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CONCEPTUALIZATION OF INTELLIGENT CONTROL SYSTEM FOR HUMANITARIAN DEMINING ROBOTIC COMPLEXES BASED ON VERBAL METHODS

Introduction. *Humanitarian demining is characterized by growing attention to the problems of creating and using robotic systems. The most important aspect of their use is the control method.*

Problem Statement. *At present, the first generation robotic complexes (controlled devices) have been the most common, the second generation complexes (semi-autonomous devices) have been improving. To switch to the third generation complexes (autonomous devices), it is necessary to develop intelligent control systems based on artificial intelligence technologies. The most used for system development are quantitative methods, but such models are "black box models" that do not provide complete clarity about their behavior.*

Purpose. *To develop conceptual model of intelligent control systems for humanitarian demining robotic complexes based on verbal methods.*

Materials and Methods. *Formal logic methods, verbal analysis qualitative methods, and BPMN.*

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Results. *Conceptual model of intelligent control systems for humanitarian demining robotic complexes and symbolic models of representing relevant declarative and procedural knowledge based on verbal methods have been developed.*

Conclusions. *The conceptual model makes it possible to formulate Symbolic Models in the notations of selected verbal methods. At the decision-making level, the ordinary classification method by denotation of the terms used by experts in the selected subject area has been chosen. At the executive level, the BPMN method has been chosen to create process diagrams in graphical notation. The verbal methods make it possible to create "white-box models" that unambiguously interpret the dependence of output and input variables and to explain the model behavior. Symbolic models in the notations of selected verbal methods allow the implementation of an intelligent control systems for a specific humanitarian demining robotic complex.*

Keywords: conceptual model, intelligent control systems, and verbal analysis.

According to the report by the International Campaign to Ban Landmines (ICBL) for 2020, 2019 was one of the most tragic years in terms of mortality from mine explosions in the world. Afghanistan, Colombia, Iraq, Mali, Nigeria, Ukraine, and Yemen had the highest deaths from mine explosions. One third (33%) of deaths from anti-personnel mine explosions in 2019 were recorded in 55 countries that joined the Ottawa Treaty. Anti-personnel mine explosions in 2019 claimed at least 2,170 lives worldwide, another 3,357 people were injured. More than 80% of mine deaths are civilians, 43% of whom are children [1]. Also, according to the United Nations estimates it has been found, for example, that during the years of the military conflict in the Donbas, about 30% of the Ukraine territory (about 270,000 sq. km) was contaminated with unexploded explosive objects (mines, shells, air bombs, etc.). It will take 25—30 years to clear the territories contaminated with explosive objects.

Humanitarian demining — a set of activities carried out with the aim of eliminating the dangers associated with explosive objects (EO), including non-technical and technical survey of territories, mapping, detection, neutralization and/or destruction of EO, marking, preparation of documentation after mine clearance, provision of information to the public about mine action and the transfer of the cleared area [2]. Humanitarian demining is primarily aimed at reducing the harmful effect of EO on people's livelihoods. The goal of humanitarian demining is to reduce the risk of mines to a level where people can live safely; in which economic, social and physiological development can proceed unimpeded, unaffected by the constraints imposed by landmines.

With regard to military operations and humanitarian demining, an increase in attention to the problems of creating and using military robotic systems (MRS) is characteristic. This is due to the attempts of the United States and other NATO countries to save the life of a soldier in battle, in the context of which the use of the MRS allows achieving positive results [3]. In addition, this trend is explained by the rapid development of the latest technologies in the information sphere, that is, the "robotization" of various areas of human activity, in particular the military sphere, quite logically corresponds to the content of modern concepts of a post-industrial society. The above problems, according to experts, should be solved only in a complex of organizational and technical measures, one of which is robotic complexes and systems for military, special and dual purposes.

One of the most important aspects of the use of robotic systems is the method of control. This is confirmed by the illustrative classifications of the MRS:

- by generation:

1) the first generation robots — devices with software and remote control that can only work in an organized environment;

2) the second generation robots — adaptive, having synthetic organs of "intuition" and capable of functioning in previously unknown conditions and adapting to changing situations;

3) the third generation robots — intelligent, having a control system with elements of artificial intelligence;

- according to the degree of dependence on the operator:

1) "human-in-the-loop": this category includes unmanned vehicles that can independently identify targets and carry out their selection, but the decision to destroy them is made only by the human operator;

2) "human-on-the-loop": this category includes systems that can independently identify and select targets, as well as make decisions on their destruction, but a human operator acting as an observer, in any the moment can intervene and correct or block this decision;

3) "human-out-of-the-loop": the works assigned to this category are able to identify, select and destroy targets without human intervention.

The above classifications are based on differences in the MRS control system, that is, the level of its "intelligence", which makes the development of such systems a very important topic from a scientific point of view.

Work on the creation of robotic means and systems, including military (dual-purpose) and special purpose robotic means, is widely conducted throughout the world.

Thus, experts in the development and production of mobile robots [4] define an "intelligent robot" as having a so-called model of the external world or internal environment, which allows the operation in an uncertain information environment. In this way, an intelligent robot is a robot includes an intelligent control system (ICS). ICS means a computer system for solving problems that a person cannot solve in real time, or their solution requires automated support or gives results comparable to human solutions. At the same time, among other things, it is understood that for the tasks to be solved, the ICS does not provide for the completeness of knowledge, and the IMS itself should be able to streamline data and expertise with the allocation of significant parameters, adapt to changes in the set of facts and knowledge, etc. Consequently, despite the many proposed criteria for intelligence, the strictest requirement remains that the role of a person in interacting with the ICS should be reduced only to setting a task. Intelligent systems are a necessary component for solving the problems of creating a model of the world, a system for planning actions and managing goals. The knowledge base in intelligent systems is one of the main parts of the world model and its transformational functions.

Shortcomings include the general nature of the information without considering specific methods for developing ICS.

In [5] the requirements for MRS were considered and proposals were developed regarding their application in humanitarian demining. It has been established that the organization of the humanitarian demining system with the use of MRS should include the reconnaissance of EOs, search, marking, identification and direct demining, which are integral parts of the control system.

Shortcomings include the general nature of the article and the focus on technical means, in particular manipulators and detectors, which should be included in the MRS.

In [6], an analysis of modern developments on intelligent control methods for robotic systems was carried out and approaches were formulated for the construction of such control systems that are invariant with respect to the specifics of operation, taking into account the incompleteness of incoming information and various types of uncertainty. To achieve the goals set, a number of tasks were solved: an analysis of the architectures of intelligent control systems for robotic systems was carried out; a generalized algorithm for situational identification of a robotic system was developed; developed an intelligent control system for a robotic platform for the needs of production.

Shortcomings are that the article is of a general nature and does not contain a description of the control systems intellectualization methods for robotic platforms.

In [7] presents an overview of measures to ensure the safety of the population in emergency situations of a peaceful nature, lists the dangers of a military nature and the principle of survival in combat conditions. Currently, in modern conditions of conducting military operations, in order to reduce the loss of soldiers and officers, robots, robotic mobile systems are being created and the concepts of their use are being considered. In the armies of developed countries, it is planned to create completely autonomous robotic formations. The review considers various ground-based military robots, aircraft and android robots being developed in many countries of the world.

Shortcomings are the general nature of the article and, despite its title, the focus on the combat component of the analyzed MRS, rather than ensuring the safety of the population in emergency situations of a peaceful nature.

Research [8] analyzes modern concepts of artificial intelligence and definitions of the term "level of intelligence." In robotics, an artificial intelligence system is defined as a system that works intelligently and optimally. The author proposes to use methods for optimizing the design of ICS by work. The article formalizes the tasks of designing an ICS as a class of extremal problems with constraints. The solution of these problems is quite difficult due to the high dimensionality, polymodality and a priori uncertainty. The decomposition of extremal problems according to the method proposed by the author allows us to reduce them to a sequence of simpler problems that can be successfully solved by modern computing technologies. The article considers several possible approaches to solving such problems.

Shortcomings: the proposed methodology uses quantitative methods that have a number of shortcomings associated, on the one hand, with the need for highly qualified developers of such control systems, and on the other hand, with the errors introduced into them by the applied mathematical models.

In [9] illustrates the main principles and development of advanced methods for the implementation of intelligent robotic systems. It talks about strategies by which a robot (manipulators, mobile robot, quadcopter) can learn its own kinematics and dynamics from data. In this context, two main issues were considered; in particular, the stability of systems and experimental checks. The algorithms and learning methods described in this book can easily be extended to other robotic systems. The book contains MATLAB-based examples and coding for robotic operating systems for experimental verification.

Shortcomings are that the main attention is paid to the algorithms for implementing the control of individual mechanisms of robotic systems based on quantitative methods, and not to the development of ICS as a whole.

In [10], it is said that it is generally believed that demining operations are carried out by unmanned vehicles with special onboard equipment and the entire process is controlled from the operations center. But at the same time, it is noted that all actions in dangerous areas, for example, in minefields, require the use of specific approaches to search, precise localization of single targets, neutralization and other work. The operation of unmanned vehicles in such an area assumes that they have a certain degree of autonomy to resolve particularly critical situations. This poses a challenge for future research.

Shortcomings are that considerable attention has been paid to technical means, in particular, the modular concept of building MRS, flywheel drive mechanisms and other accessories used in the demining process.

According to the description of the developer [11], the unmanned (autonomous) platform LASKA 2.0, thanks to the neural network, can autonomously (if GPS is available) patrol the perimeter, move from point to point, return "home", when the control channel is lost, and move without GPS during the operation of the Electronic warfare.

The disadvantages of using neural networks are well known, but from the point of view of MRS, the following can be distinguished:

- problems that arise during the preparation of the training sample, related to the difficulties of finding a sufficient number of training examples;
- network training in some cases leads to deadlock situations;

- long time costs for performing the training procedure often do not allow the use of neural networks in real-time systems;
- the behavior of a trained neural network cannot always be clearly predicted, which increases the risk of its use for managing expensive technical objects.

Given the use of verbal methods for building decision-making systems (DMS), which are the basis of MIS, publication [12] is closest to the research topic. Based on the verbal information received from experts in terms of their subject area, and the method related to the verbal analysis of decisions, the so-called "decision rule" is built. The decision rule in the form of a table contains a verbal (criterial) description of all possible situations that may arise, distributed by class. A class is a decision made in a given situation. The decision rule is built on the basis of logical, qualitative transformations of verbal variables in compliance with the psychological and mathematical correctness of these transformations.

The disadvantages of the article include its economic orientation, which makes it necessary to adapt the proposed method to the needs of building an ICS MRS.

All this gives grounds to assert that:

- now the most common MRS of the first generation (controlled devices);
- the second-generation systems (semi-autonomous devices) are rapidly improving;
- in order to switch to the third-generation MRS (autonomous devices), it is necessary to develop ICS based on artificial intelligence technologies;
- mathematical, quantitative methods are the most common in relation to the construction of MIS.

However, the ability to implement quantitative methods for building DMS is often limited. In the methods, an implicit assumption is made that a person measures a certain quantitative parameter once. The resulting value is the only one that reflects the preference of the decision maker (DM).

However, studies by psychologists [13], as well as practical experience in the application of these methods, cast doubt on the correctness of the assumption.

As is known, DM is not an accurate measuring device that does not allow errors in quantitative measurements. Psychophysics provides quantitative evidence of a person's inaccuracy in measuring physical characteristics (weight, length, etc.). As a result, the direct assignment of quantitative weights of criteria is always carried out with errors [14]. The need to take into account errors in quantitative measurements is rightly pointed out in [15]. In psychological experiments [13] was shown that human "heuristics and biases" lead to significant errors in the information received (for example, when quantifying the probabilities of events). In the situation, expert (verbal) assessments are the only means of solving similar problems [16].

The advantages of expert assessments include ease of use for forecasting almost any situation, including in conditions of incomplete information.

With regard to systems, the three general categories can be distinguished [17]: the concrete, the symbolic, and the conceptual (Fig. 1).

The conceptual model of a concrete system is called a conceptualization; for example, the ICS model is a conceptualization of the control processes of a robotic complex. A specific model of a conceptual system is called an implementation; for example, put into effect by the ICS as an implementation of the ICS model. A conceptual model of a conceptual system is called a conversion. A symbolic model of conceptual system is called a formulation; a symbolic system is expressed in some formal language — the notation to represent the model. A conceptual model of a symbolic system is called an interpretation. A symbolic model of a symbolic system is called a transformation. At the same time all stages include social (verbal) interaction between human beings to construct a socially accepted view of the concrete system.

Thus, for the implementation of a specific system (in our case, ICS), a conceptual model based on verbal methods, which allows one to formulate symbolic models on the selected notations, should be developed.

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Therefore, the conceptualization of ICS by humanitarian demining robotic complexes based on verbal methods is relevant.

The purpose of the study is to develop a conceptual model of ICS by humanitarian demining robotic complexes based on verbal methods.

The model should provide an opportunity to implement ICSs that:

- are close to the human way of expressing knowledge;
- are based on expert knowledge in the chosen subject area;
- produce an unequivocal result;
- involve human participation only in the part of creating/changing the knowledge base.

The basic principles of verbal decision analysis are formulated as follows [18]:

- use for describing the problem of definitions and formulations of assessments of solution options in a form that is natural for the DM, his advisers and active groups, without converting such verbal formulations into quantitative values;
- construction of a decision rule based on logical, qualitative transformations of verbal variables, observing the psychological and mathematical correctness of the transformations.

That is, verbal decision methods allow creating the so-called "white box model", where we know exactly how the value of the output variables depends on the values of the input variables and can explain the behavior of the model.

At the same time, the existing methods for creating artificial intelligence models are the so-called "black box models". The problem is that the data scientist who built the model doesn't have complete clarity about the model's behavior and lacks clarity in explaining the model [19].

The process of self-organization of automation at the level of decision-making in control systems is most fully reflected in the OODA loop [20]. The **OODA** model has 4 repetitive actions in its structure: **O**bserve — **O**rient — **D**ecide — **A**ct.

At the operational level in management systems, the most adequate model of building and improving the process is the so-called Shuhart improvement cycle [21], better known as the Deming cycle or the PDCA cycle. The **PDCA** cycle includes 4 stages: **P**lan — **D**o — **C**ontrol — **A**ct.

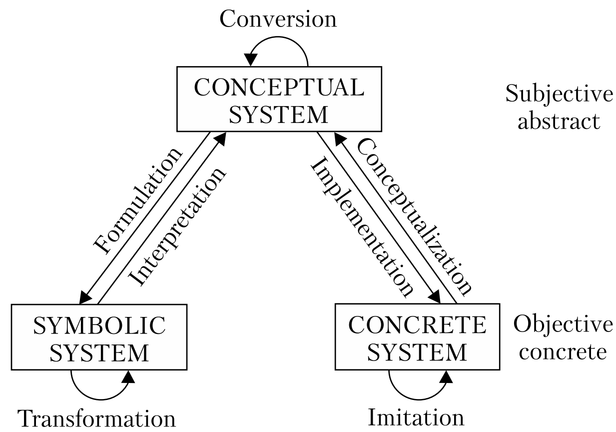

Fig. 1. The model triangle [17]

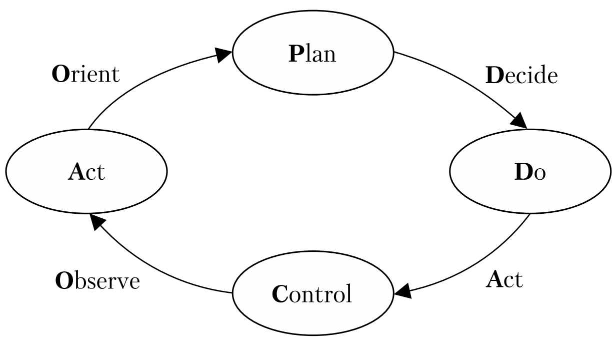

Fig. 2. Combined model of OODA and PDCA

The OODA and PDCA models complement each other (Fig. 2).

As for expert knowledge, it can be conditionally divided into two types [18]. One of them (facts, information, theories, tasks, etc.) is called **declarative knowledge** and is most often reflected in the form of tables. The knowledge answers the question "What is it?" That is, with its help, we can evaluate the results obtained during any activity (process). Another type is the human ability to solve problems, compose music, treat patients, find faults in machines and devices, etc., are called **procedural knowledge**, reflected in the form of process diagrams. The knowledge answers

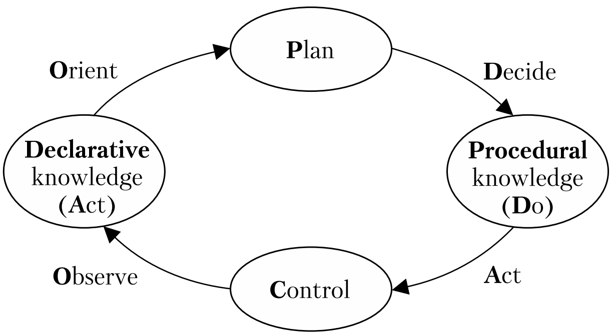

Fig. 3. Interaction of expert knowledge and the combined model of OODA and PDCA

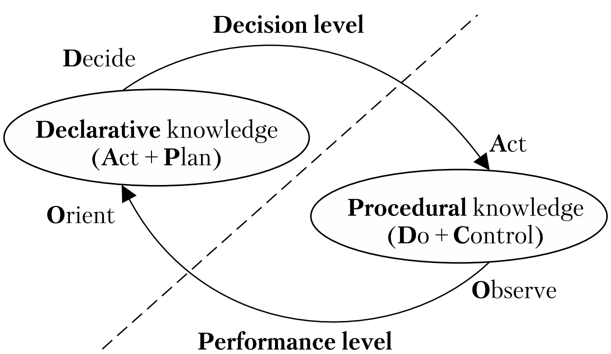

Fig. 4. Separation of the stages of the combined model by control levels

the question "How to do it?" and with its help you can get the desired results. The interaction of expert knowledge with the combined OODA and PDCA model is shown in Fig. 3.

Let us consider in more detail the form of presentation and the content of expert knowledge, which are most suitable for the requirements of the conceptual model of ICS.

Declarative knowledge in the presented in Fig. 2 of the combined model is the knowledge base for DMS. It is possible to build such a DMS using the method of ordinary classification of alternatives [18]. For this, expert knowledge should be presented in the form of a set of criteria $K = \{K_m\}_{m=1}^{M}$, where K_m is the name of the m-th criterion characterizing the alternative; M is the number of criteria. Each criterion K_m has a set of values $K_m = \{k_{m,n}\}_{n=1}^{N(m)}$, where $k_{m,n}$ is the name of the n-th value of the m-th criterion; $N(m)$ is the number of values of the m-th criterion. The values of each criterion K_m should be arranged from the best to the worst in the form of a completely ordered set $R_m = \{(k_{m,i}, k_{m,j})\} \in K_m \cdot K_m \mid k_{m,i} > k_{m,j}\}$, where symbol > means "better than".

Thus, the set $A = K_1 \cdot K_2 \cdot ... \cdot K_m$ defines all hypothetically possible alternatives. In this case, $a_i = (a_{i,1}, a_{i,2}, ..., a_{i,M}) \in A$, where $a_{i,m} \in K_m$ is a criterion description of the corresponding alternative. Some alternatives can be compared through a partially ordered set $R = \{(a_i, a_j)\} \in A \cdot A \mid a_i > a_j$ when $a_{i,m} \geq a_{j,m}$ for $\forall m = \overline{1, M}$, but $\exists m_0 = \overline{1, M}$, for which $a_{i,m_0} > a_{j,m_0}\}$.

The goal of the ordinary classification of alternatives is to partition the set $A = \cup_{q=1}^{Q} A_q$ into classes A_q, where $A_q \neq \varnothing$ and $A_q \subset A$ for $\forall q = \overline{1, Q}$; $A_p \cap A_q = \varnothing$ for $p \neq q$; Q is the number of classes. The classes are ordered from best to worst: $A_p > A_q$ for $p < q$. Therefore, the best alternative should not be in the worst class and vice versa. This task is complicated by the abundance of hypothetically possible alternatives and is solved through the use of the concept of the most informative alternative [18].

The procedural knowledge presented in Fig. 3 of the combined model is the knowledge base necessary for the full implementation of the goals of the robotic complex controlling.

Studies have shown that drawings (scheme, diagrams) can convey information more accurately than text. The human mind has separate systems for processing visual and verbal material — according to the dual channel theory [22]. Visual representations are processed by the visual system in parallel; text representations are processed sequentially by the speech system [23]. Only graphical representations are able to show (complex) relationships at the same time.

Therefore, expert knowledge is displayed by **BPMN** (**B**usiness **P**rocess **M**odel and **N**otation) that is one of the process modeling methods. BPMN refers to verbal methods and allows creating "white box models". BPMN has been adopted as an ISO/IEC standard [24] and creates models that are unambiguously interpreted by the software.

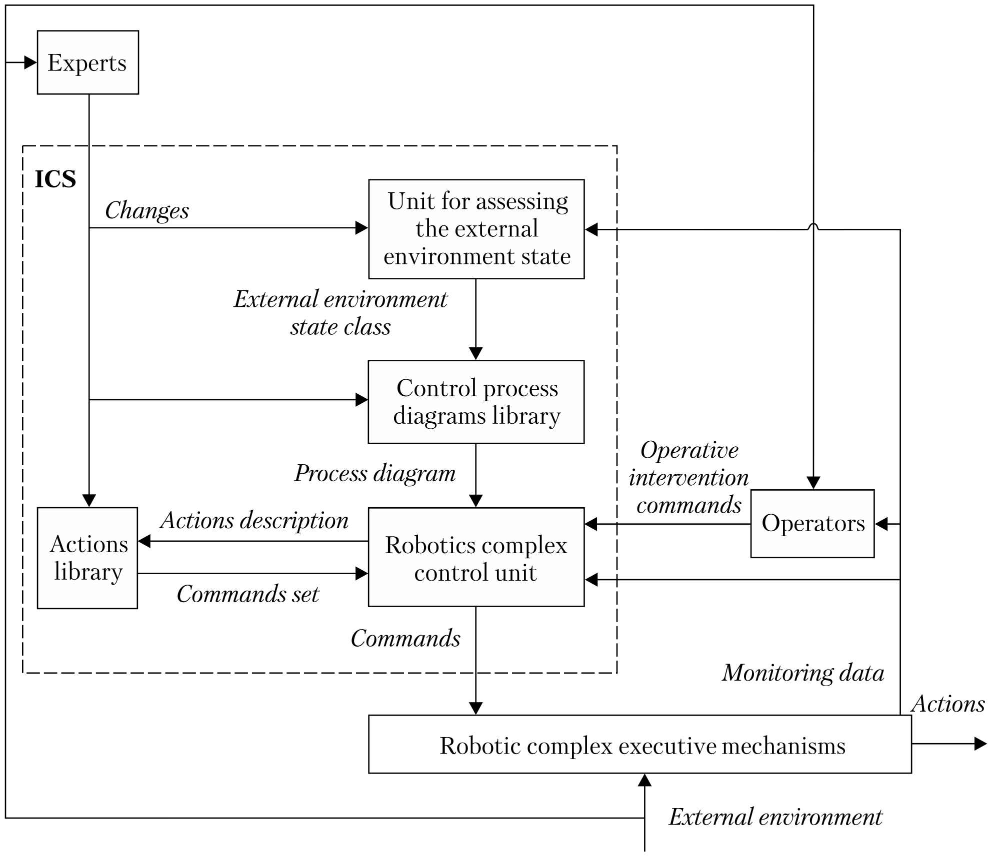

Fig. 5. Model of ISU by humanitarian demining robotic complexes based on verbal methods

Analyzing the structure and content of the described forms of knowledge representation, we can draw the following conclusions:

- ***declarative knowledge*** with an implementation mechanism constitutes the decision-making level: the choice of a strategy that includes control (***observation***) and evaluation of process indicators, as well as the choice of a process execution diagram corresponding to the current set of process indicators (***orientation***);
- ugh the process diagram (***action***), including the adoption of operational, tactical decisions "stitched" in the diagram in situations corresponding to the current set of process indicators (***decisions***).

The separation of the stages of the combined model by management levels is shown in Fig. 4.

The model presented in Fig. 4 defines the conceptual model of ICS by humanitarian demining robotic complexes based on verbal methods, which includes the following elements (Fig. 5):

- **unit for assessing the external environment state** — decision-making level. Determines to which class belongs the set of external environment monitoring data received at the entrance. Created taking into account the decisive rule developed by the verbal method of ordinary classification;
- **control process diagrams library** — process diagrams containing a description of the set and sequences of actions of the robotic complex in all situations predicted by experts. Separated into classes that are defined in the decision rule. Diagrams are developed on BPMN;

- **robotics complex control unit** — execution level. Converts descriptions of actions from process diagrams into sets of commands for a robotic complex executive mechanisms (RCEM). Within the framework of the diagram, the selection of the process execution scenario is carried out according to the set of environmental monitoring data;
- **actions library** — sets of commands for RCEM that correspond to actions from process diagrams;
- **experts** — develop a decisive rule, process diagrams and sets of RCEM commands, make appropriate changes in case of a change of the RCEM, detection of an undescribed situation or to compensate for the systematic influence of the external environment;
- **operators** — have the ability to quickly change or stop the robotic complex operation in the event of an emergency situation or an unforeseen change in the external environment.

The developed conceptual model of ICS (see Fig. 5) allows creating symbolic models in selected notations.

An example of a symbolic model of representation of declarative knowledge in ICS is the DMS "EO threat level assessment". The DMS contains a description of classes, criteria and a decision rule. Notation is the terms used by experts in the chosen subject area.

Classes of EO threat levels: low (1) — below average (2) — average (3) — above average (4) — high (5).

Criteria — EO unmasking signs (values of each sign are ordered from more unmasking to less unmasking):

- ***concentrated mass of explosive substance*** (K1): high (1) — above average (2) — average (3) — below average (4) — low (5).
- ***locally located mass of metal*** (K2): high (1) — above average (2) — average (3) — below average (4) — low (5).
- ***the design of the EO*** (K3): typical for the EO shape, body material, etc. (1) — uncharacteristic (2).
- ***violation of the homogeneity of the environment where the EO is located*** (K4): high (1) — above average (2) — average (3) — below average (4) — low (5).
- ***presence of a wired EO control line*** (K4): there is (1) — no (2).
- ***EO time control module*** (K5): clock mechanism (1) — electronic timer (2) — none (3).
- ***EO target sensor*** (K6): seismic (1) — magnetic (2) — optical (3) — none (4).
- ***presence of an antenna for EO radio receiving devices*** (K7): there is (1) — no (2).
- ***depth of EO placement in the soil*** (K8): soil surface (1) — up to 0.1 m. (2) — up to 1 m (3).

The EO unmasking state is a set of values that the EO has relative to each criterion (unmasking feature). The number of all hypothetically possible EO unmasking states is the multiplying of the number of values of all criteria: $5 \cdot 5 \cdot 2 \cdot 5 \cdot 2 \cdot 3 \times 4 \cdot 2 \cdot 3 = 36{,}000$ EO states.

EO states according to the method of ordinary classification are distributed by classes of EO threat levels in the form of a decisive rule (Table 1).

DM and expert consultants used the following logic to classify EO states:

- EO with the most unmasking value of each feature has a low level of threat (Table 2);
- EO with the least unmasking value of each feature has a high level of threat (Table 3).

The DMS "EO threat level assessment" refers to the second level DMS that are the determinants of the criteria and their values for the first level DMS. At the same time, the second level DMS corresponds to a certain criterion of the first level DMS, and the second level DMS classes correspond to the value of the criterion. For example, the second level DMS considered above corresponds to the criterion "EO threat level" of the first level DMS "External environment assessment", and the classes correspond to the value of this criterion: low, below average, average, above average, high.

An example of a symbolic model of representation of procedural knowledge in ICS in BPMN is shown in Fig. 6.

Table 1. **EO Threat Level Assessment Decisive Rule**

EO states	Criteria value									Class
	K1	K2	K3	K4	K5	K6	K7	K8	K9	
1	1	1	1	1	1	1	1	1	1	1 (low)
2	1	1	1	1	1	1	1	1	2	1 (low)
3	1	1	1	1	1	1	1	1	3	1 (low)
4	1	1	1	1	1	1	1	2	1	1 (low)
5	1	1	1	1	1	1	1	2	2	1 (low)
6	1	1	1	1	1	1	1	2	3	1 (low)
7	1	1	1	1	1	1	2	1	1	1 (low)
						...				
17997	3	3	1	5	2	3	4	1	3	4 (above average)
17998	3	3	1	5	2	3	4	2	1	4 (above average)
17999	3	3	1	5	2	3	4	2	2	4 (above average)
18000	3	3	1	5	2	3	4	2	3	4 (above average)
18001	3	3	2	1	1	1	1	1	1	2 (below average)
18002	3	3	2	1	1	1	1	1	2	2 (below average)
18003	3	3	2	1	1	1	1	1	3	2 (below average)
						...				
35994	5	5	2	5	2	3	3	2	3	5 (high)
35995	5	5	2	5	2	3	4	1	1	5 (high)
35996	5	5	2	5	2	3	4	1	2	5 (high)
35997	5	5	2	5	2	3	4	1	3	5 (high)
35998	5	5	2	5	2	3	4	2	1	5 (high)
35999	5	5	2	5	2	3	4	2	2	5 (high)
36000	5	5	2	5	2	3	4	2	3	5 (high)

Table 2. **Values of Criteria Describing EOs with a Low Level of Threat**

Criteria	Criteria value
(K1) concentrated mass of explosive substance	(1) high
(K2) locally located mass of metal	(1) high
(K3) EO design	(1) typical for the EO shape, body material, etc.
(K4) violation of the homogeneity of the environment where the EO is located	(1) high
(K5) presence of a wired EO control line	(1) there is
(K6) EO time control module	(1) clock mechanism
(K7) EO target sensor	(1) seismic
(K8) presence of an antenna for EO radio receiving devices	(1) there is
(K9) depth of EO placement in the soil	(1) soil surface

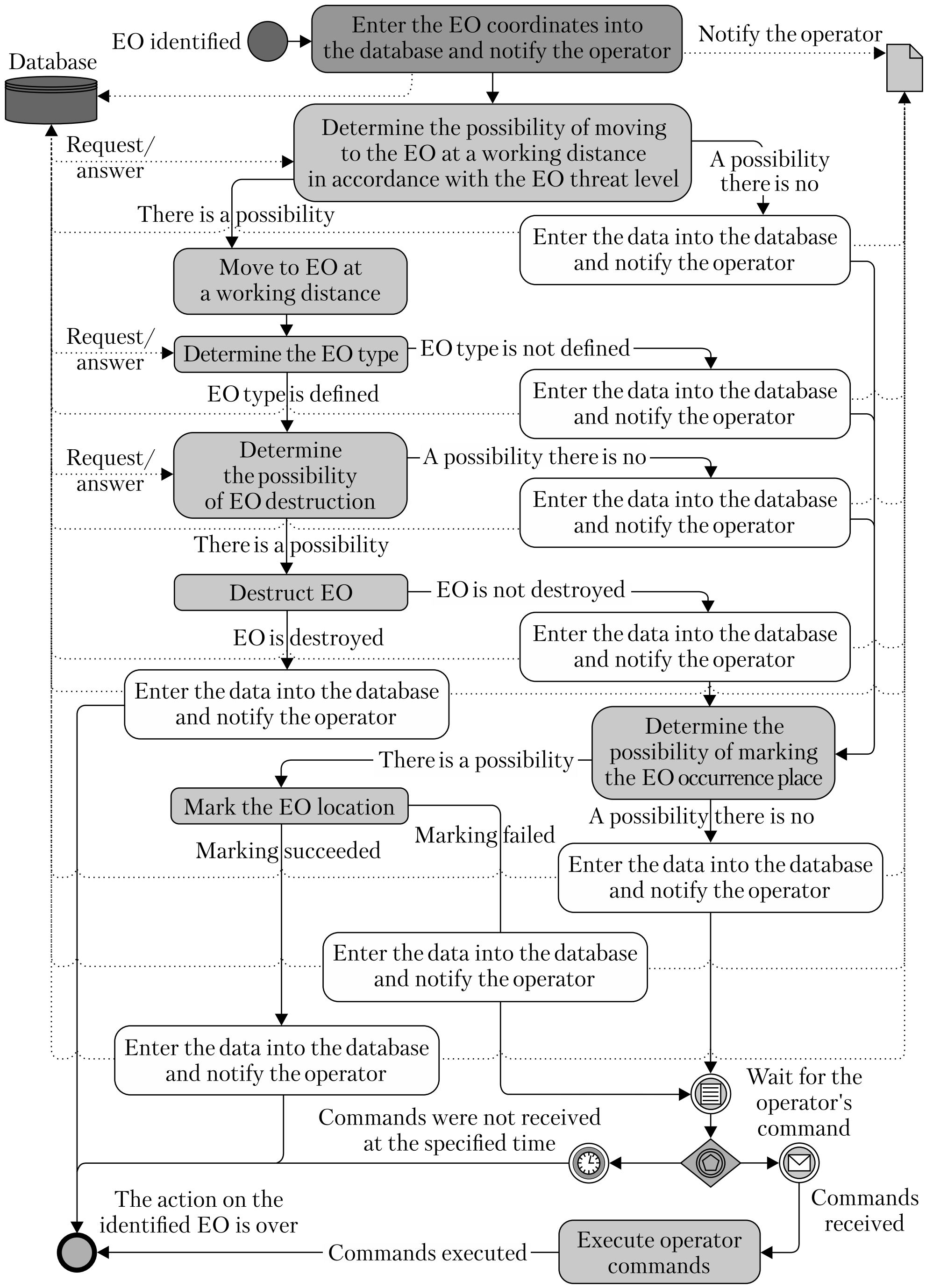

Fig. 6. The 1-level process "Actions order on identified EO" in BPMN

This is the first level process "Actions order of on identified EO" corresponds to the class "EO identified" from the first level DMS decisive rule.

BPMN is an intuitively understandable graphic notation [25]. As practice shows, experts with whom we had to work almost immediately begin to "read

Table 3. **Values of Criteria Describing EOs with a High Level of Threat**

Criteria	Criteria value
(K1) concentrated mass of explosive substance	(5) low
(K2) locally located mass of metal	(5) low
(K3) EO design	(2) uncharacteristic
(K4) violation of the homogeneity of the environment where the EO is located	(5) low
(K5) presence of a wired EO control line	(2) none
(K6) EO time control module	(3) absent
(K7) EO target sensor	(4) absent
(K8) presence of an antenna for EO radio receiving devices	(2) none
(K9) depth of EO placement in the soil	(3) up to 1 m

the diagram", regardless of age and level of technical education. This can be verified by looking at the diagram in Fig. 6. The color gradation of actions on the diagram needs an explanation. Atomic actions that do not require further explanation are indicated in blue. Actions that are sub-processes, i.e., in turn, contain sets of actions, are marked in yellow. They are refined in the form of second level process diagrams by the method of functional decomposition. The actions of the second level processes that are sub-processes, are specified in the form of third level process diagrams and so on. The number of levels of the processes hierarchy is determined by the need to reveal all "black boxes" (sub-processes) to the level of atomic actions. The methods of functional decomposition and hierarchy make it possible to create systems of process diagrams of arbitrary complexity, which as a result are "white box models".

CONCLUSIONS

1. Based on the methods of verbal decision analysis, a conceptual model of ISU by humanitarian demining robotic complexes has been developed. The model allows implementing ICSs that:
- are close to the human way of expressing knowledge;
- are based on expert knowledge in the chosen subject area;
- give an unequivocal result;
- involve human participation only in the part of creating/changing the knowledge base.

This is achieved by using definitions that are natural to DM, its advisers and activist groups, without converting such verbal formulations into quantitative values.

2. The developed conceptual model of ICS allows for the formulation of symbolic models in the notations of selected verbal methods:
- at the decision-making level, the method of ordinary classification is chosen to create DMS in notation, which are terms used by experts in the chosen subject area;
- at the executive level, the BPMN method is chosen for creating process diagrams in graphic notation.

The chosen verbal methods make it possible to create "white box models" that unambiguously interpret the dependence of output and input variables and explains the model behavior.

3. The symbolic models in the notations of the selected verbal methods allow the implementation of ICS by a specific humanitarian demining robotic complex.

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КОНЦЕПТУАЛІЗАЦІЯ ІНТЕЛЕКТУАЛЬНОЇ СИСТЕМИ УПРАВЛІННЯ РОБОТОТЕХНІЧНИМИ КОМПЛЕКСАМИ ГУМАНІТАРНОГО РОЗМІНУВАННЯ НА ОСНОВІ МЕТОДІВ ВЕРБАЛЬНОГО АНАЛІЗУ

Вступ. Для гуманітарного розмінування характерним є зростання уваги до проблем створення та застосування робототехнічних комплексів, надважливим аспектом використання яких є спосіб здійснення управління.

Проблематика. На сьогодні найбільш поширеними є комплекси 1-го покоління (керовані пристрої), удосконалюються комплекси 2-го покоління (напівавтономні пристрої), а для переходу до комплексів 3-го покоління (автономних пристроїв) необхідно розробляти інтелектуальні системи управління на базі технологій штучного інтелекту. Кількісні методи є найбільш поширеними щодо побудови подібних систем, але отримані моделі є «моделями чорної скриньки», які не дають повної ясності щодо своєї поведінки.

Мета. Розробка концептуальної моделі інтелектуальних систем управління робототехнічними комплексами гуманітарного розмінування на основі вербальних методів.

Матеріали й методи. Застосовано методи формальної логіки, якісні методи вербального аналізу, BPMN.

Результати. Розроблено концептуальну модель інтелектуальної системи управління робототехнічними комплексами гуманітарного розмінування та символічні моделі представлення відповідних декларативних і процедуральних знань на основі вербальних методів.

Висновки. Пропонована концептуальна модель дозволяє сформулювати символічні моделі в нотаціях обраних вербальних методів. На рівні прийняття рішень обрано метод ординарної класифікації, де нотацією є терміни, які використовуються експертами в обраній предметній галузі. На виконавчому рівні обрано метод BPMN для створення діаграм процесів у графічній нотації. Обрані вербальні методи дозволяють створювати «моделі білої скриньки», що однозначно трактує залежність вихідних і вхідних змінних та пояснює поведінку моделі. Символічні моделі в нотаціях обраних вербальних методів дозволяють реалізацію інтелектуальної системи управління конкретним робототехнічним комплексом гуманітарного розмінування.

Ключові слова: вербальний аналіз, інтелектуальні системи управління, концептуальна модель.