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ADAPTATION OF THE DECISION-MAKING PROCESS IN THE MANAGEMENT OF CRITICAL INFRASTRUCTURE

Perederyi V. I. – Dr. Sc., Professor of the Department of Computer Technologies and Information Security, Admiral Makarov National University of Shipbuilding, Mykolaiv, Ukraine.

Borchik E. Y. – PhD, Associate Professor of the Department of Information Technologies, Mykolaiv National Agrarian University, Mykolaiv, Ukraine.

Zosimov V. V. – Dr. Sc., Professor of the Department of Computer Engineering, Odesa National University of Technology, Odesa, Ukraine.

Bulgakova O. S. – PhD, Associate Professor of the Department of Computer Engineering, Odesa National University of Technology, Odesa, Ukraine.

ABSTRACT

Context. The problem of human factor management in the process of making relevant decisions in the management of critical infrastructure facilities is currently very important and complex. This issue is becoming increasingly significant due to the dynamic and unpredictable nature of the environment in which these facilities operate. Effective management of CIF requires the development of new models and methods that are based on adaptive management principles. These models and methods must take into account the personal emotional and cognitive capabilities of the decision maker, who is often operating under the influence of destabilizing uncertain factors. The challenge is further compounded by the need to integrate these adaptive methods into existing human-machine systems, ensuring that they can respond in real-time to the rapidly changing conditions that can affect the decision-making process. The complexity and importance of this problem necessitate a multifaceted approach that combines probabilistic methods, intellectual technologies, and information-cognitive technologies. These technologies must be capable of providing real-time adaptation and assessment of the DM's emotional and cognitive state, which is critical for making relevant and timely decisions. The current unresolved problems in the field of creating adaptive information technologies for decision support in the management of CIF highlight the urgent need for a promising approach that can address these issues effectively and efficiently.

Objective. The objective is to propose a a comprehensive method for evaluating the process of relevant decision-making, which depends on the functional stability of critical infrastructure facilities and the adaptation of factors related to the emotional-cognitive state of the decision maker. This method aims to provide a systematic approach to understanding how various factors, including the psycho-functional state of the DM, influence the decision-making process. Additionally, the objective includes the development of adaptive information and intellectual technologies that can support real-time evaluation and adjustment of the DM's emotional and cognitive states. This approach seeks to ensure that decisions are made efficiently and effectively, even under the influence of destabilizing uncertain factors. By addressing these aspects, the method aims to enhance the overall reliability and resilience of the CIF management processes. Furthermore, the objective encompasses the integration of Bayesian networks and a comprehensive knowledge base to facilitate the decision support system in providing timely and accurate information for decision-making.

Method. To implement this method, probabilistic methods, intellectual and information-cognitive technologies were used to provide acceptable adaptation and evaluation of the relevant decision-making process in real-time.

Results. The proposed method, based on intellectual and information-cognitive technology, allows for real-time assessment and adaptation of the emotional and cognitive state of the decision maker during the process of making relevant decisions. The implementation of probabilistic methods and Bayesian networks has enabled the development of a robust decision support system that effectively integrates adaptive management principles. This system ensures that the decision-making process remains stable and reliable, even in the presence of destabilizing uncertain factors. The real-time capabilities of the system allow for prompt adjustments to the psycho-functional state of the DM, which is critical for maintaining the functional stability of critical infrastructure facilities. The results demonstrate that the use of intellectual technologies and a comprehensive knowledge base significantly enhances the DM's ability to make informed decisions. Experiments have shown that this method improves the overall efficiency and effectiveness of CIF management, providing a promising approach for future applications in adaptive decision support processes. The results obtained from these experiments validate the potential of the proposed method to revolutionize the management of CIF by ensuring that decisions are both timely and appropriate, thereby contributing to the resilience and reliability of these essential facilities..

Conclusions. The results of the experiments allow us to recommend the use of the proposed method of rapid assessment and adaptation of the emotional and cognitive state of the decision maker for the process of making relevant decisions in real-time. The integration of intellectual and information-cognitive technologies into the decision support system has proven to be effective in enhancing the stability and reliability of the decision-making process in the management of critical infrastructure facilities. The real-time capabilities of the system facilitate prompt adjustments to the psycho-functional state of the DM, ensuring that decisions are made efficiently and effectively, even under the influence of destabilizing uncertain factors. The experimental results demonstrate that the proposed method significantly improves the overall efficiency of CIF management by providing a robust framework for adaptive decision support. The results obtained can be used in the development of adaptive DSS in the management of CIF, offering a promising approach for future applications. This method not only enhances the decision-making capabilities of DMs but also contributes to the resilience and reliability of CIF, ensuring their functional stability in dynamic and uncertain environments.

KEYWORDS: human-machine systems, decision making, adaptation, decision maker, information-cognitive technologies, intelligent technologies, Bayesian networks, information security, cybernetic security.

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ABBREVIATIONS

HMS is a human-machine systems;
DM is a decision maker;
DMP is a decision making process;
DSS is a decision support system;
BN is a Bayesian networks;
DS is a decision support;
CIF is a critical infrastructure facilities;
PFS ia a psycho functional state;
KB is a knowledge base.

NOMENCLATURE

Sw is a main factors associated with the current psycho-emotional state of the DM;
F is a physical and emotional fatigue;
ET is an emotional tension;
PR is a productivity;
Sp is a main factors associated with the current cognitive state of DM;
PI is a perception of information;
RT is a reaction time;
DT is a decision-making time;
C is a concentration;
IS is an information security;
CS is a cyber security;
Risk is a risk state of the production process of a critical facility;
Pi is a probability of the implementation of the *i*-th threat to the production process of a critical facility;
Ci is an amount of damage from the implementation of the *i*-th threat;
FS is a functional stability of a critical infrastructure facility;
Ad EC is an adaptation of the emotional and cognitive state of the DM;
REL is a relevance of decision-making;
u_1 is a linguistic variable "decision-making time";
u_2 is a linguistic variable "reaction time";
u_3 is a linguistic variable "perception of information";
u_4 is a linguistic variable "productivity";
u_5 is a linguistic variable "physical and emotional fatigue";
u_6 is a linguistic variable "emotional tension";
u_7 is a linguistic variable "concentration";
v is a linguistic variable;
{"standard", "not standard"} is a term-set of variables u_i;
{"low", "average" , "high"} is a term-set of the variable *v*;
R^* is a critical value of the measure of relevance of the decision making;
$f_1()$ is a function for assessing the degree of adaptation of DM's emotional-cognitive state factors;
$f_2()$ is a function for assessing the degree of functional stability of CIF;
$f_3()$ is a function for assessing the degree of relevance of decisions made by DM.

INTRODUCTION

The human factor in emergency situations, as one of the most important in safety, has become a subject of fundamental and applied scientific research and development in recent years. Recent events indicate the importance of the influence of destabilising factors of the external and industrial environment on the decision-making process of the DM, which leads to an increase in the probability of wrong decisions, especially in multi-level CIF with increased risk in management.

The classical methodology of decision-making with a given number of alternatives and complete information about them is not suitable for these conditions, because the information is limited and incomplete, while decisions should be made promptly, relying on the psycho-emotional and cognitive state of the DM.

In this regard, one of the most important problems is mutual adaptation and optimal distribution of functions between technical means and the operator, taking into account his psychophysiological and cognitive capabilities. However, the solution of this problem goes beyond the possibilities of traditional methods and means of solving these issues. For this purpose, an essential role should be given to the engineering-psychological aspect, which should be based on modern tools of artificial intelligence and information-cognitive technology.

Therefore, the technology of decision-making process in the process of CIF management should be based on the principle of hybrid intelligence – symbiotic integration of the functionality of artificial (computer) and natural (operator) intelligences.

The object of study are informational and mathematical models of decision-making process evaluation depending on the functional stability of CIF and the adaptation of factors of the DM's emotional and cognitive state of mind when managing the object.

The subject of study are models and methods of decision-making in man-machine systems in the management of CIF.

The purpose of the work is to propose a method for evaluating the process of making relevant decisions depending on the functional stability of the CIF and adaptation of factors of the emotional-cognitive state of the DM.

1 PROBLEM STATEMENT

In the process of decision-making, the DM is influenced by external factors of the production environment and factors characterising his psycho-emotional $Sw = \{ET, PR, F\}$ and cognitive $Sp = \{PI, RT, DT, C\}$ state.

It is necessary, on the basis of expert evaluations and information-cognitive technology to estimate the degree of relevance of decisions made by DM $REL = f_3(Sp, Sw, IS, CS, Risk)$ depending on the adaptation of factors of his emotional-cognitive state $Ad\ EC = f_1(Sp, Sw)$ and the functional stability of CIF $FS = f_2(IS, CS, Risk)$ in conditions of limited time in the management of the object.

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According to the results of evaluation to draw a conclusion about the degree of adaptation of the emotional-cognitive state of the decision-maker for the relevance of the decision-making process. If the value of $REL \geq R^*$ then an adaptation of the emotional-cognitive state of the DM is sufficient. In case of $REL < R^*$ it is no sufficient and requires adjustment of factors *Sw* and *Sp* in accordance with engineering-psychological standards.

2 REVIEW OF THE LITERATURE

The operation of critical infrastructure facilities is associated with both information and cyber vulnerabilities and risky process conditions and requires the development of new tools to ensure the sustainability of operation based on knowledge of the state of the management objects, the state of the operating environment and the impacts that occur. An integral element of such systems is a number of decision support subsystems, the capabilities of which directly depend on the ability to provide the DM with qualitatively balanced information characterizing the actual and forecasted states of the CIF.

In scientific works of a number of authors, it is noted that the most important problem in the theory of decision-making is to overcome the factor of subjectivity, which is caused by the presence of psychological and cognitive characteristics of the DM, in the decision-making process.

Research [1] shows the dependence of human operator efficiency on the characteristics of the workplace environment and proposes a comprehensive assessment of their impact. However, cognitive models for identifying and assessing uncertain situations of the impact of uncertain environmental and production environment factors on the DSS have not been studied.

Studies [2, 3] present human errors that depend on time and other factors affecting work productivity. A roadmap methodology for the selection and consistent application of approaches to the human factor is presented. The ergonomic functional approach to modeling control processes for the tasks of adapting the technical component to the human operator is proposed, but the models and methods of functional dependence of the efficiency of complex systems on the influence of external factors and the uncertain risk of making irrelevant decisions are not investigated; Hierarchical cognitive models for determining the optimal interaction of uncertain factors of the external and production environment on the psychophysiological state of a person in decision-making.

Publications [4-6] describe the technology and cognitive aspects of human factor engineering. The optimization of human-machine interaction at the stage of designing dynamic systems focused on the problems of physical, functional and information security is indicated. A method for analyzing the reliability of a human-machine system based on the IDA model is proposed. Recommendations for the use of various methods of formalized description of operators' activities in the process of engineering and psychological support for the development of human-machine systems have been determined. However, no study has been made of fuzzy cognitive models for determining and evaluating the optimal interaction of environmental factors on the decision-making process of DM in the management of real-time CIF.

Studies [9–11] indicate the main sources of cyber and information security factors, which differ significantly from other categories of risks, such as human behavior. The process of determining the risks from erroneous decision-making by DM under the influence of threats is presented. However, models and methods for assessing the dependence of the functional stability of a critical infrastructure facility on the impact of cyber and information security factors have not been studied.

Publications [12–14] propose methods that make it possible to determine the total amount of damage caused by threat factors for a certain period of time. It is also noted that the process of determining and assessing the risk of erroneous decision-making under the influence of threat factors is the basis and basis for research in the field of analysis and improvement of existing, as well as the invention of new methods of risk assessment, improving the accuracy of its assessment. The author recommends that in the course of functioning of the CIF, the risks of irrelevant decision-making by DM arising in unpredictable conditions, as well as special requirements to the emotional and cognitive state of a person and their admission to perform particularly responsible work should be taken into account. It is also noted that the information and cognitive aspects of human factor engineering play a key role in the safety, reliability and efficiency of the management of critical control facilities.

3 MATERIALS AND METHODS

Based on the results of the literature analysis, it is noted that the decision-making process is most significantly influenced by the factors of the emotional and cognitive state of DM shown in the information-logical model (Fig. 1), [15–18].

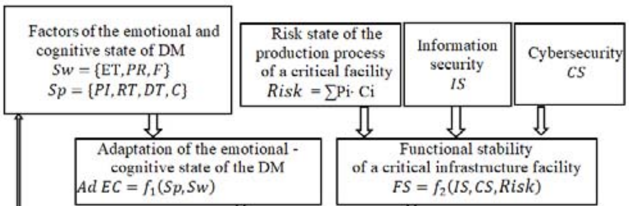

Figure 1 – Information-logical model of adaptation of the emotional-cognitive state of the decision-maker for the relevance of the decision-making process

For quantitative assessment of the degree of relevance of the decision made by the DM, it is proposed to use the BN, shown in Fig. 2. It should be noted that when building the structure of this BN and filling in the tables of conditional probabilities for the variables of the network, the requirements of engineering-psychological standards of working conditions of human operators and knowledge of experts were used.

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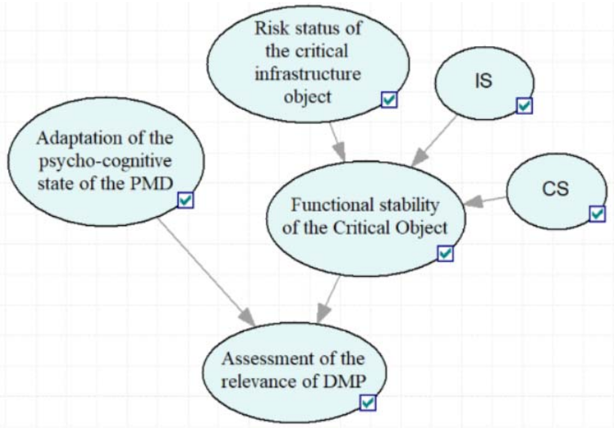

Figure 2 – A Bayesian network for estimating the probability of relevance of a decision made by a DM

All nodes of the network are binary, i.e. they have two states and are of type "Chance – General". Thus, the Risk node characterises the Risk status of the critical infrastructure object and can take only two values: "occurs" if such a risk exists and "not occur" otherwise. The IS and CS nodes characterise information and cyber security and can also take two values. If the object is informational or cybernetically fully protected, the corresponding vertices take the value "protect", otherwise they take the value "no protect". The probability that these nodes take the value "no protect" is determined by the security control modules.

Since the nodes "Functional stability of the Critical Object" and "Assessment of the relevance of DMP" each have several parent nodes, the Noisy MAX type is assigned to these nodes to reduce the labour intensity of filling in the conditional probability tables. In this case, conditional probabilities are conditioned on the separate influence of factors on the expected event rather than jointly, which makes it easier for experts to estimate the conditional probability [19]. The "Functional stability of the Critical Object" node can take the values "sufficient" and "not sufficient", and the "Assessment of the relevance of DMP" can take the values "relevant" and "irrelevant".

To describe the nodes "Functional stability of the Critical Object" and "Assessment of the relevance of DMP", the experts were asked to estimate the conditional probabilities of the possible states of these nodes. The results are presented in Tables 1–2.

Examine the node "Adaptation of the psycho-cognitive state of the DM". The random value of "Adaptation of the psycho-cognitive state of the DM" is influenced by the following factors of the emotional-cognitive state of the DM: "physical and emotional fatigue" F, "emotional tension" ET, "productivity" PR, "perception of information" PI, "reaction time" RT, "decision-making time" DT, "concentration" C. Based on engineering and psychological standards for the working conditions of a human operator [20–22] and the results of expert assessments, Table 3 shows the levels of values of these factors in relative units.

Depending on the values of emotional-cognitive factors, the degree of adaptation of the DM to the decision-making process may be different. The question arises: what is the probability that the random variable "Adaptation of the psycho-cognitive state of the DM" takes the value "negative"?

To answer this question, it is proposed to use a probability value prediction system based on fuzzy logical inference using Mamdani's algorithm on a fuzzy knowledge base, in which the values of the input and output variables are given by fuzzy sets. Taking into account that according to [21, 22] the most noticeable influence on the cognitive state of the LPR has the factors time to make decisions DT, reaction time RT, and information perception PI, the experts propose the following uncertain knowledge base:

RULE 1: IF u_1 is "not standard" AND u_2 is "not standard" THEN v *is* "high".

RULE 2: IF u_1 is "not standard" AND u_2 is "not standard" AND u_5 "standard" THEN v is "high".

RULE 3: IF u_3 is "not standard" AND u_5 is "standard" AND u_6 "standard" AND u_7 "not standard" THEN v is "high".

RULE 4: IF u_4 is "not standard" AND u_3 is "not standard" AND u_5 "not standard" AND u_7 "standard" THEN v is "average".

RULE 5: IF u_1 is "standard" AND u_3 is "standard" AND u_4 "not standard" AND u_5 "not standard" AND u_6 "not standard" THEN v is "average".

RULE 6: IF u_2 is "standard" AND u_3 is "standard" AND u_4 "standard" AND u_5 "not standard" AND u_6 "standard" AND u_7 "not standard" THEN v is "average".

RULE 7: IF u_6 is "not standard" AND u_4 is "standard" AND u_1 "standard" AND u_2 "standard" AND u_3 "standard" AND u_7 "not standard" THEN v is "low".

RULE 8: IF u_1 is "standard" AND u_2 is "standard" AND u_3 "standard" AND u_4 "standard" AND u_5 "standard" AND u_6 "standard" AND u_7 "standard" THEN v is "low".

The membership function $\mu_i(x_i)$ of the term "standard" of linguistic variables $u_i\ (i=\overline{1,7})$ will be given in the form of a two-sided Gaussian function:

$$\mu_i(x_i) = gauss2mf\left(x_i, \left[\sigma_1^i, c_1^i, \sigma_2^i, c_2^i\right]\right) = \\ = \begin{cases} e^{-(x_i - c_1^i)^2 / 2(\sigma_1^i)^2}, & if\ 0 \le x_i \le c_1^i, \\ 1, & if\ c_1^i < x_i < c_2^i, \\ e^{-(x_i - c_2^i)^2 / 2(\sigma_2^i)^2}, & if\ c_2^i \le x_i \end{cases}, \quad (1)$$

where parameters $\sigma_1^i, \sigma_2^i > 0$; $c_1^i, c_2^i \ge 0$; $c_1^i \le c_2^i$; x_i are an elements of the universal set $X = [0; 1]$, on which the terms "standard", "not standard" are defined.

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Table 1 – Conditional probabilities of the "Functional stability of the Critical Object"

Parent	Risk		IS		CS	
State	occurs	not occurs	no protect	protect	no protect	protect
not sufficient	0.2	0	0.25	0	0.35	0
sufficient	0.8	1	0.75	1	0.65	1

Table 2 – Conditional probabilities of the "Assessment of the relevance of DMP"

Parent	Adaptation of the psycho-cognitive state of the DM		Functional stability of the Critical Object	
State	no sufficient	sufficient	negative	positive
irrel	0.3	0	0.2	0
rel	0.7	1	0.8	1

Table 3 – Levels of significance of factors of emotional and cognitive state of DM

State	*ET*	*F*	*PR*	*PI*	*RT*	*DT*	*C*
high	0.85 – 1	0.8 – 1	0.75 – 1	0.8 – 1	0.85 – 1	0.86 – 1	0.76 – 1
average	0.4–0.84	0.36–0.79	0.46–0.74	0.46–0.79	0.55–0.84	0.55–0.85	0.41–0.75
low	0.15 – 0.39	0.2 –0.35	0.25–0.45	0.15–0.45	0.25–0.54	0.3–0.54	0.25–0.4

Considering the values of the factors of the emotional and cognitive state of the DM (Table 3) allows us to determine some of the values of the parameters $\sigma_1^i, \sigma_2^i, c_1^i, c_2^i \; (i=\overline{1,7})$. Then the membership functions $\mu_i(x_i)$ can be written in the form:

$$\begin{aligned}
&\mu_1(x_1) = gauss2mf\left(x_1,\left[1,0,\sigma_2^1,0.3\right]\right), x_1 \in [0,1];\\
&\mu_2(x_2) = gauss2mf\left(x_2,\left[1,0,\sigma_2^2,0.25\right]\right), x_2 \in [0,1];\\
&\mu_3(x_3) = gauss2mf\left(x_3,\left[\sigma_1^3,0.8,1,1\right]\right), x_3 \in [0,1];\\
&\mu_4(x_4) = gauss2mf\left(x_4,\left[\sigma_1^4,0.75,1,1\right]\right), x_4 \in [0,1];\\
&\mu_5(x_5) = gauss2mf\left(x_5,\left[1,0,\sigma_2^5,0.2\right]\right), x_5 \in [0,1]\\
&\mu_6(x_6) = gauss2mf\left(x_6,\left[1,0,\sigma_2^6,0.15\right]\right), x_6 \in [0,1];\\
&\mu_7(x_7) = gauss2mf\left(x_7,\left[\sigma_1^7,0.76,1,1\right]\right), x_7 \in [0,1].
\end{aligned} \tag{2}$$

For definition, the parameters σ_1^i, σ_2^i of the membership functions, which can, as the analysis of the data in Table 2 shows, take any values, are assigned the value 1 in the formula (2).

The statement "the *i*-th external factor takes the value "not the norm" is opposite to the statement the *i*-th external factor takes the value "standard". Then the membership functions $\varphi_i(x_i)$ of the term "not standard" of the linguistic variables u_i have the form:

$$\varphi_i(x_i) = 1 - \mu_i(x_i), \; (i=\overline{1,7}).$$

For the membership functions of the terms 'low', 'average', 'high' of the linguistic variable v are introduced the notations $\theta_i(y)$ $(i=\overline{1,3})$ correspondingly, where y are the elements of the universal set $Y = \{0; 1\}$, on which these terms are defined.

The function $\theta_i(y)$ is defined as a symmetric Gaussian function:

$$\theta_i(y) = gaussfm(y,[\sigma_i,c_i]) = e^{-(y-c_i)^2/2\sigma_i^2}, \tag{3}$$

where parameters $\sigma_i > 0$; $c_i \geq 0$, $(i=\overline{1,3})$.

Below are characteristic graphs of membership functions. The graphs of the functions $\mu_1(x_1)$, $\varphi_1(x_1)$, $\mu_2(x_2)$, $\varphi_2(x_2)$, $\mu_5(x_5)$, $\varphi_5(x_5)$, $\mu_6(x_6)$, $\varphi_6(x_6)$ have the form of the graphs in Fig. 3. The graphs of functions $\mu_3(x_3)$, $\varphi_3(x_3)$, $\mu_4(x_4)$, $\varphi_4(x_4)$, $\mu_7(x_7)$, $\varphi_7(x_7)$ have the same form as in Fig. 4.

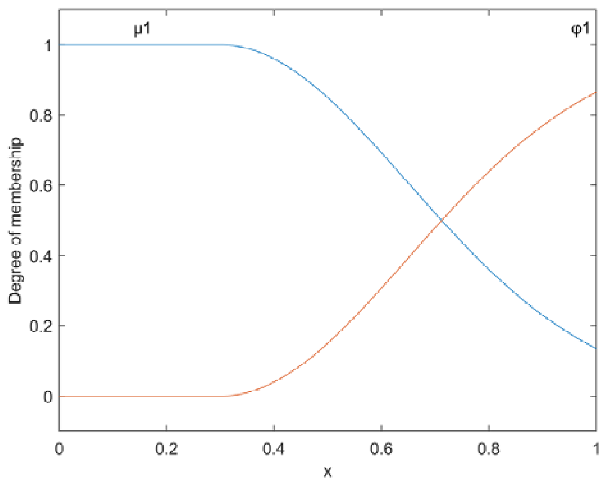

Figure 3 – Membership functions $\mu_1(x_1)$ and $\varphi_1(x_1)$

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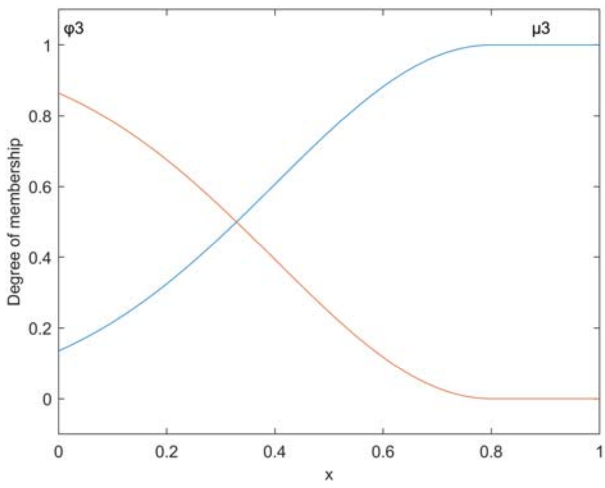

Figure 4 – Membership functions $\mu_3(x_3)$ and $\varphi_3(x_3)$

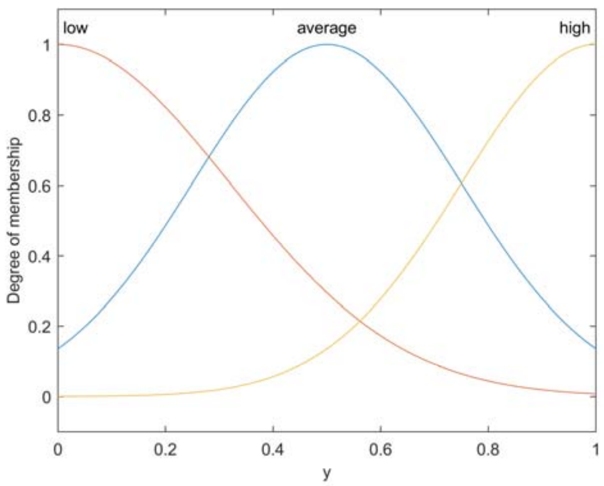

Figure 5 – Membership functions $\theta_i(y)$ $(i=\overline{1,3})$

To set up the fuzzy model F, i.e. to determine the coefficients of the model $\sigma_2^1,\sigma_2^2,\sigma_2^5,\sigma_2^6,\sigma_1^3,\sigma_1^4,\sigma_1^7;\sigma_j,c_j,(j=\overline{1,3})$, it is required that the value of root mean square deviation should be minimized:

$$R=\frac{1}{n}\sum_{k=1}^{n}(y_k-\mathbf{F}(P,E_k))^2\rightarrow \min. \quad (4)$$

Here n is the volume of the sample of experimental data connecting the inputs $E = (x_1, x_2, x_3, x_4, x_5, x_6, x_7)$ to the output y of the investigated dependence:

$$(E_k, y_k),\ k=\overline{1,n},$$

where $E_k = (x_{k,1}, x_{k,2}, x_{k,3}, x_{k,4}, x_{k,5}, x_{k,6}, x_{k,7})$ is a vector of inputs and y_k is an output in k-pair. In addition, $\mathbf{F}(P,E_k)$ is the value of the output of the fuzzy model at the value of the inputs specified by the vector E_k; $P=(\sigma_1^i,\sigma_2^i,\sigma_j,c_j)$ is a vector of coefficients of membership functions of terms of input and output variables of the fuzzy model.

Taking into account the knowledge of experts about the influence of the factors of the emotional and cognitive state of the DM on the degree of adaptation to the decision-making process, it is possible to find a solution to the mathematical programming problem (4) with the help of the Fuzzy Logic Toolbox and Optimization Toolbox packages and thus set up a fuzzy model.

4 EXPERIMENTS

To verify the proposed method, numerical experiments were carried out, the essence of which was the following.

Assume that at some point in time the corresponding control modules fix certain values of the factors of the emotional-cognitive state of the LPR. On the basis of the above proposed fuzzy knowledge base using the Mamdani algorithm and the known values of the corresponding factors, the probabilities of the states of the top of the BN "Adaptation of the psycho-cognitive state of the DM" are estimated.

According to the respective functional resilience control modules of the CIF, its information and cyber security status probabilities and risk status probabilities are determined.

The found probabilities allow us to estimate the value of the probability (relevance=rel) of relevance of the decision made by the DM according to the proposed BN (Fig. 2). Comparing the value of P(relevance=rel) with the critical value of Pcr. according to a given criterion allows us to attribute the decision taken to either relevant or irrelevant.

5 RESULTS

Numerical experiments were carried out for two cases. Let at some moment of time modules, control of factors of emotional and cognitive state of DM, fixes the following their values (Table 4).

Using Mamdani's algorithm, the probabilities of the states of the BN node "Adaptation of the psycho-cognitive state of the DM" are estimated from the data in Table 4. The values of the probabilities of a given node and the probabilities of the states of the nodes "Risk status of the critical infrastructure object", "*IS*", "*CS*" are indicated on the icons of the corresponding nodes (Fig. 6). The calculation performed in the GeNIe system shows that the probability of making a relevant decision by the DM turned out to be equal to *P*(relevance=*rel*) =0.93.

In the second case, the calculation was performed with the same values of the probabilities of the nodes "Risk status of the critical infrastructure object", "*IS*", "*CS*" and values of the emotional and cognitive parameters as in the first case, except for the RT factor, which now takes the value 0.3. The BN calculation (Fig. 2) shows that in this case the probability of making a relevant decision by the DM turned out to be equal to P(relevance=rel) =0.96

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Table 4 – The values of factors of emotional and cognitive state of DM

	ET	*F*	*PR*	*PI*	*RT*	*DT*	*C*
high			0.9	0.95	0.85		0.9
average							
low	0.15	0.2				0.5	

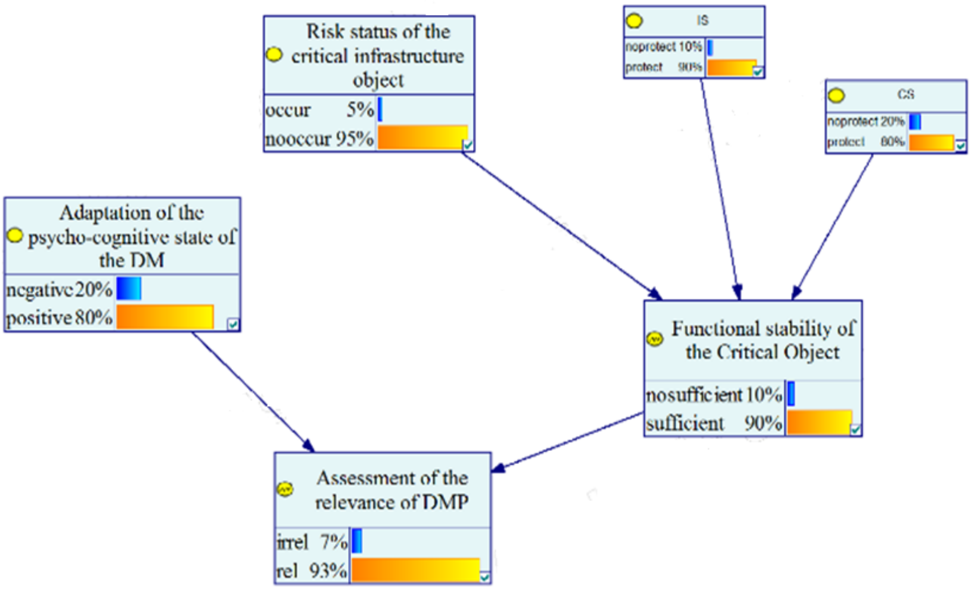

Figure 6 –Estimation of the probability of making a relevant decision by the DM at the value of the parameter RT = 0.85

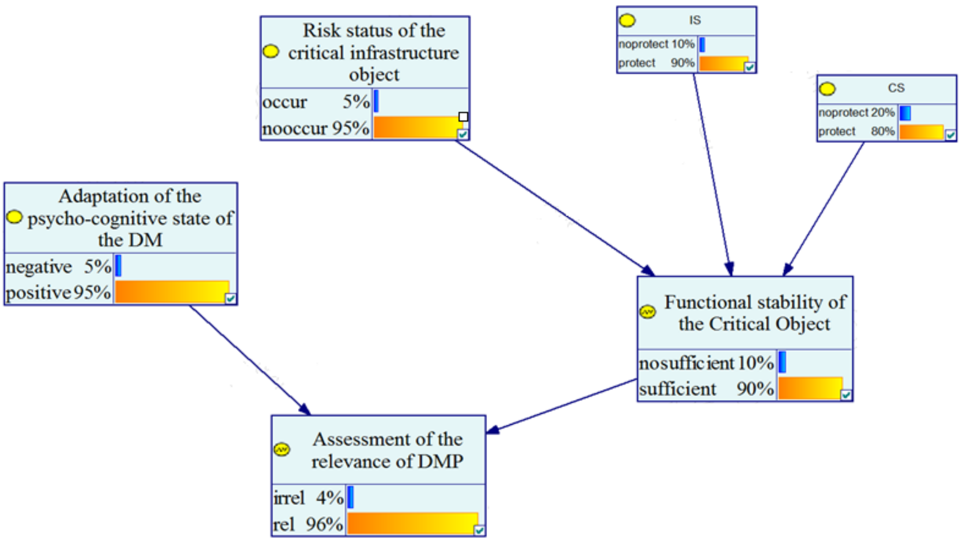

Figure 7 – Estimation of the probability of making a relevant decision by the DM at the value of parameter RT = 0.3

6 DISCUSSION

In accordance with the results of studies of literature and regulatory sources for many CIF, when the probability value *REL* ≥ 0.95, the decision made is considered relevant. Since in the first case the calculated probability is less than the permissible *Pcr* =0.93, the decision made by the DM cannot be considered relevant. The results of the BN calculation in this case are presented in Fig. 6.

It is assumed that the probabilities of the values of the BN nodes ″Risk status of the critical infrastructure object "*IS*", "*CS*" remain unchanged during the experiment. Then, it is only possible to increase the degree of decision relevance by increasing the degree of adaptation of the DM to the decision-making process. The analysis shows that the only emotional-cognitive factor whose value is out of the standard is the factor (*RT* = 0.85), the value of which is too high for an adequate response to the situation. After the adjustment of this factor in accordance with the recommendations of engineering-psychological standards, its value can be reduced to the value of 0.3. The results of the BN calculation in this case are presented in Fig. 7. After that the probability of making a relevant decision by the DM turned out to be equal to *P*(relevance=*rel*) = 0.96, which is greater than the critical probability *P*cr = 0.95. Therefore, the decision made by the DM can be considered relevant.

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The obtained results of numerical experiments are quite consistent with practical situations of decision-making in critical infrastructure systems. In the first case, the overestimated value of one of the emotional and cognitive factors (RT) – the reaction time of the DM to the situation – negatively affected the process of relevant decision-making. In this case it is necessary to correct this factor according to engineering psychological recommendations and requirements. In the second case after adjustment of the factor (RT), at the same values of other factors, the probability of relevant decision-making of the DM has significantly increased. In this case, adjustment of the degree of negative impact of factors was not required.

Therefore, the results of the experiments allow us to recommend the use of the proposed method of rapid assessment and adaptation of the emotional and cognitive state of DM to the process of making relevant decisions in real time. The results can be used in the development of adaptive DSS in the management of CIF.

CONCLUSIONS

The urgent scientific and applied problem of adaptation of the decision-making process in the process of management of the CIF, taking into account the personal emotional and cognitive capabilities of the DM under the influence of destabilising uncertain factors, has been solved.

The scientific novelty of obtained results is consist:

– the method of operative estimation and adaptation of emotional and cognitive state of DM to the process of making relevant decisions, in real time and uncertainty, when managing man-machine systems of critical infrastructure is proposed;

– on the basis of research and assessments of experts, a fuzzy knowledge base has been developed, which allows to determine the degree of adaptation of the DM to the decision-making process in real time.

The practical significance of obtained results is that the proposed method can be used for rapid assessment and adaptation of the emotional and cognitive state of the DM to the process of making relevant decisions in real time, when managing man-machine systems of critical infrastructure.

Prospects for further research are are to develop tools and methods for adapting decision making, in real time and uncertainty, to improve the efficiency of management of critical infrastructure human-machine systems.

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АДАПТАЦІЯ ПРОЦЕСУ ПРИЙНЯТТЯ РІШЕНЬ ПРИ УПРАВЛІННІ ОБ'ЄКТОМ КРИТИЧНОЇ ІНФРАСТРУКТУРИ

Передерій В. І. – д-р техн. наук, професор кафедри комп'ютерних технологій і інформаційної безпеки, Національного університету кораблебудування імені адмірала Макарова, Миколаїв, Україна.

Борчик Є. Ю. – канд. техн. наук, доцент кафедри інформаційних технологій Миколаївського національного аграрного університету, Миколаїв, Україна.

Зосімов В. В. – д-р техн. наук, професор кафедри комп'ютерної інженерії Одеського національного технологічного університету, Одеса, Україна.

Булгакова О. С. – канд. техн. наук, доцент кафедри комп'ютерної інженерії Одеського національного технологічного університету, Одеса, Україна.

АНОТАЦІЯ

Актуальність. Проблема управління людським фактором у процесі прийняття релевантних рішень в управлінні об'єктами критичної інфраструктури (ОКІ) на сьогодні є дуже важливою і складною. Це питання стає все більш значущим через динамічний і непередбачуваний характер середовища, в якому працюють ці об'єкти. Ефективне управління ОКІ вимагає розробки нових моделей і методів, що базуються на принципах адаптивного управління. Ці моделі та методи повинні враховувати особисті емоційні та когнітивні можливості особи, яка приймає рішення (ОПР), яка часто діє під впливом дестабілізуючих невизначених факторів. Проблема ускладнюється необхідністю інтеграції цих адаптивних методів у існуючі людино-машинні системи, що забезпечить їх здатність реагувати в реальному часі на швидкозмінні умови, які можуть впливати на процес прийняття рішень. Складність і важливість цієї проблеми вимагають багатогранного підходу, що поєднує ймовірнісні методи, інтелектуальні технології та інформаційно-когнітивні технології. Ці технології повинні бути здатні забезпечувати адаптацію та оцінку емоційного і когнітивного стану ОПР в реальному часі, що є критично важливим для прийняття релевантних і своєчасних рішень. Невирішені проблеми в галузі створення адаптивних інформаційних технологій для підтримки прийняття рішень в управлінні ОКІ підкреслюють потребу у перспективному підході, який може ефективно та результативно вирішувати ці питання.

Мета роботи – запропонувати комплексний метод оцінки процесу прийняття релевантних рішень, що залежить від функціональної стабільності об'єктів критичної інфраструктури та адаптації факторів, пов'язаних з емоційно-когнітивним станом особи, яка приймає рішення. Цей метод має на меті надати систематичний підхід до розуміння того, як різні фактори, включаючи психофункціональний стан ОПР, впливають на процес прийняття рішень. Додатково, мета включає розробку адаптивних інформаційних та інтелектуальних технологій, які можуть підтримувати оцінку та коригування емоційного та когнітивного станів ОПР в реальному часі. Цей підхід спрямований на забезпечення ефективного та результативного прийняття рішень, навіть під впливом дестабілізуючих невизначених факторів. Враховуючи ці аспекти, метод спрямований на підвищення загальної надійності та стійкості процесів управління ОКІ. Крім того, мета охоплює інтеграцію байєсівських мереж та комплексної бази знань для забезпечення системи підтримки прийняття рішень своєчасною та точною інформацією для прийняття рішень.

Метод. Для реалізації даного методу використовувалися імовірнісні методи, інтелектуальні та інформаційно-когнітивні технології, що забезпечують прийнятну адаптацію та оцінку процесу прийняття релевантних рішень у реальному часі.

Результати. Запропонований метод, заснований на інтелектуальних та інформаційно-когнітивних технологіях, дозволяє в реальному часі оцінювати та адаптувати емоційний і когнітивний стан особи, яка приймає рішення, під час процесу прийняття релевантних рішень. Впровадження ймовірнісних методів та байєсівських мереж дозволило розробити надійну систему підтримки прийняття рішень, яка ефективно інтегрує принципи адаптивного управління. Ця система забезпечує стабільність і надійність процесу прийняття рішень навіть за наявності дестабілізуючих невизначених факторів. Можливості системи в реальному часі дозволяють оперативно коригувати психофункціональний стан ОПР, що є критично важливим для підтримки функціональної стабільності об'єктів критичної інфраструктури. Результати показують, що використання інтелектуальних технологій та комплексної бази знань значно підвищує здатність ОПР приймати обгрунтовані рішення. Експерименти показали, що цей метод покращує загальну ефективність та результативність управління ОКІ, пропонуючи перспективний підхід для майбутнього застосування в адаптивних процесах підтримки прийняття рішень. Отримані результати експериментів підтверджують потенціал запропонованого методу революціонізувати управління ОКІ, забезпечуючи своєчасне і відповідне прийняття рішень, що сприяє стійкості та надійності цих важливих об'єктів.

Висновки. Результати експериментів дозволяють рекомендувати використання запропонованого методу швидкої оцінки та адаптації емоційного та когнітивного стану особи, яка приймає рішення, для процесу прийняття релевантних рішень в реальному

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часі. Інтеграція інтелектуальних та інформаційно-когнітивних технологій у систему підтримки прийняття рішень виявилася ефективною для підвищення стабільності та надійності процесу прийняття рішень в управлінні об'єктами критичної інфраструктури. Можливості системи в реальному часі сприяють оперативному коригуванню психофункціонального стану ОПР, забезпечуючи ефективне та результативне прийняття рішень навіть під впливом дестабілізуючих невизначених факторів. Експериментальні результати демонструють, що запропонований метод значно покращує загальну ефективність управління ОКІ, забезпечуючи надійну основу для адаптивної підтримки прийняття рішень. Отримані результати можуть бути використані при розробці адаптивних СППР в управлінні ОКІ, пропонуючи перспективний підхід для майбутніх застосувань. Цей метод не тільки підвищує здатність ОПР приймати рішення, але й сприяє стійкості та надійності ОКІ, забезпечуючи їх функціональну стабільність в динамічних та невизначених умовах.

КЛЮЧОВІ СЛОВА: людино-машинні системи, прийняття рішення, адаптація, особа, яка приймає рішення, інформаційно-когнітивні технології, інтелектуальні технології, Байєсовські мережі довіри, інформаційна безпека, кібернетична безпека.

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