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The approaches to developing the distributed information-control systems of organizational type

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Abstract. The article contains the results of research aimed at developing a scientific and methodological framework for justifying solutions for the development of distributed information-control systems of an organizational type. The structuring of the initial data is made, a formalized statement of the problem of justifying solutions for the development of distributed information-control systems of the organizational type is proposed. To solve this problem, a scientific-methodical approach is proposed, which includes methods for assessing the effectiveness of the solution and the individual indicators.

1 Statement of the problem

The management decisions in government departments, state corporations, integrated structures and enterprises of industry are implemented in the information processing and management systems specially created in the relevant other organizations. One of the main ways to improve the efficiency of the use of such systems is the integrated automation of information processing and management processes implemented in the process of creating (developing) the corresponding distributed information-control systems of the organizational type (DICS).

DICS are distributed automated information processing and management system created to automate the activities of the management bodies of the relevant ministries, agencies, agencies and other organizations in order to improve the effectiveness of the application of managed bodies (facilities). DICS, as a rule, is a multi-level system consisting of a set of functional subsystems (FS), each of which implements a number of interrelated functional processes (FP). In this case, individual FS are realized by performing complex functional tasks (FT), solved in the system at various levels of management.

The urgency of the tasks of creating, developing and modernizing complex information-control systems, some approaches and methods for their solution are given in the works [1-6].

The essence of the choice of solutions for the development of the DICS [1, 2] is that for each planned stage of forecasting (PS) system-based solutions for control centers (CC) automation should be selected by equipping the op amp with serial (equipment is possible at the current time) automation complexes (AC) or by developed AC (equipment is possible in the future after the end of the corresponding development work), taking into account the permissible (designated) resource of the use of AC within the DICS. At the same time, in the process of choosing the option for the development of the AC, the requirements for the integrated inter-level automation of the individual CC must also be taken into account, that is, the choice for the implementation in certain CC of such FT that constitute the FP under consideration.

As the initial data used to solve the problem under consideration, the following are accepted:

1. The organizational structure of the DICS, described as a set of CC and links of subordination and interaction between them. In this case, each CC can be equipped with no more than one AC of a certain type.
2. Functional structure of the DICS, described as a set of FS. Each of the FS consists of a set of FP, the constituent parts of which are FT.

Depending on the requirements for the timeliness of the implementation of the FP are divided into real-time FP and non-real-time FP. The main difference between these types of FP is that for real-time FP, there are requirements for probabilistic-temporal (PTC) or time (TC) characteristics of the duration of their performance, and for the non-real-time FP such requirements are not required.

Depending on the importance, which is determined by the degree of influence of the implemented FP on the overall efficiency of the DICS application for its intended purpose, all FP are divided into higher priority FP (FPh) and other FP (FPo).

3. Types of CC, each of them is characterized by a set of FT to be implemented in the AC.
4. Types of AC intended for automation of CC that, depending on the stage of the life cycle of the CC, are divided into operating (at the stage of operation in the CC), serial (at the stage of serial deliveries) and developed (at the stages of performing the relevant research or development works).

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5. The current version of the equipment of the CC by AC, including information on the types of AC, their resource and parameters implemented FT.
6. Requirements for PTC and TC of the FP.
7. Requirements for the design and reliability characteristics of the developed AC.
8. The list, organizational, production and financial characteristics of enterprises that perform works or can participate in the processes of development, production and supply of AC.
9. List of PS including their duration and amount of funding.
10. Initial data on standard project solutions, the application of which is possible in the development of the AC.

Taking into account the given initial data, the formalized statement of the problem of the formation of solutions for the development of the DICS in conditions of resource constraints can be written in the following form.

At each PS, it is necessary to determine the development variant of the DICS based on the choice of system engineering solutions $\mathbf{X}^*(u)$, $\mathbf{Y}^*(u)$, $\mathbf{Z}^*(u)$, which maximize the effectiveness of the implementation of FP $F(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u))$, with mandatory realization of FPh, with given maximum permissible PTC and TC of the FP implementation, with given requirements to information protection, constructive and reliability characteristics of AC ($\mho_{тр}$), with restrictions on the time $T_{\max}(u)$ and cost $C_{\max}(u)$ parameters of the process of development of the DICS:

$\{\mathbf{X}^*(u), \mathbf{Y}^*(u), \mathbf{Z}^*(u)\}=\text{Argmax } F(\mathbf{X}^*(u), \mathbf{Y}^*(u), \mathbf{Z}^*(u))$ (1)

with the constraints:

$\mathbf{\Omega}(\mathbf{X}(u), \mathbf{Y}(u)) \cap \mathbf{\Omega}_{\text{h}} = \mathbf{\Omega}_{\text{h}}$;

$\mathbf{\Omega}'_{\text{rt}} \cup \mathbf{\Omega}''_{\text{rt}} = \mathbf{\Omega}_{\text{rt}}$;

$\mathbf{\Omega}'_{\text{rt}} \cap \mathbf{\Omega}''_{\text{rt}} = \varnothing$;

$\forall\, i,\, i\in \mathbf{\Omega}'_{\text{rt}}$: $P_i(t_i(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \le t^{\max}{}_i) \ge P^{\min}{}_i$;

$\forall\, i,\, i\in \mathbf{\Omega}''_{\text{rt}}$: $\tau_i(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \le \tau^{\max}{}_i$;

$\mho(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \subseteq \mho_{\text{req}}$;

$T(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \le T_{\max}(u)$;

$C(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \le C_{\max}(u)$;

where $u \in \{1, \dots U\}$, U – the number of PS;

$\mathbf{X}(u)$ – decisions on development of AC;

$\mathbf{Y}(u)$ – decisions on AC manufacturing and CC equipment;

$\mathbf{Z}(u)$ – decisions to extend the operation of the AC;

$\mathbf{\Omega}(\mathbf{X}(u), \mathbf{Y}(u))$ – set of realized FP;

$\mathbf{\Omega}_{\text{h}}$ – set of FPh;

$\mathbf{\Omega}_{\text{rt}}$ – set of real-time FP;

$\mathbf{\Omega}'_{\text{rt}}$ – set of real-time FP with the requirements to PTC of the implementation;

$\mathbf{\Omega}''_{\text{rt}}$ – set of real-time FP with the requirements to TC of the implementation;

$P_i(t_i(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u)) \le t^{\max}{}_i)$ – probability of timely execution of i-th FP;

$P^{\min}{}_i$ – required probability of timely execution of i-th FP;

$\tau_i(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u))$ – average execution time of i-th FP;

$\tau^{\max}{}_i$ – the required average execution time of i-th FP;

$\mho(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u))$ – set of implemented requirements for information protection, constructive and reliability characteristics of AC;

$\mho_{\text{req}}$ – a set of requirements for information security, design and reliability characteristics of AC;

$C(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u))$ – cost of implementation of decisions on the development of DICS;

$T(\mathbf{X}(u), \mathbf{Y}(u), \mathbf{Z}(u))$ – duration of DICS development.

2 Scheme of the scientific-methodical approach to the solution of the problem

The general scheme of the scientific and methodological approach to solving the problem of selecting system-technical solutions for the development of the DICS includes the following main blocks:

- input of initial data and constraints;
- formation of decision options;
- evaluation of decisions;
- obtaining the results of solving the problem.

The composition of these blocks and the sequence of their application are shown in figure 1.

3 Methods for solving the problem

The analysis of the algorithmic complexity of the solution of the problem posed showed that it is NP-hard. Moreover, as shown in [2], even with the use of high-performance computing, it is possible to obtain an exact solution of such a problem by the exhaustive search method only for relatively small dimensions of the initial data. The use of other precise methods of discrete optimization also will not allow to achieve appreciable advantages, since in the general case, the number of analyzed variants of the solution can be close to the number of variants of the solution by the exhaustive search method [1, 2, 7].

We estimate the algorithmic complexity of the solution of the problem by the most labor-intensive exact method – the exhaustive search method. To do this, we introduce the following notation:

N – number of CC;

K_n – number of AC for each CC, $n \in \{1, \dots N\}$;

M_n – number of FT for each CC.

Then the total number of options for developing the AC, which must be formed and evaluated in the decision process, will be calculated in accordance with the following expression:

$$Q_1 = \left(\prod_{n=1}^{N} (K_n + 1) 2^{M_n} \right)^U . \tag{2}$$

The total number of options for AC manufacturing and CC equipment will be calculated in accordance with the following expression:

$$Q_2 = \left(\prod_{n=1}^{N} (K_n + 1) \right)^U . \tag{3}$$

The total number of options for extending the operation of the AC will be calculated in accordance with the following expression :

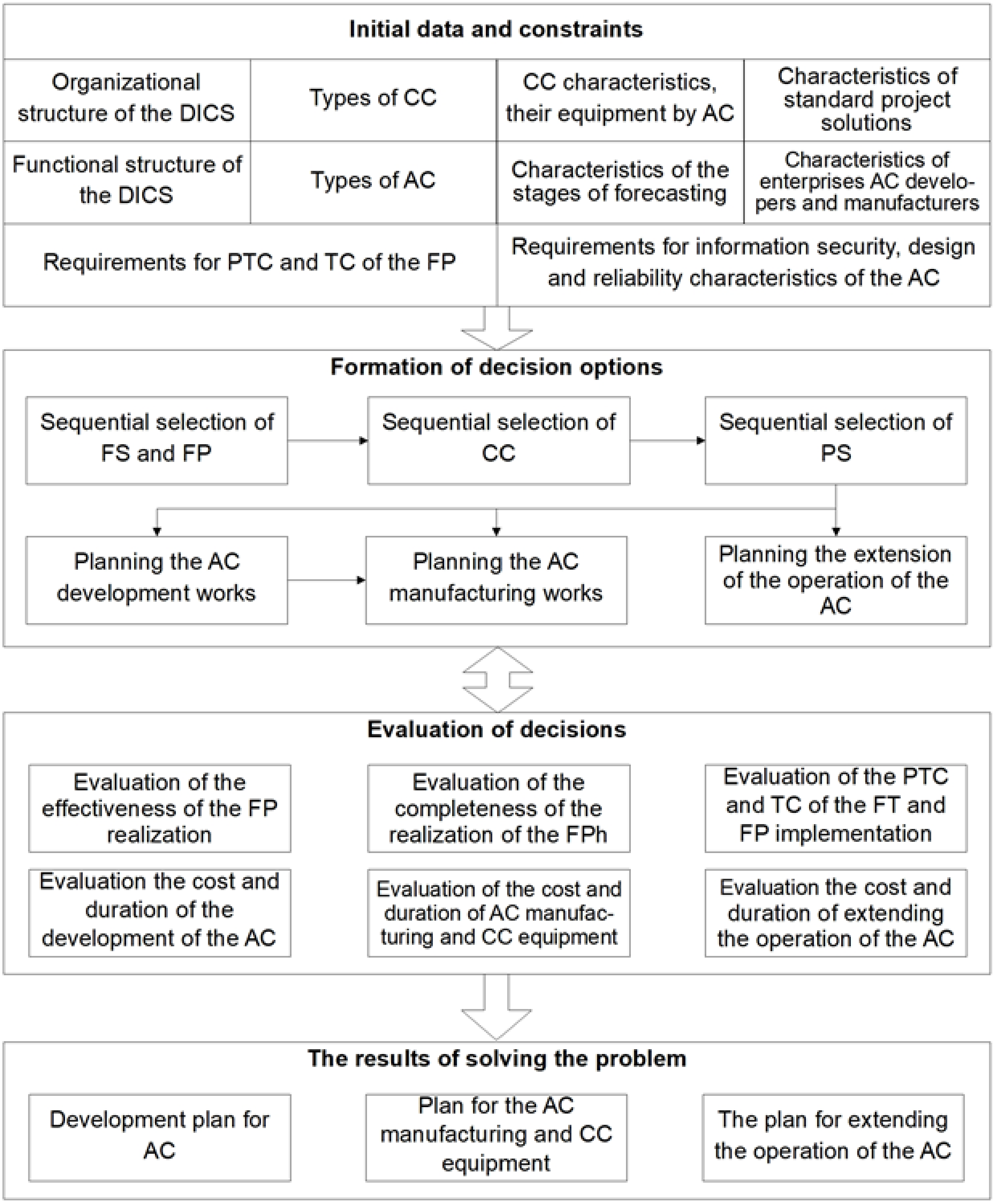

Fig. 1. Scheme of the scientific-methodical approach to solving the problem of choosing system and technical solutions for the development of the DICS

$$Q_3 = 2^{NU}. \quad (4)$$

Accordingly, the total number of solutions to the problem will be equal to:

$$Q = Q_1 \cdot Q_2 \cdot Q_3. \quad (5)$$

To estimate the practical possibility of solving the problem by the exhaustive search method, we set the following values of the initial data:
$U = 5,\ N = 8,\ K_n = 3,\ M_n = 200.$

Then the total number of solutions is equal to $2^{1800} \approx \approx 7.14 \cdot 10^{541}$. This allows us to conclude that it is practically impossible to solve the problem posed by the exact method for given dimensions of the initial data.

In [1, 2], the possibility of solving problems of a similar class on the basis of approximate optimization methods was considered and justified. It was shown that at the initial stage of the DICS design, when the input data for solving the problems of the choice of system-technical solutions for the development of the DICS are determined inaccurately, it is expedient to apply selection methods based on the "greedy" algorithm.

In this regard, to solve this problem, a complex "greedy" algorithm is proposed that consists in choosing the best of the many solutions obtained by particular "greedy" algorithms. Each of the particular "greedy" algorithms is a sequential choice of the solution based on the estimation of the parameters of the objective function and the constraints in the initial problem.

4 Methods to evaluate the effectiveness of the solution and private indicators

As an objective function for the solution of the problem it is expedient to choose a complex indicator [8], reflecting the degree of automation of the required FP, with the necessity to perform a number of FP on a real-time scale. For this we shall use below two particular indicators:

1. The indicator for estimating the realization of the FPh.
2. The indicator of the degree of automation of all FP.

The first indicator can be written as a vector discrete Boolean function that takes the value "1" if all of FPh are realized, "0" otherwise.

The second indicator can be estimated in accordance with [8].

The estimation of the PTC and TC of the FP implementation can be performed using the following types of models:

- analytical models;
- simulation models;
- combined analytical and simulation models;
- metamodels;
- semi-full-scale and full-scale models.

It was shown in [1] that at the initial stages of the design of a AC, the use of analytical and combined models is most expedient.

When obtaining estimates of cost and time indicators in the initial stages of the development of the AC, expert assessment methods, normative-calculating and analog-comparative methods can be applied [9]. The most appropriate is the joint use of these methods. In this case, we assume that the projected AC has a AC-analog, developed and manufactured for one of the CC from the DICS structure, with similar characteristics for the FT being implemented. This condition is usually satisfied in the development practice. At the same time, all estimations of cost and time indicators for the development of a projected AC will be carried out for the enterprise - developer of AC-analog. Recalculation for other enterprises that have differences in basic economic standards for the performance of design work is not difficult.

5 Conclusion

In this paper, we propose an original formulation of the problem of choosing system-technical solutions for the development of a DICS and a new approach to its solution, which consists in evaluating the algorithmic complexity and applying the solution method on the basis of a complex "greedy" selection algorithm. The methodological provisions of the proposed approach can become the main one for the formation of an automated decision support system for the justification of plans and programs for the development of automated systems for various purposes.

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