Dynamic Reconfiguration in Automated Organizational Management Systems

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Abstract. The peculiarities of construction, characteristics and requirements to the quality of modern automated organizational management systems (OMS) functioning are considered in the paper. The unpredictability of the operating environment, the complexity and ambiguity of the processes at the management objects, and potential threat of loss of control raise the issue of ensuring the management continuity and achieving the goal of the OMS. It is shown that it is expedient to use the method of dynamic structural-functional reconfiguration of the OMS, for workable management structure of automated workstations of managers and staff (AWM) formation, operational redistribution of management functions and necessary resources between workstations to achieve the required efficiency of the OMS in general for facility management, especially in conditions of functional failures, loss of resources, disruption of connectivity, occurrence of undesirable situations or destructive influences. A generalized set-theoretic model of OMS reconfiguration is presented in the form of a mathematical choice problem with advantages, where restrictions on the choice of alternatives depend on the importance of performed functional tasks and functional load of AWM officials and OMS staff, level of authority, availability of data on current state of control object, internal and external operating environment, etc. The expediency of creation of a specialized modeling complex for OMS automation for the development of basic system, design and technological solutions, development of management decisions is substantiated. The use of CMC allows us to simulate possible damage to the objects and components of the OMS, to assess the risks of loss of control, to build reconfiguration scenarios and evaluate their effectiveness under different conditions. The criterion for selecting a specific reconfiguration procedure and evaluating its effectiveness is determined. The subsystem of dynamic structural and functional reconfiguration of automated OMS is implemented as a hardware-software complex, which includes modules of monitoring, analysis, localization, selection and decision making, decision implementation, database and knowledge, and illustrates its work in real OMS.

Keywords: dynamic reconfiguration, automated organizational management system, computer modeling complex.

1 Introduction

Automated organizational management systems (OMS) are complex systems for collecting, analyzing and processing information about the object of management, its internal environment and interaction with the external environment [1], which have a social component, the elements of which are active subsystems with their own local goals, own idea of the environment and management model. OMS for their intendant purpose must adequately determine the required level of security of control objects, ensure the manageability of facilities and achieve the goal defined in the OMS.

Making sound management decisions today requires the processing of large amounts of data, which are often poorly structured or unstructured at all, obtained from different sources, from different sensors, controllers, etc. Thus, in 2019, more than 50% of companies worldwide faced the need to analyze large amounts of data (data flows), although in 2015 there were only 17% of such companies [2].

Dynamics and unpredictability of the operating environment, complexity and ambiguity of processes that take place at control objects, increasing risks of not achieving the desired result, multifactoriality lead to ambiguity of information understanding by decision makers, in the absence of reliable knowledge of the dynamics of the situation. So, it requires the incorporation into the practice of object management of model-algorithmic methods and approaches to ensure the required level of functioning efficiency of the control object and the OMS itself. Functional failures, which can occur in the automated OMS itself, sometimes threaten not only the transition the control object to a dangerous state, but also a violation of the security of some critical infrastructure.

System reconfiguration is, in the general case, the process of changing the structure, parameters, functioning technologies to restore the required level of performance and efficiency of the system or to ensure a minimum reduction of these indicators in conditions of the system functional degradation. Practice shows that the technology of reconfiguration among the means of increasing the complex systems functional stability is one of the paramount places. The organization of reconfiguration in systems of different purposes is considered in works [3-5]. The main difficulty is the need to determine when to apply the reconfiguration procedure, rules and algorithms for redistribution of existing resources and the formation of new structural relationships, maintaining continuity of management and achieving a defined purpose.

2 Reconfiguration in organizational management systems: purpose, tasks, modeling

OMS automation provides automation of functional problems solving at different levels of management, the presence of a set of mathematical methods, models, algorithms, software and hardware and special software modules that implement functional subsystems, task sets, functional tasks and automated workstations (AWM) OMS for officials and staff. Automated OMS is characterized by the following features:

• the presence of functional subsystems of different nature, complexity and purpose, which reproduce the management processes of the units of the object and provide, interacting with each other, the management of the object as a whole;

• the presence of intensive flows of information, diverse and heterogeneous in composition, purpose, method of coding, etc.;

• a wide range of changes in the states of the object of control and a high dynamics of change of these states;

• high level of automation of tasks solved in the process of functioning;

• simultaneous solution of various functional complexes of interconnected tasks;

• real-time operation.

The impossibility of performing complexes of functional tasks on the workstation of officials at all levels of management and violation of the object control process generally can lead to:

• inoperability of workstations or loss of connections between them due to their physical destruction or violation of data integrity, absence of an official;

• deterioration of technical characteristics of the computer system (speed, productivity, bandwidth, etc.);

• distortion of algorithms of functioning;

• reduction of structural redundancy, stock of resources;

• deterioration of the functioning of the elements and controllability of the automated OMS;

• fatal disability of elements or the system as a whole.

The general condition of the control system is measured by parameters and is determined by indicators that characterize: the availability and operation of software and hardware resources of the system; availability and functioning of officials-users of the workstation and their ability to perform their tasks; compliance of the current process of solving functional management problems with a given plan; compliance with the planned time indicators for solving functional management tasks; the obtained results (in comparison with normative or limit values); external and internal environment of the system.

Development and implementation of automated OMS is a complex iterative process, for the implementation of which it is advisable to use computer modeling complex (CMC), where to deploy tools to solve problems of development, research and configuration of automated workstations of OMS officials and personnel, working out the elements of control automation, carrying out officials and personnel tuition and training. CMC tools should allow to develop basic system, design, technical and technological solutions, to test design solutions, program and information software. To provide an opportunity to study the factors influencing the OMS both externally and internally, to model changes in the functioning of the OMS and the control object, to develop means to prevent their transition to undesirable states, worked out failure compensation procedures, reconfiguration (flexible redistribution in the OMS of tasks and functions performed between working or partially working workstations, available resources and tools).

The CMC can use a variety of systems and tools for modeling, simulation of management processes, regulations of interaction, to systematically organize formalized mappings of the processes of the object of management, to develop specialized tools for training and coaching staff and officials. The flexible and extensible modeling environment in CMC allows to model management functions as close as possible to the existing practice of decision-making and implementation in a specific subject area.

The architecture of CMC depends on the chosen model of the subject area, models of systems and processes that are involved in the implementation of specific management tasks. Each OMS function performed during the implementation of a certain management process is modelled on the CMC as a separate functional task. The input data for a process can be either the initial management influence or the output or intermediate data of another management process. Execution of the management process involves:

• preparation and development of decisions on streamlining the actions required to perform a functional task, in a sequence of operations implemented within the relevant technology;

• determining which people (employees), at what time, what technological processes (operations) perform in order to obtain a common desired end result (to achieve the system-wide goal of the OMS).

The implementation of the technological process requires the presence in the automated OMS not only specialists with the appropriate level of qualification, but also technical means, methods and instructions for their application, software, hardware, information and other support necessary and sufficient to perform a set of tasks in a particular subject area . The functional structure of the CMC, as a rule, is a projection of the management structure that governs the implementation of a particular business process, with a preserved hierarchy (subordination), a system of interactions and regulations. The OMS model is an orderly set of management processes with the coordination of the necessary forms of documents and database structures (information support), which requires documentation in a specific subject area.

Automated managers' workstations (AWMs) act as functional components in the automated OMS. Each workstation is a subsystem, the structure of which is determined by its functional purpose. The workstation specializes in the installation of appropriate software and communication between the components of the system. The modular principle of software development allows to easily form the necessary configuration of the workstation, as a subsystem of the OMS, to perform certain management functions. The functionality of the workstation can be extended if necessary by connecting new software modules. This creates a flexible scalable environment for the implementation of management functions.

The introduction of dynamic reconfiguration technology in automated OMS should be preceded by an assessment of the feasibility of this based on the analysis of resource costs and changes in the indicators of functional stability of the automated OMS. The main thing is to ensure the continuity of the management process, which is implemented by performing a set of tasks $\Phi = (\phi_1, \phi_2, ..., \phi_n)$ on the workstation of officials-users of the workstation in the current operating conditions.

For the rational redistribution of functions between the operational components of the automated OMS, it is necessary to take into account the current characteristics of the tasks and functions performed at the facilities, analyze and assess the current state of the infrastructure of the workstation interaction; to carry out operational calculations, assessment and analysis of information and technical capabilities of the OMS. Reconfiguration in the OMS is not only a technological solution to compensate for failures, but also a management process to ensure the prompt redistribution of management functions and necessary resources between the workstations of officials to achieve the required efficiency of the OMS as a whole.

The development and implementation of dynamic reconfiguration technology in the automated OMS involves the formulation and solution using the tools of the CMC of the following tasks:

• modeling possible situations of management objects and components of the OMS damage to identify those whose impact is most significant for management processes;

• assessment of the feasibility of using one of the three possible strategies to reduce the values of risks for the management of the object, namely:

- reducing the probability of an adverse event,
- reduction of losses that will occur in the case of an adverse event,
- simultaneous reduction of the probability of occurrence and magnitude of losses from the adverse event;

• construction and modeling of dynamic reconfiguration scenarios of the OMS in the event of an undesirable situation at the control object or the presence of various destructive influences that may lead to violations in the functioning of the control facility;

• development and testing of the dynamic reconfiguration technology of the automated OMS in the cases of dynamic change of a control object state;

• simulation of the implementation of different OMS reconfiguration scenarios for training and coaching of personnel and officials.

The basis for the construction of a computer model of structural-functional re-configuration can be a generalized set-theoretic model of reconfiguration of a complex system, proposed in [6], in the form of a mathematical structure of choice:

$$\left\langle Q(s,w), \Delta, \left\{ \mathrm{r}_i^{\alpha}(w) \right\}_{i\in\Gamma}, \left\{ \mathrm{r}_j^{\beta}(w) \right\}_{j\in\Gamma_1}, \left\{ \mathrm{F}^{k}(w) \right\}_{k\in\Gamma_2}, \Omega = \left\{ w \right\} \right\rangle,$$

where $Q(s,w)$ - some initial structure of the type s, which determines the type of model (static, dynamic, mathematical, logical-algebraic, deterministic, with uncertainty, etc.);

Δ - many alternatives (plans, methods) of structural and functional reconfiguration, among which there is a choice;

$\left\{ \mathrm{r}_i^{\alpha}(w) \right\}_{i\in\Gamma}$ - a set α of relationships that limit the choice, which are introduced directly in the formulation of selection problems and reflect the main spatio-temporal, technical and technological constraints associated with the operation of a complex system;

$\left\{ \mathrm{r}_j^{\beta}(w) \right\}_{j\in\Gamma_1}$ - a set β of relations of preferences, set on $\Delta\times\Omega$ and characterize the various advantages when choosing a rational solution;

$\left\{ \mathrm{F}^k(w) \right\}_{k \in \Gamma_2}$ - a set of conciliatory rules that allow to determine the resulting relationship of the advantage of the problem of structural and functional reconfiguration of the system;

$\Omega = \{ w \}$ - a set of events (set of uncertainties).

This model provides ample opportunities for various tasks of reconfiguration of a complex system. The corresponding organizational structure, technological (functional) structure of the automated OMS, structure of software-mathematical and information support, technical structure, etc. can act as initial structure $Q(s, w)$ at modeling of reconfiguration of the automated OMS. Restrictions on the choice of alternatives will depend on the importance of the functional tasks performed and the functional load of the workstation of officials and staff of the OMS, the level of authority, availability of data on the current state of the facility, internal and external environment, etc. It is desirable to introduce information into the problem statement, which would allow to remove the criterion and model uncertainty and reduce the problem with uncertain factors to its deterministic variant [6].

Modeling of dynamic reconfiguration of the automated OMS on CMC allows to work out not only the processes realized on the basis of functional redundancy [7] or construction of fault-tolerant schedules of performance of tasks for set of working states of system, but also those considering structural and functional distribution of system and allow you to use real and virtual resources to perform management functions.

3 Criteria for selecting the reconfiguration procedure

Reconfiguration in automated OMS is initiated to preserve the functionality of the system, ensuring its implementation of a set of functions that achieves the goal of operation - continuity of management of the object with a given quality, in conditions of accumulation of system components damages and loss of resources.

Assume that in the absence of failures in the automated OMS, a set of tasks $\Phi = (\phi_1, \phi_2, \dots, \phi_n)$ is performed on the workstations of officials-users of the workstations. The set of tasks is performed with a given quality and the required efficiency. Let us denote the set of critical management tasks, non-fulfillment of which will cause undesirable changes in the state of the object of management, through $\phi^S \subset \phi$, $\phi^S = (\phi_1^s, \phi_2^s, \dots, \phi_r^s)$. Performing tasks that are a set of management tasks independent or information-related, from the set ϕ^S, requires the availability of OMS resources to perform functions $F = \bigcup_{i \in I} F_i = \{ f_1, f_2, \dots, f_l \}$.

Assume that the workstation Φ_k, after installing the appropriate software and setting up the necessary connections, can potentially perform some subset of management tasks $\varphi_н : \{1, 2, \ldots, p\} \to P(F)$, where $P(F)$ is the set of all subsets F .

If $\varphi_н(k) = \{f_{i_1}, f_{i_2}, \ldots, f_{i_j}\}$, $1 \le i_r \le n$, then the functional component of the OMS workstation Φ_k can perform functions $f_{i_1}, f_{i_2}, \ldots, f_{i_j}$. The functionality of the workstation can be changed if necessary, connecting other software modules or changing the connection structures, i.e. by performing a reconfiguration procedure in the OMS.

At each specific point in time, a specific OMS workstation Φ_k performs its assigned management task, i.e. implements a number of management tasks $\varphi_{men} : \{1, 2, \ldots, p\} \to P(F)$. On the workstation Φ_k it is possible to perform functions $f_1, f_2, \ldots, f_n$, if $\varphi_{men}(k) = \{f_{i_1}, f_{i_2}, ..., f_{i_j}\}$, $1 \le i_r \le n$. If $\varphi_{men}(k) = \varnothing$, the OMS workstation Φ_k does not perform any task from the set of critical management tasks.

Assuming that each function $f_i \in F$ is characterized by some performance efficiency c_i, we can determine the configuration efficiency function of the automated OMS in relation to the performance of a set of critical management tasks ϕ^S [8]: $\psi_{еф} : F \times \{1, 2, ..., p\} \times P(F) \to C$, where C is a certain numerical set.

The expression $\psi_{еф}(f_i, k, \varphi_{men}(k)) = c_{i_k}$ means that if the configuration of the OMS workstation Φ_k is focused on the implementation of management tasks $\varphi_{men}(k) = \{f_{i_1}, f_{i_2}, ..., f_{i_j}\}$, the efficiency of execution $f_i \in \{f_{i_1}, f_{i_2}, ..., f_{i_j}\}$ is equal c_{i_k}. c_{i_k} should not be less than some specified value (depending on the subject area).

The reconfiguration procedure in the OMS should be considered effective if the OMS performs all management tasks, i.e. the following conditions are met:

$$\bigcup_{k=1}^{p} \varphi_н(k) \supseteq F, \quad (1)$$

$$\varphi_{men}(k) \subseteq \varphi_н(k), \quad \forall k = \overline{1, p} \quad (2)$$

$$\sum_{k=1}^{p} \psi_{еф}(f_i, k, \psi_{men}(k)) \ge c_i, \quad \forall i = \overline{1, n}, \quad (3)$$

In case of functional failure (impossibility to perform the workstation Φ_k at least one of the functions $f_i \in F$ required to solve the tasks that make up the management task), the corresponding function φ_{men} of the workstation Φ_k changes. Violation of condition (2) is possible only in case of control errors. If the narrowing of the functionality Φ_k and the implementation of the reconfiguration procedure leads to a violation of conditions (1) - (3), the efficiency of the OMS is likely to decrease. In reconfiguration procedures, it is advisable to use the minimum number of workstations, thereby minimizing the number of changes φ_{men}. The number of changes φ_{men} should be chosen as the criterion for choosing the reconfiguration procedure.

4 Example of dynamic reconfiguration implementation

The subsystem of dynamic structural and functional reconfiguration of the automated OMS is implemented as a hardware-software complex, which includes the following main components: monitoring module, analysis module, localization module, selection and decision-making module, decision implementation module, database and knowledge base (DKB).

The hardware-software complex works in automatic mode, without human intervention. There is a continuous process of monitoring the state of the control system and its elements according to the specified indicators. If deviations from the specified normal operating mode are detected, which can lead or have led to non-normal situations, the dynamic reconfiguration subsystem is activated. In the conditions of functional failures there is a search, finding and realization of a rational variant of available resources of OMS using to support the continuous object management and performance of available administrative tasks.

Consider the purpose and functions of the components of the subsystem of structural and functional reconfiguration.

1. The *monitoring module* is a software component designed to collect data on the OMS workstation status. Data collection is in accordance with the list of monitoring indicators. The obtained data are recorded, indicating the exact time of their receipt, in the appropriate tables of specialized DKB. The main functions of the monitoring module: definition of monitoring indicators, setting their normative and limit values; monitoring of the OMS workstation set indicators; formation of a specialized DKB for storage of time series of monitoring indicators.

2. The *analysis module* is a software component designed to detect deviations in the operation of the OMS workstation. The analysis module uses the values of selected indicators obtained at the monitoring stage and stored in a specialized database. Detection of indicators deviations allows to reveal workstations which are potentially dangerous for stable functioning of OMS, and also to estimate their influence on other workstations functioning. A list of these workstations is built, which is sent for processing to the localization module.

The main functions of the analysis module: detection of deviations of indicators; criticality analysis of indicator deviations; formation of the list of OMS workstations on which deviations appeared; formation of a list of connections between the OMS workstations on which deviations appeared; forecasting the impact of detected deviations on the other workstations functioning; formation of alarms.

The indicators values obtained at the monitoring stage are constantly checked for compliance with the limits set for each indicator. An example is the load indicator of the CPU of the workstation, for which a limit of 30% is set. If the set limit is exceeded, the analysis module activates an alarm signal, which generates a corresponding message about exceeding the limit of the indicator.

The results of the analysis module will be:

- *in the absence of a threat and the results of its manifestation* - the normal functioning of the workstation OMS;

- *in case of threat and results of its manifestation* - indication of its presence and formation of the list of workstations on which realization of this threat is possible, and also the forecast of threat influence on other OMS workstations.

Thus, the analysis module on the basis of monitoring data diagnoses the state of the system, determines the criticality of the detected deviations and produces a command to further work out the situation. The results are recorded in the DKB.

3. The *localization module* is a software component that is designed to further work out the situation, in case of receiving a command from the analysis module to localize workstations where critical deviations are detected.

Detected at the stage of analysis OMS workstations, vulnerable to adverse effects, require immediate localization. Localization means actions against the spread and implementation of a threat to the operation of the OMS, so the main task at the stage of localization is to perform actions that will exclude workstations that are under undesirable influence from the working configuration of the OMS in the shortest possible time.

For the subsystem of dynamic structural and functional reconfiguration, only those actions are considered that can be performed automatically by software. Actions to physically disconnect an element, for example by de-energizing it or physically disconnecting it, are not considered.

The main functions of the localization module: calculation of the localization area; choice of localization methods; localization of workstations on which critical deviations in functioning were shown; formation of the list of officials-users of the workstation who need to be informed about the results of localization; formation and sending notifications to officials-users of the workstation about the results of localization; formation of the list of OMS workstations which can be used for development of the further decision (working workstations).

First of all, at the localization stage, an attempt is made to localize the workstation, for example, to try to turn off the computer remotely by software. If this attempt is successful, the localization function ends. In the event of a failed localization attempt, an attempt is made to localize the connection, or several connections associated with this workstation. If the connection attempt is successfully completed, the localization function ends.

After the localization of workstations vulnerable to undesirable effects is completed, a list of workstations is formed from the rest that can potentially be used for reconfiguration - redistribution of functional tasks (FT). The list formed at this stage will be used at the stage of selection and decision-making.

Localization of workstations vulnerable to adverse effects leads to the stabilization of the entire OMS and stops the further spread of adverse effects. However, this stage does not return the system to normal operation.

4. The *selection and decision-making module* is a software component designed to form a decision on the application of the reconfiguration procedure to restore the management process and solve functional problems on the OMS workstation.

The main functions of the selection and decision-making module: definition of FT for redistribution; determination of restrictions for each of the FT which are is the subject to redistribution; determination of the list of workstations and their properties for FT redistribution; solution of the problem of FT redistribution taking into account certain restrictions.

First of all, the selection and decision-making module of prepares a list of FT, which were performed at the time of localization on the workstations, vulnerable to undesirable effects, as well as tasks to be performed by these workstations in the future. As a result of information collection, two groups of FT are formed: the first - tasks that were interrupted during localization and which did not end in normal mode, the second - tasks that must be performed after the interrupted tasks according to the requirements of the process.

For each of the tasks from these two lists you need to build constraints that formalize the properties and requirements of the FT. In particular, the priorities of the FT are determined; restrictions are placed on the qualifications and access rights of officials who are allowed to comply with these FT; the physical and territorial location of the potential executor of the FT is determined, etc.

The second block of input information for solving the FT redistribution problem is the OMS workstation list of elements, which are currently active and on which potentially can be executed FT from the earlier built list. This list is formed on the basis of the list of elements constructed at the last step of the localization module work. Naturally, the list of workstations for the FT redistribution may be smaller than the list of workstations generated by the localization module.

The next step for each workstation from the last list is to form a list of properties: performance, bandwidth, current load, scheduled load, and so on. The prepared information about the FT, the FT restrictions, the list of workstations and their properties are the input information for solving the reconfiguration problem - the FT redistribution problem. The result is a set of solutions consisting of pairs "workstation - set of FT". From the set of decisions that are ranked according to certain criteria, the one with the highest rank is chosen. The obtained results are recorded in DKB.

5. The *implementation module* is a software component designed to implement the decision made in the previous stage. Functions of the solution implementation module: solution implementation; formation of a list of officials who need to be informed about the results of the FT redistribution; formation and distribution of reports to officials on the results of the FT redistribution.

The implementation module launches the FT, which were accidentally completed as a result of the localization process, on certain workstations, makes the necessary changes in the sequence structure for performing the complex of tasks and makes these changes to the task manager, which monitors the sequence of their execution. Because some low-priority tasks can be excluded from further execution, this leads to a change in the structure of relationships between tasks. Next, a list of officials-users of the workstation, which were assigned new FT, is formed, the formation of the relevant message texts and sending messages through the sub-system of messages OMS is done.

6. *Database and knowledge base* - is a specialized DKB, designed to store data and knowledge necessary for the subsystem of dynamic structural and functional reconfiguration functioning: a list of indicators and their parameters (limit and normative values); time series of values of indicators obtained as a result of monitoring; list of workstations to be localized; methods and mechanisms of localization of workstations that have failed. The need to use a specialized database and knowledge base is determined by the fact that the amount of information received for storage per unit time is determined by the number of indicators that are monitored, as well as the frequency of information. For such purposes, the industrial relational database can not be used because it is not designed to solve problems involving large amounts of data.

Figure 1 shows the result of the application of the dynamic structural-functional reconfiguration procedure in case of one of the OMS workstations (N.6) failure.

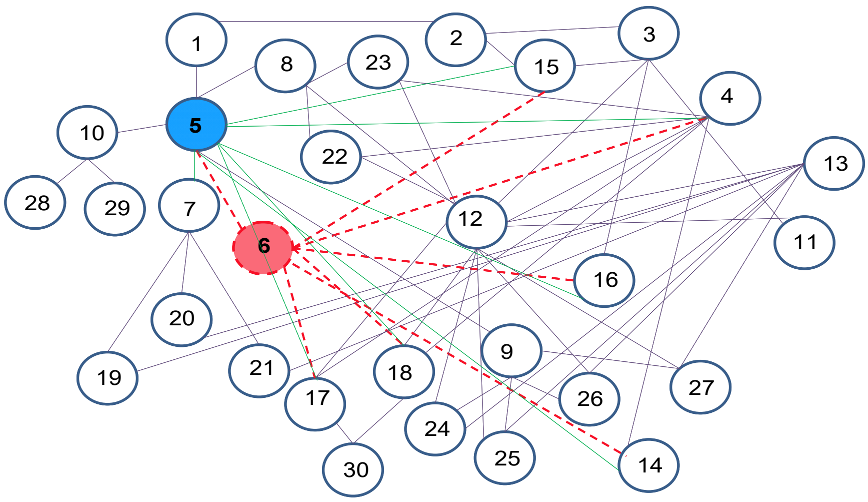

Fig. 1. Structural-functional reconfiguration in OMS

The subsystem of dynamic structural-functional reconfiguration of the OMS in the automatic mode invented and implemented a new configuration, while the functional tasks and information connections of the workstation N.6 were accordingly automatically redistributed and directed to the workstation N.5.

5 Conclusion

Practical experience of automated OMS support shows that the introduction of the dynamic reconfiguration procedure allows to increase the functional stability of the OMS and, accordingly, the quality of management.

Adjustment and testing of dynamic reconfiguration of officials and staff workstations should be carried out at a specialized CMC, where you can simulate the management task inherent in a certain professional field, the occurrence of deviations in the management process, localization of management violations, activation and implementation of reconfiguration. In the environment of CMC it is possible to carry out a choice and approbation of practically suitable procedures of OMS dynamic reconfiguration with clarity of results and taking into account the existing system of subordination and interaction in OMS. It becomes possible to construct a sequence of reconfiguration procedures that can be used in the case of time-critical.

When working out the processes of performing functional tasks and interaction between officials-users of AWP, it is possible to move from intuitive assessments to quantitative ones, formalize the experience of experts, which objectifies management decisions and will improve their quality. In the future, the modeling complex can become an analytical resource of the OMS, its tools can be used to develop strategic management decisions and justify current management decisions.

The analytical resource developed during the development of the OMS workstation, formalized methods of maintaining the safety of critical infrastructures will increase the efficiency and validity of management decisions, clarity of management results even in the system of subordination and interaction changes in the OMS caused by undesirable changes in critical infrastructure functioning.

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