Cognitive and Information Decision-Making Technologies and Risk Assessment in Technogenic Systems

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Abstract

The article considers information technology of formation and decision – making, in the conditions of risk construction methods, for technogenic systems management with use of cognitive model of operator activity as a basis of decision – making processes intellectualization. It is substantiated, on the basis of system analysis, the decomposition of the management problem on the problem of solving which is necessary for decision making. The structural interaction scheme of intellectual ACS with the management (team) person is constructed and the information technology of dialogue in technogenic system management structure is developed. The interaction scheme of conflicting active systems in the conditions of resources redistribution is substantiated. The classification of management tasks, using system analysis and information technology, to assess the situation in the system is presented. The structure of the cognitive-logical formation of management tasks procedure in risk conditions on the basis of the intellectual agent model and the generator of procedures for their solution, situational tasks is developed.

Keywords

System, information, situation, knowledge, risks, decisions, cognitive procedures, conflicts, logical rules, management.

1. Introduction

Integrated human-machine systems, control structures, automated personnel training systems are hierarchical systems characterized by uncertainty in the structure and dynamics of control objects. Therefore, decision-making in such systems with incomplete data on the problem and functional structure of technological processes and under the influence of disturbing influences with a priori unknown statistical characteristics, is a complex intellectual procedure that includes the selection of adequate object models, algorithms for data selection and processing, and accordingly, the formation of approaches to the synthesis of decision-making procedures using the theory of possibility and the theory of fuzzy sets in the assessment of situations based on the object state images recognition

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[1, 2, 4–7].

Purpose. Substantiation of information technologies methods, system analysis, logical-cognitive models for control systems of technogenic structures in the conditions of threats creation.

2. References analysis

In the fundamental work [1] the principles of complex control structures of automated human-machine systems creation are considered and large systems development forecast is given. In [2, 3] the hierarchical systems construction methods using manager operator cognitive models are analyzed. Problems of operator activity on management in ACS and operative thinking at decision-making are considered in monographs [4, 5]. Management problems in the conditions of a situation change at action of disturbances on process of decision-making are shown in [6, 8]. The monograph [7] highlights the logical problems of artificial intelligence for use in control systems. The monograph [16] is devoted to the study of mathematical modeling methods of data processing processes by a human operator in human-machine systems and the detection of errors due to factors influencing its activities. Monographs [15, 17] are devoted to data processing methods for decision making, artificial intelligence, theory of knowledge and learning, modern technologies of process analysis and technical logic.

In [11, 12] the analysis of risks models which arise in hierarchical technogenic systems is carried out.

In [9] construction methods of information technology of formation and decision-making under risk conditions are considered for management of technogenic systems with use of cognitive model of operator activity. In [10] the problem of decision-making in the risk conditions and conflict situations in the presence of terminal restrictions is considered at the time of resolving the crisis in the complex system management structure.

The results of research used in the [13, 14, 19–21] are devoted to the analysis of information technologies, the concept of their development, platforms and standards, software and expert systems, fuzzy logic.

In [22] the use of data mining to improve energy efficiency in complex systems is substantiated.

The paper [23] is devoted to developing the Multi-hazard Risk Assessment Framework containing models, scenarios, and methods for analyzing the risk related to multi-hazards. The multi-layered spatial model and the model of the Human-Infrastructure System based on hierarchies and having great scalability in time and space are proposed. These models take into account all possible relations between people, objects of infrastructure, natural environment, and corresponding spatial areas [24]. The proposed event-based scenario representation model provides sufficient detailization in space and time and can properly represent multi-hazards, including compound events, cascading effects, and risk-related processes driven by environmental and societal changes.

3. Presentation of the main research material

Decision-making under active threats in hierarchical organizational and production systems is a complex problem and is characterized by both a game component and clear decision-making procedures in the management of technological processes (TP) and organizational and administrative structures (OAS), both in normal and in extreme conditions that arise due to information-type attacks and cognitive failures of managers.

Decomposition of making managerial decisions problem in terms of threats risks can be divided into a set of tasks:

– creation of new intelligent control systems for the processes of autonomous control systems functioning (ACS) of TP and SCA;
– existing ACS operating modes diagnostics, their optimization and adaptation to the effects of disturbances and threats and changes in their target orientation.

3.1. Classification of intelligent control information systems

Here is the classification of intelligent information systems (IIS) [2, 3], which are components of automated control systems (human-machine complexes):

– problem-oriented expert systems using artificial intelligence for data processing and classification;
– intelligent information systems of man-made and organizational structures situational management that operate in the face of threats and attacks to change strategies and goals;
– computational and logical modeling systems of dynamics of potentially dangerous objects (PBO) – design objects;
– intelligent educational systems in the structure of universities;
– intelligent simulators for special training of personnel working in conditions of threats and cognitive disruptions;
– intelligent agents, as goal-oriented structures in hierarchical control systems of technogenic systems.

3.2. Consideration the classes of problems, the solution of which ensures the reliable operation of man-made (technogenic) systems in the face of active threats

Problem area and types of tasks that can be performed by the information-intellectual system (IIS) [16, 17] in the development of management strategies and ensuring resilience to active threats, information attacks on the ACS system and technogenic structures:

– ault diagnosis of complex systems and software products;
– planning a targeted actions sequence for the strategies implementation;
– observation of situations, recognition and classification of images;
– object management in accordance with the setted strategies and goals.

Here is a block diagram of the interaction of intelligent systems (IS) – Figure 1.

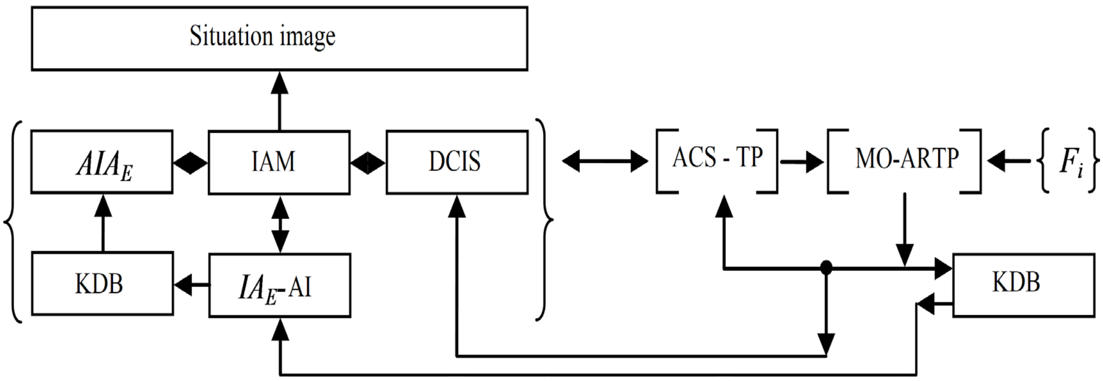

Figure 1: Block diagram of the intelligent systems interaction (ACS-LPR)

Such a complex intellectual structure performs the function of object management with a certain type of technological process $\{T\Pi_j \leftarrow F_i\}$, which is affected by disturbing factors from the external environment and the dynamics of market environment changes in the parameters. The task of the system is to keep the object in the target operation area in case of resource type failures and interferences. To effectively solve management problems, it is necessary that the structure of decision-making procedures and data structure have a conjugate, consistent, formalized, logical-mathematical and informational representation Figure 2 and appropriate meaning in the perception of the situation content by the operator cognitive system.

The task, in the general case, is a situation with uncertainty that motivates purposeful actions of the intelligent system to achieve a certain goal at a given time interval and its effective solution based on proven strategies, methods, algorithms, procedures and cognitive methods.

The target in such a system is encoded in the solving system (IPS – intelligent problem solver). Then it acts as requirements description for the state of the system in which the target is formed. An intelligent system (IPS) is characterized by an algorithm and a procedure for finding a strategy for problem task and situation solving, based on a given goal orientation.

V. Glushkov pointed out the important role of information technologies for the creation of problems solving methods and procedures that arise in the design of systems (man-made, publishing and organizational) in his research [8].

Substantiating their automation based on the use of information models of dialog mode, inference, generating hypotheses and decision making methods, it was first identified the role of management intellectualization in schemes for constructing procedures for the algorithms synthesis for solving constructive problems. This did not take into account the cognitive, but only the energy aspects of the operator's behavior when assessing the situation in the system under the influence of active type interference and threats – Figure 2.

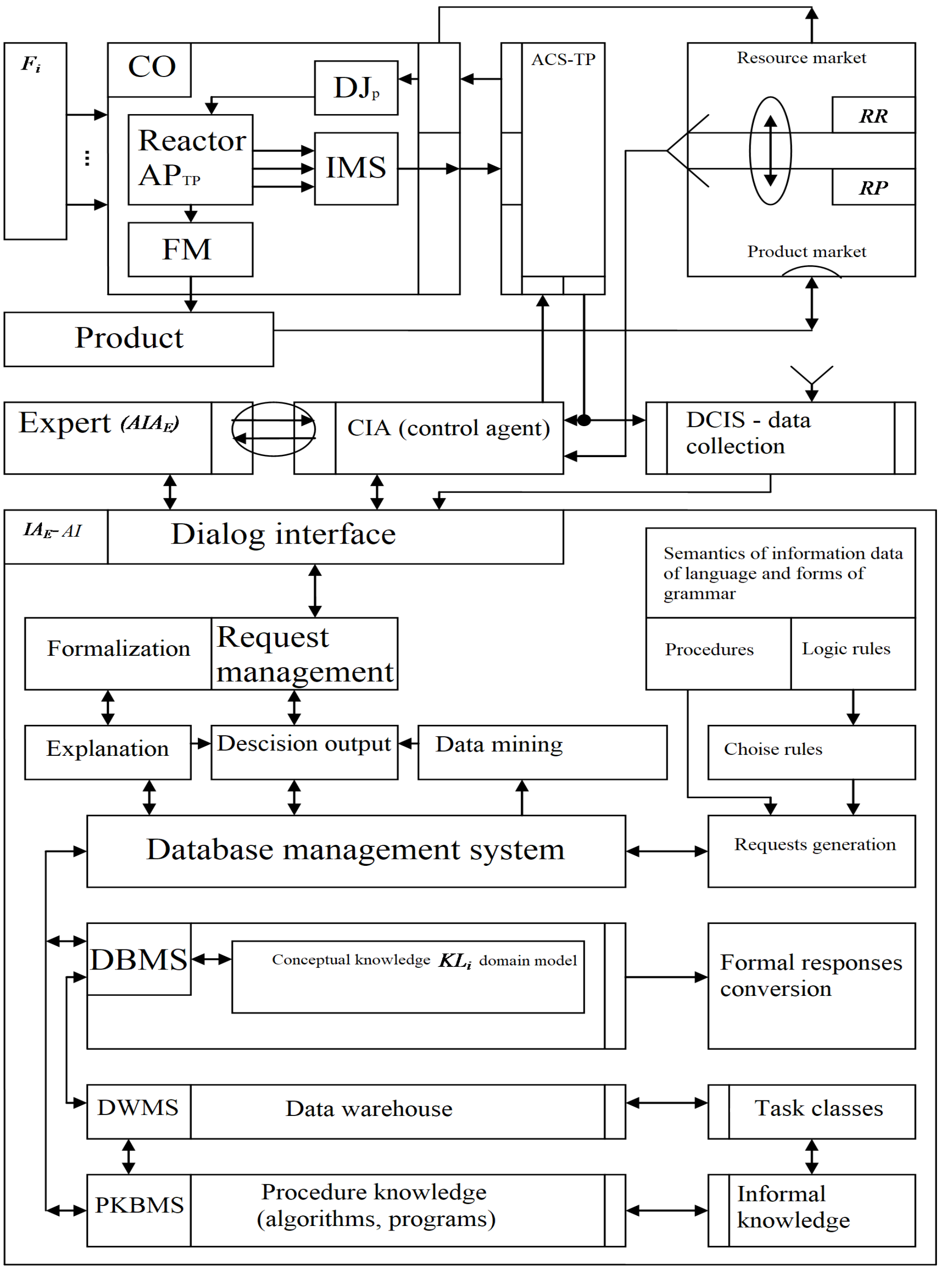

Figure 2: Information technology and interaction scheme of the agent with artificial intelligence with the expert and the coordinating managing agent (IACS-TP) of the control system

4. Models of data perception in the ACS-TP operator field of attention in the limit modes of energy-active object operation

The operator's perception of analog and digital data from the control devices of the control object state has its own features in assessing their content in the field of attention, which are that when analyzing the situation in the object:

– digital data is stored in memory but not visible from previous trajectory history $(F_n trak)$;

– fuzzy orientation, according to the data on the distance to the modes boundary lines $(F\Delta \alpha r)$;

– the tendencies change trajectory dynamics at control actions performance on a short terminal time interval is not traced $\left(F_{\Delta}^{*} trakX(t)\right)$;

– the input of the system usually has border loads of the technological structure at maximum power, it is impossible to clearly determine the allowable distance to the limit mode and the time of transition to the emergency state in a short time interval $(t_{02}\text{-}t_{04})$ of energy-intensive object, $\left(F_{\Delta}^{0}\left(L_A - L_g\right)\right)$;

– indication of maximum values changes the perception of the data content by the operator and puts him in a stress state due to the alarm of the system transition to an uncontrolled emergency state (t_{04}, t_{05}) $F\left(HL(L_A)\right)$.

At perception of analog signals in the graphic form there are some lacks, and possibility of the trajectory forecast the operator in terminal time is complexed at the expense of associative figurative display of data in the attention field and scenario interpretation of events. (T_i) by classifier of the situation – Figure 3. Only the trajectory interpretation leads to distortion of the display scale values in different intervals of numerical values of measurement and when the trajectory enters the mode boundary areas, causing stress in decision-making on management (t_{04}, t_{05}), of ACS operator cognitive system.

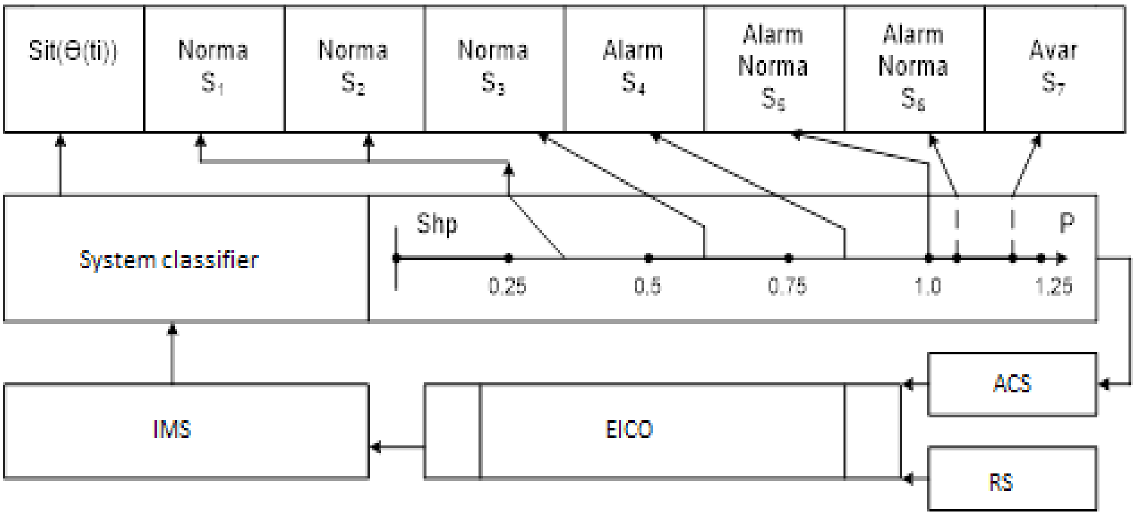

Figure 3: Situation classifier block diagram

Designation to the structural scheme: $\{Si\}$ – system state, $DSit(\theta(t_i))$ – dynamic in the time moment t_i by parameter Q, $(ALARM)$, $(AVAR)$ – state of alarm and accident, IMS – information measuring system, ACS – automated control system, TS (EICO) – technological system with energy-intensive control object, RS – source of resources.

Based on the analysis of real load modes and standards, critical parameters are determined and a permissible states regime map of the energy-active control object is formed, which is the basis for developing a situations system classifiers based on the choice of power scale class $Sh(P)$.

With the target task of increasing the power of the energy-active object, the operator performs complex (tracking) control according to on a given trajectory – Figure 4.

On a certain control cycle to the maximum load, the operator (Zi), depending on the value of power load, perceives the situation on the basis of data with different levels of mental stress, which can lead his neurocognitive system, from fear of an accident, to systemic-cognitive failure.

Data perception distortion scheme (Fig. 4) by a person operator of ACS-TP reflects the influence of many factors and interpretation of the situation content depending on the uncertainty in the description of dynamic objects and units according to the confidence degree in the readings of devices (correct), which are the part of IMS-ASU structure using current state change trajectory images and assessment of membership functions $\{Mi\}$.

The reason for the existence of uncertainties should be considered incompleteness and inconsistency of data from different devices that control the unit, incompleteness of the selected information base of the IMS, aging of devices during long service life, measurement errors from the type of control and management problem (which is being solved) according to the event development scenario – Figure 3.

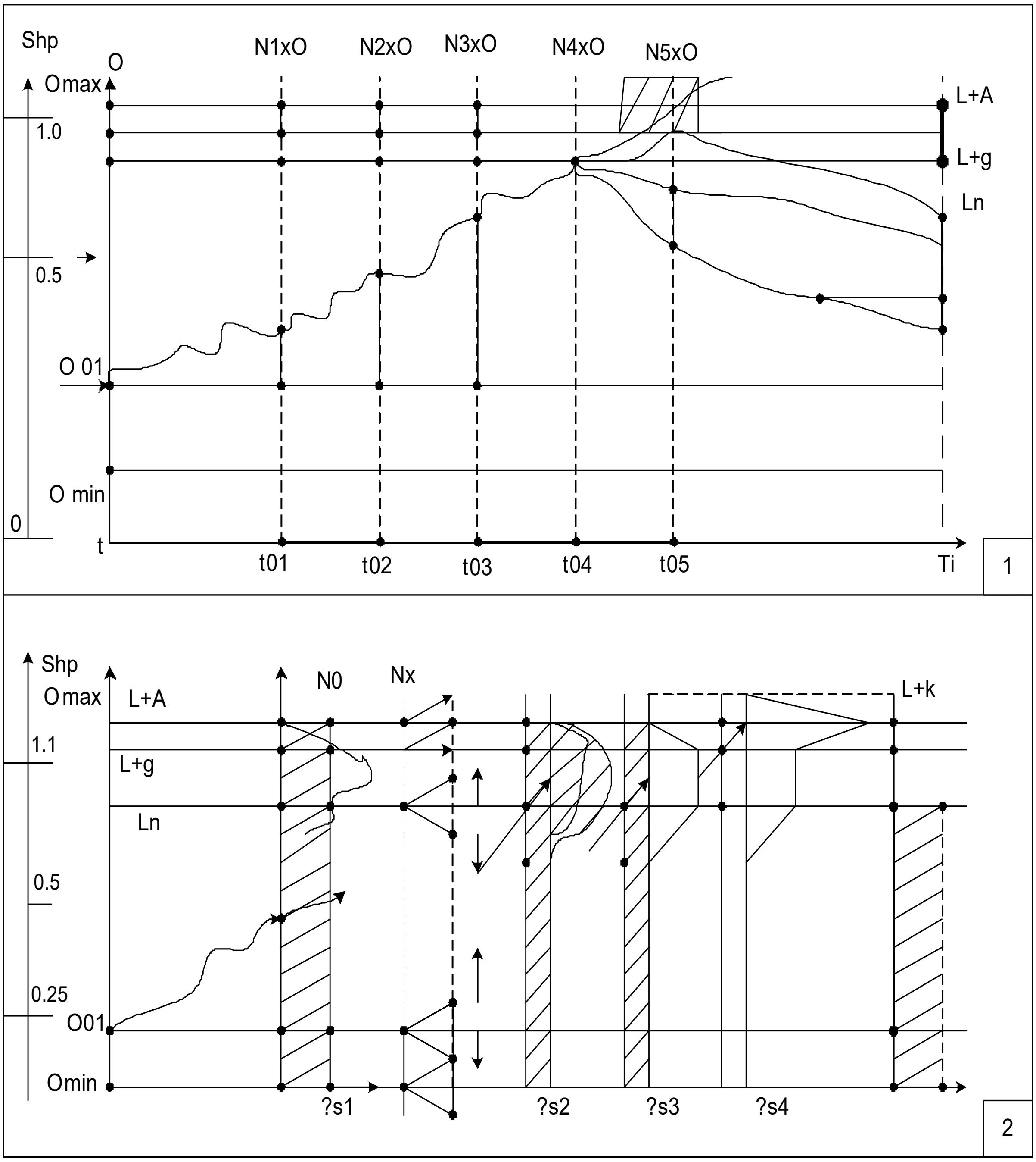

Figure 4: Data perception distortion scheme in the field of view of the ACS-TP operator in the conditions of loading traffic growth

According to the type of tasks to be solved by the operator, uncertainties are formed in the generated situations under the influence of obstacles:

– Uncertainty due to the ambiguity of existing knowledge about the object in the database and knowledge base and blurring and ambiguity, incomplete professional knowledge of the operator and his ability to make decisions in stressful situations;

– Uncertainty caused by incomplete knowledge about the object for different subject-oriented area hierarchy levels of control object units and blocks description, which have a physical or linguistic nature.

According to the situation, the uncertainties are divided into:

Linguistic uncertainty – is caused by the vagueness and ambiguity of individual words of grammatical constructions, which have syntactic, semantic and pragmatic components and represent a description of the situation.

Cognitive uncertainty – is generated by the perception peculiarity of different types of data devices in the field of operators attention and their interpretation.

Physical uncertainty – is caused by a low level of knowledge about physico-chemical energy processes in the management object and misunderstanding of their essence, which leads to incorrect management decisions, increased risk of accidents, technological process instability.

Physical uncertainty is associated with the stochasticity of events, phenomena, processes, their causal relationships, the error in the data selection at different times when changing the technological process dynamic modes in the object units and blocks.

When approaching the limit modes, the operator on the basis of information from the data stream from the multimedia board and analog and digital devices that are in his field of vision forms situation image in the system target space according to the mode specified by the manager.

According to the load, the operator decides to correct the situation in the event of resource disturbances, information threats, system attacks, malfunctions appearances, that can cause accidents and risks in the system. The modes dependence on the load level, leads to cognitive stress when making decisions on the correction of state control and the anxiety growth when approaching the allowable normative values.

In such a situation, the operator as a cognitive intellectual agent must have a certain intellectual potential that ensures effective management decisions. Intellectual potential depends on the knowledge of professional training, the ability to make decisions in unusual situations. Accordingly, this approach is the basis for the separation of activity factors.

Selected factors of ability to manage, in terms of risk and extreme situations, are formed in the tables:

Table 1 – factors of operator disorientation while decision making;

Table 2 – uncertainties factors in the data selection on the object state to assess the situation by the operator;

Table 3 – cognitive factors in assessing the reliability of data and management decisions;

Table 4 – knowledge required to perform the management decisions by the operator.

The values of factors (coefficients) are obtained in the process of testing according to the logical-cognitive approach of their construction [2, 3].

Table 1

Factors of operator disorientation in decision makingce

№	Facts	Factor content	k_F
1	$F_n(trak\ X_i)$	When digitally represented N_{Xi} the state change trajectory is not traced	$F(N_X)$
2	$F_n(\Delta\alpha_r)$	Loss of orientation by the operator when the	FG_r

		trajectory approaches to the boundary mode line	
3	$F_{\Delta}^{U}(trak\ X)$	There are no tendencies to change the trajectory $x(t,u)$ under the action of management U in conditions of noise	F_{Δ}^{U}
4	$F_{\Delta}^{U}(L_{\Delta}-L_{G})$	Disorientation of the operator when approaching the emergency state of systems under the control and interference action	$F_{\Delta}(L_{A})$
5	$\frac{F(HL(L_{A}))}{max\ N_{X}}$	Occurrence of stress in the operator when approaching the emergency line and when estimating the maximum devices readings	$F(max\ i$
6	$F(N_{X}\pm\Delta_{i})$	Distortion of data perception by the operator at disturbances action	$F(sen\ L$
7	$F_{D}(\hat{N}_{X})$	The operators confidence degree in the devices readings on the reliability level	$F_{D}(\hat{N}_{X})$
8	$F_{N}(sit\ \Pi G)$	The situation uncertainty factor in the operator imagination under the interference influence	$F_{N}(\hat{X})$

Table 2

Uncertainties factors in selecting object status data for operator for event assessment

№	Facts	Factor content	k_F
1	$F_{nd}(V_{pi}\|_{i=1}^{U})$	Data incompleteness and inconsistency from different devices	F_{nd}
2	$FIB(N_{X})$	Incomplete information base of various devices scales	$F(Sh)$
3	$F_{sni}(N_{X})$	Contradictory data from different devices values	F_{sn}
4	$F_{T\in}(N_{X})$	Changing readings due to aging devices	$F_{\Delta}N_{X}$
5	$F(NT)$	Devices terminal reliability during system operation	F_{T}
6	$F(\Delta X(\xi))$	Device errors under interference action	$F_{\Delta X}$
7	F_{RS}	Errors dependence on the type of control tasks importance	F_{R}
8	F_{US}	Dependence on the type of management tasks (need)	F_{U}
9	$F_{V}(A\,lg\,VD)$	Data reliability factor for selected measurement algorithms	$F_{V}(\hat{D})$
10	$F_{D}(A\,lg\,\hat{N}_{X})$	Data reliability factor for selected data processing algorithms	$F_{n}(\hat{D})$
11	$F_{nZ}(D_{i}(\xi))$	Uncertainty factor due to incomplete knowledge of system functions	F_{UZ}
12	$F_{\mu}(Ndi)$	Data blur	F_{μ}

Table 3
Cognitive factors in assessing the data reliability and management decisions

№	Facts	Factor content	k_F
1	F_{nZ0}	Low, disordered professional knowledge of a professional operator about the object	K_{nZ0}
2	F_{nR}	Low level of training	K_{nR}
3	F_{VR}	Ability and ability to make operational decisions	K_{UR}
4	$F_S(sit)$	Ability to make decisions in a stressful situation	K_{SS}
5	F_{nf}	Misunderstanding of physical processes in units and blocks	K_{nf}
6	$F_L(sit)$	Ability to linguistically meaningful description of the situation	K_{LS}
7	$F_{KZ}(PR_U)$	The impact of interference on cognitive failure in decision-making on management	K_{KZ}
8	$F_\mu(sit \to Iconsit)$	The ability to imagine the image of the situation	K_{PU}
9	$F_{ПС}(Iconsit)$	Ability to correctly assess the situation in the space of goals	$K_{ПС}$
10	$F_{KI}(D_i / T_m)$	Ability to detect constructive information from the data stream	K_{Ki}
11	$F_{nr}(UR_i)$	Indecision in making management decisions	F_{nrU}

Table 4
Knowledge that needed to make management decisions by the operator

№	Facts	Factor content	k_F
1	Z_{sd}	Knowledge of the object's structure and dynamics	F_{sd}
2	Z_{ps}	Knowledge of how to represent the spaces of goals and states of the object	F_{ps}
3	$Z_M\left(F \xrightarrow{R} sit\right)$	Model of the object's reaction to the influencing factor	$F_{m,f}$
4	$Z_{SU}^P((U,F) \to sit)$	Ability to use knowledge to predict changes in the state under the action of management and threats	F_{SU}^P
5	$Z_V(strat(U/C_i))$	Ability to build optimal strategies for achieving goals in the face of threats	F_{CU}
6	$Z_{pn}^K(F \to U_d)$	Ability to evaluate cause-and-effect diagrams of the threat factors influence on the cognitive agent management actions	F_{pn}^K
7	$Z_{PR}^K(KsitU_i)$	Ability to make decisions in crisis and emergency situations based on system knowledge and experience	F_{PR}^K
8	$Z_\mu(Д_i)$	Ability to process fuzzy data	$F_{\mu d}(Д_i)$
9	$Z_{ЛI}(ПД_i)$	Ability to interpret blurred data	$F_\mu(Д_i)$

Based on the testing and the results obtained, it is possible to assess the level of operational staff training at existing enterprises and optimize them to minimize incorrect decisions that lead to emergencies due to incorrect assessment of measurement data about objects state and their interpretation under threats and information attacks.

According to the situation that occurs in the system, table 5 and table 6 are constructed, which characterize the ability of the operator to make management decisions.

Expert assessments of cognitive components (CF_i, PR_i) for decision making by the manager.

Table 5

Cognitive operations for management

Factor	Cognitive acts	Kd intervals	Kr value
CF_1	goal realization	0,8-10	0,6-0,9
CF_2	goal orientation	0,8-1,0	0,5-,8
CF_3	generation of strategies	0,7-1,0	0,5-0,8
CF_4	control logic	0,6-1,0	0,4-0,7
CF_5	assessment of actions taken	0,5-1,0	0,5-0,7
PR_1	action planning	0,6-1,0	0,5-0,8
PR_2	choice of alternatives	0,6-1,0	0,5-0,8
PR_3	wrong choice Ω_i	0,5-1,0	0,3-0,7
PR_4	creativity	0,7-1,0	0,6-0,9
PR_5	goal generation	0,8-1,0	0,6-0,8
PR_6	assessment of situations	0,5-1,0	0,5-0,9
PR_7	logic procedure RZ	0,7-1,0	0,7-0,9
PR_8	coordination procedures	0,8-1,0	0,7-0,9

Expert evaluation (II) logic of thinking

Table 6

IT-technology cognitive components (KCi)

Components	Information operations	Intervals Kd, Kr	
KCm	whole oriented thinking cognitive models	0,6-0,95	0,50-0,95
KCd	analytical data analysis	0,5-0,95	0,50-0,95
KCe	logic of thinking, CIA	0,15-0,95	0,4-0,95
KCa	cognitive processes algorithmization	0,10-0,95	0,25-0,90
KCz	situational tasks and problems essence cognitive analysis	0,15-0,85	0,40-0,55
KCp	cognitive procedures for forming problem-solving schemes	0,14-0,90	0,4-0,85
KCi	identification of the problem tasks information essence	0,25-0,90	0,60-0,95
KCr	use of information technology to solve problems	0,30-0,90	0,60-0,95
KCdv	cognitive processing of CIA data streams received from the object	0,30-0,85	0,40-0,90
KCl	cognitive models of decision-making logic by an intelligent agent	0,4-0,90	0,40-0,90

Cognitive coefficients of intellectual abilities expert assessment are determined on the basis of test data processing $\left\{PRi\big|_{i=1}^{n}\right\}$, $\{\forall PR_i \in [0{,}5-1{,}0]\}$, $\left\{KCi\big|_{i=1}^{b}\right\}$, $\{\forall KCi \in [0{,}7-1{,}0]\}$, and determine the quality of decision-making by the operator in the face of threats.

Accordingly, there are assessments of the decision-making quality for the intelligent agent management

$$IA_n\begin{bmatrix} & \to [0{,}5-0{,}7] \to [Rick \to n] \\ \underset{i}{\wedge}\{PR_i | i=1,n\} & \to [0{,}7-0{,}8] \to [Alarm] \\ & \to [0{,}8-1{,}0] \to [Norma] \end{bmatrix}.$$

The assessment of the risk level is based on the following models that characterize the processes of management decisions by the IA operator:

1. Probabilistic model of risk at the moment $(t \in T_{nk})$

$$Risk(t_i \in T_{nk}) = L_{pi}\{P_i / C_i\}_{ti} \to \{P_{i+1} / C_{in}\}_{ti+1} \to |Alarm|$$

where P_i – the probability of wrong decisions that lead to consequences $\{C_i\}$ – failure of the target task in the emergency area.

2. Unprofitable risk assessment model [22] when assessing an emergency situation:

$$Risk(P / Cui) \to \varnothing \to \begin{Bmatrix} H_{ij} : C_i \in C_V \to (\alpha_r \to 0) \\ H_{i2} : C_i \notin C_v \to (\alpha_r \to 1) \end{Bmatrix}.$$

Determines the maximum loss when exiting the target control area (C_V).

3. Risk assessment based on the decision tree in the threats management of the maximum load of man-made system energy-intensive units – Figure 5.

4. Methods of payment functions for the loss of structure, resources, products.

5. To assess the risk level in the face of threats and management failures, hypothesis testing procedures were used in the form:

$$H_1:\ \forall x[P(x) \Rightarrow Q(x)],\ P(x) = Z_j \in B_i;$$
$$H_2:\ \forall x[Q(x) \Rightarrow R(x)],\ Q(x) = Z_{j+1} \in B_{j+1}.$$

Then the condition of reaching the target state is set

$$C_i : \forall x[P(x) \Rightarrow R(x)],\ traR(x) \equiv (Z_j \to Z_{j+1} \to Z_{j+2}),\ R(x) \equiv Z_{j+2} \in B_c.$$

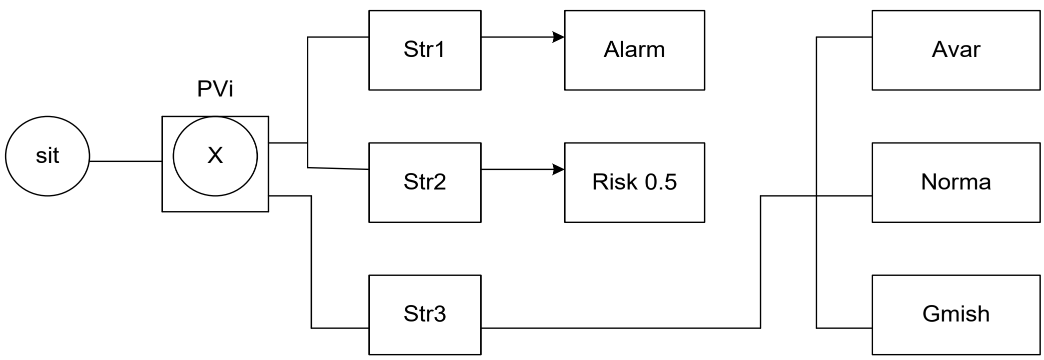

Figure 5: Block diagram of risk assessment, where *PVi* – selection procedure, $\{Str_i\}$ – strategies for choosing control actions

These chains can be blocked under stress, which leads to the failure of management actions and emergencies.

5. Conclusion

The logical substantiation problem of decision-making rules in intellectual systems is considered, the dialogue scheme and the decision – making scheme are substantiated as bases of persons admissible behavior strategies synthesis (active agent). It is shown that in stupor state, the deployment circuits in the process of logical goal-oriented output inference and event scenario evaluation can be blocked, which leads to the IACS loss of control for a certain terminal time.

The problem of forming target decision-making strategies for managing complex objects on the basis of an active intelligent agent as a target-made system in the integrated automated control systems structure is considered. The expert assessments construction methods for checking the operators-intelligent agents cognitive abilities are substantiated.

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