Methodology for dialogue management in human-machine systems under the risks

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Abstract

This paper analyzes the features of the concept of " Operator 5.0 ." and considers the problem of dialogue session management in complex human-machine systems under conditions of changing environment and psychophysiological state of the operator. The concept of agent approach to dialogue management is proposed, requirements to agent-manager for dialogue management are developed. Models allowing to manage the process of dialogue "man-machine" in conditions of risk and to adapt the course of dialogue to the current conditions of the operator's activity are developed. Examples from various subject areas (the process of controlling an unmanned aerial vehicle, dialogic interaction in an e-learning system) are given to demonstrate the practical implementation of the proposed approach.

Keywords

Ergonomics, human-machine interaction, reliability, optimization, interface, Operator 5.0

1. Introduction

In modern conditions, when the control of complex technological systems (such as power grids, aviation complexes, industrial robots) becomes more and more automated, the risks associated with the human factor increase [1-4]. The cost of operator error can be catastrophic [5-7]. Traditional systems of human-machine interaction often proceed from the assumption of stability of the external environment and constancy of the operator's psychophysiological state [8-10]. In reality, these factors are subject to significant changes.

Situations of fatigue, stress, as well as external influences such as a continuous flow of tasks, noise, vibration or equipment malfunctions can significantly reduce the efficiency and reliability of control. Added to this are new threats, in particular cyber-attacks that can compromise the integrity of data and control signals. There is an urgent need to develop adaptive human-machine systems that can dynamically adjust the dialogue session depending on the current situation to prevent errors and ensure security [10-12].

2. Analysis of the research area and problem statement

In recent years, more and more attention has been paid to the problem of human factors: conceptual issues of ergonomics [13-17], human-computer interaction [17-19], harmful environmental factors [20-21], human-operator reliability and risks [22-24] The task of

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constructing adaptive human-machine interfaces [25-29] is particularly emphasized Before the Second World War, the concept of human-machine interaction was based on the principle "humans adapt to machines", whereas after the war, research in engineering psychology and ergonomics came to the conclusion that "machines must adapt to humans" [30]. This often proved to be a difficult task, especially in the case of inherently maladaptive systems (the changing complexity and pace of work had a catastrophic effect on the state of the operator). The next step in the development of the methodology was cognitive systems in which two-way adaptive interaction between human and machine was possible. For many years the human-centered approach became the basis of ergonomics. Today ergonomics is moving from a human-centered concept to a human-centered method using artificial intelligence [13-14, 29], the concept of this approach is generalized in Fig. 1.

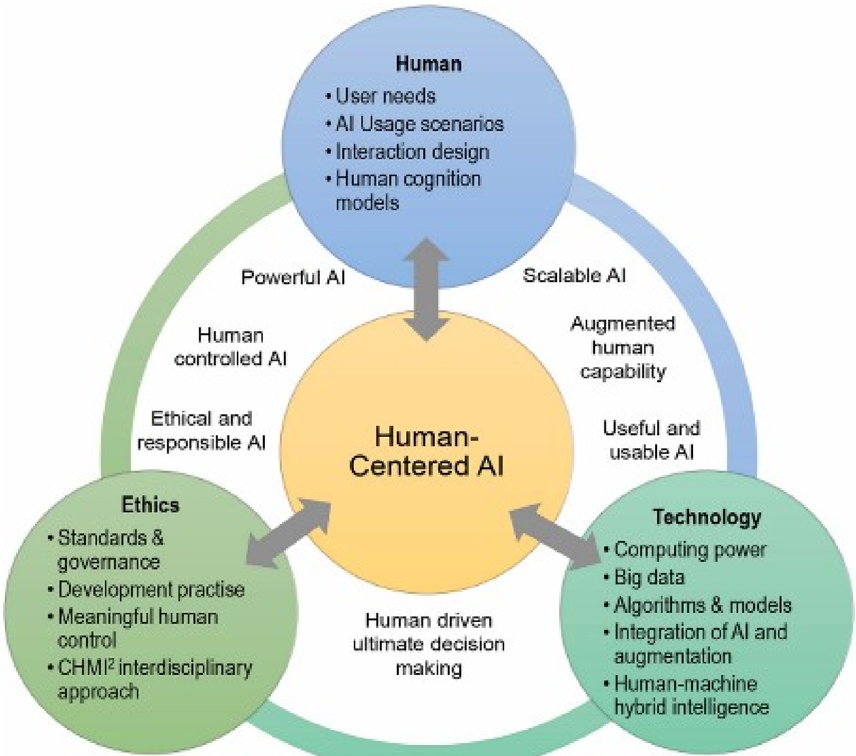

Figure 1: The modern concept of interface design [13-14].

The Operator 5.0 concept represents the evolution of the human worker in the era of Industry 5.0, emphasizing a human-centric approach that uses technology for the well-being and health of the operator, not just to improve productivity. In this model, ergonomics is critical to designing systems that take into account a person's physical, cognitive and sensory capabilities, using wearable sensors, motion capture technologies and machine learning to objectively assess risks, monitor fatigue and optimize workplaces to reduce musculoskeletal disorders and improve overall working conditions.

The main principles of the Operator 5.0 concept are [13-14, 29]:

- Human-centered: the operator is at the center of the production process and their health, well-being and capabilities are priority alongside business objectives;
- Synergy with technology: operators interact with advanced technologies such as robots and artificial intelligence, rather than being replaced by them;
- Resilience and health: the focus is shifting to improving the operator's physical and cognitive resilience and continuous monitoring of their condition.

Functional networks and semi-Markov processes [30, 31] stand out among the most effective approaches to modeling the human-machine interaction required to implement adaptation procedures. These models allow describing the dialogue as a sequence of states and transitions. The works of scientists of the scientific school of Professor AI Gubinsky have made a significant contribution to the development of these models, showing their applicability to the description, analysis and optimization of dialogue processes [32 -37]. Directly the problems of adaptive control in human-machine systems were solved in the works [38 -39].

Unfortunately, despite significant achievements, the problem of operational control of dialogue in a rapidly changing environment taking into account risks such as cyberattacks, deterioration of external conditions and changes in the operator's state is not completely solved.

Problem statement: to develop a conceptual framework for managing the dialogue "man-machine" on the basis of a set of models that should take into account the current state of the man-machine system, as well as possible risks of the external environment and at certain points in time to offer a person the optimal alternative aimed at improving the reliability and safety of management.

3. Results

3.1. An agent-based approach to dialogue management

In connection with the described problems, we propose the implementation of agent-based approach for human operator decision support (Fig.2).

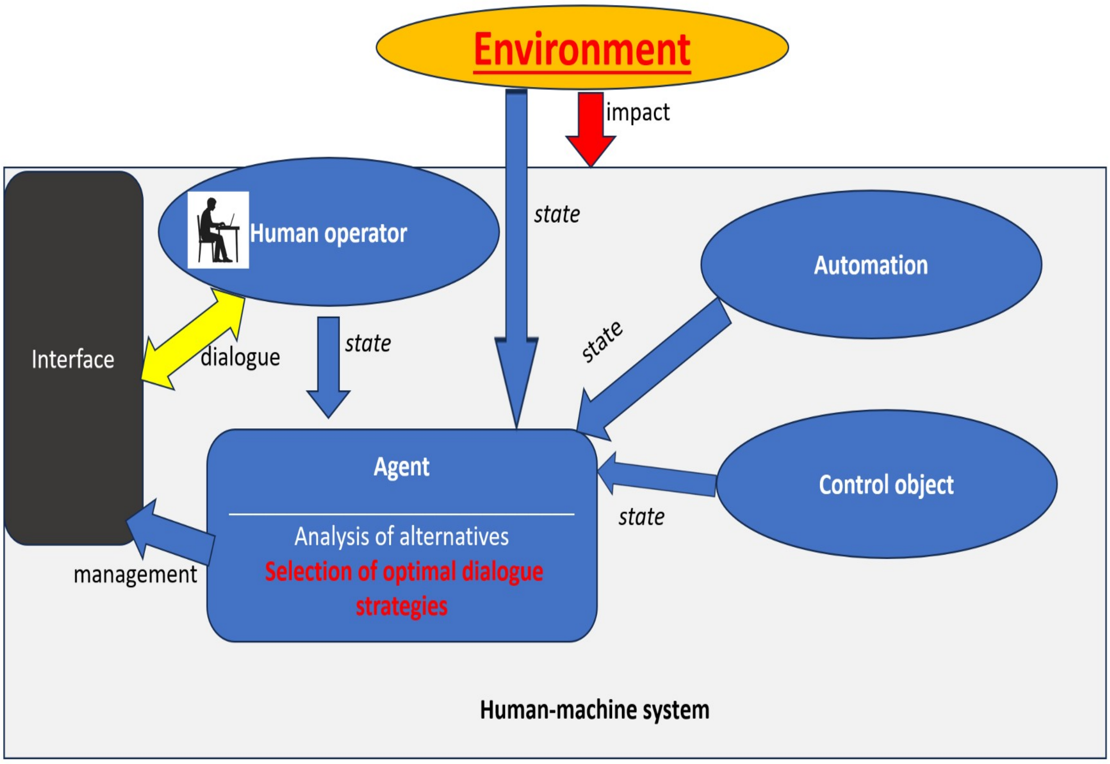

Figure 2: An agent-based approach to dialogue management.

The agent is built on a set of models:

- Descriptions of the current state of all elements of the human-machine system;
- Description of the current state of the environment (including risks of negative impacts and cyberattacks);

- Descriptions of alternative variants of human-machine interaction;
- Estimates of human-machine interaction reliability;
- Estimation of ergonomic indicators of operator's activity;
- Selection of optimal variants of human-machine interaction under the conditions of the current state of the system and the environment.

The task of building agents to implement the "Operator 5.0" concept is the global challenge of the next decade.

In the following we will consider only some aspects and examples of building such agents.

3.2. Approach to setting and solving the task of dialogue management

To solve the problem of optimizing human-computer interaction, we developed a bank of optimization models , some of which are described in [21, 30-39].

In most cases , these models are related to the task of maximizing the probability of error-free and timely execution of functions within the constraints of ergonomic and economic indicators.

The developed methods can and should become the basis for building the agent in question. Further, we will limit ourselves to describing the task of multi-criteria optimization.

In some cases, especially in critical situations, the reliability maximization criterion alone may not be sufficient. Other, often conflicting, criteria, such as speed of execution and operator status, must be taken into account to make better decisions.

Objective: Find the optimal sequence of actions that best satisfies all criteria.

The problem is formulated as a vector optimization problem

$$\begin{cases} F_1(X) \to \max, \\ F_2(X) \to \min , \\ F_3(X) \to \min \\ X \in S, \end{cases}$$

where:

$F_1(X)$ – total probability of error-free execution of dialogue procedures;

$F_2(X)$ – mathematical expectation of the time of implementation of the dialogue interaction process;

$F_3(X)$ – average tension of the operator's activity throughout the session;

X – variable describing the method of dialogue interaction;

S – set of combinations of dialogue interaction options.

Assessment of indicators $F_1(X)$, $F_2(X)$, $F_3(X)$ is a rather complex scientific and technical task. We propose that such an assessment be carried out using a "functional network" model, which describes the logical and temporal connections between machine operations and human actions. We have developed some models for automating such assessments while solving other problems, for example, in works [32-39], but they can also be used to implement a bank of agent-manager models. The impact of adverse conditions and operator stress should be taken into account by recalculating the "control points" based on special risk analysis models.

To do this, we use the procedure “Dynamic generation (recalculation) of initial data”.

The peculiarity is that at each step the transition probabilities and transition times between process states are recalculated depending on the current parameters:

- R_c – risk of cyberattack occurrence;
- R_e – risk of unfavorable changes in the external environment;
- α – man-operator stress level.

Since criteria may conflict (eg, increasing speed may increase operator workload), a compromise solution must be found that best meets current priorities.

Here we consider only one of the simplest methods based on Thomas Saaty's approach, which naturally does not exhaust the whole bank of optimization models that are included in the agent's model bank.

When the system (dialog management agent) detects a risk and it is necessary to offer the operator an optimal response, it uses a procedure of multi-criteria expert analysis of alternatives based on the method of hierarchy analysis [40-43].

Sequence of agent actions:

- *B1. Hierarchy construction.* On the basis of the available knowledge base or the dialog with the operator-manager, the agent forms a hierarchy of decisions, where, for example, at the top level is the goal ("Optimization of the dialog session"), at the middle level are the criteria, eg, "Safety", "Speed", "Operator load", and at the bottom level are alternative scenarios for continuing the dialog at the current step;
- *B2. Pairwise comparison of criteria and alternatives.* The agent's knowledge base or (in urgent cases) direct instructions from the operator -manager) are used;
- *B3. Automatic synthesis of recommendations.* Based on the comparison matrix, the system calculates the priorities for each criterion and then the overall priority for each alternative. The alternative that has the highest priority is selected. This is the optimal action that the system suggests to the operator;
- *B4. Formation of interactive recommendations to the operator (adaptive interface element*).

3.3. Examples of agent-based dialog management implementation

3.3.1. An example from the field of unmanned aerial vehicle control

Consider an operator controlling a unmanned aerial vehicle (UAV) to monitor a critical facility. Normal operation mode:

- System state: the UAV is flying along a given route;
- Operator state: α is at a low level (eg, 2.5 on a 10-point scale);
- Interface: Standard, displays full set of information: video stream, map, telemetry (speed, altitude, battery charge).

Risk Occurrence. Scenario:
The monitoring system detects two threats simultaneously:

- External environment (Re): The system detects increase in wind and radio interference. Risk Re goes up to 0.8;
- cyberattack (Rc): Detection of unauthorized access attempts to the UAV control system. Risk Rc rises to 0.7.

The model, receiving this data, recalculates all parameters. In an operator, due to stress, α starts to increase (eg, to 7.5).

Adaptive management: decision making. The system, using a multi-criteria model and hierarchy analysis method, proposes three alternatives to adjust the UAV's dialog and behavior:

- Alternative A (Safe Return): Return to base via the shortest safe route;
- Alternative B (Continuation with Enhanced Protection): Continue the mission, but switch to a protected communications link and to manual control to compensate for weather conditions;
- Alternative C (Emergency Landing): Make an emergency landing in the nearest safe area.

An example of the input data for analyzing the UAV control strategies when a threat occurs is shown in Fig. 3. and the solution results are shown in Fig. 4.

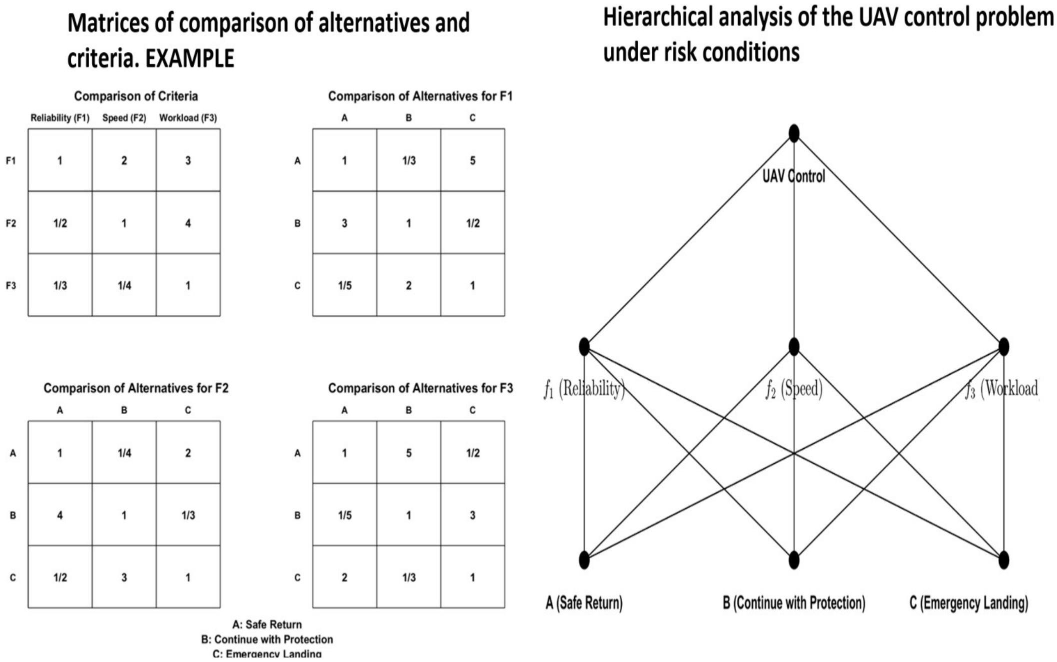

Figure 3: Example of input data for analyzing UAV control strategies when a threat occurs.

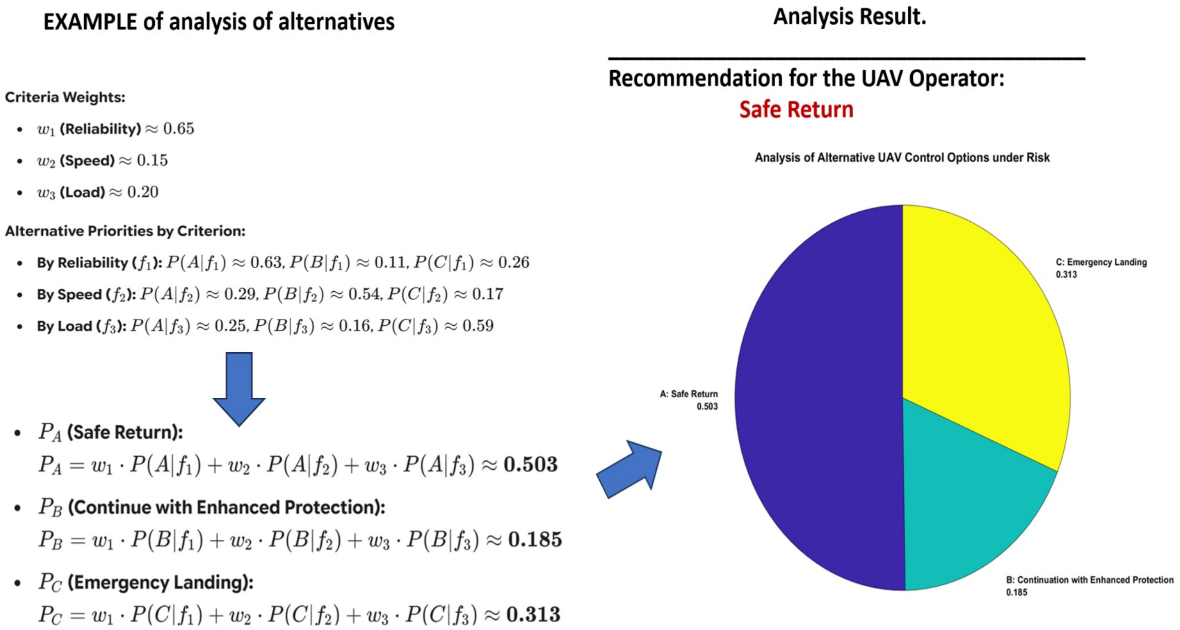

Figure 4: Results of solving the UAV control problem when a threat occurs. Example.

Adaptive interface. In this scenario, when the system selects Alternative A (Safe Return) because of the high priority, the operator interface adapts instantly to minimize cognitive load and ensure that this action is performed quickly and safely.

The interface changes to reflect the critical situation. The background turns dark red.

The video stream is minimized and a large warning appears in the center to return immediately.

The auxiliary controls are deactivated, leaving only two active buttons:

- *"Confirm Return";*

- *"Reject".*

This significantly reduces the cognitive load on the operator.

3.3.2. Example of an Agent-manager for managing a dialogue in e-learning

The developed agent-based approach for dialog management can be applied in a variety of fields of activity. Despite the fact that e-learning is not directly related to the risks of accidents and disasters, the learning environment can also be aggressive and often carries risks to human health [22,44].

The formulation of the optimization problem underlying the agent is somewhat different from the above (different objects have their own specifics) and has the following form:

$$\begin{cases} K(g) \to \max, \\ Z(X_g) \to \max, \\ T\left(X_g\right) \leq T_0, \\ Z\left(X_g\right) \geq z_0, \\ W\left(X_g\right) \leq w_0, \\ X_g \in R_g, \end{cases}$$

where:
g – the number for a specific electronic learning module. Each module is different in how it shares information, $g = \overline{1, G}$;
G – how many learning modules are available for the same subject;
$K(g)$ – a rating of how comfortable a student feels mentally when using an electronic module g;
X_g – a variable that describes the type of dialogue used in electronic module g;
$T(X_g)$ – the average time of implementation of interaction X_g;
T_0 – the longest time you are allowed to train;
$Z(X_m)$ – the points a student gets for finishing module m;
z_0 – the lowest score you must get on a knowledge test;
$W(X_g)$ – how difficult the learning process is, in points;
w_0 – the highest level of difficulty that is allowed;
$R(g)$ – all the possible ways to have a dialogue in module a set of combinations of dialogic interaction options for module g.

Fig. 5 shows the principal structure of a manager agent for learning management [44].

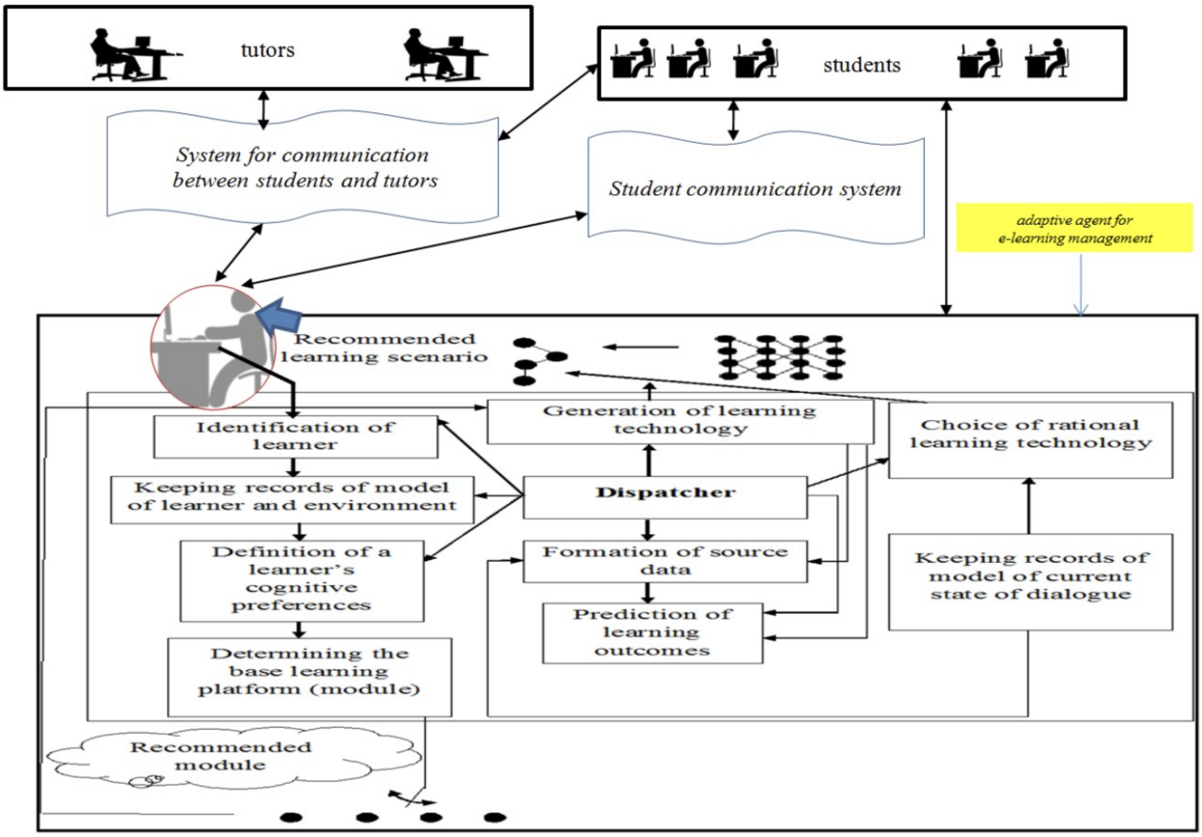

Figure 5: Example of an agent-manager structure for e-learning.

The presented agent uses a neural network to analyze the functional state of a human operator by analyzing the current keyboard handwriting.

4. Testing

The approach has been used many times to build adaptive control systems for complex objects:

- control systems for flexible production;
- chemical enterprise;
- gas transportation system;
- banking;
- e-learning;
- etc.

5. Conclusions

Modern automated systems are becoming increasingly susceptible to human operator error. People often work under conditions of stress caused by negative environmental influences, cyberattacks and other risks. The "Operator-5.0" concept envisions an increased focus on ensuring human operator comfort, especially in the face of negative influences. To ensure a comfortable human-machine dialog it is advisable to use an agent-based approach. The agent forming the current information model of the operator and adaptive interface should be based on a set of models such as models for: description of the current state of all elements of the man-machine system; description of the current state of the environment (including the risks of negative impacts and cyberattacks); description of alternative options of man-machine interaction; assessment of the reliability of man-machine interaction; assessment of ergonomic indicators of the operator's activity; selection of optimal variants of man-machine interaction.

Optimization models should take into account as parameters the risks of cyberattacks and deterioration of operating conditions. The arsenal of models should include both single-criteria and multi-criteria problems and provide for automatic changes in interface parameters (depending on current conditions).

The novelty of the results lies in the fact that, in contrast to the known static models of human-machine interaction optimization, procedures for dynamic adjustment of the interface are proposed, taking into account the current state of the operator, the system and various risks.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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