатических систем*, Радио и связь, Москва, 1987.

PROCENA POUZDANOSTI OPERATORA PRIMENOM EKSPERTNOG METODA PARNOG UPOREĐIVANJA

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U radu je razmatran značaj procene pouzdanosti čoveka u proizvodnim sistemima. Dati su pristupi za kvantifikaciju njegove pouzdanosti. Posebno su analizirani faktori koji utiču na pouzdanost operatorske delatnosti i izvršena je njihova kvantifikacija. Objedinjavanje uticaja pojedinih faktora pouzdanosti izvršeno je metodom parnog upoređivanja. Na taj način je formiran kompleksni pokazatelj pouzdanosti, na osnovu koga je moguće proceniti pouzdanost operatorske delatnosti.