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EVALUATION OF THE INFLUENCE OF ENVIRONMENTAL FACTORS AND COGNITIVE PARAMETERS ON THE DECISION-MAKING PROCESS IN HUMAN-MACHINE SYSTEMS OF CRITICAL APPLICATION

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ABSTRACT

Context. A feature of human-machine systems of critical application operating in real time is that they include as elements both technical systems and people interacting with these systems. At the same time, the main difficulties are associated not only with the improvement of hardware and software, but also with the insufficient development of methods for reliably predicting the impact of the production environment on the human factor and, as a result, on the relevance of decisions made by decision makers. As a result, the task of developing methods for determining the mutual influence of environmental factors and cognitive parameters of decision makers on the decision-making process becomes very relevant.

Objective. The aim of the work is to propose methodological foundations for the development and study of fuzzy hierarchical relational cognitive models to determine the influence of environmental factors and cognitive parameters of decision makers on the DMP.

Method. When building FHRCM methods of "soft computing", methodologies of cognitive and fuzzy cognitive modeling were used, providing an acceptable formalization uncertainty of mutual influence of factors on the DMP.

Results. A fuzzy cognitive model based on a fuzzy Bayesian belief network has been developed, which makes it possible to draw a connection between qualitative and quantitative assessments of mutually influencing factors on the DMP. The proposed model makes it possible to probabilistically predict the influence of factors and choose rational ways of their interaction in the DMP.

Conclusions. The results of the experiments make it possible to recommend using the developed model, which takes into account the mutual influence of factors of various nature, including cognitive ones, in the DMP in order to improve the efficiency of HMSCA management as a whole.

KEYWORDS: man-machine systems of critical application, decision making, decision making person, fuzzy cognitive models, environmental factors, working environment factors, relational cognitive models.

ABBREVIATIONS

HMSCA is a human-machine systems of critical application;

DM is a decision maker;

FHRCM is a fuzzy hierarchical relational cognitive model;

BBN is a Bayesian trust networks;

DS is a decision support;

DMP is a decision making process;

MRD is a making relevant decision;

OTSCA is an organizational and technical system of critical application;

HMS is a human-machine system.

NOMENCLATURE

In is an indicator of noise level;

EN is an indicator of electromagnetic field level;

L is an indicator of workplace lighting;

Te is an indicator of room temperature;

H is an indicator of room humidity;

S is an astate of the technological process;

T is an indicator of fatigue degree;

F is an indicator of psychological tension;

I is an indicator of informational stress;

E is a possibility of error;

D is a decision time;

R() is a relevance of decision making;

A_i is a value of i-th fuzzy numbers;

n_i is a modal value;

$\tilde{N}()$ is a fuzzy interval;

N is a result of defuzzification;

b_j is a value of j-th number on a BBN;

B is a vertex on a BBN;

P() is a probability of joint distribution of a Bayesian belief network;

$S_e()$ is a function that characterizes the influence of external and production factors;

$S_p()$ is a function that characterizes the influence of psychological and cognitive factors on the state of decision makers;

$\mu()$ is a membership function;

$\tilde{P}()$ is a fuzzy probability;

$\tilde{H}()$ is a fuzzy interval;

e_i is a value of the i-th BBN *E*-vertice;

r_i is a value of the i-th BBN *R*-vertice;

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d_i is a value of the *i*-th BBN *D*-vertice;
f_i is a value of the *i*-th BBN *F*-vertice;
t_i is a value of the *i*-th BBN *T*-vertice.

INTRODUCTION

Today, when creating HMSCA, the solution of the problems of managing and monitoring processes and phenomena of an anthropogenic and natural nature comes to the fore, followed by the adoption of appropriate decisions at each hierarchical level of the system.

Modern HMSCAs are built, as a rule, on the basis of computer networks, which, together with software and users, are designed to increase management efficiency. Currently, the issues of assessing the performance of HMSCA enough attention are paid, but there is no single conceptual approach to the study of such systems.

It is noted that, in general, research in this area is reduced to the study of the perception of information in verbal and visual form, its analysis, and comparison of DS alternatives. However, there are practically no studies of the mutual influence of external factors of various natures, including cognitive ones, on the DMP.

Also, issues related to management decisions at each hierarchical level of the system have not been sufficiently developed, due to the imperfection of the mathematical, statistical and intellectual tools used.

The objects of study are fuzzy hierarchical relational cognitive decision-making models in multi-level OTSCA.

The subjects of study are models and methods of decision-making in multi-level HMSCA.

The purpose of the work is to introduce methodological fundamentals of development and research of fuzzy hierarchical relational cognitive models to determine the mutual influence of environmental factors and cognitive parameters of DMs on the DMP.

1 PROBLEM STATEMENT

In the process of work, the decision maker is under the influence of external factors of the environment and the production environment and factors that characterize his psychological and cognitive state.

It is required to assess the degree of relevance of decisions made by the decision maker, under the influence of the above factors, in multi-level OTSCA in a limited time.

Suppose that the values of external and production, as well as psychological and cognitive factors *H*, *S*, *Te*, *EN*, *In*, *L*, *F*, *D*, *T*, *E* are known.

It is necessary, based on an expert assessment of the degree of relationship between these factors, to estimate the value of the function $R=f(H,S,Te,EN,In,L,F,D,T,E)$, which characterizes the degree of relevance of the decision maker's decision in real time and draw a conclusion about the relevance of the decision made by the decision-maker, provided: the decision is relevant if $R \geq R^*$ and irrelevant if $R < R^*$.

2 REVIEW OF THE LITERATURE

In the scientific works of a number of authors, it has been noted that one of the most important methodological problems in the theory of decision making and multi-criteria choice is the problem of overcoming the factor of subjectivity, which is due to the presence of psychological characteristics of the behavior of individuals participating in the DMP. In works authors [2-5] noted that the decision-making function "crystallizes" in specific formations – structures of individual qualities that affect individual stylistic differences in the selection processes. Therefore, the management of the mental processes of the decision maker impossible without an assessment of these individual qualities.

Research in ergonomics and engineering psychology conducted over the past decades has made it possible to identify a number of factors that affect the DMP of a human operator. Among these factors, it is necessary to single out those that can dynamically, chaotically change in the process of HMSCA. But such changes cannot be predicted in advance, at the design stage.

Literature analysis [6, 7] allows you to establish the relationship between factors from the group of environmental impact on the psycho-functional state of the decision maker, which in turn affects the adequacy of its actions. However, the adequacy of actions is determined not only by external conditions, but also by the ability of the decision maker's organism to prevent the negative impact of external conditions. These factors include the level of the cognitive component and the tension of the nervous system. The variety of relationships between the characteristics of the psycho-functional state of the decision maker, external factors and the quality of his activity complicates the task of constructing mathematical models for assessing the mutual influence of these factors on the process of making appropriate decisions.

In works [8, 9] an algorithm for increasing the efficiency of interaction between an operator and technical devices in "man-machine" systems is proposed, which allows solving the problem of ensuring the efficiency of managing complex technical and production systems under conditions of fuzzy risk. The results of studies of the influence of the functional state of operators on efficiency and quality in the "man-machine" systems are presented. Based on the above analysis, it was concluded that it is necessary to develop modern methods for improving efficiency, taking into account the dependence of the functional state of operators on the influence of external and internal factors on the process of making adequate decisions.

In literature [10, 11] issues considered determination of a comfortable working environment for the decision maker during the operation of the system. Developments on the creation of mathematical models and algorithms for assessing the relevance of decisions taken are considered in detail, taking into account the influence of external and personal factors on the safety of HMS. Algorithms for formalizing the relationship between external factors and psycho-functional characteristics of decision makers are

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proposed to optimize decision making. But all this does not make it possible to describe with maximum accuracy the factors for which there are no known exact patterns and for which it is necessary to make an association between qualitative and quantitative assessments of factors affecting the effectiveness of HMSCA.

Common questions analyzed building fuzzy cognitive models of information technology to determine and evaluate the influence of factors on the DMP in multilevel HMSCA using [12].

Determination of the functional dependence of the effectiveness of multi-level systems of critical purpose on the influence of external factors and the fuzzy risk of making inadequate decisions by the decision maker, as well as the construction of fuzzy cognitive models of DMP under conditions of fuzzy risk is considered in [13–17]

In [18–20] the development of mathematical models and algorithms for determining and evaluating the optimal influence of external factors of the working environments on the cognitive state of decision makers.

Based on the analysis of literary sources, it is noted that in order to overcome the difficulties caused by uncertain factors (inaccuracy, fuzziness) for solving assessment problems their influence on DMP, in a multilevel HMSCA is a need to improve and develop new modern methods of work efficiency HMSCA. It is advisable to apply DS methods using “soft computing”, the methodology of cognitive and fuzzy cognitive modeling, which provides an acceptable formalization of uncertainty due to the presence of subjective judgments of experts.

3 MATERIALS AND METHODS

Because acceptance decisions defined by many influence factors external and production environment and factors characterizing the current psychological and cognitive state of the decision maker, then one of stages of assessing its relevance is to identify cause-and-effect relationships and dependencies between these factors.

The information model of the above factors of influence on the DMP is shown in Figure 1.

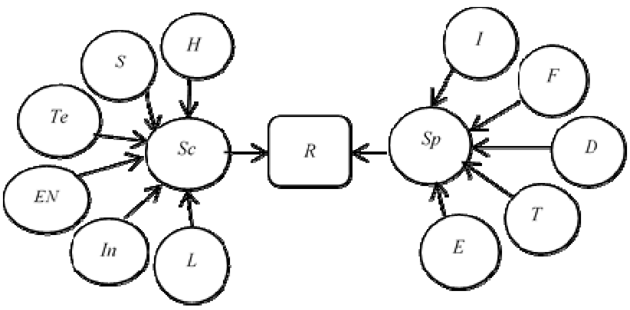

Figure 1 – Information model of the influence of factors on the DMP

Here S_e=$f(H,S,Te,EN,In,L)$ is a function that characterizes the influence of external and production factors; S_p= $f(I,F,D,T,E)$ is a function that characterizes the influence of psychological and cognitive factors on the state of decision makers, and R=$f(H,S,Te,EN,In,L,F,D,T,E)$ is a function that characterizes the degree of relevance of decisions made by decision makers.

Exploring and revealing causal relationships and dependencies between the factors of the information model allows building the following relational model, Fig. 2.

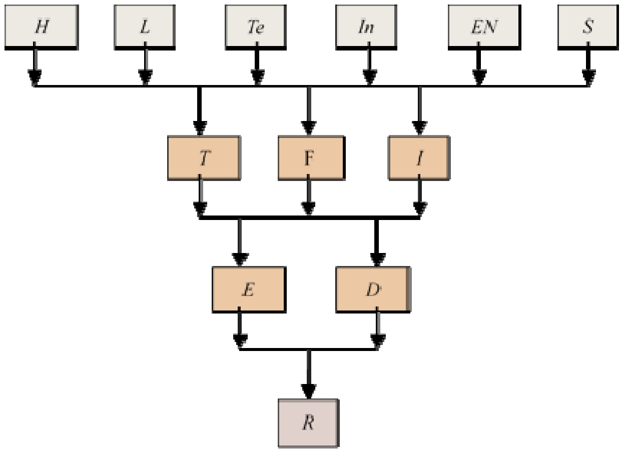

Figure 2 – Relational model of mutual influence of factors on the MRD

In [21] Bayesian Belief Networks are used as a mathematical tool, which have shown themselves well in modeling complex systems with uncertainties.

BBN is a probabilistic graphical model, which is a set of random variables and their conditional probabilities using an acyclic directed graph.

For any set of random variables (vertices) $A_1, A_2,\ldots,A_n$ of a Bayesian belief network, the probability of joint distribution is calculated from conditional probabilities according to the chain rule as follows:

$$P(A_1,\ldots,A_n)=\prod_{i=1}^{n}P(A_i|\ Parents(A_i)) \quad (1)$$

To calculate the probability that a variable B takes on the value b_j on a BBN consisting of vertices $B, A_1,\ldots,A_n$ the formula is used:

$$P(B=b_j)=\sum_{A_1,\ldots,A_n}P(B=b_j,A_1,A_2,\ldots,A_n). \quad (2)$$

Here the summation is over all values of the variables $A_1, A_2,\ldots, A_n$. Taking into account (1), formula (2) for calculating the probability at the vertex B takes the form:

$$P(B=b_j)=\sum_{A_1,\ldots,A_n}P(B=b_j|\ Parents(B))\times \times\prod_{i=1}^{n}P(A_i|\ Parents(A_i)) \quad (3)$$

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These formulas are enough to perform direct inference on a Bayesian network, i.e. determining the probability of the values of the vertex-leaf by the known probabilities of the values of the input (root) vertices and the conditional probabilities of the values of the remaining vertices of the BBN.

Based on the relational model of the mutual influence of factors on the adoption of appropriate decisions, a Bayesian trust network is built (Fig. 3) to assess the MRD.

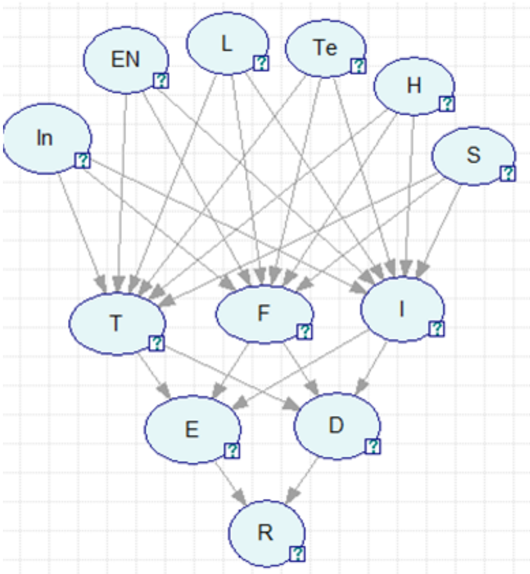

Figure 3 – BBN for a MRD Evaluation

The vertices of the BBN (Fig. 3) have the same names as the vertices of the relational model (Fig. 2). All vertices of the proposed BBN, with the exception of vertex R, take on two values: <vertex name>$_1$=“within normal limits”. <vertex name>$_2$=“out of normal limits”. For example, if the vertex *In* takes the value $in_{1,}$ then it means, that the intensity and level of noise are within the normal range. If the vertex *In* takes the value in_2, then it means, that the intensity and level of noise are outside the norm. Vertex *R* takes values r_1 =“irrelevant”. r_2 = “relevant”.

Since the values of the unconditional probabilities of the root vertices *In*, *EN*, *L*, *Te*, *H*, *S* and conditional probabilities of vertices *T*, *F*, *I*, *E*, *D*, *R* established on the basis of the results of an expert survey, they are defined vaguely. Therefore, fuzziness is introduced into the Bayesian network (Fig. 3) by replacing the probabilities of states with fuzzy numbers, and ordinary arithmetic operations on real numbers with extended operations on fuzzy numbers [22].

All unconditional and conditional probabilities of the considered Bayesian network are estimated by fuzzy intervals $\widetilde{N}(n_1, n_2, n_3, n_4)$ defined on the universal set $\{x|0\leq x \leq 1\}$, where *x* is a probability of a vertex states. In this case, the membership function of these intervals is given by the formula (4):

$$\mu_L(x) = \begin{cases} 0, & x < 0, \\ \dfrac{x-n_1}{n_2-n_1}, & n_1 \leq x \leq n_2, \\ 1, & n_2 \leq x \leq n_3, \\ \dfrac{n_4-x}{n_4-n_3}, & n_3 < x \leq n_4, \\ 0, & x > 1, \end{cases} \tag{4}$$

where $n_1 \leq n_2 \leq n_3 \leq n_4$ are some real numbers, and $0 \leq n_2 \leq n_3 \leq .1$; n_2, n_3 are lower and upper modal values, respectively; $n_2 - n_1$, $n_4 - n_3$ are left and right fuzziness coefficients of a fuzzy interval $\widetilde{N}(n_1, n_2, n_3, n_4)$. In particular, if $0 \leq n_1 \leq n_2 \leq n_3 \leq n_4 \leq 1$, then the membership function (4) defines a trapezoidal fuzzy number.

Rules for addition and multiplication of fuzzy intervals $\widetilde{N}(n_1, n_2, n_3, n_4)$ and $\widetilde{P}(p_1, p_2, p_3, p_4)$, determined by the membership functions (4), when using the principle of generalization to arithmetic operations take the form (5).

$$\begin{aligned} &\widetilde{N}(n_1,n_2,n_3,n_4)\,\widetilde{\oplus}\,\widetilde{P}(p_1,p_2,p_3,p_4) = \\ &= \widetilde{S}(n_1+p_1, n_2+p_2, n_3+p_3, n_4+p_4), \\ &\widetilde{N}(n_1,n_2,n_3,n_4)\,\widetilde{\oplus}\,\widetilde{P}(p_1,p_2,p_3,p_4) = \\ &= \widetilde{H}(n_2p_2-\alpha, n_2p_2, n_3p_3, n_3p_3+\beta), \\ &\alpha = n_2(p_2-p_1)+p_2(n_2-n_1), \\ &\beta = n_3(p_4-p_3)+p_3(n_4-n_3). \end{aligned} \tag{5}$$

If it is necessary to compare fuzzy probabilities, it is considered that of the two fuzzy probabilities, the one whose defuzzified value of the membership function is greater is greater. As a defuzzification method, the center of maxima method is used, which consists in finding the arithmetic mean of the elements of the universal set that have the maximum degrees of membership. This method is for fuzzy numbers $\widetilde{N}(n_1, n_2, n_3, n_4)$ with membership function (4) gives:

$$N = \frac{\int_{n_2}^{n_3} x\,dx}{\int_{n_2}^{n_3} dx} = \frac{n_2+n_3}{2}. \tag{6}$$

In (6) *N* is the result of defuzzification, the “exact” value of the fuzzy number.

When calculating fuzzy probabilitie $\widetilde{P}_f$ at the vertices of the Bayesian network, formulas (1), (3) are transformed by replacing the probabilities of states with fuzzy numbers, and ordinary arithmetic operations on real numbers with extended operations on fuzzy numbers, into formulas for calculating the fuzzy joint probability distribution and fuzzy probability, respectively:

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$$\widetilde{P}_f(A_1,\dots,A_n) \cong \widetilde{\bigoplus_{i=1}^{n}} \widetilde{P}_f(A_i \mid Parents(A_i)). \tag{7}$$

$\widetilde{\bigotimes_{i=1}^{n}} A_i$ denotes the product of fuzzy numbers $A_1,\dots, A_n$, i.e. $\widetilde{\bigotimes_{i=1}^{n}} A_i = A_1 \widetilde{\otimes} A_2 \widetilde{\otimes} \dots \widetilde{\otimes} A_n$.

$$\widetilde{P}_f(B=b_j) \cong \widetilde{\bigoplus_{A_1,\dots,A_n}} \widetilde{P}_f(B=b_j \mid Parents(B)) \widetilde{\otimes} \widetilde{\oplus}\left[\widetilde{\bigoplus_{i=1}^{n}} \widetilde{P}_f(A_i \mid Parents(A_i))\right]. \tag{8}$$

Expression (7) is called the chain rule for the fuzzy joint probability distribution. Formula (8) makes it possible to calculate the fuzzy probability at the vertex B, which takes the value b_j, on the BBN, which consists of vertices $B, A_1,\dots,A_n$.

It should be noted that for ease of determining conditional probabilities by experts, it is considered that the conditional probability at any vertex depends on the values of the parent vertices individually, and not on the joint distribution of the values of these vertices. Then, if among the vertices $A_1,\dots,A_n$ only the vertex A_1 has parent peaks and these peaks are peaks $A_2, A_3,\dots,A_n$, then the last assumption allows rewrite formula (7) as:

$$\widetilde{P}_f(A_1,\dots,A_n) \cong \widetilde{\bigotimes_{i=2}^{n}} \widetilde{P}_f(A_i) \widetilde{\bigotimes_{j=2}^{n}} \widetilde{P}_f(A_1 \mid A_j) \tag{9}$$

In the following, a simplified Bayesian network will be considered as an example (Fig. 4).

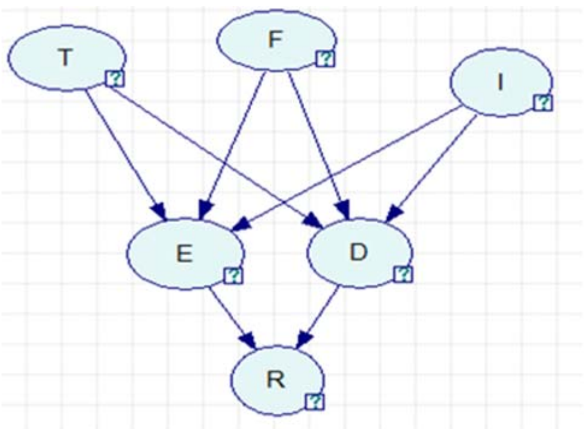

Figure 4 – Fragment of fuzzy BBN

The procedure for calculating the probability values for this Bayesian network includes the following steps. At the first stage, using (7)–(9), the fuzzy total probabilities of the vertices E, D, which have 3 parent vertices T, F, I are calculated:

$$\begin{aligned}\widetilde{P}_f(E=e_2) &\cong \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(e_2 \mid T,F,I) = \\ &= \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(e_2 \mid T,F,I) = \\ &= \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(e_2 \mid T) \widetilde{\otimes} \\ &\widetilde{\otimes} \widetilde{P}_f(e_2 \mid F) \widetilde{\otimes} \widetilde{P}_f(e_2 \mid I).\end{aligned} \tag{10}$$

$$\begin{aligned}\widetilde{P}_f(D=d_2) &\cong \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(d_2,T,F,I) = \\ &= \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(d_2 \mid T,F,I) = \\ &= \widetilde{\bigoplus_{T,F,I}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(d_2 \mid T) \widetilde{\otimes} \\ &\widetilde{\otimes} \widetilde{P}_f(d_2 \mid F) \widetilde{\otimes} \widetilde{P}_f(d_2 \mid I).\end{aligned} \tag{11}$$

According to formulas (10–12) in the MATLAB environment, the values of the fuzzy probability of the nodes of the network under consideration were calculated. Then, using formula (7), the defuzzification values of these probabilities were calculated. Based on the defuzzification value of the probability $P(R=r_2)$, a conclusion was made about the degree of relevance of the decision made by the decision maker.

At the second stage, with (7)–(9) the fuzzy total probabilities of the leaf-vertex are calculated:

$$\begin{aligned}\widetilde{P}_f(R=r_2) &\cong \widetilde{\bigoplus_{T,F,I.E.O}} \widetilde{P}_f(r_2,T,F,I,E,D) = \\ &= \widetilde{\bigoplus_{T,F,I,F,D}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(E \mid T,F,I) \widetilde{\otimes} \\ &\widetilde{P}_f(D \mid T,F,I) \widetilde{\otimes} \widetilde{P}_f(r_2 \mid E,D) = \\ &= \widetilde{\bigoplus_{T,F,I,E,D}} \widetilde{P}_f(T) \widetilde{\otimes} \widetilde{P}_f(F) \widetilde{\otimes} \widetilde{P}_f(I) \widetilde{\otimes} \widetilde{P}_f(E \mid T) \widetilde{\otimes} \\ &\widetilde{\otimes} \widetilde{P}_f(E \mid F) \widetilde{\otimes} \widetilde{P}_f(E \mid I) \widetilde{\otimes} \widetilde{P}_f(D \mid T) \widetilde{\otimes} \widetilde{P}_f(D \mid F) \widetilde{\otimes} \\ &\widetilde{\otimes} \widetilde{P}_f(D \mid I) \widetilde{\otimes} \widetilde{P}_f(r_2 \mid E) \widetilde{\otimes} \widetilde{P}_f(r_2 \mid D).\end{aligned} \tag{12}$$

4 EXPERIMENTS

To test the proposed model, numerical experiments were carried out, the essence of which was as follows.

Specialist experts were asked to evaluate the unconditional and conditional probabilities of the possible states of the factors influencing the decision maker for the process of making relevant decisions. The results are presented as fuzzy values of unconditional $\widetilde{P}_f(T)$, $\widetilde{P}_f(F)$, $\widetilde{P}_f(I)$ and conditional probabilities in Tables 1–3.

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5 RESULTS

Numerical experiments were carried out for two characteristic cases. In the first case, the probability values that the decision maker is in a state of significant fatigue (factor *T*) or significant psychological tension (factor *F*) were taken low, and the susceptibility of the decision maker to informational stress was considered unlikely. In the second case, the probability value that the decision maker is in a state of significant fatigue (factor *T*) was considered high. The results of numerical calculations are given in Table 2 and Table 3.

Table 2 shows that in the first case, the probability of implementing the relevant decision of the DM is equal to $P(R=r_2)=0.78$.

In accordance with the results of research in the literature and normative sources, for many human-machine systems of critical application, at a probability value $P(R=r_2)\geq 0.7$, the decision taken is considered relevant.

In the second case, as can be seen from Table 3, the probability of making a relevant decision is $P(R=r_2)=0.56$, which is less than 0.7. Therefore, in this case, it cannot be considered that the decision made by the decision maker is relevant.

Table 1 – The result of evaluating fuzzy conditional probabilities at nodes *E, D, R*

	Fuzzy probability value		Fuzzy probability value	
	Vertex *E*		Vertex *D*	
T	$\widetilde{P}_f(E=e_1\,\vert\,T)$	$\widetilde{P}_f(E=e_2\,\vert\,T)$	$\widetilde{P}_f(D=d_1\,\vert\,T)$	$\widetilde{P}_f(D=d_2\,\vert\,T)$
t_1	(0.7; 0.8; 0.9; 1.0)	(0.0; 0.1; 0.2; 0.3)	(0.3; 0.4; 0.4; 0.5)	(0.5; 0.6; 0.6; 0.7)
t_2	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)
F	$\widetilde{P}_f(E=e_1\,\vert\,F)$	$\widetilde{P}_f(E=e_2\,\vert\,F)$	$\widetilde{P}_f(D=d_1\,\vert\,F)$	$\widetilde{P}_f(D=d_2\,\vert\,F)$
f_1	(0.4; 0.5; 0.6; 0.7)	(0.3; 0.4; 0.5; 0.6)	(0.1; 0.2; 0.3; 0.4)	(0.6; 0.7; 0.8; 0.9)
f_2	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)
I	$\widetilde{P}_f(E=e_1\,\vert\,I)$	$\widetilde{P}_f(E=e_2\,\vert\,I)$	$\widetilde{P}_f(D=d_1\,\vert\,I)$	$\widetilde{P}_f(D=d_2\,\vert\,I)$
i_1	(0.1; 0.2; 0.3; 0.4)	(0.6; 0.7; 0.8; 0.9)	(0.0; 0.1; 0.2; 0.3)	(0.7; 0.8; 0.9; 1.0)
i_2	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)	(0.0; 0.0; 0.0; 0.0)	(1.0; 1.0; 1.0; 1.0)
	Vertex *R*			
E	$\widetilde{P}_f(R=r_1\,\vert\,E)$		$\widetilde{P}_f(R=r_2\,\vert\,E)$	
e_1	(0.4; 0.5; 0.6; 0.7)		(0.3; 0.4; 0.5; 0.6)	
e_2	(0.0; 0.0; 0.0; 0.0)		(1.0; 1.0; 1.0; 1.0)	
D	$\widetilde{P}_f(R=r_1\,\vert\,D)$		$\widetilde{P}_f(R=r_2\,\vert\,D)$	
d_1	(0.2; 0.3; 0.4; 0.5)		(0.5; 0.6; 0.7; 0.8)	
d_2	(0.0; 0.0; 0.0; 0.0)		(1.0; 1.0; 1.0; 1.0)	

Table 2 – The results of calculating the probabilities in the nodes of the fuzzy BBN in the first case

Values of the BBN vertices	Fuzzy probability value	Defuzzification result	Values of the BBN vertices	Fuzzy probability value	Defuzzification result
T			*F*		
	$\widetilde{P}_f(T)$	*P*(*T*)		$\widetilde{P}_f(F)$	*P*(*F*)
t_1	(0.1; 0.2; 0.2; 0.3)	0.2	f_1	(0.2; 0.3; 0.3; 0.5)	0.3
t_2	(0.7; 0.8; 0.8; 0.9)	0.8	f_2	(0.5; 0.7; 0.7; 0.8)	0.7
I			*E*		
	$\widetilde{P}_f(I)$	*P*(*I*)		$\widetilde{P}_f(E)$	*P*(*E*)
i_1	(0.0; 0.1; 0.1; 0.3)	0.1	e_1	(–0.2;0.3;0.35;0.85)	0.32
i_2	(0.7; 0.9; 0.9; 1.0)	0.9	e_2	(0.15; 0.65; 0.7; 1.2)	0.68
D			*R*		
	$\widetilde{P}_f(D)$	*P*(*D*)		$\widetilde{P}_f(R)$	*P*(*R*)
d_1	(–0.54; 0.14; 0.18; 0.85)	0.16	r_1	(–1.65;0.14; 0.3; 1.81)	0.22
d_2	(0.15; 0.82; 0.86; 1.54)	0.84	r_2	(–0.81; 0.7; 0.86; 2.65)	0.78

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Table 3 – The results of calculating the probabilities in the nodes of the fuzzy BS in the second case

Values of the BBN vertices	Fuzzy probability value	Defuzzification result	Values of the BBN vertices	Fuzzy probability value	Defuzzification result
T			*F*		
	$\widetilde{P}_f(T)$	*P*(*T*)		$\widetilde{P}_f(F)$	*P*(*F*)
t_1	(0.5; 0.7; 0.7; 0.8)	0.7	f_1	(0.2; 0.3; 0.3; 0.5)	0.3
t_2	(0.2; 0.3; 0.3; 0.5)	0.3	f_2	(0.5; 0.7; 0.7; 0.8)	0.7
I			*E*		
	$\widetilde{P}_f(I)$	*P*(*I*)		$\widetilde{P}_f(E)$	*P*(*E*)
i_1	(0.0; 0.1; 0.1; 0.3)	0.1	e_1	(0.19; 0.63;0.71;1.04)	0.67
i_2	(0.7; 0.9; 0.9; 1.0)	0.9	e_2	(–0.04; 0.29; 0.37; 0.81)	0.33
D			*R*		
	$\widetilde{P}_f(D)$	*P*(*D*)		$\widetilde{P}_f(R)$	*P*(*R*)
d_1	(–0.38; 0.33; 0.36; 1.02)	0.34	r_1	(–1.16; 0.34; 0.54; 1.63)	0.44
d_2	(–0.02; 0.64; 0.67; 1.38)	0.66	r_2	(–0.63; 0.46; 0.66; 2.16)	0.56

6 DISCUSSION

The obtained results of numerical experiments are in good agreement with practical decision-making situations in critical systems. In the first case, the negative impact of cognitive factors on decision makers was low. Therefore, the decision maker made the relevant decision with sufficient probability. At the same time, it was not required to adjust the degree of negative impact of factors affecting the decision maker. In the second case, the negative impact of one of the cognitive factors became high. This led to the fact that the decision taken by the decision maker cannot be considered relevant. In this case, it is necessary to correct the degree of negative impact on the decision maker of the corresponding factor in accordance with engineering and psychological recommendations and requirements.

Thus, the results of the experiments make it possible to recommend the use of the developed model, which takes into account the mutual influence of factors of various nature on the decision-making process of the decision maker, to improve the efficiency of the management of the HMSCA as a whole.

CONCLUSIONS

The actual scientific and applied problem of assessing the influence of factors of various nature, including cognitive ones, on the decision-making process of the decision maker to improve the efficiency of the management of the HMSCA as a whole has been solved.

The scientific novelty of the results obtained lies in the fact that for the first time:

– fuzzy hierarchical relational cognitive models are proposed that allow assessing the impact of qualitative and quantitative factors of various nature, including cognitive ones, on the decision-making process of decision makers;

– to assess the influence of fuzzy factors on the relevance of decision-making, a fuzzy BBN is proposed and an algorithm for calculating the fuzzy probabilities of its nodes is developed.

The practical significance of the results obtained lies in the fact that the proposed fuzzy hierarchical relational cognitive models can be recommended for assessing the influence of environmental factors and cognitive parameters of decision makers on the decision-making process in human-machine systems of critical application.

Prospects for further research are to develop of tools and methods for modeling and regulating the process of making relevant decisions in real time and uncertainty to improve the efficiency of functioning of human-machine systems of critical application.

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ОЦІНКА ВПЛИВУ НЕЧІТКИХ ФАКТОРІВ НАВКОЛИШНЬОГО СЕРЕДОВИЩА НА ПРОЦЕС ПРИЙНЯТТЯ РІШЕНЬ В ЛЮДИНО-МАШИННИХ СИСТЕМАХ КРИТИЧНИХ ЗАСТОСУВАНЬ

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АНОТАЦІЯ

Актуальність. Особливість людино-машинних систем критичного застосування, що працюють в режимі реального часу, полягає в тому, що в якості елементів вони включають як технічні системи, так і людей, що взаємодіють з цими системами. При цьому основні труднощі пов’язані не тільки з удосконаленням апаратного і програмного забезпечення, але і з недостатньою розробленістю методів достовірного прогнозування впливу виробничого середовища на людський фактор і, як наслідок, на релевантність рішень, прийнятих особами, що приймають рішення. В результаті задача розробки способів визначення взаємного впливу факторів зовнішнього середовища і когнітивних параметрів ОПР, на процес прийняття рішень стає актуальною.

Мета роботи – методологічна основа розробки та дослідження нечітких ієрархічних реляційних когнітивних моделей для визначення впливу факторів навколишнього середовища та когнітивних параметрів осіб, що приймають рішення, на процес прийняття рішень.

Метод. При побудові нечітких ієрархічних реляційних когнітивних моделей використані методи «м’яких обчислень», методологія когнітивного і нечіткого когнітивного моделювання, які забезпечують прийнятну формалізацію невизначеності взаємного впливу факторів на процес прийняття рішень.

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Результати. Розроблені нечіткі когнітивні моделі на основі нечітких байєсівських мереж довіри, які дозволяють провести зв'язок між якісними та кількісними оцінками факторів взаємного впливу на процес прийняття рішень особами, що приймають рішення. Запропоновані моделі мають можливість імовірнісного прогнозування впливу факторів і вибору раціональних способів їх взаємодії в процесі прийняття рішень.

Висновки. Результати експериментів дозволяють рекомендувати розроблені моделі, що враховують взаємний вплив факторів різної природи, в тому числі когнітивних, на процес прийняття рішень особами, що приймають рішення, та підвищують ефективність управління в людино-машинних системах критичного застосування в цілому.

КЛЮЧОВІ СЛОВА: людино-машинні системи критичного застосування, прийняття рішень, релевантні рішення, нечіткі когнітивні моделі, фактори навколишнього середовища, фактори робочого середовища, реляційні когнітивні моделі, особа що приймає рішення.

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