UDC 519.612:533.69
DOI: 10.15587/1729-4061.2024.304996

METHOD FOR SYNTHESIZING THE CONCEPT OF AUTOMATING THE SYSTEM TO MANAGE PERSONNEL TRAINING PROCESSES BASED ON CATEGORIAL ANALYSIS

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This paper considers a three-level system for managing personnel training within the Ministry of Defense of Ukraine.

When devising the concept of automating control processes in systems of this kind, the key issue is to ensure completeness in significant aspects of the management process. Insufficient conceptual completeness compromises effectiveness of the automated system for organizational control (ASOC) and causes difficulties (impossibility) in its further modernization.

A method has been proposed for formulating functional tasks (FTs) in specialized software (SSW) for ASOC based on categorical analysis in combination with the provisions of the conceptual design of automated control systems (ACS). The application of this method was demonstrated using an example of the system for managing personnel training. Categorical analysis of the management process was carried out for the strategic, operational, and tactical hierarchical levels of the system based on three dual pairs. Eight control aspects were obtained. On their basis, 79 FTs were stated for the strategic level. For the operational and tactical levels, by taking into account the specificity of training, the number of aspects was 2; FTs – 204 and 195, respectively. An example has been given for two of the eight aspects of control, their interpretation and formulation of FTs for the strategic level of management.

The generated FTs represent the concept of ASOC and provide, within the established boundaries of analysis, the completeness of control aspects in personnel training.

The reported results are of interest in the conceptual design of large ASOC, as well as in the formation of technical specifications for software developers

Keywords: heuristic task, synthesis of structures, functional task, synthesis of systems, software

Received date 01.03.2024
Accepted date 24.05.2024
Published date 28.06.2024

How to Cite: *Nykyforov, A., Nykyforov, A., Antoshchenkov, R., Polyansky, P., Halych, I., Kis, V., Dombrovska, A., Kilimnik, I., Usyk, A. (2024). Method for synthesizing the concept of automating the system to manage personnel training processes based on categorial analysis. Eastern-European Journal of Enterprise Technologies, 3 (3 (129)), 16–31. https://doi.org/10.15587/1729-4061.2024.304996*

1. Introduction

When designing corporate automated control systems (CACS) or automated systems for organizational control (ASOC), the greatest difficulty is always the task of forming the structure and functional content of specialized software (SSW) for such systems. In other words, the development of a concept for automating control processes.

In many ways, the success or failure of automated control systems projects depends on how well the conceptual design problem is solved, how fully the management functions are taken into account and automated, and how conveniently the control processes are combined. As a rule, success here is determined by the level of competence of the project author, his/her awareness and insight in the relevant area of corporate governance. The path of evolutionary improvement of implemented automated control system projects often does not lead to the desired result if the system concept is initially incorrect (incomplete). It makes no sense to improve the software in particular if critical management functions are not taken into account as a whole. Often, in order to include these emerging new management aspects into an automated environment, it is easier to implement a new automated control system project than to modify an existing version.

The task to provide the completeness of the conceptual design of an automated control system is complex due to the large dimensionality of information that the designer has to deal with when synthesizing the structure of information and the procedures used for its transformation. It is extremely difficult to establish in one step meaningful parametric groups, relationships between them, and procedures for transforming data in established groups. Despite the fact that such a synthesis procedure is informal (heuristic), nevertheless, there are approaches that make it possible to reduce it to some ordering of heuristic procedures, but of a lower dimensionality. These methods include morphological and categorical analysis, constructive design, solving inventive problems. Such approaches make it possible to reduce the complexity of design due to the fact that one large synthesis procedure is replaced by a system of similar procedures of relatively small size. As they are completed, a unified concept of the ASOC project is formed, taking into account as fully as possible the significant aspects of organizational control in the area under consideration.

Thus, the task of developing some universal algorithm that reduces the difficulty (dimensionally of the problem) of the conceptual design of automated control systems seems relevant. This algorithm should provide the most complete consideration of significant management aspects, as well as streamline and facilitate the designer's reasoning process when developing SSW.

2. Literature review and problem statement

The first attempts to devise universal methods of conceptual design are associated with the development of methods for activating search. The most famous among search activation methods is brainstorming [1]. This method, if well organized, makes it possible to get away from ideas imposed by psychological inertia. However, as practice has shown, difficult tasks cannot be attacked. Brainstorming is only effective when solving simple problems. Good results can most often be obtained by «attacking» not inventive but organizational problems (finding new applications for manufactured products, improving advertising, etc.).

There are other methods for activating search. In morphological analysis [2], first, axes are identified – the main characteristics of the object, and then elements are written down along each axis – all possible options. For example, when considering the problem of starting a car engine under winter conditions, we can take as axes: sources of energy for heating, methods of transmitting energy from the source to the engine, methods of controlling this transmission, etc. Elements that can be taken, for example, for the axis «energy sources» may include: a battery, a chemical heat generator, a gas burner, a running engine of another car, hot water, steam, etc. Having a record of elements along all axes and combining combinations of different elements, one can get a very large number of various options. In this case, unexpected combinations that would hardly come to mind «just like that» may come into view.

If necessary, the morphological analysis can be repeated for the selected solutions, specifying the nodes (axes) and their variants (elements of the axes). However, the problem of choosing the axes of morphological analysis is solved on the basis of the subjective perception of the researcher. This approach is acceptable for relatively simple systems – technical, or with the inductive accumulation of initial information about the object of study, its preliminary structuring. When considering complex, ergatic systems, morphological analysis does not provide completeness. It is easy to overlook the essential aspects of an object.

The most powerful method of activating search is synectics [3]. The word «synectics» means «... connecting together various, often apparently incompatible elements». Synectics is based on brainstorming, but this storming requires the mandatory use of four special techniques based on analogy:

– direct (how problems similar to this one are solved);

– personal (try to enter into the image of the object given in the problem and try to reason from this point of view);

– symbolic (give a figurative definition of the essence of the task in a nutshell);

– fantastic (how fairy-tale characters would solve this problem).

Just like morphological analysis, synectics does not provide the opportunity to structure the problem being solved in its entirety. The search for solutions is carried out in the initially given structure of the problem situation.

The fundamental drawback of search intensification methods is their unsuitability for solving quite difficult problems, when the «cost» of the problem is 10,000 or more samples.

In [4], a universal algorithmized method is proposed for activating creativity and solving technical problems, which is based on objective laws of development of technical systems. On this basis, using special techniques and knowledge structured in a certain way, ideas and solutions are immediately generated, without going through empty options. The method is termed TSIP (the theory of solving inventive problems) or ASIP (algorithm for solving inventive problems). ASIP is a sequence of actions with recommendations for choosing parameters for the stages of solving a problem. TSIP is a knowledge system that gives an idea of the essence of solving an inventive problem as a process of eliminating organizational, technical, and physical contradictions. ASIP has been modernized many times over several decades, starting from the mid-1950s. Basic ASIP includes up to 50 techniques or principles for resolving technical contradictions (TC). At the same time, it employs the following four mechanisms to eliminate them:

1) transition from the technical system problem given in the model to an ideal system by formulating an ideal final result (IFR);

2) transition from TC to physical contradiction (PC);

3) use of Su-field (real-field) transformations to eliminate PC;

4) the use of a system of operators, reflecting in a concentrated form information about the most effective ways to overcome TC and PC (lists of typical techniques, tables

for the use of typical techniques, tables, and an index for the use of physical effects).

ASIP also includes 76 inventive standards (rules for choosing a strategy for solving an inventive problem).

The TSIP methodology is recognized as the most effective means for solving heuristic problems related to the technical field. The international recognition of TSIP is confirmed by the following facts [5]:

– use of the TSIP system by such companies as: Ford, Caterpillar, Proctor and Gamble, IBM, Motorola;

– creation of the International TSIP Association (MA TSIP), with headquarters in St. Petersburg, in 1998. In the same year, the Altshuller Institute was founded in the USA;

– The European TSIP Association – ETRIA (European TSIP Association) began its work in 2000.

The development of TSIP was carried out over several decades by the method of inductive accumulation of information about methods for implementing powerful inventions (more than 40 thousand patents). At the same time, it was found that strong inventions were made when the problem was structured with the help of physical (PC) and technical contradictions (TC) existing in a technical object. The formulated PCs and TCs in the TSIP data bank make it possible to apply a deductive approach to solving problems of technology development. However, this approach – proactive development of technology – remained unrealized. Also, TSIP is difficult to use in the conceptual design of SSW for ASOC since its subject area is limited only to the technical domain.

Subsequently, the TSIP methodology was repeatedly supplemented and expanded by taking into account new aspects and incorporating new elements. In [6], TSIP was supplemented with functional cost analysis (FCA), which allows for a quantitative comparison of alternatives based on utility and cost indicators.

Bio-TSIP is presented in [7], in which a system of operators for searching for effective solutions for resolving TC and PC is built on the basis of information about the evolution of biological objects. The method is shown to be highly effective in the conceptual design of individual components of technical units and systems. However, for complex ergatic (organizational) systems, the scope of application of the method is limited. The limitation is due to the impossibility of a sufficiently complete description of such systems in biological terms. For example, the cost factor affecting socio-economic relations is not represented at the level of individual biological objects.

In [8], the TSIP methodology for sustainable conceptual design of fault-tolerant systems is proposed. Design sustainability is provided through the redundancy of the conceptual scheme of the created system.

In [9], a software product for conceptual design is presented, which allows for the targeted formation of an information environment to suit the needs of a specific designer. A method for sharing, reusing, and integrating knowledge in web service-based mechanical system design evaluation is proposed to help designers leverage interdisciplinary design knowledge. The service design model for providing and integrating knowledge in the design process is based on the TSIP platform with precedents.

In [10], the TSIP methodology is supplemented with elements of deploying the quality (utility) function of a product.

In [6–10], an expansion of the scope of TSIP application is presented, which, however, continues to lie within the boundaries of the technical domain, which is clearly insufficient for the design of organizational control.

For organizational systems involving both technical and social aspects, conceptual design methods have developed based on the theory of synthesis of conceptual schemes (structures) and the use of constructs (creative templates).

The method of creative templates for technical objects was proposed in [11]. The creative template method is much easier to use compared to the innovative TSIP method. However, the use of this method is only possible for existing products, for the development and improvement of their main and auxiliary functions.

A conceptual design method based on the synthesis of conceptual schemes was proposed in [12]. Using the example of the security domain for complex subjects (teams, states), conceptual schemes of subject-object and subject-subject relations obtained using the method of forming stages of sets are presented [13]. The proposed approach is applicable for the conceptual design of automated control systems, but it is necessary to additionally solve the problem of interpreting the resulting logical expressions (constituents) for the generated conceptual schemes. Due to the extremely large dimensionally of constituents, a special language is needed for their representation and presentation to a person. This problem has not yet been resolved.

In [14], an approach to the design of ASOC SSW based on the use of the apparatus of set stages is proposed. The subsets of data that make up the information in ACS (state of the control object, conditions, input measurements and messages, control, points in time), as well as classes of procedures and relationships between data groups, are considered. A method is shown for synthesizing the structure of an automated control system database, in the form of a metagraph, based on the use of the apparatus of set stages. The resulting conceptual structure of ACS information, being structurally complete, requires its interpretation in relation to the automated process. If with such groups of parameters as output parameters and external conditions everything is quite obvious, then the state and control parameters require additional analysis. Actually, the detailing of state parameters, which are a model of the control object, in combination with control parameters, represents the concept of automation of the management circuit.

In [15], a method of categorical analysis is proposed as a way to structure management information in the conceptual design of ASOC. Categorical analysis, in contrast to morphological analysis, provides greater completeness. This advantage is due to the fact that when generating combinations of categories, the objective law of the unity and struggle of opposites is used, while morphological analysis is limited by the researcher's subjective understanding of the problem being solved. However, the method is not self-sufficient when designing ASOC. The resulting concept in the form of a system of aspects of the control process under consideration should be detailed in the form of a data structure and a list of functional tasks of SSW. In this regard, the merger of [14, 15] may have a positive effect.

Thus, the subject area of conceptual design includes:

– search activation methods (brainstorming, morphological and categorical analyses);

– methods for solving inventive (heuristic) problems (TSIP, ASIP);

– methods of forming conceptual schemes (device of stages of sets).

When developing the concept of SSW for ASOC (forming a list and logical structure of functional tasks), the main problem is «not to miss anything». That is, take into account, as fully as possible, all management aspects of the future ASOC. Here, search activation methods (categorical analysis) are mainly applicable, allowing one to expand the list of management aspects in comparison with design methods that are subject to psychological inertia and an inductive approach (from particulars to generalities).

Also, it seems promising to apply approaches to the conceptual design of automated control systems [14] in application to the management aspects of the system obtained on the basis of categorical analysis. This combination of methods will make it possible to obtain some universal rules for the formulation of multi-aspect lists of PCs for SSW of the designed ASOC.

3. The aim and objectives of the study

The purpose of our study is to devise a universal method for compiling a multidimensional list of functional tasks for ASOC SSW based on categorical analysis and the provisions of the conceptual design of automated control systems. This will streamline and facilitate the process of conceptual design of ASOC, provided that management aspects are fully taken into account.

To achieve this goal, the following tasks must be solved:

– to conduct a categorical analysis of the training control process;

– using the conceptual scheme of ACS information, build groups of data and functional tasks of SSW for ASOC when training personnel for synthesized and interpreted categorical integrity (aspects of management).

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of the study is a three-level training management system for the Ministry of Defense of Ukraine.

The main hypothesis assumes that the degree of completeness of the conceptual model of an object increases as it is consistent with the objective laws of the existence of matter. This is the position of dialectics that any processes, events, systems are the result of the emergence and resolution of contradictions that exist in them.Accepted assumptions and simplifications:

– management of personnel training for the Ministry of Defense of Ukraine is carried out centrally, the management powers of the subjects are established according to their hierarchical position in the management system;

– control processes are subordinated to the mechanisms of functioning of multi-level organizations;

– the scheme of information circulating in ASOC corresponds to the structure of data groups and the template of procedures that are represented in the conceptual design of the automated control system [14].

4. 2. Mechanisms for the functioning of the personnel training system

The process of functioning of the personnel training system within the Ministry of Defense is built in accordance with the mechanisms of functioning of multi-level organizational systems, namely [16, 17]:

– a mechanism for functioning under conditions of full awareness of the highest management body;

– a mechanism of functioning with a counter method of data generation (with incomplete information).

The mechanism of functioning under conditions of full information involves consistent detailing of decisions made, moving from top to bottom, with the provision of the opportunity to subordinate management bodies to determine the parameters for carrying out activities to which their powers apply. When forming decisions, the method of decomposition of the general criterion for the success of achieving the goal of a set of measures, as well as multi-criteria optimization, is used.

The mechanism of functioning with a counter method of data generation involves the formation of decisions by higher management bodies on the basis of proposals submitted by subordinates. Decision making is carried out by summarizing the presented proposals (ordering alternatives) and selecting the dominant alternative. The decision-making method here is based on the problem of allocating limited resources using the principles of proportionality; inverse priorities and optimality.

Also, when designing SSW for ASOC for personnel training, the following features should be taken into account:

– hierarchy;

– centralization of management;

– personal responsibility of officials for decisions made;

– distribution of the decision-making process.

The following subjects (decision-making centers) can be included in the hierarchy of personnel training management bodies (Fig. 1).

At the strategic level, the subjects of management are:

– President;

– Prime Minister, Minister of Defense, ministers of key ministries;

– Chief of the General Staff (GS);

– Secretary of the National Security and Defense Council (NSDC), other representatives depending on the aspect of the decision being made.

The NSDC is entrusted with the function of detailing decisions and preparing proposals. Also, with similar functions, the list of subjects of the strategic level includes the main directorates of the General Staff and departments of the Ministry of Defense (other ministries as necessary), research organizations (R&D) of the General Staff, other ministries, and the National Academy of Sciences (NAS) of Ukraine.

At the operational level, the following are represented as management bodies:

– operational (air) commands;

– commands of the armed forces and branch research and development organizations;

– special commands created for the purpose of conducting special operations (carrying out individual missions) and which are limited in place and time of their operation.

The tactical level is represented by the command of military units, training grounds, training centers; management of educational institutions.

Information exchange in the control system is carried out in forward (top-down) and reverse (bottom-up) directions. Information is exchanged directly between adjacent hierarchical levels, as well as bypassing the intermediate level: strategic and tactical level bodies.

The diagram (Fig. 2, 3) shows the content of information transmitted between the hierarchical levels of the management system under the planning and operational management modes (implementation of generated plans).

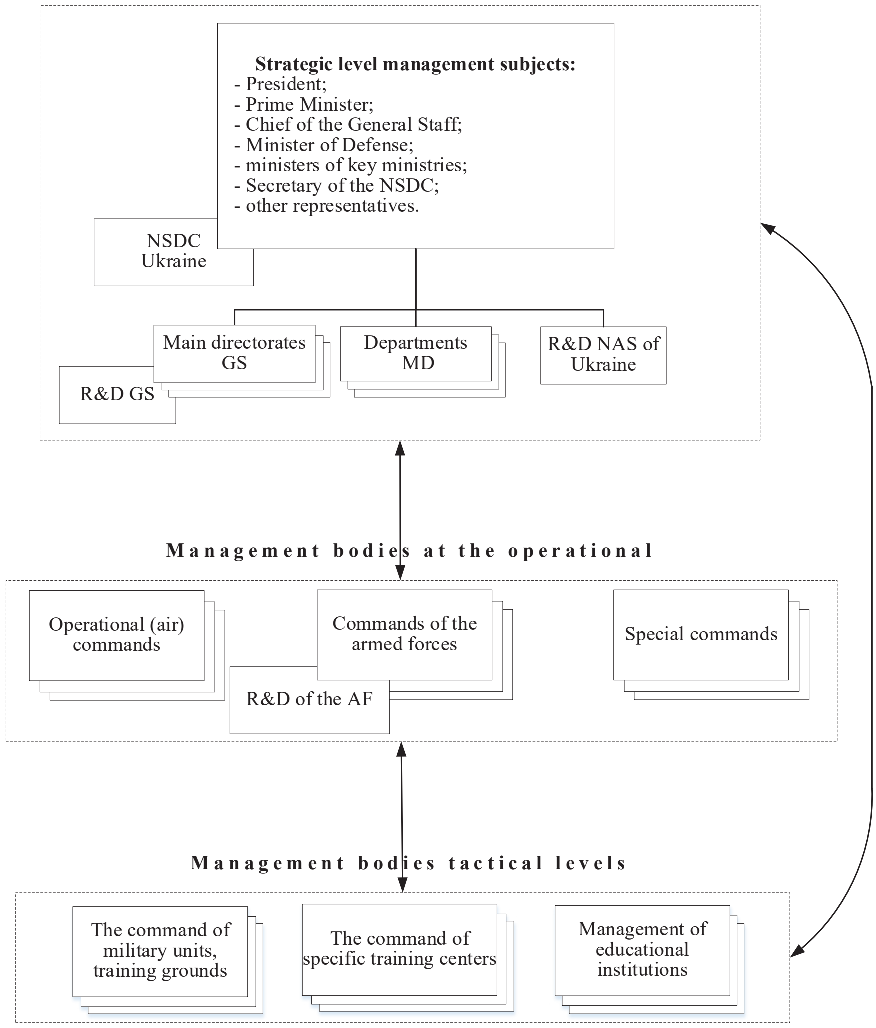

Fig. 1. Structure of bodies governing the personnel training process in the Ministry of Defense of Ukraine

Under planning mode (Fig. 2):

– on the basis of the following, formulated within the framework of planning the strategic development of the Armed Forces: the quantitative and qualitative composition of weapons and military equipment (WME); tasks and methods of using the armed forces (PC) – the goals (criteria) of personnel training for the Ministry of Defense are formulated. Development forecasting and analysis of the resource and functional capabilities of educational institutions (EIs), training grounds, training centers, and other components of the personnel training system for the armed forces is carried out. General goals for the development of the training system are developed into specific tasks for: commands of the armed forces, service units, training grounds, training centers, and other subjects of the control system. The bodies in which the main information and analytical work is carried out are the main directorates of the General Staff and departments of the Ministry of Defense of Ukraine. Particular tasks are descended for further detailing and planning the functioning of subjects of the lower hierarchical level (threads ① and ②, Fig. 2). In the absence of the necessary initial data in the strategic level management bodies, lower management bodies are involved in the goal-setting process. They prepare proposals for decisions of higher authorities. Proposals contain alternative options for achieving pre-set private goals, ordered by the achieved effect, required resources and time costs (③ and ④, Fig. 2). If planning is carried out under conditions of full awareness of higher authorities, then flows ③ and ④ do not contain alternative options, but the only preliminary plans of the performers represented to the top;

– based on the proposals submitted from a lower hierarchical level, the General Staff makes a decision on the development of the training system. The tasks, directions and periods of troop training, parameters (criteria) for the development of the training system are determined. To support decision making, methods for distributing limited resources are used: decomposition of optimization problems; priority and proportional distribution of resources. The solution contains: formulations and volumes of personnel training tasks; distribution of resources between performers and preparation activities; tasks for developing the training system and the procedure for implementing these tasks. The results of planning at the strategic level are formalized in the form of a program for the development (reform) of the personnel training system with an implementation horizon of 5–10 years. The decision of the General Staff is sent down to the operational and tactical level control bodies for further detail and drawing up operational plans (⑤, Fig. 2). At the operational level, after detailing the tasks lowered from the strategic level, particular tasks for the tactical level are also formulated (⑥, Fig. 2).

Based on the initial data ⑤ and ⑥, programming of training activities (scheduling) is carried out at the operational and tactical levels. At the operational level, the planning results are formalized in the form of a program for training troops and developing (reforming) the system of specific training facilities, training grounds, and training centers. The planning horizon is 2–5 years. At the tactical level – in the form of private event programs for the academic year. The results of programming the activities of performers in the personnel training system are taken into account when drawing up the weapons and military equipment development program in the form of personnel restrictions and conditions.

Under the mode of operational management of personnel training (implementation of development programs and troop training activities) (Fig. 3):

– ongoing monitoring of the progress of planned activities is carried out based on reports and control signals coming from tactical and operational level performers (flows ⑦ and ⑧, Fig. 3). When executing control, the current parameters of the state of the personnel training system are assessed and they are projected onto the established criteria for the success of achieving training and development goals;

– based on the results of the analysis of the progress of implementation of plans by the subjects of the management system, corrective actions are developed that correspond to the powers of these subjects. At the strategic level, the General Staff makes decisions to adjust programs for reforming the training system, action plans for international and interservice training of troops. At the operational level, the commands of the Armed Forces make decisions to adjust the calendar plans for the development of HEI, training grounds, training centers, and personnel training programs. At the tactical level, decisions are made to adjust the calendar of events planned for the current academic year. Correction commands are communicated to the performers at lower levels of the preparation management system (threads ⑨ and ⑩, Fig. 3).

Thus, the personnel training management system for the Ministry of Defense of Ukraine is a three-level hierarchy. The functioning of subjects in this system is carried out by making management decisions that differ in content, planning horizon and detail in accordance with their hierarchical level and powers. Decisions are made under the modes of top-down detailing, as well as the preparation of initial data in a counter-movement. The content of decisions made covers the following processes:

– development of a system of specific training facilities, training grounds, training centers;

– conducting events for international, interspecific, and service-specific training of troops;

– basic training of military personnel in the HEI of the Ministry of Defense and the Ministry of Education.

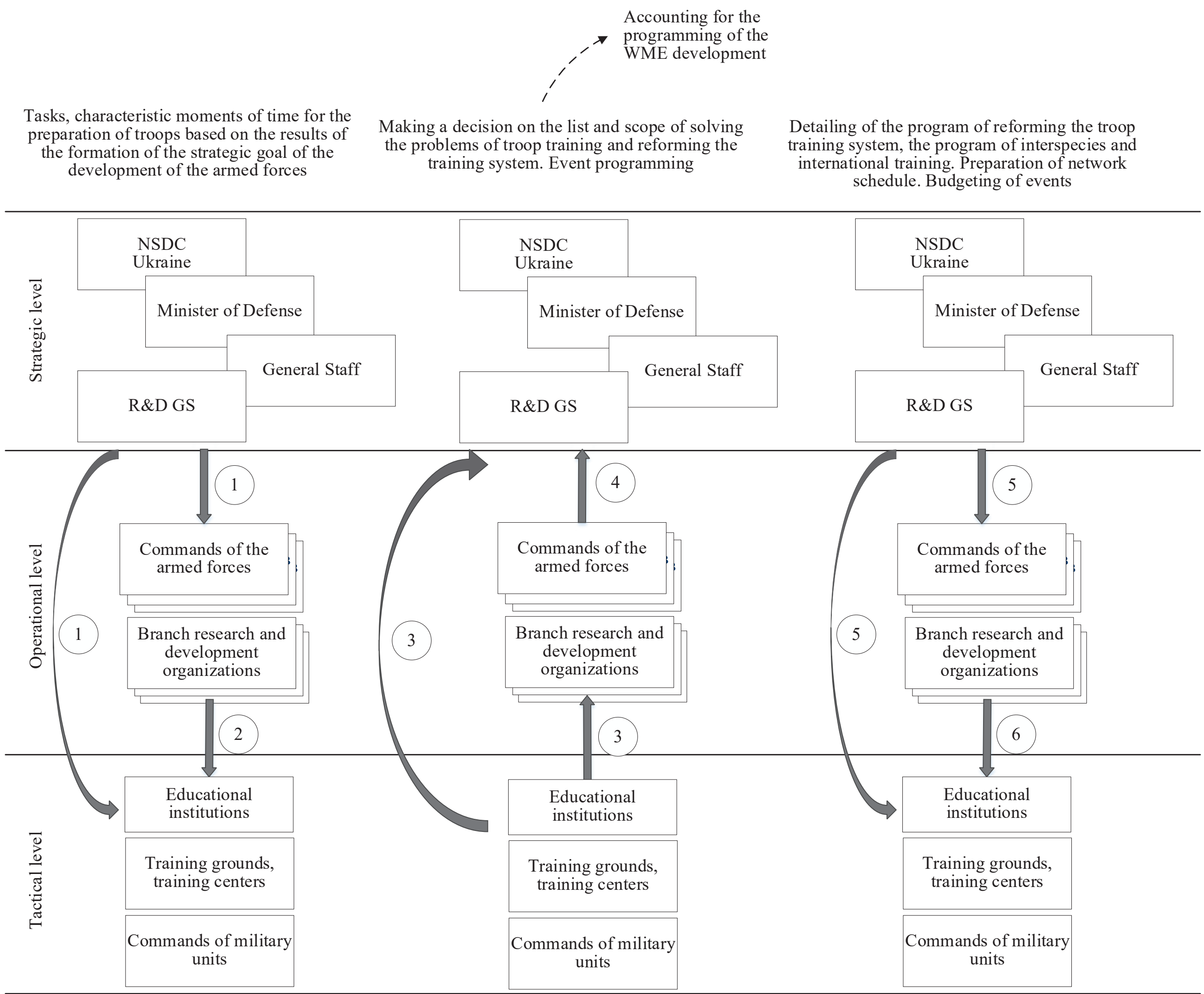

Fig. 2. Information exchange between personnel training management bodies under planning mode

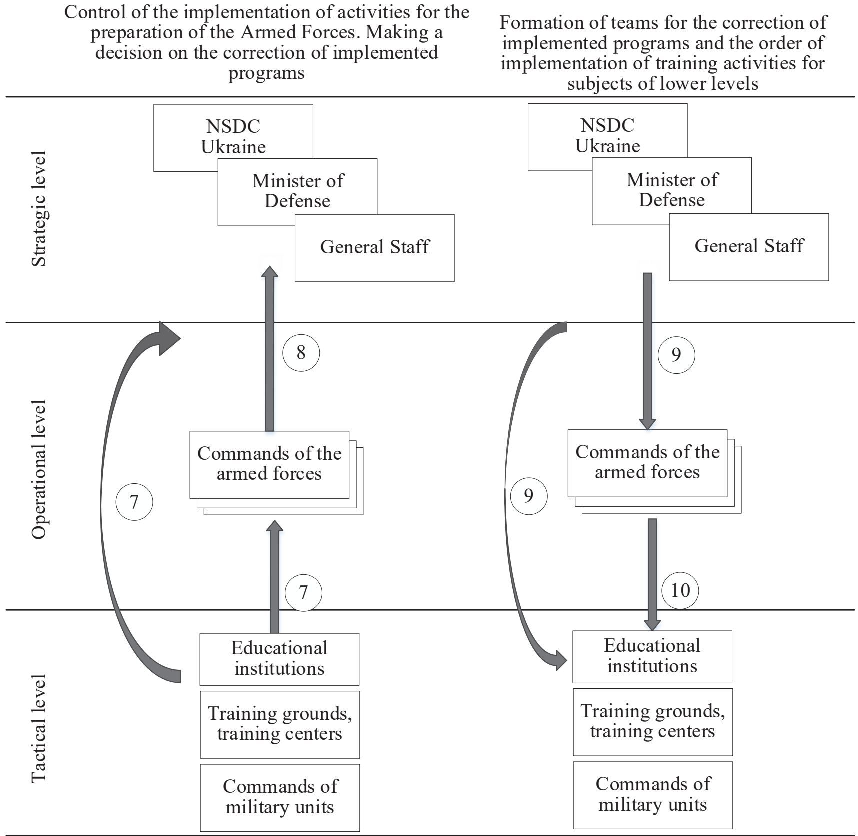

Fig. 3. Information exchange between personnel training management bodies under operational management mode (implementation of formed plans)

4. 3. Method of categorical analysis

The method of categorical analysis consists in applying a deductive approach to the processes of multilateral analysis of integrity [15]. An example of using a deductive approach in analyzing and structuring a subject area is Mendeleev's periodic table of chemical elements.

The method is based on such a statement of dialectics that any observable objects, systems, processes (integrities) are the result of the interaction of the opposites found in them. The real world is contradictory. Its evolution occurs through the emergence and resolution of contradictions. Therefore, the thinking apparatus will be more effective the more it takes this feature into account.

The effectiveness of taking into account objective laws of development in conceptual design is confirmed by the success of using TSIP [4], in which objective laws of development of technical systems are used, considered as processes for resolving technical and physical contradictions.

Unlike morphological analysis [2], where the axes of the morphological table (aspects of analysis) are chosen arbitrarily, at the discretion of the researcher, in categorical analysis this is due to the choice of the initial list of categorical pairs. Each categorical pair divides the analyzed entity into two parts, in accordance with the content of this pair. For example, «Whole – Particular»; «Present – Future»; «Defense – Attack». Due to this, the analysis process becomes focused and orderly.

The process of generating analysis aspects using a list of categorical pairs is as follows.

Each of the two opposites of any categorical pair can be considered as an integrity, side, or aspect of the analyzed object. For example, in the application to the design of SSW for ASOC, the categorical pair «Management – Execution» (**M** – **E**) characterizes the following parties or aspects of the SSW system. **M** are algorithms that ensure decision-making and programming the functioning of the system for an established planning horizon. **E** – implementation of the generated program, monitoring the progress of its implementation and correction of control in case of deviations that arise.

Each of these individual opposites may contain the opposites of another categorical pair. So, if we add another categorical pair into consideration: «Goal – Means» (**G** – **Mn**), then four essences or sides (aspects) of the analysis of SSW for ASOC will be formed. These include:

M|**G** – **E**|**Mn**,

and

M|**Mn** – **E**|**G**.

Integrity (aspect of the analysis of SSW) of the U|C means that the decision-making process is considered in relation to the objectives of the operation. That is, we are talking about formulating criteria for successfully achieving goals for the planned period. The integrity of the V|C characterizes the process of monitoring the progress of achieving set goals and adjusting them in the event of deviations from the implemented program. U|S characterizes the planning of the use of funds (distribution of tasks, resources, determination of the order (modes) of use). B|C is monitoring the functioning of funds during the implementation of the plan, adjusting the distribution of resources and funds among tasks, changing their operating modes.

When considering three categorical pairs, the number of aspects increases to eight. With four pairs – up to sixteen, etc.

The selection of the initial list of categorical pairs carries an element of subjectivity and depends on the competence of the researcher in the subject area under consideration. However, when performing further steps, the synthesis of aspects is carried out using a formal procedure of enumerating combinations of opposites of the categorical pairs under consideration. The list of analyzed aspects created in this way is complete, within the established boundaries of the study. Completeness is ensured by following the objective law of the existence of matter about the unity and struggle of opposites.

The bottleneck of the method is the problem of assigning research boundaries. The question of selecting the initial list of dual pairs is decided subjectively. To reduce the likelihood of making mistakes when making such a choice, it is advisable to use the list of recommended dual pairs given in [15].

4. 4. Provisions of the theory of conceptual design of ASOC

When designing ASOC, a conceptual information diagram is used [14] (Fig. 4). This scheme represents a certain structure of sets of numerical and linguistic values of established data groups used in automated control, as well as a system of relationships and procedures for converting data during their processing.

The data sets present in ASOC include:

– set of characteristic moments of time, **T**;

– set of output parameter values, **Y**;

– set of values of operating conditions parameters, **S**;

– set of values of control parameters, **U**;

– set of values of control object state parameters, **X**.

Characteristic moments of time **T** are understood as those values on the time axis that correspond to the moments:

– updating output parameter values, **Y**;

– updating the values of operating conditions parameters, **S**;

– application of management influences, **U**;

– determination of predicted values of output parameters after applying appropriate controls.

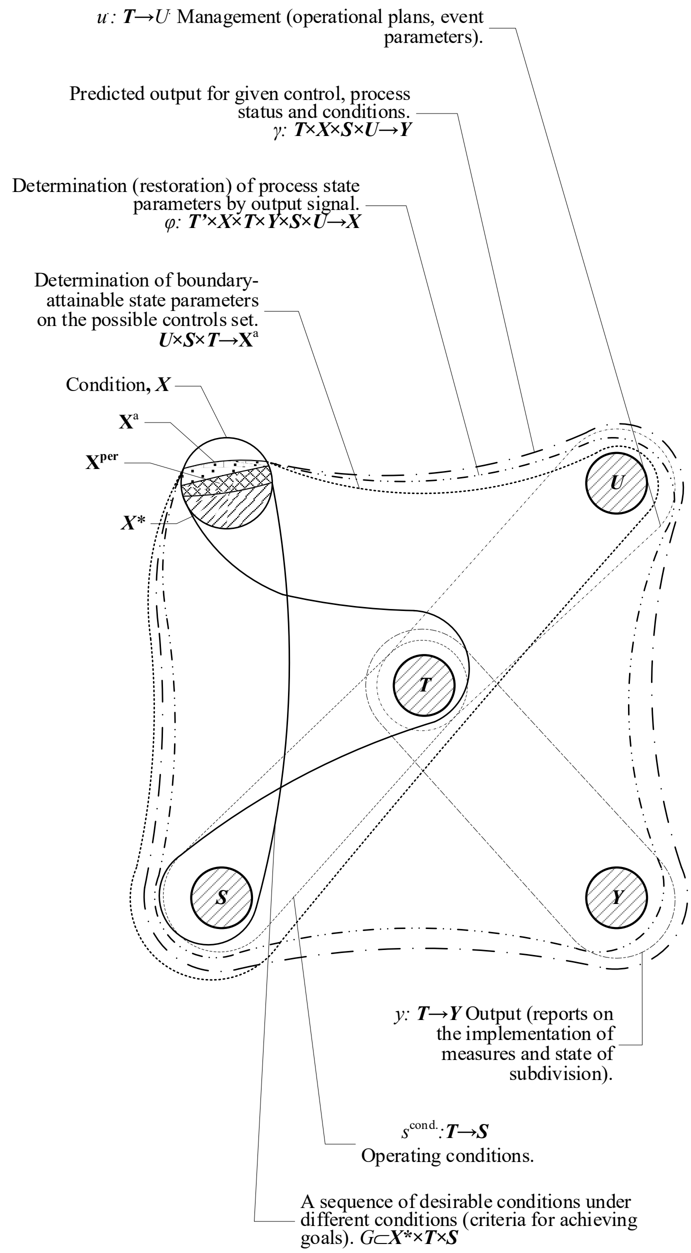

Fig. 4. Conceptual diagram of information in automated systems for organizational control

The output parameters, **Y**, mean everything that enters ASOC as input data (sensor readings, human data input, information from senior, interacting and subordinate decision-making centers).

Control parameters, **U**, refer to the data that is generated by the control system to change the state of the control object in order to achieve a specified desired state. The following can be considered management parameters: network schedule of planned activities; commands to change the operating modes of organizations; results of task and resource distribution, etc.

The parameters of the operating conditions of the control object, **S**, are understood as data characterizing the influence of the external environment on the output parameters, restrictions on the state parameters of the control object. The following conditions can be considered as parameters of conditions: regulatory guidelines for personnel training; Air Force development goals; level of development of weapons and military equipment, etc.

State parameters, **X**, are understood as data that describe the process of functioning of the control object as it is perceived by the control subject (decision maker (DM)). The following can be considered to be state parameters:

– parameters of professional suitability of personnel in the parametric space of current tasks and methods of using AF;

– levels of achievement of private training goals;

– current risks, degrees of threats;

– warning signals, etc.

The set of state parameter values contains the following regions of the state space: region (boundary) of limiting achievable states, $\mathbf{X^a}$; the region of desired states, $\mathbf{X^*}$, and the region of permissible deviations from the desired states, $\mathbf{X^{per}}$. The region of maximum achievable states, $\mathbf{X^a}$, characterizes those values of the state parameters of the control object that can be theoretically realized under certain operating conditions and with a given control. That is, these are parameters that measure the potential capabilities of a control object if its functioning is tuned to a specific narrowly focused result. The area of desired states, **X***, contains those values of state parameters that characterize the purpose of the ongoing training activities. The specific formalization of the purpose of functioning of the personnel training system (its model) depends on the aspects of management taken into account. The region of permissible deviations from the desired state, $\mathbf{X}^{\mathbf{per}}$, is a set of permissible intervals for changing the values of state parameters defined on the topology of the space of parameters of the desired state.

Between the given groups of data, various binary relations and transformation (display) procedures are established, which are represented as:

– binary relations between discrete time values and parameter values of operating conditions, s^{cond}: $\mathbf{T}\rightarrow\mathbf{S}$. These relationships can be defined in the form of sets of constants that remain unchanged over specified time intervals; functions of the dependence of conditions parameters on time in tabular or analytical form; differential equations (DE) (DE systems);

– binary relations between discrete time values and output parameter values, y: $\mathbf{T}\rightarrow\mathbf{Y}$. These relations are also specified either in the form of sets of constants, or sets of tables, or analytical expressions, or DEs;

– binary relations between discrete time values and control parameter values, u: $\mathbf{T}\rightarrow\mathbf{U}$. In other words, these relationships are a functioning plan (changes in control parameters over time);

– a selection of combinations of desired values of state parameters, condition parameters and time values, $G\subset\mathbf{X}^{*}\cdot\mathbf{S}\cdot\mathbf{T}$, considered as a model of the functioning goal (time transformation of desired states for established environmental conditions);

– binary relationships between combinations of control parameter values, condition parameters, time points and values of the maximum achievable state parameters that correspond to these combinations, $\mathbf{U}\cdot\mathbf{S}\cdot\mathbf{T}\rightarrow\mathbf{X}^{a}$. To determine this kind of relationship, as a rule, a model of the functioning of a control object under different conditions with a variety of controls is used. This is a set of models for calculating the efficiency of operation, cost, time expenditure for various aspects of the process under consideration;

– binary relationships between combinations of state parameter values, control parameters, condition parameters, time values and their corresponding predicted values of output parameters, y: $\mathbf{U}\cdot\mathbf{S}\cdot\mathbf{T}\cdot\mathbf{X}\rightarrow\mathbf{Y}$ (output forecast). To determine relationships of this kind, models of the dynamics of output (observable) processes of the control system are used;

– binary relationships between combinations of values of control parameters, state, output, conditions, time values at which these parameters were observed, values of the current (future) time and the values of state parameters corresponding to these combinations, φ: $\mathbf{U}\cdot\mathbf{S}\cdot\mathbf{Y}\cdot\mathbf{X}\cdot\mathbf{T}^{\mathbf{1}}\cdot\mathbf{T}\rightarrow\mathbf{X}$. Otherwise, this relationship is also called state restoration based on output data. To determine this kind of relationship, special models of transformation (transformation) of output parameters into state parameters are used, taking into account the content of the control process in relation to a specific decision maker.

The conceptual scheme of ASOC information in combination with the method of categorical analysis is used in the conceptual design of SSW. Categorical analysis makes it possible to organize the reasoning for a multidimensional analysis of the control process, and the conceptual scheme of information provides procedural and parametric templates, the filling of which, in fact, makes it possible to form a list of functional tasks of the designed SSW.

4. 5. Method for formulating functional tasks of SSW for ASOC

The method for formulating FT of SSW for ASOC involves performing the following sequence of actions (Fig. 5):

– determining the boundaries of the subject area of SSW analysis by selecting an initial list of categorical pairs;

– synthesis of aspects of automated control for analysis. Synthesis is carried out by enumerating combinations of opposites of categorical pairs from the selected initial list. Each combination of opposites is interpreted in relation to the content of the control process under consideration;

– detailing groups of ASOC parameters for each aspect of automated control;

– formulation of FT for each aspect of management, taking into account the received detail of groups of parameters and template of automated control system procedures.

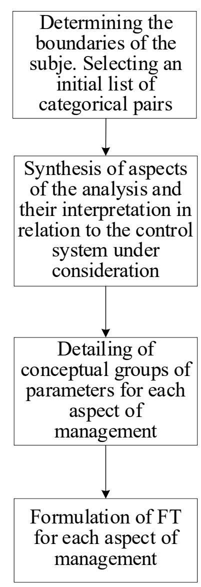

Fig. 5. Sequence of actions when formulating functional tasks

When using the results of multidimensional interpretation, the task of structuring management information is significantly simplified due to a decrease in its dimensionally. Parallel consideration of the variety of aspects is replaced by their sequential analysis.

The formulated FT on the synthesized aspects of management will be complete within the boundaries of the categorical analysis carried out. At the very least, the structure of ASOC database will be laid down, in which all significant connections and relationships are taken into account. This will make it possible to modernize SSW relatively painlessly during the operation of ASOC.

5. Results of the study to devise a method for formulating functional tasks

5. 1. Results of a categorical analysis of the training control process

A categorical analysis of the training control process for the Ministry of Defense was carried out using the following categorical pairs:

– «Management – Execution» («U – V»). The pair is interpreted as preliminary decision-making (planning) and its implementation (execution of the plan);

– «Goal – Means» («Ts – S»). The pair is interpreted as the goal of the actions performed and the means (resources) through the use of which this goal is achieved;

– «Base – Superstructure» («B – N»). The pair is interpreted as receiving basic training (training in educational institutions) and subsequent training (training in the military).

Based on the proposed categorical pairs, the following categorical combinations were formed, which represent management aspects. These include:

M|G|B | F|G|B,

M|M|B | E|M|B,

M|G|S | E|G|S,

M|M|S | E|M|S.

That is, 8 aspects (sides) of the training control process were obtained.

Table 2 gives the results of interpretation of these aspects for the strategic level of the management system. The interpretation was obtained taking into account the fact that at the strategic level the main content of the troop training process is the acquisition of competencies in interspecific interaction and conducting combined arms combat.

At the operational and tactical levels of management, the area of analysis was determined using the same initial categorical pairs but supplemented by structuring according to the characteristics of the specific training of the armed forces. These are the features of preparation in:

– Air Forces (air training for the tactical level);

– Navy (naval training);

– Ground Forces (ground training).

That is, compared to eight management aspects for the strategic level, 24 aspects were considered at the operational and tactical levels.

5. 2. Multi-aspect concept of automation of personnel training management

5. 2. 1. Data groups for synthesized control aspects

A fragment of detailed management information on two of the eight aspects of management at the strategic level is given in Table 2.

Table 2 gives details of control data on two aspects of management out of eight aspects formulated for the strategic level of the personnel training management system for the Ministry of Defense of Ukraine.

Table 1

Interpretation of aspects of personnel training management for the Armed Forces of Ukraine at the strategic level of the management system

No. of entry	Categorical combination	Interpretation
1	M|G|B	«Management – Goal – Basis». Formation of requirements for the competencies of specialists and planning of their graduation in military and civilian institutions. Competencies of interspecific interaction, combined arms combat, confrontation in information and outer space (based on the current concept of military confrontation)
2	F|G|B	«Fulfillment – goal – basis». Assessment of the completeness and quality (sufficiency of specialists in terms of their number and level of competence) of the implemented training programs. Adjustment of programs
3	M|M|B	«Management – Means – Basis». Formation of programs for the development of HEI of the Armed Forces (teaching and engineering staff, training and laboratory base) in relation to the goals of training competencies in accordance with the current concept of military confrontation
4	E|M|B	«Execution – means – basis». Monitoring the implementation of programs for the development of the military and civilian HEI, adjusting programs
5	M|G|S	«Management – Goal – Superstructure». Formation of professional training courses for specialists at the strategic and operational level in the Military Academy, action plans for interspecific training of troops, goals and objectives of training of the Armed Forces to solve the problems of interspecific interaction and conducting combined arms combat, confrontation in information and outer space
6	E|G|S	«Execution – Goal – Superstructure». Assessment of the degree of readiness of troops according to the established list of competencies, according to the criteria for the implementation of the goals and objectives of interspecific training of the Armed Forces for the current period. Adjustment of academic training programs, goals, and objectives of interspecific training of troops
7	M|M|S	«Management – Means – Superstructure». Distribution of tasks and resources (consumables, equipment, training equipment) between the units of the Armed Forces Academy, interspecific training centers, training grounds. Planning the development of the training and laboratory base, staffing of the training system in the interests of acquiring the competencies of combined arms combat and interspecific interaction
8	E|M|S	«Execution – Means – Superstructure». Monitoring the implementation of the plan of measures for the interspecific training of military units and the plan for the development of training centers, training grounds of the Armed Forces

Table 2

Detailing of management information for automation of personnel training management at the strategic level of the management system (fragment)

No. of entry	Categorical combination	Interpretation	Data group	Data description
1	M|G|B	Formation of requirements for the competencies of specialists and planning of their graduation in military and civilian institutions. Competencies of interspecific interaction, combined arms combat, confrontation in information and outer space (based on the current concept of military confrontation)	Output	1. The concept of tactics of conducting combined arms combat, other aspects of military confrontation. 2. IWT Development Program. 3. Capital Construction Program. 4. Proposals from the operational (tactical) level management bodies on: – training programs; – the number of trained specialists; – resource needs for the content and development of the educational and laboratory base
			Conditions	1. Ontology of basic training of specialists in the Educational Institutions of the Ministry of Defense and the Ministry of Education for the acquisition of competencies of interspecific interaction, combined arms combat, confrontation in information and outer space. 2. The system of HEI of the Ministry of Defense, civil institutions of secondary and higher education: – competencies; – the level of quality of education; – the capacity (capacity) for the training of specialists
			State	1. The degree of coverage of the needs of the troops by competencies and the number of specialists. Available and required functional capacity of the Armed Forces units for the implementation of: – interspecific interaction; – combined arms combat; – confrontation in the information and space domains
			Control	1. Criteria for the formation of training programs and plans for the graduation of specialists in HEIs of the Ministry of Defense and the Ministry of Education: – a list of necessary competencies for graduates of established specialties; – levels of competence development (volumes of theoretical and practical training); – the number of graduates by specialties. 2. Training programs (taking into account proposals from management bodies at the operational and tactical levels): – thematic plan; – distribution of training time by topics. 3. Plans for the graduation of specialists from the system of HEIs of the Ministry of Defense and the Ministry of Education (taking into account proposals from management bodies at the operational and tactical levels). 4. Tasks for the management bodies of the operational (tactful) level to prepare proposals regarding: – training programs (topics and time allocation); – the number of students in the specialization; – resource needs for the content and development of the educational and laboratory base
⋮	⋮	⋮	⋮	⋮
7	M|M|S	Distribution of tasks and resources (consumables, equipment, training equipment) between the units of the Armed Forces Academy, interspecific training centers, training grounds. Planning the development of the training and laboratory base, staffing of the training system in the interests of acquiring competencies in combined arms combat and interspecific interaction	Output	1. Criteria for the formation of: – training programs, plans for the graduation of specialists of the strategic and operational level at the Academy of the Armed Forces; – action plans for interspecific training of troops in the light of the implementation of the modern concept of military confrontation. 2. Curricula (thematic plans) and the plan for the graduation of specialists by the units of the Academy of the Armed Forces. 3. Plans of measures for interspecific training of troops. 4. Proposals from the departments of the Academy: – training programs (topics and time distribution); – the number of trained specialists; – resource needs for the maintenance and development of the educational and laboratory base. 5. Proposals from the operational level management bodies on: – measures of interspecific training of troops; – development of the training and control and measuring base of interspecific training centers and training grounds
			Conditions	1. Ontology of the development of the educational and laboratory base of the Academy of the Armed Forces for the professional training of specialists at the strategic and operational levels. 2. Ontology of the development of the training and control and measurement base of interspecific training centers, training grounds of the Armed Forces to ensure interspecific training of troops. 3. The state of the units of the Academy of the Armed Forces, the system of training grounds and interspecific training centers: – the competencies taught; – the level of quality of training; – the throughput (capacity) for the training of specialists
			State	1. Required and available capacity of the Armed Forces Academy units, interspecific training centers, training grounds, training grounds for solving certain training tasks depending on the characteristics of the educational and laboratory, training and control and measurement base, resource support: – quality of training; – number of trained specialists
			Control	1. Plan for the development of the educational and laboratory base and resource support for the activities of the units of the Academy of the Armed Forces (based on proposals from the Academy). 2. Plan for the development of the training and control and measurement base and resource support for the activities of interspecific training centers, training grounds (based on proposals from centers and training grounds, operational level management bodies)

The data is grouped into four groups.

These include:

– output;

– conditions;

– state;

– control.

The output data group contains information on:

– the results of planning for the development of weapons and military equipment and capital construction, which serve as the initial conditions for making decisions regarding personnel training;

– parameters and content of departments formed on related aspects of the preparation process or at previous stages of the management cycle;

– information (signals) about the progress of fulfilling assigned tasks and implementing formed plans.

The group of data on conditions contains information about existing standards and procedures for implementing personnel training activities and operating the material resources used in this process. This information is represented in the form of ontologies of the relevant areas of activity of subjects in the personnel training system.

The status data group contains information on actual, maximum achievable and desired indicators:

– specialization, competence, and number of graduates of educational institutions;

– specialization, qualifications, and number of teaching staff;

– technical excellence, educational efficiency, and capacity of the material and technical base of educational institutions, training centers and training grounds.

State parameters reflect the training process in terms of goals and objectives solved in the control loop for an established aspect of personnel training.

The control data group contains information on:

– parameters and content of the generated decisions (proposals for superiors, action plans);

– executive teams;

– reports (signals) on the progress of plans and ad hoc commands.

5. 2 .2. Functional tasks of specialized software

For management information detailed by the considered aspects of management (Table 2), Table 3 gives a list of FTs formulated on the basis of the ASOC procedure template.

Table 3

Functional tasks for automating the management of personnel training at the strategic level of the control system (fragment)

No. of entry	Name of the procedure (relationship)	Functional tasks
1	2	3
1	Operating conditions, s^{cond}: $\mathbf{T}\to\mathbf{S}$	1. 1. Input (editing) of data on the state of the KM system of the Ministry of Defense and the Ministry of Education (competencies being formed, the level of quality of education provided, the capacity for training specialists, the state of the educational and laboratory base, current personnel and resource support)
		1. 2. Introduction (editing) of the ontology of basic training of specialists at HEI of the Ministry of Defense and the Ministry of Education for the development of competencies regarding interspecific interaction, combined arms combat, other areas of military confrontation (information and outer space)
		⋮
		1. 4. Input (editing) of data on the state of the Armed Forces Academy units, interspecific training centers, training grounds (competencies being formed, the level of training quality ensured, the capacity for training specialists, the state of the educational laboratory, training and control and measuring base, personnel, resources)
		⋮
		1. 6. Input (editing) of the ontology for the development of the educational and laboratory base of the Armed Forces Academy to ensure further professional training of specialists at the strategic and operational level
		1. 7. Introduction (editing) of the ontology for the development of the training and control and measurement base of the centers of interspecific training and training grounds of the Armed Forces to ensure the interspecific training of troops
2	Output, y: $\mathbf{T}\to\mathbf{Y}$	2. 1 Clarification of the goals and objectives of the education system for the formation of competencies and the number of specialists, based on: – the Concept of tactics for conducting combined arms combat, other aspects of military confrontation; – weapons and military equipment development programs; – Capital Construction Programs
		2. 2 Generalization of proposals from operational (tactful) level management bodies on training programs and the number of trained specialists
		⋮
		2. 15. Clarification of the goals and objectives for the development of the educational and laboratory base, personnel and resource support of the Armed Forces Academy, based on: training programs and plans for the graduation of specialists at the strategic and operational levels
		2. 16. Clarification of the goals and objectives for the development of the training and control and measurement base, personnel and resource support of interspecific training centers, training grounds, based on: action plans for interspecific training of troops
		2. 17. Generalization of proposals from the units of the Academy of the Armed Forces on plans for the development of the training and laboratory base, personnel, and resource support for the training of specialists at the strategic and operational levels, taking into account the current concept of military confrontation
		2. 18. Generalization of proposals from interspecific training centers, training grounds, operational level management bodies on plans for the development of training and control and measurement base, personnel and resource support for interspecific training activities
		⋮

Continuation of Table 3

1	2	3
3	Control, u: $\mathbf{T}\rightarrow\mathbf{U}$	3. 1. Formation of tasks for management bodies of the operational (tactful) level for the preparation of proposals for training programs (topics and time allocation), the number of trained specialists, the necessary resources for the development of the educational and laboratory base
		3. 2. Programming of basic training of specialists at HEIs of the Ministry of Defense and the Ministry of Education (thematic plan and distribution of training time, calendar terms) (based on the generalization of proposals from the operational (tactful) level bodies)
		3. 3. Planning the recruitment of applicants and the graduation of specialists at HE institutions of the Ministry of Defense and the Ministry of Education according to the criterion of implementing the functions of interspecific interaction, conducting combined arms combat, and other aspects of the modern concept of military confrontation
		⋮
		3. 21. Planning the development of the training and laboratory base of the Armed Forces Academy to ensure the process of professional training of specialists at the strategic and operational level (based on the generalization of proposals from the units of the Armed Forces Academy)
		3. 22. Planning the development of training, control and measurement base in interspecific training centers, training grounds of the Armed Forces in order to implement the process of interspecific training of troops (based on the generalization of proposals from centers, training grounds, operational level management bodies)
		3. 23. Planning of the training of teaching staff in the units of the Academy of the Armed Forces in order to implement the program of training specialists of the strategic and operational level (based on the generalization of proposals from the units of the Academy of the Armed Forces)
		⋮
4	A model of the purpose of functioning, $\mathbf{G}\subset\mathbf{X}^{*}\cdot\mathbf{S}\cdot\mathbf{T}$	4. 1. Formation of criteria for training specialists in HEI of the Ministry of Defense and the Ministry of Education on the basis of understanding the goals and objectives of the training system for the formation of competencies and the number of specialists necessary for the implementation of the functions of interspecific interaction, combined arms combat, and other aspects of military confrontation
		⋮
		4. 5. Formation of criteria for the development of the educational and laboratory base, training of personnel of the Academy of the Armed Forces, which ensure the implementation of the goals and objectives of training specialists at the strategic and operational level
		4. 6. Formation of criteria for the development of the training and control and measurement base of the centers and ranges of the Armed Forces, which ensure the implementation of the goals and objectives of interspecific training of troops
5	Maximum achievable parameters of state, $\mathbf{U}\cdot\mathbf{S}\cdot\mathbf{T}\rightarrow\mathbf{X}^{a}$	5. 1. Assessment of the values of the absolute maximum achievable indicators of the power of the Armed Forces units for the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of reaction to enemy actions, information superiority, global control) depending on the parameters of basic training programs for specialists
		5. 2. Assessment of the values of the absolute maximum achievable indicators of the capacity of HEI facilities of the Ministry of Defense and the Ministry of Education for the training of specialists of established specialties with specified lists of competencies under the current state of staffing and educational and laboratory facilities
		5. 3. Assessment of the values of the absolute maximum achievable indicators of the power of the Armed Forces units for the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of reaction to enemy actions, information superiority, global control) depending on the parameters of training programs for specialists at the strategic and operational levels
		5. 4. Assessment of the values of the absolute maximum achievable indicators of the power of the Armed Forces units for the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of response to enemy actions, information superiority, global control) depending on the parameters of the plans of measures for interspecific training of troops
		5. 5 Assessment of the values of the absolute maximum achievable indicators of the capacity of the units of the Academy of the Armed Forces for the training of specialists of the strategic and operational level of the established specialties with the established sets of competencies depending on the state of staffing and the educational and laboratory base of the Academy
		5. 6 Assessment of the values of the absolute maximum achievable indicators of the capacity of training centers, ranges of the Armed Forces for the implementation of the established measures of interspecific training of troops depending on the state of their staffing, training and control and measurement base
6	Output forecast, y: $\mathbf{U}\cdot\mathbf{S}\cdot\mathbf{T}\cdot\mathbf{X}\rightarrow\mathbf{Y}$	6. 1 Forecasting the progress of plans for the basic training and graduation of specialists of the Ministry of Defense and the Ministry of Education on the basis of reports on the state of affairs
		⋮
		6. 4 Forecasting the implementation of the plan for the development of the educational and laboratory base, training of personnel for the Academy of the Armed Forces on the basis of reports on the state of affairs
		6. 5 Forecasting the implementation of the plan of measures for interspecific training of troops in training centers and training grounds on the basis of reports on the state of affairs
		6. 6 Forecasting the implementation of the plan for the development of training and control and measuring facilities for interspecific training centers and aircraft training grounds based on reports on the state of affairs

Continuation of Table 3

1	2	3
7	Recovery of state based on output data, φ: $\mathbf{U{\cdot}S{\cdot}Y{\cdot}X{\cdot}T^1{\cdot}T{\to}X}$	7. 1 Assessment of the values of absolute and relative indicators of the power of the Armed Forces units for the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of reaction to enemy actions, information superiority, global control) depending on the actual state of staffing of troops by specialists of relevant HEI
		7. 2 Assessment of the values of absolute and relative indicators of the capacity at HEI facilities of the Ministry of Defense and the Ministry of Education for the training of specialists in certain specialties depending on the staffing and resource support, the state of the educational and laboratory base of the HEI facility
		7. 3 Assessment of the values of absolute and relative indicators of the power of the Armed Forces units in the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of response to enemy actions, information superiority, global control) depending on the actual state of staffing of troops by specialists of the strategic and operational level – graduates of the Armed Forces Academy
		7. 4 Assessment of the values of absolute and relative indicators of the capacity of the units of the Academy of the Armed Forces for the training of specialists of the strategic and operational level depending on the personnel and resource support, the state of the educational and laboratory base of the Academy
		7. 5 Assessment of the values of absolute and relative indicators of the power of the Armed Forces units for the implementation of certain functions of the concept of military confrontation (speed of territorial advance, adaptive ability, speed of reaction to enemy actions, information superiority, global control) depending on the actual implementation of the plan of interspecific training
		7. 6 Assessment of the values of absolute and relative indicators of the capacity of training centers, aircraft ranges for certain interspecific training activities depending on personnel and resource support, the state of the training and control and measuring base

In total, for the strategic level of management, the list included 79 FTs. For the operational level – 204 FTs. For the tactical level – 195 FTs.

The relatively large number of FTs that were formulated for the operational level of management is explained by the intermediate position of the operational link in the three-level management system. Control bodies of this level need to carry out simultaneous interaction with both the lower and upper hierarchical levels. The strategic link interacts only with junior (subordinate) management bodies, and the tactical link – only with the senior level.

6. Discussion of results of categorical analysis and the formation of functional tasks

The method of categorical analysis provides the opportunity to structure and streamline the expert's reasoning process when developing an automation concept. The generated management aspects (Table 1), being considered in the light of established data groups (Fig. 4) and superimposed on standard procedures (relations) of the automated control system, allow us to consider the control process as fully as possible (in the sense of the established boundaries of analysis) (Tables 2, 3). In this study, the boundaries of categorical analysis were established by using:

– dividing management modes into planning mode (category «Management» (U)) and operational management, plan implementation (category «Implementation» (B));

– dividing the control loop into goals (category «Goal» (C)) and means, resources (category «Means» (C));

– dividing the personnel training process into the basic training stage (category «Basis» (B)) and the stage of training in the military (category «Superstructure» (N)).

The listed opposites are contained in the process of personnel training. Their combination creates various contradictions, the resolution of which leads to improvement and development of the system for managing this process. In total, 8 such combinations of aspects were obtained (Table 1) for the strategic level of management and 24 aspects for the operational and tactical levels.

Unlike the method of morphological analysis [2], in which the axes of analysis are chosen arbitrarily by the researcher, here the enumeration of aspects is carried out in a formalized manner. The ordering of the reasoning process of the researcher is ensured, which sequentially goes through all aspects of the process (object) within established boundaries. Along with ensuring the completeness of the analysis, this also «saves» the designer's thinking power since it reduces the dimensionality of the heuristic problem. One large design problem is replaced by a series of problems that are solved sequentially.

The proposed method is a fairly universal tool for the conceptual design of SSW. It can be used not only in the design of large organizational control systems but also for various automated control systems of technical objects and complexes. Thus, in [18] the application of this method in the conceptual design of an automated control system for a group of unmanned aerial vehicles was demonstrated.

The power of the categorical analysis method can be increased by taking into account, when forming a list of analyzed aspects, the nature of the influence of opposites in dual pairs. So, for example, the dual pair «Management – Execution» can be considered taking into account the following aspects of the interaction of opposites:

– +M|+F, management has a positive effect on the process of execution (strengthens it), and the process of execution strengthens the process of control (planning);

– –M|–E, processes are mutually weakened;

– +M|–E, control has a positive effect on performance, and execution weakens management;

– –M|+E, control weakens execution, and execution strengthens management.

That is, instead of one initial dual pair, four pairs of opposites are analyzed. The number of aspects considered increases manifold.

The method of categorical analysis, while providing a certain formalism in the formation of aspects of analysis (structuring the conceptual design problem being solved), nevertheless, relies heavily on the subjective experience and competence of the designer. For example, when formulating a federal law, in addition to detailed control data and a template for automated control systems procedures, the researcher's experience in using mathematical methods and models in solving certain decision-making problems plays a great role. This paper uses network planning methods and an ontological approach as a basis. Although, this is far from the only modeling method that can be used in organizational control.

It is obvious that FTs from SSW should not be based on models that assume different accuracy of calculations and different labor intensity (update frequency). This provision is consistent with one of the laws of technology development, which is used in TSIP [4, 5] – the law of equal frequency in a technical system. This aspect (of the «equal strength» of SSW) is taken into account implicitly when conducting the analysis.

Also, when forming the list of aspects, the mechanisms of functioning of multi-level organizational systems were not considered [16]. This concerns inter-level interaction of management bodies, the peculiarities of solving management problems under conditions of full and incomplete information of decision-makers, information, and logical connections with parallel management circuits (development of arms and military equipment, capital construction). This was brought into the conceptual design not from direct interpretations of aspects but using the additional knowledge of the expert.

The wording of FTs, in the example given, is quite general. Rather, they can be classified as groups of FTs, which should be detailed in the course of further design of the ASOC SSW. Nevertheless, our result allows us to significantly structure and streamline the software design and development process. Based on it, it is advisable to develop technical specifications (private technical specifications) for contractors participating in the project to create ASOC.

Our method combines methods of categorical analysis and conceptual design of automated control systems. Conceptual design of an automated control system provides a constructive (conceptual) diagram of information and a template of procedures for its transformation, and categorical analysis is a way to fill out (interpret) this diagram. This streamlines the designer's reasoning process while simultaneously creating a multidimensional analysis space. Moreover, often, some of the managerial aspects formed and analyzed later are not obvious from the beginning. For example, such aspects as: «Implementation – Goal – Basis» and «Implementation – Goal – Superstructure» (Table 1) reflect the fact that information coming from the field must not only be correlated with the level of implementation of planned activities but also transform into cognitive structures of pursued goals. Often, when designing software for ASOC, this aspect is forgotten. Therefore, information models displayed on automation tools are replete with many tables and diagrams that are difficult to perceive in the context of achieving previously set goals. In the future, when operating the ASOC, under pressure from users (managers at different levels), it is necessary to modify the software to ensure a figurative representation of information in accordance with the cognitive management model of a particular manager. This cannot always be successfully accomplished due to the incompleteness of the conceptual database model. It is impossible to establish the necessary connections and take into account additional data without a deep rework of the entire software. It can be easier to start a new project than to modernize an old one. Therefore, the initial consideration of such aspects of management will allow us to design a conceptual structure of data and procedures that will provide the ability to increase the level of automation in the required completeness of management functions.

In the practical field, it is advisable to use the method when:

– conceptual design of large ASOC (sectors of the economy, military domain, individual organizations (enterprises));

– organization of research and development systems;

– development of technical specifications (private technical specifications) for organizations (enterprises) participating in the project to create ASOC.

The scope of application of the method covers problems of structuring problems with insufficient initial information about the object of study. The method forms the scheme (outline and aspects) of the researcher's reasoning but does not replace the researcher when interpreting (filling out) the structural scheme.

Further research into the development of the method is planned to be carried out in relation to the formation of lists of FTs for automated control systems: development of weapons and military equipment; capital construction, and use of the Ukrainian Armed Forces.

It seems appropriate to advance the method in terms of taking into account the features of organizational control mechanisms (full or incomplete information, management based on self-organization).

7. Conclusions

1. Based on the results of a categorical analysis of the personnel training management system for the Ministry of Defense, 8 management aspects were obtained for the strategic level and 24 aspects each for the operational and tactical levels of the management hierarchy. The formation of aspects was carried out on the basis of a formalized procedure for combining the categories of three categorical pairs, taking into account the characteristics of the specific training. This made it possible to ensure the completeness of the conceptual project of ASOC within the framework of the initially established categorical pairs.

2. The generated lists of FTs for ASOC SSW contain 79, 204, and 195 tasks for the strategic, operational, and tactical levels of the control system, respectively. In terms of their content, these lists of FTs represent a concept for automating the process of managing personnel training for the Ministry of Defense of Ukraine. A significant part of the formulated FTs would not be obvious initially if the concept of ASOC was developed without using the proposed method.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

The manuscript has associated data in the data repository.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Yang, Y., Liu, B., Wang, J., Chen, Y., Ren, Y. (2023). An improved multi-objective brainstorming algorithm with the application of rapeseed germination characteristics optimization. Computers and Electronics in Agriculture, 209, 107865. https://doi.org/10.1016/j.compag.2023.107865
2. Späker, L., Mark, B. G., Rauch, E. (2021). Development of a Morphological Box to Describe Worker Assistance Systems in Manufacturing. Procedia Manufacturing, 55, 168–175. https://doi.org/10.1016/j.promfg.2021.10.024
3. Gordon, W. (1961). Synectics: The Development of Creative Capacity. Harper & Brothers, 180.
4. Altshuller, G. S. (1984). Creativity as an Exact Science. Gordon and CRC Press, 320. https://doi.org/10.1201/9781466593442
5. Savransky, S. D. (2000). Engineering of Creativity. CRC Press. https://doi.org/10.1201/9781420038958
6. Cho, H., Park, J. (2019). Cost-effective concept development using functional modeling guidelines. Robotics and Computer-Integrated Manufacturing, 55, 234–249. https://doi.org/10.1016/j.rcim.2018.01.007
7. Bai, Z., Mu, L., Lin, H.-C. (2020). Green Product Design Based on the BioTRIZ Multi-Contradiction Resolution Method. Sustainability, 12 (10), 4276. https://doi.org/10.3390/su12104276
8. Guo, X., Liu, Y., Zhao, W., Wang, J., Chen, L. (2021). Supporting resilient conceptual design using functional decomposition and conflict resolution. Advanced Engineering Informatics, 48, 101262. https://doi.org/10.1016/j.aei.2021.101262
9. Chen, W., Wu, Z., Jie, W., Ling, C., Xin, G., Kai, Z. (2016). Strategy of Innovative Design Based on Requirements and Conflicts Solving. J. Sichuan Univ., 4, 168–174.
10. Yang, W., Cao, G., Peng, Q., Sun, Y. (2021). Effective radical innovations using integrated QFD and TRIZ. Computers & Industrial Engineering, 162, 107716. https://doi.org/10.1016/j.cie.2021.107716
11. Goldenberg, J., Mazursky, D. (2002). Creativity in Product Innovation. Cambridge University Press. https://doi.org/10.1017/cbo9780511674464
12. Nikanorov, S. P., Vybornov, S. V., Ivanov, A. Yu., Korshikov, S. E., Kostyuk, A. V., Kuchkarov, Z. A. et al. (2006). Safety research. Moscow.
13. Bourbaki, N. (1956). Eléments de Mathématique. XX. Première partie. Les structures fondamentales de l'Analyse. Livre I Théorie des Ensembles. Hermann et Cie, 118.
14. Nikanorov, S. P., Nikitina, N. K., Teslinov, A. G. (2007). Introduction to conceptual design of automated control systems: analysis and synthesis of structures. Moscow.
15. Gvardeytsev, M. I., Kuznecov, P. G., Rozenberg, V. Ya. (1996). Mathematical support for control. Measures for the development of society. Moscow.
16. Enaleev, A., Novikov, D. (2021). Sustainable Control of Active Systems: Decentralization and Incentive Compatibility. IFAC-PapersOnLine, 54 (13), 13–18. https://doi.org/10.1016/j.ifacol.2021.10.410
17. Dodonov, O. G., Nikiforov, O. V., Putiatin, V. G. (2019). Trends and problems of the development of automation military forces control. Mathematical Machines and Systems, 3, 3–16. https://doi.org/10.34121/1028-9763-2019-3-3-16
18. Nikiforov, A., Kliushnikov, I. (2021). Applying the Method of Categorical Analysis for Conceptual Design of an Automated Control System of a Group of Unmanned Aerial Vehicles. Journal of Physics: Conference Series, 1828 (1), 012069. https://doi.org/10.1088/1742-6596/1828/1/012069