Chapter 8

Decision-Making Problems in Sociotechnical Systems

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Additional information is available at the end of the chapter

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Abstract

The object of research is a human in complex sociotechnical systems (STS). A particular case of the sociotechnical system is the human-machine system (HMS). The subject of research is the professional activity of a person in the sociotechnical system, the structure of his professionally important qualities, the methods of assessing the professional suitability of a person, and the methods of training and training of operational personnel. The model of vocational aptitude and the process of decision-making in the class of hierarchical systems were developed based on the hierarchy analysis method. Intelligent processing of data was requested to be carried out by the use of decision support systems, which provides support to multicriteria decision in a complex system. The experimental research of vocational aptitude assessment for operators of transport-technological machines was carried out. The outputs of the decision support systems were obtained individual operator's portraits (IOP) and integrated estimation capabilities. As a result, it became possible to reduce the preparation cost of professionals and to raise the level of the operator's professional skills. In addition, based on the IOP, we can customize the HMC interface.

Keywords: man-machine systems, human-operator, professionally important qualities, decision-making

1. Introduction

Nowadays, it becomes evident that the future of our civilization to a great extent depends on the global community's capacity to mitigate technology-related hazards inherent to the contemporary technological level of manufacturing processes.

The objectives of technogenic safety and concerns for technology-related hazards become the issues of international importance that is proved by the specific activity of the UN Economic

Commission for Europe and by the Convention on the Transboundary Effects of Industrial Accidents signed by 72 countries.

Technological inferiority, obsolescence, and depreciation of technological equipment and its usage under potentially hazardous conditions, low qualified, and undertrained operational personnel—all these can stipulate high probability of technogenic accidents and industrial disasters practically in all the branches of production. At the same time, it is well-known that remediation of consequences even of smaller accidents costs 30 times more expensive than their prevention and preliminary mitigation of their risks.

Solution of some particular issues related to safety of separate subsystems of a technogenic object does not result in its sufficient reliability as a whole and does not meet the contemporary requirements to safety.

Thus, the modern society faces the need for a new methodological approach to ensuring comprehensive safety of a technogenic object and all its subsystems, which is the only ground for the desired effect in the scale of the whole industrial sector.

A contemporary technogenic object is a complex dynamic system being a combination of separate subsystems (that are different from each other by the elaboration level, energy type, organizational system, etc.) and connections between them.

According to this, the first objective of assuring reliability of a technogenic object is an analysis of its structure, revealing critical areas most prone to emergences and identifying the direction of the security effort.

The literature review shows that the modern concept of *reliability of technogenic objects* is based on the theory of sociotechnical systems (STS); where, *STS* refers to a complex operating system including a human-operator as its integral part, and the main objective is optimal distribution of functions between the operator and the device and their mutual complementation.

The analysis of accidence in the STS states that over 56% of accidents are caused by a human factor, and as for the STS of moving objects, their accidence index rises up to 70% including 80% of accidents caused by a human-operator (HO) working under tension, off-nominal conditions, or time pressure.

Consequently, as one of the most important STS subsystems HO in fact determines the quality of STS's functioning and restricts its performance, reliability, and effectiveness, and therefore, the problem of evaluation and assurance of HO reliability within STS is considered to be important and currently central.

An analysis of the HO's activity, evaluation of their reliability and a dynamic forecast of effectiveness of their vocational functions make it possible to assure a higher-level integration of a person with a technical or informational system, to implement a human-oriented design of newly developed STSs, and can predetermine the development of adaptive human-machine interfaces.

According to this, the first objective of assuring STS's reliability is an analysis of its structure, revealing critical areas most prone to emergences and identifying the direction of the security effort, particularly within the distribution of functions between HO and a machine, the organization of HO's work and support of an operator's activity.

2. Issues of man: machine interaction

A significant number of research investigations are dedicated to the issue of man-machine interaction. Mostly, the emphasis is made on man-machine systems (MMS). The term *man-machine system* refers to a system that includes a human-operator, a machine, which they use for their work activity, and a working site environment. The operator's working site environment is a combination of physical, chemical, biological, and psychological factors that impact on the operator at their working site during their activity.

As for STS, we accept a wider definition of this term: systems of man-machine-environment-society-culture-nature interaction, **Figure 1**.

Therefore, in a broad sense of assuring comprehensive technogenic safety it is more appropriate to use the term *STS*, and from the point of view of assuring compatibility of a man and a technical system it is reasonable to use the concept of *man-machine system*.

HO refers to the personnel; *Machine* refers to technological equipment; *Work environment* refers to the space where they function; *Technology* refers to a combination of techniques used for modifying of a work object and including safety measures; *External environment* is everything beyond MMS that can affect the MMS's functioning and, in turn, may alter due to the MMS's functioning.

One of the system objects is a human-operator, and their involvement is determined by the following generally known factors:

- a person sets the purpose of functioning of both the control object and the operation system and controls them for attaining this purpose;

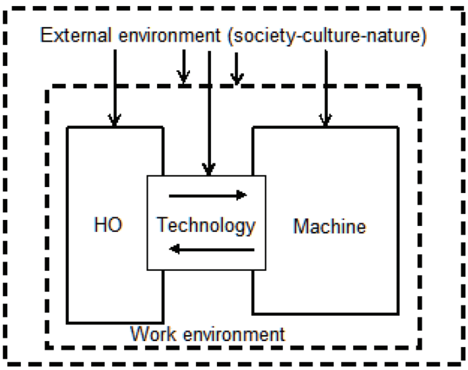

Figure 1. Scheme of sociotechnical systems.

- due to a number of reasons STS cannot be absolutely reliable, therefore the operator's involvement is necessary for control, diagnostics, search for and trouble shooting.
- due to imperfection of our knowledge about all the STS processes the external environment may produce the situations, which are called algorithmically unsolvable.

Assurance of human-operator efficiency is a sophisticated problem. From the systematic point of view, an operator is a complex, dynamic, stochastic, nonlinear, nonsteady, and self-organizing open system. In this connection, we face a challenge of revealing informative parameters that can ensure accurate and confident evaluation of the system activity as a whole. Besides, we should take into consideration the diversity of STSs implying the diversity of operational activities.

The main advantages of a man and a machine over each other are generally known and can be expressed as the following formulas:

- a man is capable to simultaneously perceive information both by separate analyzers and by their combination (sight, hearing, etc.), a man is capable to differentiate signals by their main and additional attributes; a man typically has a number of activity programs for consideration of attitudes and factors of the environment that can help fulfill operations under the conditions when it is difficult or impossible to predict the machine work;
- a machine assures high-quality programmed operations and functioning under the conditions that are impossible for a man.

It is obvious that within a firmly standardized technological process the abilities of technical systems prevail over the abilities of a man that results in developing automatic control systems. Under conditions of ambiguity and incomplete information, as well as in critical situations, the abilities of a man prevail over the abilities of technical systems.

In general, most researchers admit the dominating role of the anthropocentric approach to a man and technical systems that can be opposed to the machine-centered- or technocentric-approach.

The reasonability of the anthropocentric approach is determined by changes of both qualitative and quantitative parameters of the man and machine activities. Thus, particularly, work of the contemporary human-operator in STS is marked by the increase in the number of control objects and their parameters, in the capacity of symbolic information, in the speed and elaboration of control processes, which raise demands for operators' accuracy and response rate, their responsibility for the results of their own actions. In this context, we can observe the increase of the memory span and speed-of-response with associative mentality and brain structure interaction giving a cumulative effect in the development of human intelligence.

Severization of requirements to human-operator efficiency resulted in new forms and technologies of personnel training [1, 2], in particular, the technology of the virtual and introduced realities [3], the technology of biomechanical and cognitive support for the operator [4, 5].

The review of research literature shows that a typical causal chain of technogenic accidents is the following sequence of prerequisite events: an error of a person, equipment failure and/or an external adverse impact, emerging of a hazard (an energy or substance flow) in an unexpected place and/or in a wrong time; absence or defects of the protective equipment intended for such cases and/or improper actions of people in such situation; expansion or impact of hazardous factors on unprotected equipment, people and/or environment; damage to human, material, or natural resources due to deterioration of their properties and/or integrity [6].

At the same time, accuracy of operator's actions depends on many factors [7]:

- tight time (frequency of errors in information processing is a logarithm function of the information rate);
- information overload (a number of errors increases by overload, particularly, when the number of information sources increases);
- qualification (operators with higher qualification make on average less errors);
- psychological characteristics of a person (for example, if a person is interested in the work they are doing, as a rule, they make less errors);
- sensory impoverishment (an increase in the frequency of errors during long-time monotonous work due to a low load of sensory receptors).

According to the statistical analysis, the probability of operator's errors in working with elaborated technical equipment may be up to 0.15, while in working with simple devices—from 0.01 to 0.05 [8].

As it was found out, principles of image formation of visual targets, a signal-to-noise ratio, and perceptive and functional complexity of images influence the effectiveness of object recognition [9, 10] and the effectiveness of operator' activities on the sensory level.

From the point of view of operator's actions, the process of decision-making is the most difficult issue, especially under conditions of imperfect information, critical situations, and tight time.

It is commonly believed that in critical situations an operator can respond using some standard procedures, or under ambiguous conditions using the procedures that include definition and development of action strategies. In such case, the probability of wrong decision-making under conditions of uncertainty is much higher [11].

The functional status of an operator makes a significant influence on proper decision-making, in particular, their stress level [12], and their emotional intelligence [13].

As it was found out, for the successful training and effective professional activity the operator should have professionally important qualities (PIQs) that are defined as physical, anatomic, physiological, psychic, and personal properties necessary for solution of their professional tasks. In this connection, numerous approaches to PIQ evaluation are developed, and they are based on testing and laboratory experiment methods and intended for simulation of an operator's activity.

At the same time, evaluation of the vocational aptitude is a sophisticated problem due to the incomplete and ambiguous information about the operator's vocational aptitude structure, complexity of formalization of the operator's activity, numerous cross-connections between PIQs and criteria of their selection.

3. The model of decision-making on HO's efficiency

Currently, there are sufficient number of models representing HO's activity in the STS structure and their efficiency in the professional activity.

Speaking generally, it is possible to state that evaluation of the HO's vocational aptitude can be based both on the assessment of their PIQ level and on the analysis of their efficiency at different stages of the operational activity.

Such structure of knowledge about the process of vocational aptitude evaluation is related to the hierarchical structures that allow employing bulk information at the certain levels of the hierarchy.

For the purpose of representation and analysis of knowledge about the HO's professional activity in the STS structure, the process of interaction between the human-operator, the technical system, and the environment is represented as a semantic network, **Figure 2**.

As for the term of *act* within the operator's activity, we understand an act within the operator's activity as a completed sequence of individual nonrepeated operator's actions implementing a single control cycle.

According to this, further we consider the operator's activity as a cyclic implementation of such operator's acts.

Taking into account, the known division of the operator's activity into several typical stages, we can assume relevance of division of the operator's act into separate steps (Eq. (1)):

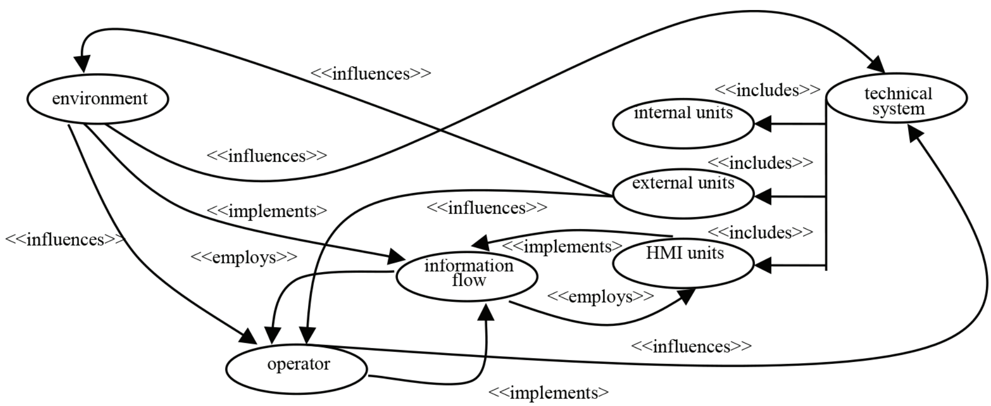

Figure 2. The analysis model of the interaction process within STS.

$$S_t = \{S_{t_i}\}, i = 1, N \quad (1)$$

where St_i is the system element representing a single stage of the operator's activity (*system element* refers to a simplest atomic operation), i is the number of the operator's activity stages.

By means of a generalized structural analysis, the operator's activity is suggested to be divided into a set of hierarchical levels, each of them determines the modification of an operational control model [14, 15], **Figure 3**.

According to this system model, the operator's activity can be considered as sequential execution of the operator's activity stages: acceptance and perception of information, assessment and processing of information, decision-making, and implementation of the decision made.

In this model, the input data are the information from a sensory system about the control object status and the current state of the environment. At this stage of the operator's activity, the operator's actions are subject to the initial program control model.

After the input data are accepted and perceived, at the stage of information assessment and processing the data are transformed into the meaningful data. At this stage, it is possible to initiate a re-regulation process, in case if there is divergence between the accepted data and their admissible starting values specified by the program control model, and to replace the control model by interrupt control.

The control decision on modification of the control program should be made at the stage of decision-making when the situation model is constructed in dependence on the situation development.

Further, at the stage of the made decision implementation, the control impact on the system is formed on the base of the conceptual control model intended for defining the vector of the control impact for the purpose of the implementation of the further control program.

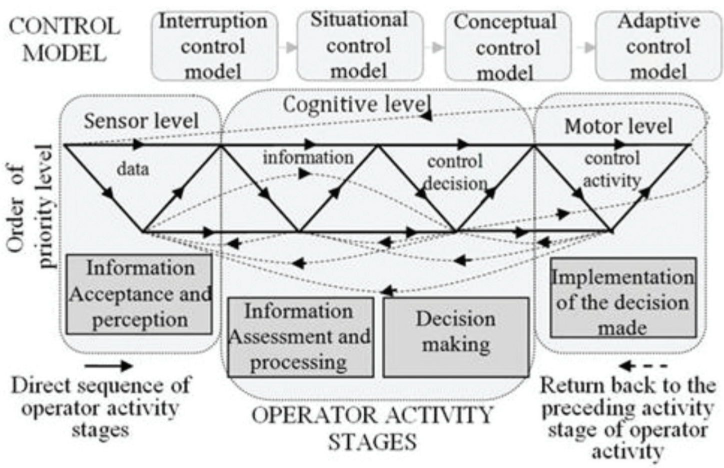

Figure 3. The system model of human-operator functions.

The outcome of this stage is the formation of the adaptive control model intended for defining the value of mismatching between the control impact made by the operator and the changes in the behavior of the control object.

The above described sequence of the actions is represented in the diagram by a solid line indicating the situation development. At the same time, it should be noted that a number of stages may be omitted when the full cycle of the operators' actions is implemented and repeated many times. Besides, it is possible to return to the previous stage of the operator's activity, or recursion. The mentioned situations are represented in the diagram by a dash line; the frequency of such situations, first of all, depends on the operator's experience and their effectiveness at the operator's activity stage. For example, if the control decision-making on the base of the available information is difficult, there is an alternative choice between decision-making under existing ambiguous conditions, additional assessment of the available information or returning to the stage of information acceptance and perception with the aim of data updating.

Obviously, the PIQ set for each certain case should be unique and depend on the specificity of professional work. Nevertheless, the diagram representing the interconnection between the operator's activity stages and the PIQs can be taken as an example for wide range of occupations related with control of moving objects, **Figure 4**.

Among these parameters the emphasis should be made on the following:

- the parameters describing the ability to sensory perception of information;
- the parameters describing the ability to the cognitive activity;
- the parameters describing the ability to the motor activity.

Among the parameters of sensory perception, the parameters describing the sight and hearing perception are the most valuable.

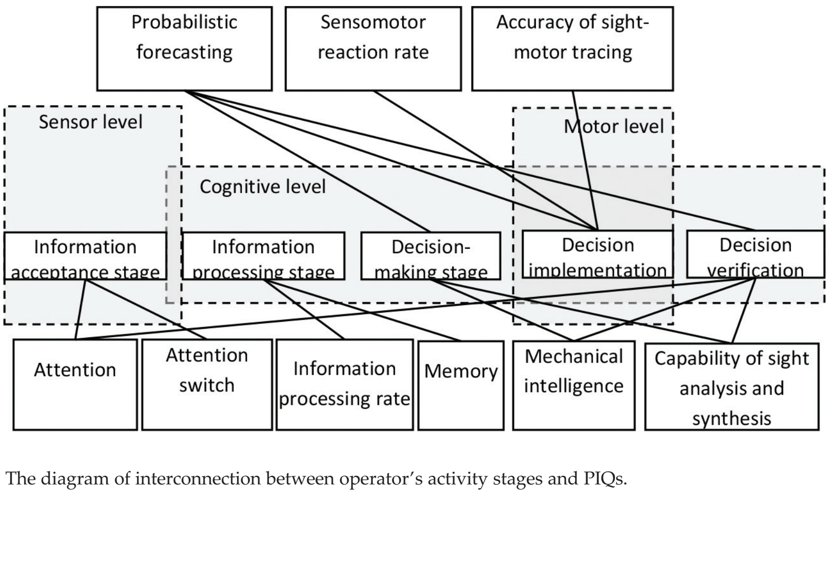

Figure 4. The diagram of interconnection between operator's activity stages and PIQs.

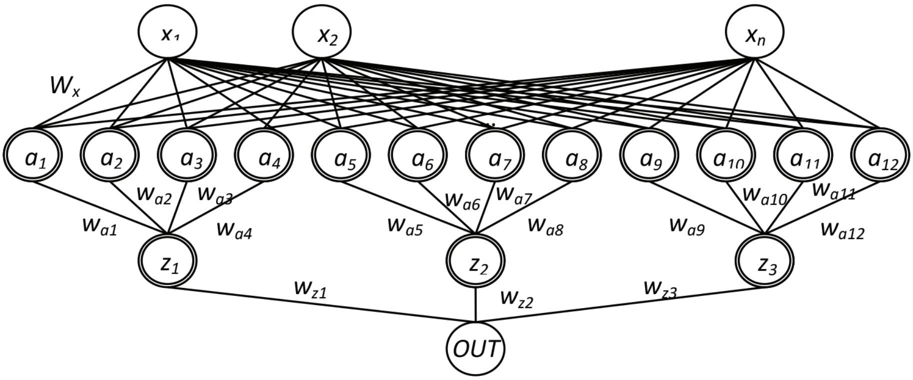

Figure 5. The hierarchical system of the logic inference for the STS operator's vocational aptitude level.

Among the parameters of the cognitive activity, the parameters describing the rate of information processing, memory, mechanical intelligence, and the ability to forecasting the situation development are the most important.

At the motor level, the parameters describing accuracy and the rate of motor program are the most significant.

The analysis of the system model and the pathways of the operator's actions makes it possible to reveal the most significant stages of the specific type of the operator's activity taking into account its peculiarities and to define a set of the operator's functions that determine the effectiveness of the operator's work in the greatest extent as well as to define the correspondence between the priority levels of operator's actions and the stages of the operator's activity.

In order to improve the confidence of vocational aptitude evaluation of the STS operator, the number of PIQs should tend to infinity. On the other side, it causes a combinatorial explosion and excessive complexity of computational algorithms.

According to this, we offer a methodological approach to evaluation of the integral index of vocational aptitude within the hierarchical system class on the base of the analytic hierarchy process; it includes the selection of 12 PIQs that are the most significant for the certain type of the operator's activity and their division into three groups: most important qualities (MIQ), important qualities (IQ), and less important qualities (LIQ), **Figure 5**.

Each group consists of its own set of four PIQs having weighting factors (Eq. (2)):

$$W = (w_1, \ldots, w_n) \tag{2}$$

The dependence of vocational aptitude value on the PIQs is modeled as follows (Eq. (3)):

$$OUT = f(P) = f(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12}) \tag{3}$$

on the basis of four knowledge bases that describe such dependences (Eq. (4)):

$$z_1 = f_2(a_1, a_2, a_3, a_4), z_2 = f_2(a_5, a_6, a_7, a_8), z_3 = f_2(a_9, a_{10}, a_{11}, a_{12}), z = f_3(z_1, z_2, z_3) \qquad (4)$$

In other words, *OUT* is a tree root, the operator's vocational aptitude; z_1, …, z_3—nonterminal nodes, the second stage convolutions; a_1, …, a_{12}—nonterminal nodes, the first stage convolutions; x_1, …, x_n—terminal nodes, individual impact factors, and $W = [W_x = (w_{x_1}, \ldots, w_{x_n}), W_y = (w_{y_1}, \ldots, w_{y_n}), W_z = (w_{z_1}, w_{z_2}, w_{z_3},)]$—weighting factors.

For assessment of certain PIQs, we suggest employing an analytical laboratory experiment. According to it, a certain fragment of the professional activity is reproduced *in vitro*, while the rest elements are purposefully eliminated, it allows to some extent segmenting the certain stages of the operator's activity.

One of the analytical *in vitro* experiments is testing, or tests. According to the traditional terminology, *test* refers to a task used for verification of the development level of the operator's psychophysiological properties. This type of experiment is usually deployed for investigation of the impact of different conditions on certain elements of the activity.

In this case, we can formally describe the relationships between the PIQs and the assessment tests undertaken for assessing the PIQ development level as follows: $a_i = f(x_1, \ldots, x_n)$, where $(x_1, \ldots, x_n)$ are the results of the assessment tests.

The system output is an integral assessment of the vocational aptitude within the range from 0 to 100%.

In addition to it, we need assessments of the certain PIQ development level within the range from 0 to 100% marking the efficiency of the operator's functions at the different stages and constituting an individual PIQ portrait of a testee.

For this purpose, we offer the inference $A = \{a_1, \ldots, a_{12}\}$, where $\{a_1, \ldots, a_{12}\}$ are the set of certain PIQs constructing an individual psychophysiological portrait of a testee, **Figure 6**.

An individual psychophysiological portrait may be used both for operational personnel training and for adaptive adjustment of an informational and technical component of the ergatic system to the user's abilities taking into account their current functional state.

To accomplish this, the combination of individual psychophysiological portraits that provide the general vocation aptitude level "*not worse than normal*," was defined by using simulation methods.

From the point of view of assuring, the whole system reliability such conditions as "*the PIQ level is not worse than bad*" and "*the PIQ level is not worse than normal*" are chosen as marginal ones.

Under the condition $\mathrm{PIQ}_{\mathrm{ij}}^{\mathrm{testee}} < \mathrm{PIQ}_{\mathrm{ij}}^{\mathrm{norm.}} \mathrm{PIQ}_{\mathrm{ij}}^{\mathrm{test.}} < \mathrm{PIQ}_{\mathrm{ij}}^{\mathrm{norm.}} a_{ij}^{testee} < a_{ij}^{\mathrm{norm.}}$, the controlling action is formed in accordance with the set quality functional. Such controlling action is intended for operational personnel training that is for the development of the certain PIQs ensuring improvement of the general level of the operator's vocational aptitude (Eq. (5)):

$$\Delta a_{ij} = a_{ij}^{norm} - a_{ij}^{testee}, \qquad (5)$$

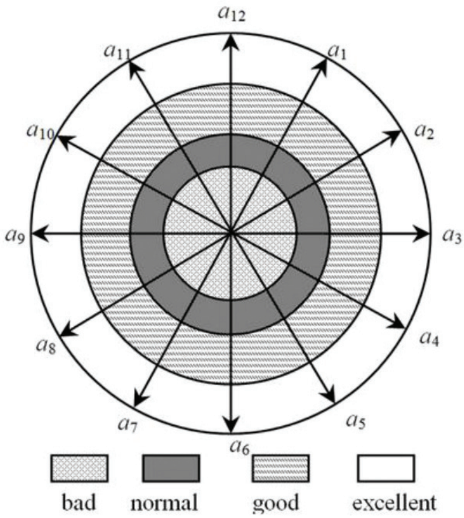

Figure 6. The individual PIQ portrait of the operator.

where $a_{ij}^{testee.}$ is the PIQ development level, a_{ij}^{norm} is the PIQ level "*the PIQ level is not worse than normal*."

So, the quality functional for practicing the certain PIQ of the greatest importance can be presented as the following (Eq. (6)):

$$J1 = \max_{ij \in k} f\left(w_{ij}, c_{ij}, \varphi\left(a_{ij}{}^{testee}, a_{ij}^{norm}\right)\right), \tag{6}$$

where w_i is a weight coefficient of the PIQ significance in the general structure of the vocational aptitude, c_i is a weight coefficient of the PIQ development difficulty that divides the PIQs into developing, conventionally developing, and nondeveloping ones, $\varphi\left(a_{ij}{}^{testee.}, a_{ij}^{norm}\right)$ is a function describing possibilities of the PIQ development in compliance with the initial level law.

The quality functional for practicing the PIQ combination may be presented as follows (Eq. (7)):

$$J2 = \sum_{ij \in k} f\left(w_{ij}, c_{ij}, \varphi\left(a_{ij}{}^{testee.}, a_{ij}^{norm}\right)\right), \tag{7}$$

At the same time, according to the initial level law, $\varphi\left(a_{ij}{}^{testee}, a_{ij}^{norm}\right)$ represents a nonlinear dependence of the possible change of the current a_{ij}^{testee} value on its relative level and may be expressed in the exponent form (Eq. (8)):

$$\varphi\left(a_{ij}^{testee}, a_{ij}^{norm}\right) = \exp\left(a_{ij}^{norm}\right) - \exp\left(a_{ij}^{testee}\right), \tag{8}$$

Practical evaluation of the operator's activity using of the hierarchical system of the logical inference for the STS operator's vocational aptitude level is offered to perform on the base of analyzing the PIQs' development level that have been defined by the test outcomes.

According to this, we face the challenge of developing a decision-making support system, which should connect local assessments from tests with the PIQ assessment and the evaluation of the operator's vocational aptitude in general.

Due to the difficulty of formal expression and structuring of the STS operator's activity both at the certain stages of the operator's activity and in general, it is proposed to use the fuzzy set theory for the operator's vocational aptitude evaluation.

The analysis of possible approaches to handle the problem of evaluation of the operator's activity shows that the use of so-called soft computing is one of the promising approaches to such tasks.

For modeling the operator's vocational aptitude, the mathematic model on the base of the fuzzy logic and the system of fuzzy inference have been developed, **Figure 7**.

In accordance with the proposed inference scheme, we can accept that on the first stage of evaluation the input variable x_i is the values of the assessment test (AT) outcomes (T_i).

We can accept the variation range of the input variable x_i as the universe of discourse. Space partition of the input variables was performed on the base of certain minimal and maximal values of the input variables—the AT values: $x_i \epsilon \left[x_i^{(min)}, x_i^{(max)}\right]$, where $x_i^{(min)}$ is the minimal

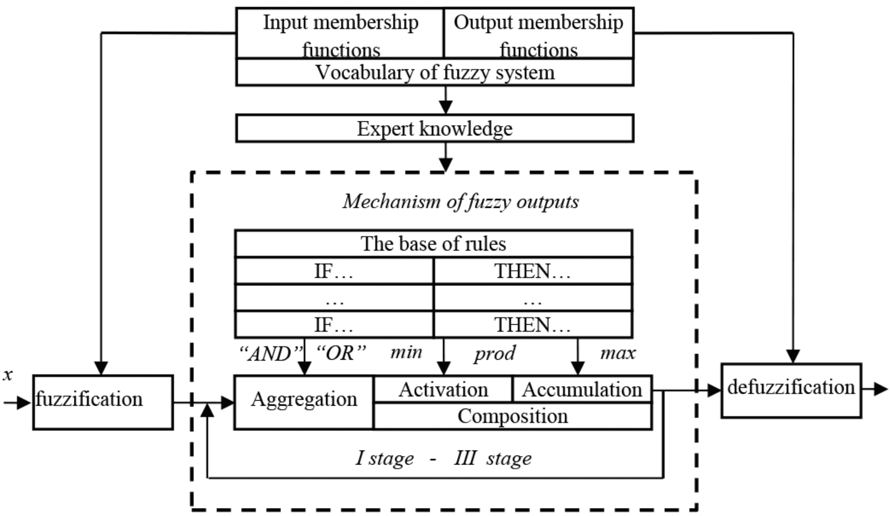

Figure 7. Structure of the fuzzy inference system.

value of the input parameter; $x_i^{(max)}$ is the maximal value of the input parameter. The membership function was preset for each part. According to the fuzzy logic theory, we can accept the existence of the crisp set X that is the universe of discourse.

In accordance with the hierarchical inference scheme, we can accept the existence of multiple pairs corresponding to the certain PIQs, (Eq. (9)):

$$T_i = \left\{ \left(x_i, \mu_{T_i}(x_i) \right); x_i \in X \right\} i = 1, \dots, n, \tag{9}$$

where x_i is the input variable - the outcome of the T_i test, μ_{T_i} is the membership function.

The values of a linguistic variable are presented as a range of five fuzzy variables "very bad," "bad," "normal," "good," and "excellent."

As all the input parameters, $X = (x_1, \dots, x_j, \dots, x_n)$ make a different influence on the ultimate outcome, we used input ranking with weight factors.

The formation of a rule base for the certain operator's activity is performed by using special methods of expert assessment for each case. It allows transferring the general vocational aptitude model to the specific spheres of the operator's work. The whole process can be expressed as (Eq. (10)):

$$\begin{aligned} R_1 &: IF\ (x_1.IS.L_{11}).AND.(x_2.IS.L_{12}).AND.\dots.AND.(x_n.IS.L_{1n}),\ THEN\ a = B_1 \\ R_i &: IF\ (x_1.IS.L_{i1}).AND.(x_2.IS.L_{i2}).AND.\dots.AND.(x_n.IS.L_{in}),\ THEN\ a = B_i \\ R_m &: IF\ (x_1.IS.L_{m1}).AND.(x_2.IS.L_{m2}).AND.\dots.AND.(x_n.IS.L_{mn}),\ THEN\ a = B_m \end{aligned} \tag{10}$$

where x_k is the input variables; a is the output variable; L_{ik} is the specified fuzzy sets with membership functions.

The inference scheme has been chosen taking into account that the Sugeno algorithm restricts the linearity between the input and output data, while the Mamdani mechanism allows using nonlinear membership functions. Besides, it is known that the Mamdani inference mechanism is more appropriate for expert systems due to transparency of the Mamdani fuzzy models. It is believed that the Mamdani inference mechanisms are more appropriate for applied problems, where the possibility of content interpretation is more important than simulation fidelity.

In this connection, it is proposed to present the inference on the base of the Mamdani mechanism using a mini-max composition of fuzzy sets.

As the scheme of the hierarchical fuzzy inference implies the operations with intermediate variables, it was considered to use two methods of their organization: with the intermediate procedure of defuzzification and fuzzification for the intermediate variables and without this procedure.

As according to the requirements to the decision-making support system, it is necessary to perform assessment of the PIQs; then at the first hierarchical level, we accept the scheme including two procedures: (i) the procedure of the output of inference result from the intermediate knowledge base as a fuzzy set without defuzzification and fuzzification of the intermediate variables and the transfer of the found membership degrees to the fussy inference mechanism of the next hierarchical level, and (ii) the procedure of defuzzification of the results with the aim to construct an individual professional portrait of a testee and their PIQs.

This can assure equivalency of fuzzy sets before and after the procedures of defuzzification and fuzzification of the intermediate variables transferred to the next hierarchical level.

On the other side, this allows obtaining crisp values in the output of the first hierarchical level for construction of an individual professional portrait of a testee and their PIQs.

At the second stage, PIQ_i is used as a linguistic variable, it is preset by a range of five elements, and the fuzzy variables are preset as follows (Eq. (11)):

$$PIQ_i = \left\{ \left(a_i, \mu_{PIQ_i}(a_i) \right); a_i \in A \right\} i = 1, \dots, 12, \tag{11}$$

where a_i is the input variable—the PIQ (PIQ_i) values, $\mu_{PIQ_i}(a_i)$ is the input value degree of membership in this fuzzy set.

The input for the third stage of evaluation is the result of the second stage output. The fuzzy sets in this case are (Eq. (12)):

$$GPIQ_i = \left\{ \left(z_i, \mu_{GPIQ_i}(z_i) \right); z_i \in Z \right\} i = 1, 2, 3, \tag{12}$$

where z_i is the input variable—the Grouped PIQ ($GPIQ_i$) values, $\mu_{GPIQ_i}(z_i)$ is the input value degree of membership in this fuzzy set.

Defuzzification makes it possible to transform the obtained fuzzy set into a crisp value by means of the known methods.

The formation of rule bases for the certain operator's activity is performed by using special methods of expert assessment for each case. It allows transferring the general model to the specific spheres of the operator's work.

4. Results

The developed evaluation system was applied for experimental research into evaluation of the vocational aptitude of the transport-technological machine operators performed in the group of 100 testees at the Interregional Forestry Resource Center (Yoshkar-Ola, Russia).

First of all, the main operator functions were singled out, **Figure 8**.

Then, according to the developed methodology, using qualification criteria, the experts identified PIQs, divided them into groups, and represented their correlation with a set of the developed and known ATs (psychophysiological tests), **Figure 9**.

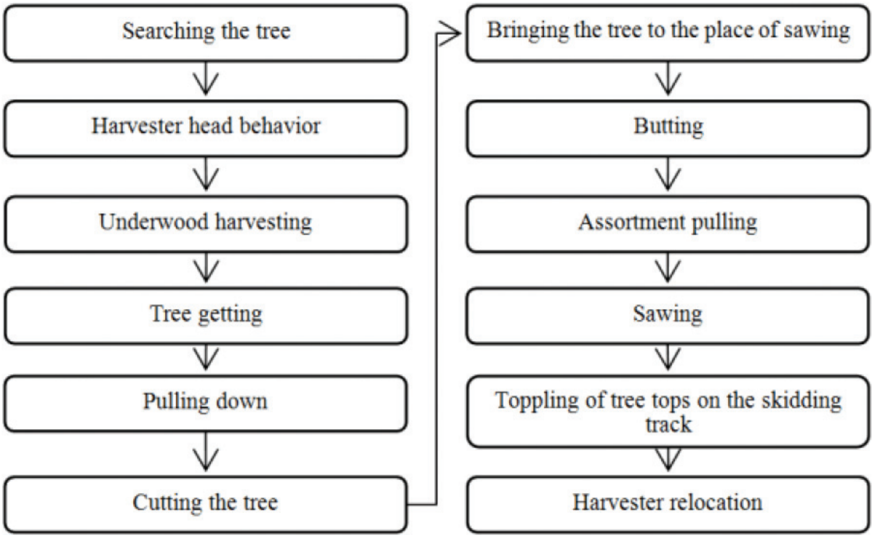

Figure 8. Correlation structure of PIQs and ATs.

weight coefficient		PIQ	Persistence of vision	Visual perception time	Accelerating object response time	Visual analyzer lability	Ability to correct actions	Response time to the object moving towards the	Predictability	Visual analysis ability assessment	Excitement and suppression correlation	Landolt ring test	Mixed lines test	Eysenck Personality Questionnaire	Sensomotor reaction time	Nervous system strength	Nervous system instability	Fatigue tolerance during visual-motor tracking
	PIQs of special importance																	
0,95	PIQ 1	Accuracy of visual-motor tracking					0,85	0,9			0,7				0,6			
0,9	PIQ 2	Speed of central processing, nervous system lability	0,7	0,8		0,9											0,8	
0,9	PIQ 3	Probabilistic forecasting					0,75	0,8	0,9									
0,85	PIQ 4	Concentration, refocusing	0,6	0,7						0,8					0,6			
	Important PIQs																	
0,6	PIQ 5	Emotional stability												0,9				
0,7	PIQ 6	Emotional balance									0,9							
0,6	PIQ 7	Object identification accuracy		0,6	0,9		0,7			0,7								
0,55	PIQ 8	Attention span										0,9			0,7	0,9		
	PIQs of little importance																	
0,5	PIQ 9	Attention allocation											0,9					
0,45	PIQ 10	Accuracy of visual analysis	0,6	0,7							0,8					0,6		
0,55	PIQ 11	Efficacy and fatigability																0,85
0,5	PIQ 12	Adaptive capacity					0,9										0,8	

Figure 9. Correlation structure of PIQs and ATs.

The research into the vocational aptitude included the cycles of data base compiling and the development of a rule base of the informational support system for decision-making, the procedures of assessment testing and the procedure of the analysis and evaluation of the vocational aptitude. The input of the transport-technological machine operator model comprised of individual AT assessment grades of each testee obtained at the stage of the psychophysiological tests. The vocational aptitude value of each testee expressed in percents and

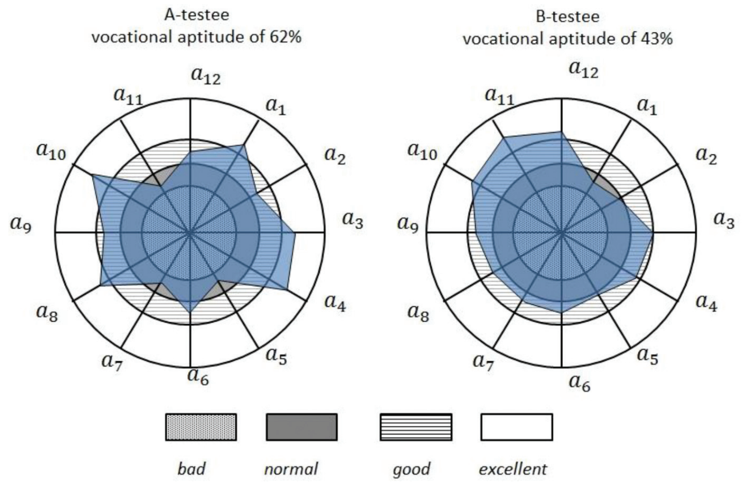

Figure 10. Individual portraits.

the individual professional portrait were obtained at the evaluation system output after defuzzification.

So, for example, for the quality of PIQ_1, such tests as AT_5, AT_6, AT_9, and AT_{13} are responsible. That is, the best result ("excellent") at the output of these tests: *If* (x_5 is "excellent") and (x_6 is "excellent") and (x_9 is "excellent") and (x_{13} is "excellent"), then (a_1 is "excellent").

The constructed individual portrait provides an opportunity to make a conclusion about the PIQ development level; it may be used both for training the operational personnel and for adaptive adjustment of informational and technical components of ergatic control systems to the user's abilities taking into account their current functional state, **Figure 10**.

The experiments showed the effectiveness of the developed methods for evaluation of the vocational aptitude within the occupational selection for operators of transport-technological machines. It was found out that application of the decision-making support system for enrollment into student groups specializing in operation of transport-technological machines helped reduce the dropout of students during the professional training by 1.5–2 times; it proves the effectiveness of the developed decision-making support system.

5. Conclusion

Thus, the concept of decision-making for evaluation of the human factor influence on the STS is presented; this concept is based on the analysis of the action effectiveness at each stage of the operator's activity and the priority levels of the operator's actions considering the known requirements to the PIQ content.

It is obvious that each type of the operator's activity corresponds to its own specific PIQ set, which determines the performance quality of professional functions.

In order to define a necessary set of PIQs, it is required to make a profound analysis of the professional activity, as each type of the operator's activity has its own peculiarities conditioned by the technology (work types and the work process elements, different work modes, shifts, different intensity of work, different levels of automation within the production process, etc.).

According to the proposed experiment model, special tests or test sets can be selected for each stage of the operator's activity, and they help to characterize the corresponding capabilities of a testee.

Application of different tests provides an opportunity to effectively simulate most types of the operator's activity in different environments of a human-operator, when different factors of the ambient environment affecting them, and to obtain quantitative and qualitative characteristics of their working capacity.

The special feature of the proposed model is application of the fuzzy analysis already at the stage of testing and application of the outcomes of one AT for evaluation of a number of PIQs. The proposed model, in general terms, represents the functional dependence of the operator's vocational aptitude index on the PIQ development level, while these PIQs are defined by the outcomes of testing on the base of fuzzy methods.

The feature of novelty of the developed model of the vocational aptitude consists in the integral evaluation of the vocational aptitude in a hierarchical system class; it makes it possible to take into consideration the system of interconnections between the PIQs and the AT outcomes, to improve the completeness and accuracy of the made decisions, to form quality functional for the training of operational personnel.

The main advantage of the developed evaluation system and the evaluation model is the possibility of the focused training of the certain operator's functions and the development of the certain PIQs that can improve the vocational aptitude indicators. This allows to intensify the training process of the operational personnel and reducing resource and time expenditures for their training.

Thus, it was established that the developed system of the vocational aptitude evaluation can be applied for evaluation of the human factor within research into STSs including elaborated technogenic objects.

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