

Technology of large-scale objects system optimization

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Abstract. The analysis of system factors determining the efficiency of large-scale objects is performed. Structural description and purposes of large-scale objects constructing are formalized. A three-level decomposition scheme for the problem of objects system optimization including the set of tasks for their system design, planning of development, adaptation and reengineering is proposed. The composition and the scheme of relationship on input and output data of the tasks between main stages of large-scale objects system optimization are determined. Based on the decomposition of the problem, its systemological analysis was carried out. This allowed to develop a technology for system optimization of large-scale objects, taking into account the relationship between the whole set of problem-related tasks.

Key words: large-scale objects, structure, design, reengineering, topology, optimization.

INTRODUCTION

With the increase in the scale of systems for services, transports, logistics, telecommunication, monitoring their cost and functional characteristics are increasingly dependent on topology, i.e. spatial organization. Such objects are called territorially distributed or large-scale [1-5]. In the processes of design and management of large-scale objects (LSO) in conjunction with traditional problems of structural synthesis, it is necessary to solve the problems of their topological optimization. The structural, parametric, cost and functional characteristics of LSO are largely determined by the topology of their subsystems and elements. The topology of subsystems and elements, in turn, determines the topology of communication links that provide the functioning of systems as a whole, realizing the exchange of resources, energy, information between elements and systems [6]. The close interrelationship of structural, functional, parametric and topological synthesis problems, which requires their joint solution, leads to a complex problem. For the solution of this problem a corresponding methodology has been developed [1, 6-7]. The review of the current state of LSO system optimization problem shows that existing technologies assume a conditionally independent solutions of structural, topological, parametric and technological optimization problems. This does not allow the full use of the possibilities of formal methods and modern computers to obtain the most effective solutions. To provide the effectiveness and continuity of the decisions making at all stages of the life cycles of LSO, it is necessary to develop a unified

methodology for their system optimization. This methodology is supposed a correct decomposition of the problem into complexes of problems related to different levels of the object description and the stages of its optimization, development of complex of appropriate mathematical models, methods and technologies.

OBJECTIVES

The aim of the study is to increase the effectiveness of procedures for system optimization of large-scale objects by providing the continuity of decisions made at all stages of their life cycles.

To achieve this aim it is necessary:

- to make formalization of system description and the purposes of large-scale objects creating;
- to propose a decomposition scheme for the problem of large-scale objects system optimization, taking into account the main stages of their life cycles;
- to develop a technology for system optimization of large-scale objects, reflecting the relationship of the whole set of problem-related tasks.

FORMALIZATION OF SYSTEM DESCRIPTION AND PURPOSES OF LARGE-SCALE OBJECTS CREATION

Large-scale object, represented in the traditional form $s = \langle E, R \rangle$ (where E – set of elements; R – set of relations between elements E), can be realized by a set of different topologies G^* . Proceeding from this, to each of the object topological realizations $G \in G^*$ will correspond the original set of properties [1-5]:

$$\varphi : (E, R, G) \rightarrow P, \quad (1)$$

where: φ – some mapping.

Representation of the LSO in the form $s = \langle E, R \rangle$ is quite general and can only be considered as its conceptual model at the stage of pre-project studies. When solving problems of structural optimization and control, the description of LSO should reflect its topological properties:

$$s = \langle E, R, G \rangle, \quad G = \langle G_E, G_R, G_A \rangle \quad (2)$$

where: G – topological realization of object structure $\langle E, R \rangle$; G_E – elements topology; G_R – relations topology; G_A – topology, determined by the technology of object functioning.

Based on analysis of object's purposes, at the first stage of structural optimization it is necessary to single out a subset of its most important properties P' . Selected properties P' are subset of properties set that can be obtained on the universal sets of elements E^U , relations R^U and topologies G^U : $P^U = \varphi(E^U, R^U, G^U)$.

The mapping of P' to sets of elements E^U , relations R^U , and topologies G^U implicitly defines subsets of elements E' , relations R' and topologies G' on which a LSO with selected properties P' can be realized. It defines the space of the LSO existence $S' = \{s\}$, which narrows to an acceptable space based on existing constraints $S^* = \{s\}$: $S^* \subseteq S'$, $E^* \subseteq E' \subseteq E^U$, $R^* \subseteq R' \subseteq R^U$, $G^* \subseteq G' \subseteq G^U$.

In subsequent stages, the problem of LSO structural optimization reduces to the selection of such subsets of elements $E^o \subseteq E^*$, relations $R^o \subseteq R^*$ and topologies $G^o \subseteq G^*$ from $S^* = \{s\}$, which provide the most effective achievement of the required properties P' .

The aim of LSO optimization is to maximize its effectiveness. This involves obtaining the maximum ratio of the effect from its functioning Q and the resources that it expends on it. The functional effect is considered as a no decreasing function of the resources that were spent for its achievement $\bar{Q} = F(\bar{C})$ (where \bar{Q} , \bar{C} – are generalized scalar estimates of the effect and resource costs, F – is an operator reflecting resource usage strategy). The functional effect is considered as a no decreasing function of the resources that were spent for its achievement $\bar{Q} = F(\bar{C})$ (where \bar{Q} , \bar{C} – are generalized scalar estimates of the effect and cost of resources, F – is an operator reflecting resource usage strategy).

Taking into consideration given constraints on the effect and cost indicators, the LSO optimization task can be presented in one of the following forms:

$$s_1^o = \arg \max_{s \in S^*} (\bar{Q}(s) - \bar{C}(s)) : \bar{Q}(s) \geq \bar{Q}^*, \bar{C}(s) \leq \bar{C}^*; \quad (3)$$

$$s_2^o = \arg \max_{s \in S^*} (\bar{Q}(s) / \bar{C}(s)) : \bar{Q}(s) \geq \bar{Q}^*, \bar{C}(s) \leq \bar{C}^*, \quad (4)$$

where: \bar{Q}^* , \bar{C}^* – boundary levels for resulted estimations of effect and cost of object S .

Particular cases of problems (3) - (4) are:

– in the conditions of given resources (costs) restrictions, choose the option of LSO constructing that maximizes the effect from its utilization:

$$s_3^o = \arg \max_{s \in S^*} (\bar{Q}(s) : \bar{C}(s) \leq \bar{C}^*); \quad (5)$$

– in the conditions of given restrictions on the effect level, choose the option of LSO constructing that minimizes the resulted costs for its creation and (or) operation:

$$s_4^o = \arg \min_{s \in S^*} (\bar{C}(s) : \bar{Q}(s) \geq \bar{Q}^*). \quad (6)$$

Formalization of CMO creation purposes and tasks of their optimization in the form (3) - (6) is quite general. To obtain practical solutions, their detailing is required. The detailing establishes the connection of the effect Q and cost C indicators with object's structural, parametric, topological and technological characteristics.

DECOMPOSITION OF THE SYSTEM OPTIMIZATION PROBLEM

Large-scale objects, as a rule, consist of a large number of elements with a complex scheme of relationships between them. Creating a single description in the process of their structural optimization is a complex problem. It is weakly structured and consists of a set of incompletely defined problems. Models and methods for these problems solution have not been constructed yet [6, 8].

Let's represent the problem as a meta task MetaTask, which consists of a set of tasks $\{Task_i^l\}$ belonged to different hierarchical levels, with their relationships by input data and decision results (Fig. 1):

$$MetaTask = \{Task^l\}, Task^l = \{Task_i^l\}, l = \overline{1, n_l}, i = \overline{1, n_i},$$

where: n_l – the number of description levels; i_l – the number of tasks at level l .

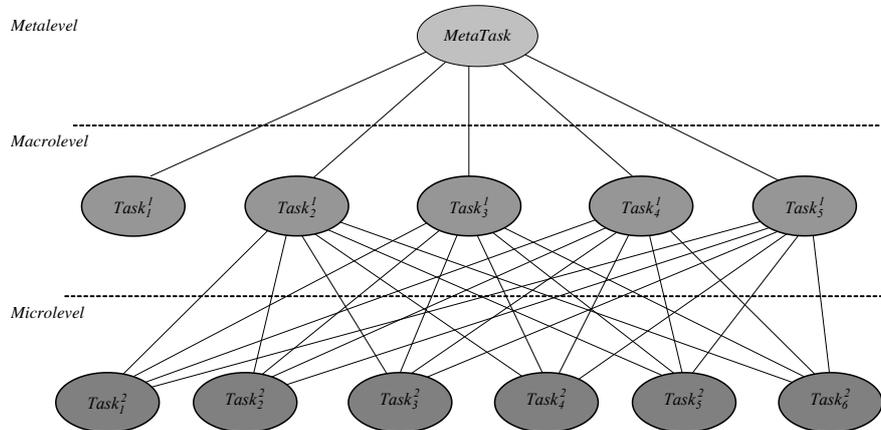


Fig. 1. The decomposition scheme of LSO structural optimization problem

Each of the tasks at this stage will be presented as a data convertor:

$$Task_i^l : In_i^l \rightarrow Out_i^l, \quad l = \overline{1, n_l}, \quad i = \overline{1, n_i}, \quad (7)$$

where: In_i^l, Out_i^l – respectively, the input and output data of the i task at the l level.

At the *metalevel* ($l = 0$), the problem *MetaTask* is considered as a whole. Its place among other optimization problems of the municipal or regional scale is analyzed.

Most of the tasks of *macrolevel* ($l = 1$) are, in their essence, tasks of system optimization. They are diffed by limitations that reflect the specificity of LSO's life cycle stages [8]:

$$Task^1 = \{Task_i^1\}, \quad i = \overline{1, 5}, \quad (8)$$

where: $Task_1^1$ – the formation of requirements for LSO and the development of a technical assignment for its optimization; $Task_2^1$ – system design; $Task_3^1$ – development planning; $Task_4^1$ – adaptation; $Task_5^1$ – reengineering.

In the process of solving the problem $Task_1^1$, the purposes of LSO constructing are determined, the circle of problems solved by LSO is clarified, the properties of the external environment and characteristics of its impact on the object are investigated, and possible principles Π for object constructing are determined.

The task of system design $Task_2^1$ is in determining the best in the sense of the chosen set of efficiency criteria K variant of an object constructing. This task is solved under the conditions of admissible principles of object's construction Π , and specified structural, topological, parametric, and technological constraints, levels of effect Q^* and (or) cost of resources C^* .

The task of LSO development planning $Task_3^1$ is to select for given set of time moments $t_0, t_1, t_2, \dots, t_n$ variants of its construction s_i^o when external conditions change, for example, resources C_i^* or required level of effect Q_i^* . This requires solving a number of system design problems of kind $Task_2^1$ related by input and output data.

The task of LSO adapting $Task_4^1$ is solved in the process of its operation and is associated with the need for relatively insignificant structural, technological, topological or parametric changes of the variant $s^o \in S^*$. The variant s^o can be obtained as a result of solving the problems (3) or (4), due to changes in the required effect levels \tilde{Q}^* and (or) costs \tilde{C}^* .

The task of LSO reengineering $Task_5^1$ is solved in the process of its operation and is associated with the need for fundamental structural, technological, topological or parametric changes. These changes can be related with changes in a set of functional tasks, the improvement of the elements base and (or) technology of the implementation of object functions, making the existing version of its construction s^o ineffective [11, 12]. At the

same time, both modernization and complete replacement of the object's elements E^o and the relations R^o , which realize the interaction between them is allowed.

The complex of *microlevel* tasks ($l = 2$) covers the whole range of LSO system optimization issues arising at the stages of pre-project research, design, creation and operation:

$$Task^2 = \{Task_i^2\}, \quad i = \overline{1, 6}, \quad (9)$$

where: $Task_1^2$ – choice of principles for object constructing; $Task_2^2$ – choice of structure; $Task_3^2$ – definition of elements and relations topology; $Task_4^2$ – choice of operation technology; $Task_5^2$ – definition of elements and relationships parameters; $Task_6^2$ – evaluation of effectiveness and choice of solutions.

The choice of LSO construction principles from the set of permissible $\pi \in \Pi$ in the process of solving the problem $Task_1^1$ is carried out by informal methods on the basis of knowledge and experience of system analysts. The variants set of the system existence domain S' is determined by admissible sets of elements E' , relations R' and topologies G' . Further it narrows down to the set of admissible variants for LSO construction $S^* \subseteq S'$, defined by admissible sets of elements $E^* \subseteq E'$, relations $R^* \subseteq R'$, and topologies $G^* \subseteq G'$.

The task of choosing the system structure $Task_2^2$ is to determine the variant of LSO construction s_{AB} with predetermined operation technology $A \subseteq A^*$, parameters of elements and relations $B \subseteq B^*$, the number of elements $|E|$ and relationships between them $R \subseteq R^*$.

The selection task of the elements and relations topology $Task_3^2$ is to determine for the variant of LSO's construction s_{ERAB} with the given sets of elements $E \subseteq E^*$, relations between them $R \subseteq R^*$, their parameters $B \subseteq B^*$ and the operation technology $A \subseteq A^*$ its territorial location $G \subseteq G^*$.

The task of choosing the functioning technology $Task_4^2$ is to determine for the variant of LSO construction s_{ERGB} with the given sets of elements $E \subseteq E^*$, topologies $G \subseteq G^*$ and parameters $B \subseteq B^*$ its functioning technology $A \subseteq A^*$.

The problem $Task_5^2$ consists in defining for the variant of LSO construction s_{ERGB} with given sets of elements $E \subseteq E^*$, relations between them $R \subseteq R^*$, their topology $G \subseteq G^*$ and the technology of functioning $A \subseteq A^*$ the parameters of elements and relations $B \subseteq B^*$.

The problem of determining the effectiveness of variants and the choice of solutions $Task_6^2$ consists in evaluation of LSO construction options $s \in S^*$ with given sets of elements $E \subseteq E^*$, relations between them $R \subseteq R^*$, their topology $G \subseteq G^*$, the technology of functioning $A \subseteq A^*$, the parameters of elements and relations $B \subseteq B^*$ over a set of local efficiency criteria

$K(s) = \{k_i(s)\}$, $i = \overline{1, m}$ and choosing the best variant for system constructing $s^o = \arg \underset{s \in S^*}{opt} K(s)$ [12-16].

When implementing the system approach in LSO optimization problems, it is necessary to determine the rational sequence of solving the selected problems (8)-(9).

LOGICAL SCHEME OF SYSTEM OPTIMIZATION

The proposed technology for solving the problem of LSO system optimization is based on the ideas of the aggregative-decomposition approach, system analysis and system design of complex systems [9, 10]. The tasks of system design $Task_2^1$, development planning $Task_3^1$, adaptation $Task_4^1$ and reengineering $Task_5^1$ (8) are varieties of the LSO system optimization problem.

Based on formalization the LSO's creating goals (4) - (6) and their decomposition into complexes of interrelated problems (8) - (9), lets develop a network model for the problem of its system optimization [7, 9]. On the network model basis, a logical scheme of system optimization that determines the rational sequence for complex of problems solution (9) will be constructed.

To create a scheme for LSO system optimization *SysOptS* (*System Optimization Scheme*), it is necessary to define the five sets [7, 9, 10]:

$$SysOptS = \langle Tasks, InDat, Res, DesDec, ProcDec \rangle, \quad (10)$$

where: $Tasks = \langle Task_i^2 \rangle$, $i = \overline{1, 6}$ – ordered set of tasks (9); *InDat* (*Initial Data*) – set of tasks initial data; *Res* (*Restrictions*) – set of tasks restrictions; *DesDec* (*Design Decisions*) – set of project optimization decisions; *ProcDec* (*Procedures of the Decision*) – the solving procedure, which puts each pair $\langle InDat_i^2, Res_i^2 \rangle$ in correspondence with a nonempty set $\{DesDec_i^2\}$ $i = \overline{1, 6}$.

The entire set of tasks *Tasks* (9) is completely solvable if for all problems $Task_i^2$ there are project procedures $ProcDec_i^2$, $i = \overline{1, 6}$ and each project solution is the only one $|\{ProcDec_i^2(InDat_i^2, Res_i^2)\}| = 1$.

In the process of analyzing the interrelationships between the models of system optimization problems (9), each of the models will be represented as:

$$\begin{aligned} ModTask_i^2 : \{InDat_{iE}^2, InDat_{iI}^2, Res_i^2\} \rightarrow \\ \rightarrow DesDec_i^2, \quad i = \overline{1, 6}, \end{aligned} \quad (11)$$

where: $InDat_{iE}^2$ – set of input data that are external to the complex of problems (9); $InDat_{iI}^2$ – set of input data that are internal to the complex of problems (9); Res_i^2 – set of tasks restrictions; $DesDec_i^2$ – tasks solutions.

As a result of analysis the complex of problems (9), it is established that the external initial data $InDat_{iE}^2$, for all problems $i = \overline{1, 6}$ are the same [10].

The analysis of input and output data of models for system design problems $ModTask_i^2$, $i = \overline{1, 6}$ showed that they are all dependent on each other by internal input and output data.

It is expedient to build the solving technology for the general problem of system design on the sequential iterative scheme basis [9].

In this case, from the received project decision $DesDec_i^2$ of the task $Task_i^2$, $i = \overline{1, 5}$, the initial data $InDat_{i+1}^2$ and restrictions Res_{i+1}^2 in the solving procedures $ProcDec_{i+1}^2$ for the following tasks $Task_{i+1}^2$ will be formed. Thus, the «closure» of the sequential circuit tasks is carried out [9, 10]:

$$\exists DesDec_i^2 \in DesDec \quad Tr(InDat_{i+1}^2 \vee Res_{i+1}^2 \in DesDec_i^2), \quad i = \overline{1, 5}, \quad (12)$$

where *DesDec* – set of project decisions; *Tr* (*True*) – truth of statement $(InDat_{i+1}^2 \vee Res_{i+1}^2 \in DesDec_i^2)$.

In determining the sequence of tasks $Task_i^2$, $i = \overline{1, 6}$, within the sequential scheme, one should aspire to minimize the degree of their insolvability by the initial data and minimize the complexity of the solving procedure.

In view of this, the task of choosing the LSO constructing principles $Task_i^2$, which determines the restrictions on the set of permissible variants of its construction S^* for all problems, must be solved before others. The task of evaluating the options effectiveness and selecting a global solution $Task_6^2$ uses the output data (project solutions) of all other tasks of the complex and, therefore, must be solved in the last turn. The definition of the LSO topology $Task_3^2$ is impossible without the knowledge of its organizational or functional structure, determined as a result of solving the task $Task_2^2$. Therefore, the solution of the task $Task_2^2$ must precede the solution of the task $Task_3^2$.

In view of the fact that an object can be built on different types of elements and relations between them, and elements can use different functioning algorithms, tasks of their definition $Task_3^2$ and $Task_4^2$ is expedient to be solved after the task $Task_2^2$. Within the limits of this task their number is determined.

As the final choice of the functioning technology can be carried out only taking into account the trajectories of territorial displacements inside the object, it is expedient to find the solution of the technology selecting task $Task_4^2$ after solving the task $Task_3^2$. The task of selecting the functioning technology $Task_4^2$ can be solved both before and after selecting parameters of elements and relations of the system $Task_5^2$. In the second case, the situations of nonfulfillment of restrictions for given values of the parameters of elements and relations, which require a repeated solution of previous problems can arise more often. It is proposed to solve the task of parametric

synthesis $Task_5^2$ after finding the solution of the technological synthesis task $Task_4^2$, obtained under conditions of maximum (least strict constraints) parameter values.

As an elementary unit on the basis of which we will perform tasks ordering, let's use the design cell. The design cell describes a task that is essentially solvable $Task_i^2$ with the help of a certain solving procedure $ProcDec_i^2$, based on its initial data $InDat_i^2$ and restrictions Res_i^2 , $i = \overline{1,6}$.

The design solutions of the problem $DesDec_i^2$ can be represented in the model categories $ModTask_i^2$, $i = \overline{1,6}$ and are allowed to be compared by a set of criteria $K(s)$ [9]. The cell can be considered as a scheme for presenting the design procedure in the form of:

$$\begin{aligned} Task_i^2 : ProcDec_i^2 \{ InDat_i^2, Res_i^2 \} \rightarrow \\ \rightarrow DesDec_i^2 / ModTask_i^2, \quad i = \overline{1,6}. \end{aligned} \quad (13)$$

On the basis of results the network model (13) analysis on restrictions, input and output data, it is proposed a sequential scheme of LSO system design:

$$\begin{aligned} Task_1^2 \rightarrow Task_2^2 \rightarrow Task_3^2 \rightarrow Task_4^2 \rightarrow \\ \rightarrow Task_5^2 \rightarrow Task_6^2. \end{aligned} \quad (14)$$

To implement it, it is needed to additionally define the initial data of the tasks $Task_2^2$, $Task_3^2$ and $Task_4^2$. For this we transform the linear scheme (14) into an iterative scheme for obtaining a general solution $DesDec_2^1$, that makes it possible to form the missing initial data from the results of solutions of previous iterations (Fig. 2).

Due to the impossibility of solution the problems $Task_i^2$, $i = \overline{2,5}$ by the input data, in the sequence (14) the input data $InDat_i^2$ and restrictions Res_i^2 , $i = \overline{2,5}$ for them at the initial iteration will be formed on the basis of predictive (expert) estimates. In other iterations, the results of solving the following problems $DesDec_j^2$, $j > i$, $i = \overline{1,5}$ of the sequential circuit (14) will be used as inputs $InDat_i^2$ and restrictions Res_i^2 , $i = \overline{2,5}$.

The practical implementation of the scheme (14) and the system optimization technology involves choosing the most effective or developing new mathematical models and methods for solving the complex of particular problems (8) - (9).

CONCLUSIONS

1. It is established that existing technologies suppose conditionally independent solution of problems of large-scale objects structural, topological, parametric and technological optimization. This does not allow the full use of the formal methods and modern computer facilities to obtain the most effective options for such an objects construction.

2. Taking into account the relationships between the tasks of structural, topological, parametric and technological optimization, formalization of the system description and the purposes of creating large-scale objects reflecting the indicators of their effect and the resource costs for their creation and operation is performed.

3. The decomposition of the problem of large-scale objects system optimization was performed. It made it possible to isolate the problems of large-scale objects analysis and synthesis, which are solved at the main stages of their life cycles. This helps to ensure the continuity of decisions taken at all stages of objects life cycles.

4. Taking into account the relationship of the defined tasks on the input and output data, a scheme and technology for the large-scale objects system design taking into account the interconnection of the whole set of problem-related tasks has been developed. Using the developed technology will improve the efficiency of system optimization procedures for large-scale objects.

5. The proposed technology of system optimization was used and demonstrated its effectiveness while solving practical problems of large-scale objects design and reengineering [17-23].

6. Practical application of the obtained results allows to reduce the terms for solving the problems of objects design and development planning, to reduce the costs of their creation and operation. Due to joint tasks solution it is possible to improve the decisions quality and on this basis to improve the functional characteristics of large-scale objects.

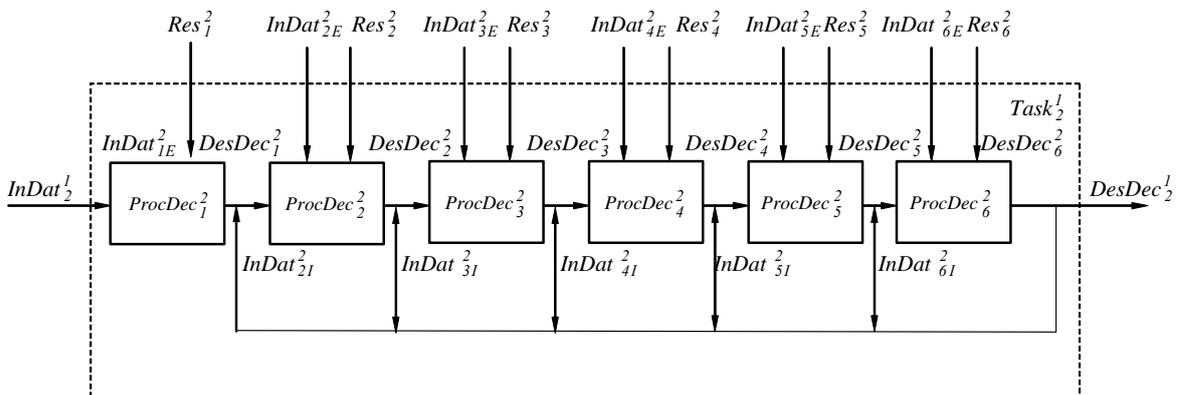


Fig. 2. Iterative scheme of LSO system optimization

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