Information and Cognitive Components of Knowledge Formation in Procedures for Assessing Dynamic Situations in Cyber-Physical

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Abstract

The article considers the logical aspects of knowledge formation in the construction of procedures for assessing dynamic situations in technogenic systems in crisis condition. It is shown that planning of clear and constructive decisions by an intelligent system or a person is based on understanding of physicochemical and energy processes occurring in technological systems and the ability to clearly identify constructive connections, the ability to quickly form logical schemes of interconnected structures, to synthesize effective action plans.

According to the problem of solving situational goal-oriented decision-making tasks on the management of man-made systems with a hierarchical structure (cyberphysical) it is necessary to correctly identify the levels of energy-intensive technological lines of resource processing units, the system of selection and processing of heterogeneous data on the state of the object to assess the situation according to the target task, the levels of operational and strategic management of the goal-oriented cyberphysical system.

The problem of decision-making support in crisis and emergency situations under the influence of information, resource and structural threats is solved on the basis of the advisory center (DMSS) - a decision-making support system. The complexity of the tasks requires a high level of knowledge from the staff - professional and scientific (logical - systemic) and cognitive abilities. In addition, the structure of DMSS should include an appropriate hardware for the implementation of information and system solutions support and structured knowledge and data bases as a basis for quality management.

Keywords

logic, information, data, strategy, management, time limit, cognitive thinking pace, intellectual person.

1. Introduction

The problem of human decision-making in the structure of integrated human-machine automated control systems has not lost its relevance due to the expansion of factors of influence: human errors, stress in decision-making, resource and information attacks on the organization or company. Solving such problems requires breaking (decomposition of) the problem into components: intellectual, mental, management, resource, structural and organizational ones, the study of the modes, and then their integration into a constructive action plan [2-5, 8, 9, 12, 14].

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The intensification of production based on information and computer technologies of management of complex objects, which operate in the limits of productivity, has sharply reduced the ability to make the right management decisions. This gap in requirements and intellectual ability to management arose due to the lack of new knowledge in the operator's skills, which led to high emotional stress in the assessment of production situations and forced to look for new schemes, programs and methods of staff training. Accordingly, the requirements for the staff training (professional, scientific-engineering, intellectual) have changed, which would provide a holistic view of the problem situation in the system and decision-making.

The aim of the study – to form professionally-oriented and system-structural knowledge based on cognitive and information components, to assess the situation in dynamic situations in technogenic systems in the conditions of threats and active information-system attacks.

The object of the study is the process of knowledge formation by the cognitive system of the operator-manager with limited time of decisions execution in the energy-active system.

2. References analysis

In the foundations of intelligent control systems are substantiated [1]. In [2, 3] the foundations of systemology of complex systems are presented. Monographs [4] outline the foundations of management decision theory in complex systems as well as the basics of management risk assessment. Cognitive concepts of management decision-making in the conditions of risk and action of active factors on management systems are stated in works [5, 6]. In [7] the analysis of risk models which arise in hierarchical technogenic systems is carried out. In [8] the system and logical-cognitive aspects of management in complex systems are considered. Problems of operational management are considered in [9], as well as decision-making procedures.

The development of methods and tools as knowledge control of projects, which requires an integrated approach using the theory of data processing, interpretation of data and situations and decision making are discussed in [10, 11]. In [12] the problems of reliability of multilevel systems that arise in the process of designing their systems are considered. In [13, 15, 19] the problems of management in the conditions of change of the situation under the influence of infringements of decision-making process are considered. In [14] the methods of system analysis of the decision-making process in social, organizational and technological structures are substantiated. In [16-18] the methods of developing the concept of an intelligent agent as a model of a person who forms management decisions as a basis for developing of effective (quality) software using a neural network approach are considered.

3. Analysis of the decision-making problem in technogenic structures

The current condition of technogenic structures, in which technological complexes and teams of specialists-operators and managers of different levels of hierarchy interact with lack of material and energy resources and vague goals make mistakes in the process of forming decision-making strategies in the formation of management actions for a given terminal time of the management cycle which can make the technological process face an emergency or catastrophe [2, 8].

Structures the components of which are technological systems, computerized control processors and which interact in the development of control actions with a human operator or team, belong to the ergatic class, they are closed, purposeful systems with the appropriate class of models of management strategies based on knowledge of management theory, logical and mathematical theories, physico-chemical theories of energy exchange, decision-making psychology. At the same time, the person from the management team is the bearer of activity and goal orientation in ergatic systems, which later developed into a new class – cyber-physical ones.

Each class of ergatic systems in the sense [4] is characterized by the main classes of management tasks that they can solve:

- goal-setting tasks at the top levels of the hierarchy;

- targeting tasks at the strategic level of management;
- program management tasks on operational – technical level;
- stabilization and ensuring the state of equilibrium in the automated control system of technological process with the help of the technological energy-active process;
- finite management on the basis of energy-active models of technogenic system objects;
- optimal, game and reflexive management in the face of threats and attacks, such as cyber-physical ones.

The main problem for these systems is the intellectual process of formation and decision-making, within the specified strategies and actions that lead the system to the target area, and this raises the problem of logical justification of decision-making procedure, logic of action formation and control teams [2, 8, 15, 19]. It is necessary to create the condition of compatibility (the automated control system – the operational management) to solve the target task for all system components.

Based on the information-resource concept of analysis of the dynamics and synthesis of management strategies [2, 8, 13], the elements of the logical-information scheme of formation of management decisions in purposeful systems (Figure 1) are analysed as subsystems of cyber-physical one.

The structural scheme includes the following functionally defined components:

TS – is a technological system;

PMD – is a person who makes decisions;

NC – is a control and measuring monitoring system;

CP-PS – is a control processor of the problem-solving;

CSKB – is a control system of the knowledge base;

CKB – is a conceptual knowledge base;

MSiRZ – is a model of problem-solving strategies;

EP-IMC – is an executive processor for implementing management commands;

FOD sit(ti) – is the formation of the situations image at the moment (ti);

DR – is a source of resources;

MCi, MTSi – are models of the condition and target space;

IR, IRisk – are quality and risk criteria.

According to the given scheme one can single out the most important problem tasks of management of a technogenic cyber-physical system: [1-3, 7, 9-12, 14].

1. A model of strategic functioning of technogenic system and its function in the description of management processes;
2. Models of regular and boundary modes of energy-active objects and the determination of the system's vulnerability to resource attacks and failure of management actions;
3. Causes of problem situations and synthesis of cause – effect diagrams and scenarios of the event development;
4. The assessment of the risk level of an emergency situation under the influence of attacks and threats;
5. The logic of forming images of situations and their classification;
6. A model of strategy and the way of solving the problem situation;
7. A strategy of formation of a new purposeful task on the interval of admissible time of decision-making on the model basis;
8. The logic of the goal formation when changing the dynamic situation;
9. The logic of forming management strategies and forming action plans;
10. The construction of the scenario of the event development on a management cycle in the conditions of threats liquidation;
11. Synthesis of commands and control programs for the implementation of control information and management actions by executive mechanisms in the structure of the energy-active object;
12. The assessment of the results of actions and effectiveness of strategies, risks of new accidents;
13. The continuation of the new management cycle.
14. Problems reflect the dynamics of man-made energy-active system.
15. Tasks reflect the system analysis and logic of decision making.

16. Task information components of the assessment of events in the functioning process.
17. Tasks determine managerial loyalty in the implementation of goals.

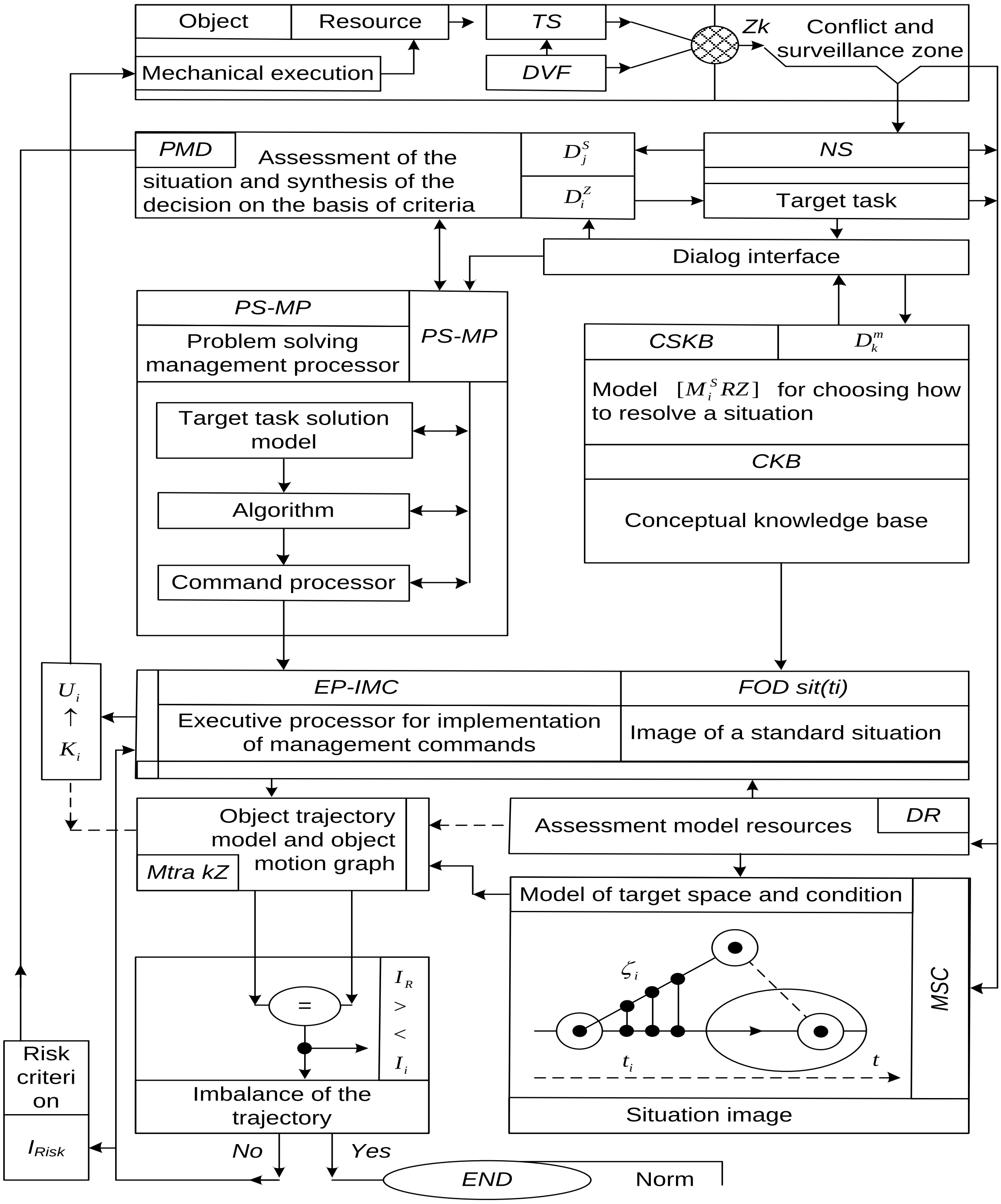

Figure 1: Logic-information scheme of formation of managerial decisions in cyber-physical purposeful systems

4. Logical aspects of the formation of procedures and schemes for solving management problems

Informal and formal theories as instrumental foundations for constructing the logic of actions in complex energy-active systems are based on a set of concepts:

$$T_F\left[I_F,\left\{\Pi_i\left|_{i=1}^{m}\right.\right\},\left\{A_j\left|_{j=1}^{m}\right.\right\},\{S_k\},Siq\{f_i,p_i\}StruktI_F\right],$$

where T_F – is a formal theory; I_F – is formalized theory language; $\{\Pi_i|\}$ – is a set of action rules; $\{A_j|\}$ – are axioms selected as true on the basis of rules; $\{S_k\}$ – is a system of statements formed according to the rules; $Siq\{f_i,p_i\}$ – is a signature as a set of predicate and functional constants; $StruktI_F$ – is a structure, as some interpretation of the language; $T_F(I_F)$ – is the theory of a particular language I_F.

Then the theorems are a logical consequence of a set of the theory axioms, and accordingly the structure of all axioms is a model of the theory under consideration, which reflects a certain reality and can be both concrete and abstract, according to the tools of semantic representation. There are two components of the theory: adequacy and completeness with the condition of probability of conclusions.

Accordingly, the theory T is related to the language $L=\{I_{FT}\}$ and possible models of the theory μ_T, then one can have the following statements:

Definition 1. If the theorems in L for the theory T are true, then they are true in μ_T.

Each theorem is a formula introduced and fixed in the axiomatic system of predicate numbering in the logical basis [14].

In such a system of theories $\{T,L,\mu_T\}$ one gets the following definitions:

Definition 2. A theory is constructive (solvable), if there is an algorithm that allows for a finite number of steps to decide whether the formula $A\subset T$ is a theorem or a chain of infinite operations in an attempt to reach the target.

Definition 3. A theory is complete if every formula of the language is a theorem or its negation and, accordingly, has finite chains of strategies description.

Definition 4. A theory is categorical if it allows the existence of the models unity up to isomorphism.

Accordingly, the definition in $\{T,L,\mu_T\}$ is introduced for the complete concept of the theory:

Definition 5. An algorithm is a way to solve a problem in theory $T\left(I_{FT},\{\Pi_i\},\{A_j\}\right)$ – as a way, method, model of constructing a procedure for selecting the answer from many alternatives with an infinite set of concretizations.

Definition 6. A problem is a way to describe a complex dynamic – structural situation in an energy-active system:

- the image of conflict in making uncoordinated decisions;
- questions with many possible answers about the situation;
- the definite set of concretization of alternative answers;
- the way to describe the situation features.

Definition 7. A procedure is a semi-algorithm that guarantees a positive but not complete solution to the problem in terms of its concretization (there is an element of uncertainty in the decision-making process).

If there are constructive schemes in the theory, it allows the existence of a finite algorithm, not a procedure, then it has a formal representation in a formalized language and is the basis for forming strategies.

5. A set of information and cognitive threat factors as a basis for assessing and predicting emergencies in the system

The occurrence of an emergency situation in the system is based on a set of factors of resource, information type and reliability of units and by virtue of the impact on the system has a stochastic, spatially distributed structure, leading to different classes of emergencies in the technogenic structure if the intensity of active factors (*AFi*) and threats (*AZi*) exceeds the permissible level:

$\sum_{i=1}^{n} R_i\left(AF_i\right) \to \alpha_F\left(Tn\right) \le \alpha_{Fd}$ – are active information factors that lead to management failure;

$\sum_{j=1}^{m} K_{Zj}\left(AZ_i\right) \to \alpha_Z\left(T_{\mathrm{m}}\right) \le \alpha_{Zd}$ – are active resource threats that lead to the failure of the operation mode;

where $\left(K_{Zi}, K_{Fi}\right)$ – are coefficients of factors influence on the objects modes;

$\alpha_1\left(T_n\right)$ – is a level of influence of threats and factors on the management cycle;

$\left(\alpha_{Fd}, \alpha_{Zd}\right)$ – are levels of robustness of the control system for attacks and threats.

An important component that changes the level of the system stability and robustness is the cognitive characteristics of both the operator and the team, the ways of distributing powers and responsibilities in the operational management system, which requires appropriate thinking and the level of ordered expert knowledge, the ability to use them in extreme situations.

The management quality assurance is based on a comprehensive analysis of all components of the management structure and the team of the operational and upper levels of possible risks assessment according to (Figure 2).

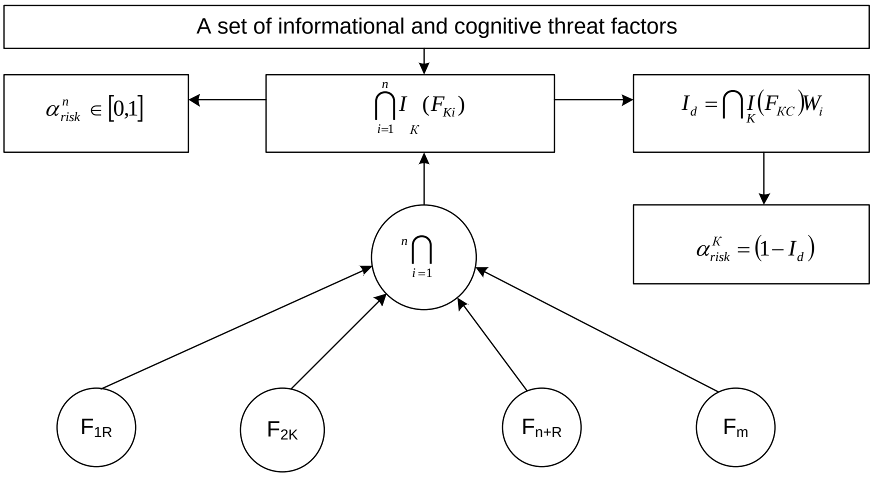

Figure 2: Scheme of risk assessment of management loss

The designation on the scheme of the risk assessment:

$\left\{F_{ik}\right\}$ – are factors of informational influence on the decision-making process during attacks;

$\left\{F_{ui}\right\}$ – are factors influencing the process of managing resource threats and targeted attacks;

$\left\{F_{ik}\right\}$ – are cognitive factors of professional suitability;

$I\left\{F_{Ki}\right\}$ – are coefficients of the factor influence on decision-making with the range of values $K_i \in \left[0.1\right]$ – which depend on the psycho-physical characteristics of the person;

W_i – is a normalizing factor coefficient on the interval of reliability scales;

I_d – is a criterion of management quality which depends on cognitive factors $I_d = I\left(kF_{Ki} \ldots kF_n\right)$ (systematicity, analytics, logic, knowledge);

α^n_{risk} – is the risk of reducing the reliability of the technological structure units;

α^K_{risk} – is the cognitive risk – inability and indecision in assessing the situation and making decisions in the face of threats;

α^i_{risk} – is the risk of information attacks on the management process.

Accordingly, there is an overall risk assessment based on the analysis of cognitive and informational components that are needed to identify influences in the form of a composition of factors that generate processes of management failure:

– the allocation of maximum risk $\max \alpha_{risk} = \bigcap_{i=1}^{n} I_K\left(F_{Ki}\right), \left(F_{Ki} \subset M\left[F_K\right]\right)$;

– the assessment of the total by the quality criteria $I_d = \max\left[\bigcup_{i=1}^{n} I\left(F_{Ki}\right)\right] \rightarrow \left[\alpha_{risk} \le \alpha_m\right]$.

Based on system analysis and cognitive actions for risk assessment (cognitive and informational) one can form a table of decision-making ability on the basis of expert opinions and tests which determines the operation code, the impact coefficient $K_n \in [0.1]$, the risk level at values $\alpha_{risk} \in [0.1]$, according to the assessment of knowledge and skills of the operator.

6. The results of experimental studies of decision-making in cyberphysical systems under conditions of a complex of threats

To conduct the research on the cognitive characteristics of operational personnel who performed the functions of managing the modes of operation and level of knowledge of personnel (LKP-A) - department of control and measurement systems and automation, developed cognitive map (Fig. 3) of management process using intelligent agent model according to the scheme (Fig. 1).

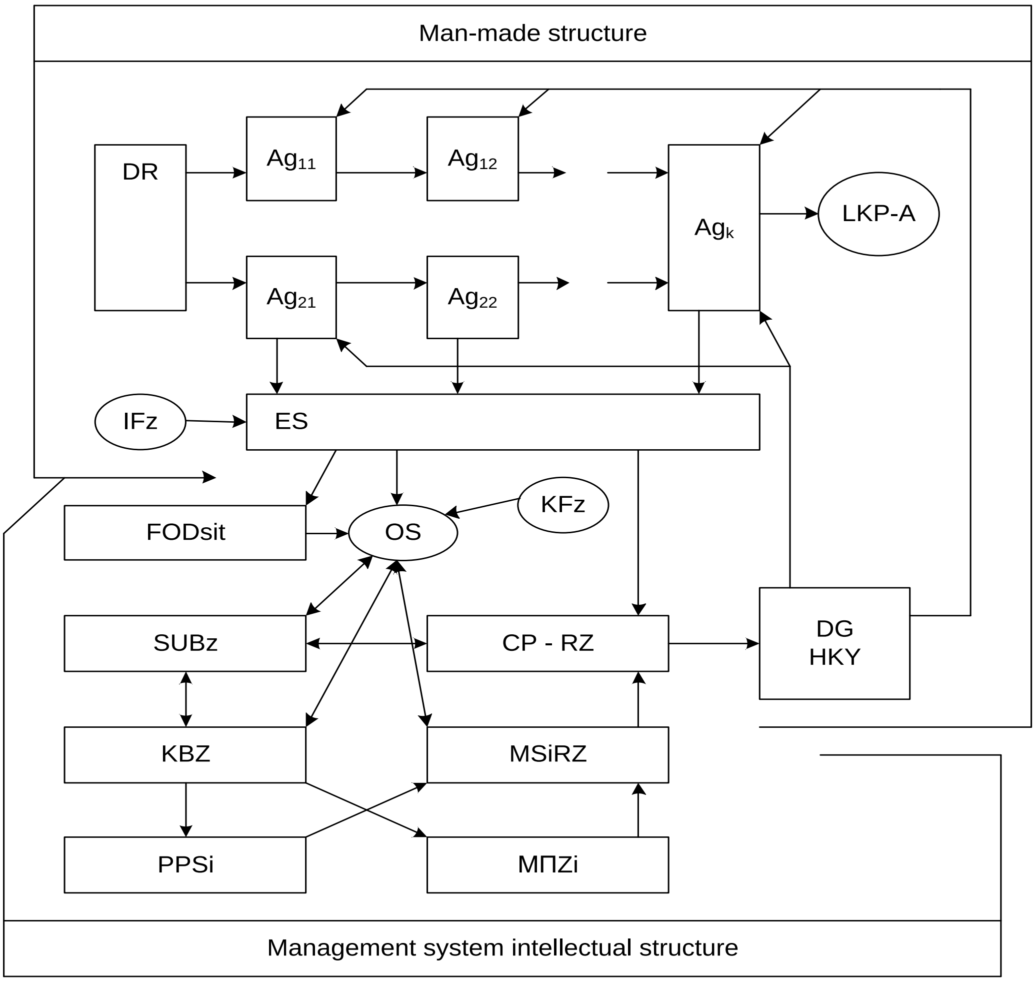

Figure 3: The cognitive map ofmanagement process based on the concept of intelligent agent

DR – is a source of resources;
Ag – agent;
LKP-A – department of control and measurement systems and automation;
OS – operational staff;
ES – emergency situation;
IFz – information factor of influence;
KFz – cognitive factor of influence;
FODsit – image of the reference situation;
SUBz – knowledge base management system;
CP-RZ – problem solving processor;
DG HKY – executive processor implementation of management commands;
KBZ – conceptual knowledge base;
MSiRZ – is a model of problem-solving strategies;
PPSi – support for situational decision making;
MПZi – model target space and state.

For each operator based on the assessment of cognitive and intellectual factors, templates of membership functions of skills, knowledge, abilities are constructed.

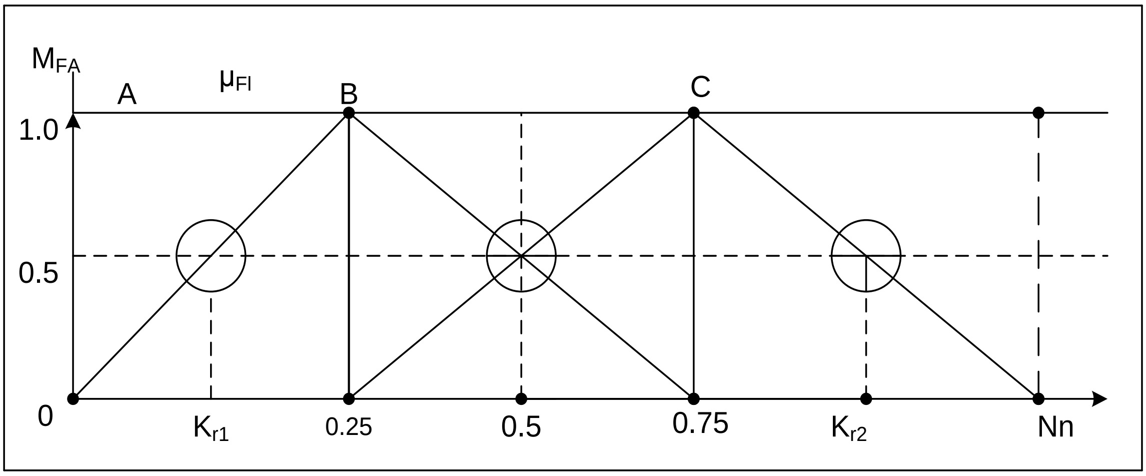

Figure 4: Functions of distribution of intellectual factors in the operational management team

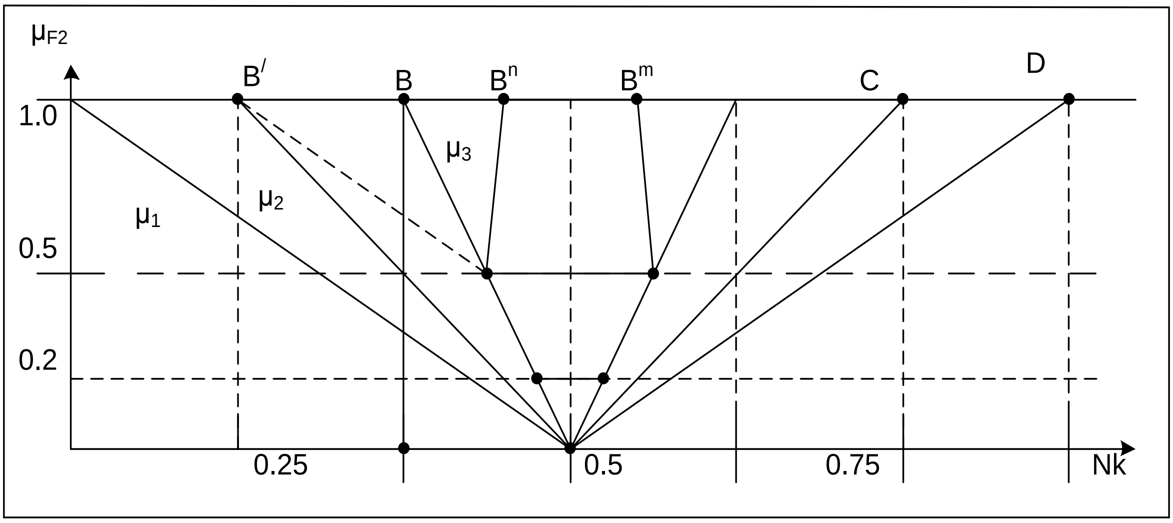

Figure 5: Functions of distribution of information factors of skills and knowledge in the operational management team

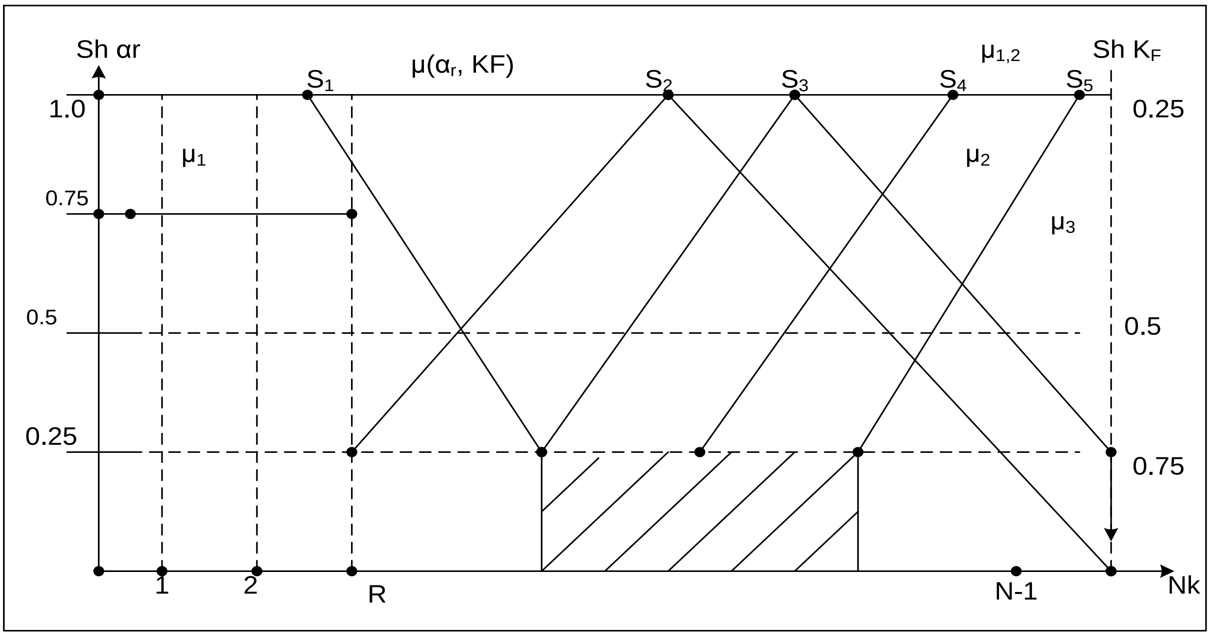

Figure 6: Risk functions of making incorrect decisions by the operational team

The test table (Table 1) is the basis for the formation of management teams according to their integrated quality coefficient of decision-making abilities (team portrait) based on fuzzy logic.

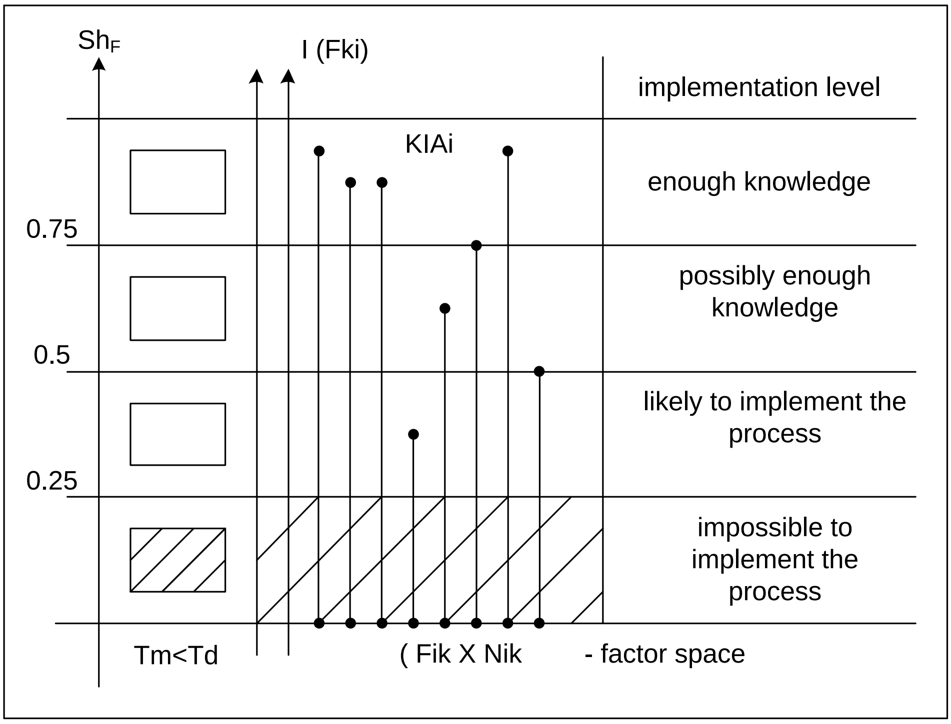

Figure 4: Information diagnostic scheme of the team portrait according to the integral coefficient for each member kI, A

To assess the quality of management skills and expert training, a table of the ability of operational management actions in the face of threats and risk of accidents is developed, which is presented in Table 1.

Table 1
Information – system and cognitive factors of effective decision-making

№	Operation type	Factor code	Coefficient K_{IT}	$\alpha risk\left(R_n < K_d\right)$
1	Forming images of situations from data flows over time $(t_i + T_m)$	$KI_{con}S$	0,5-1,0	≥ 0.5
2	Cognitive operations of perception of a situation	$KogIS$	0,5-1,0	≥ 0.5
3	To recognize images of dynamic situations	$R\left[SitT_m\right]$	0,5-1,0	≥ 0.5
4	Generation of tactics of actions	$\varsigma taktD_i$	0,7-1,0	≥ 0.7
5	Risk assessment over time T_m	$V_{risk}T_m$	0,8-1,0	0,8-1,0
6	Cognitive perception of images of situations formed from data flows on the interval T_m	IPD_S	0,4-1,0	0,2-1,0
7	To assess the meaning of the quality and ability data	$I_{Sens}D$	0,8-1,0	0,2-1,0
8	Cognitive system that perceives the image of the situation and assesses the risk	KS_n	0,5-1,0	0,1-1,0
9	The ability to perform system tasks	ZI_{S1}	0,5-1,0	0,1-1,0
10	The ability to be aware of the situations risks	ZI_{S2}	0,3-1,0	0,5-1,0
11	The ability to generate risk prediction for the event scenarios	ZI_{S3}	0,7-1,0	0,3-1,0
12	Cyber-physical thinking	KF_m	0,8-1,0	0,01-0,2

7. Conclusion

The article considers the logical aspects of knowledge formation in the construction of procedures for assessing dynamic situations in cyber-physical technogenic systems in crisis condition. It is shown that planning of clear and constructive decisions by an integrated purposeful intelligent system or person is based on understanding of physicochemical and energy processes occurring in technological systems and the ability to clearly identify constructive connections, the ability to quickly construct logical schemes [13] of interconnected structures, to synthesize effective action plans. The ability of management is to fully understand the structure, dynamics, goal orientation of the technogenic system on the cycles of terminal time.

The studies show that the selected system-information and cognitive factors that determine the ability to clearly perceive the crisis situation in the technogenic structure and accept and implement them in the acceptable terminal time is the basis for preventing an emergency or conflict situation.

The effectiveness and quality of goal-oriented decisions depend on the way of thinking and the ability to implement them in an extreme situation based on targeted mobilization of intellectual resources of the operational and strategic management team.

8. References

[1] Bhise, V.D.: Decision-Making in Energy Systems. CRC Press, 1st edn. (2021). https://doi.org/10.1201/9781003107514.

[2] Balyk, V.M., Thuong, N.Q. Statistical synthesis of the principle of ra-tional organization of a complex technical system. In: 2019 International Conference on Engineering and Telecommunication (EnT). pp. 1{4 (2019). https://doi.org/10.1109/EnT47717.2019.9030569.
[3] M. Barankevych, Expert methods in decision making, Lviv, PC LNU named after I. Franko, 2008.
[4] C. Morvan, W. Jenkins, Judgment Under Uncertainty: Heuristics and Biases. London: Macat International Ltd., 2017.
[5] L. Sikora, R. Tkachuk, N. Lysa, I. Dronyuk, O. Fedevych, Information and logic cognitive technologies of decision-making in risk conditions, in: Proceedings of the 1st International Workshop on Intelligent Information Technologies & Systems of Information Security, IntellTSIS 2020, Khmelnytskyi, Ukraine, 2623 (2020) 340-356.
[6] L. Sikora, R. Tkachuk, N. Lysa, I. Dronyuk, O. Fedevych, R. Talanchyk, Information-resource and cognitive concept of threat's influence identification on technogenic system based on the cause and category diagrams integration. IntellTSIS 2021, Proceedings of the 2nd International Workshop on Intelligent Information Technologies & Systems of Information Security with CEUR-WS Khmelnytskyi, Ukraine, 2853 (2021) 498-516.
[7] S. Orel, M. Maliovanyi, Risk, Lviv, National University "LP", 2008.
[8] Groome, D., Brace, N., Edgar, G., Edgar, H., Eysenck, M., Gobet, F., Law,R., Manly, T., Ness, H., Pike, G., Scott, S., Styles, E.: An Introduction to Cognitive Psychology: Processes and Disorders. Routledge, 4th edn. (2021). https://doi.org/10.4324/9781351020862 Title Suppressed Due to Excessive Length 11
[9] Tamalika Chaira. Fuzzy/Intuitionistic Fuzzy Set Theory. Fuzzy Set and Its Extension: The Intuitionistic Fuzzy Set, Wiley, 2019, pp.1-40, doi: 10.1002/9781119544203.ch1.
[10] A. Barseghyan, Data and process analysis, SPB, BHV, Petersburg, 2009.
[11] D. O'Connor, I. McDermott, Systems thinking and the search for extraordinary creative solutions, Kyiv, Our format, 2018.
[12] Tattam, D.: A Short Guide to Operational Risk. Routledge, 1st edn. (2011).https://doi.org/10.4324/9781315263649
[13] S. Demri, V. Goranko, M. Lange, Temporal Logics in Computer Science, Cambridge: Cambridge University Press, 2016.
[14] V. Yevsieiev, A. Bronnikov, Comlexity development analysis of cyber-physical production systems for smart manufacturing. The X th International scientific and practical conference «Trends in the development of modern scientific thought» (Canada, Vancouver, 23–26 Nov. 2020). 699-703. doi:10.46299/ISG.2020.II.X.
[15] Y. Danyk, T. Maliarchuk, Ch. Briggs, Hybrid War: High-tech, Information and Cyber Conflicts, Connections. The Quarterly Journal. 16 2 (2017) 5–24.
[16] T. Hovorushchenko, O. Pavlova, M. Bodnar, Development of an Intelligent Agent for Analysis of Nonfunctional Characteristics in Specifications of Software Requirements. Eastern-European Journal of Enterprise Technologies. 1 2(97) (2019) 6-17. doi: https://doi.org/10.15587/1729-4061.2019.154074
[17] T. Hovorushchenko, O. Pavlova, Method of Activity of Ontology-Based Intelligent Agent for Evaluating the Initial Stages of the Software Lifecycle. Advances in Intelligent Systems and Computing. 836 (2019) 169-178. doi:10.1007/978-3-319-97885-7_17.
[18] Wiggins, M.W.: Introduction to Human Factors for Organisational Psychologists. CRC Press, 1st edn. (2022). https://doi.org/10.1201/9781003229858
[19] S. Demri, V. Goranko, M. Lange, Temporal Logics in Computer Science, Cambridge: Cambridge University Press, 2016.
[20] Andonov, S. Safety Accidents in Risky Industries: Black Swans, Gray Rhinos and Other Adverse Events. CRC Press, 1st edn. (2021).https://doi.org/10.1201/9781003230298