# Fundamentals of Complex Objects Structural Dynamics Proactive Management Theory and its Application

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***Abstract*— methodological and methodical fundamentals of the complex objects proactive management theory based on the fundamental results obtained in the interdisciplinary field of system knowledge are proposed. The paper provides information on the developed innovative polymodal complexes, combined methods, algorithms and techniques to solve various classes of problems of operational structural and functional synthesis and management of the development of the regarded classes of complex objects. The paper gives examples of solving practical problems for such subject areas as spacecraft, logistics, industrial production.**

***Keywords*— *proactive control; structural dynamics; complex objects; combined methods; algorithms and techniques***

## I. INTRODUCTION

One of the main features of modern complex objects (CO) is that their parameters and structures at different stages of the lifecycle change under the influence of objective and subjective reasons. In other words, in practice we constantly face the structural dynamics of COs. Under these conditions to increase (maintain) the performance and capabilities of CO or to ensure the least possible degradation of these systems, it is necessary to manage their structures (including the CO structures reconfiguration management). Currently, there are various options for controlling the structural dynamics of CO: change of methods and goals of CO functioning, their content, sequence of execution in different conditions; relocation of separate elements and subsystems of CO; redistribution and decentralization of functions, tasks, control algorithms, information flows between different levels of CO; use of flexible(reduced) management technologies; reconfiguration of CO structures upon their degradation.

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The tasks of controlling the structural dynamics of CO belong to the structural and functional synthesis class of problems and the formation of appropriate programs for managing their development. The main difficulty and feature of the solution of these regarded problems is as follows. Determination of optimal control programs of the basic elements and subsystems of the CO can be performed only after all functions and algorithms of information processing and control, which should be implemented in these elements and subsystems, become known. In turn the distribution of functions and algorithms on the elements and subsystems of CO depends on the structure and parameters of the control laws of these elements and subsystems. The difficulty of resolving this controversial situation is exacerbated by the fact that under the influence of various reasons, the composition and structure of the CO at different stages of its lifecycle changes over time.

## II. FUNDAMENTALS OF PROACTIVE MANAGEMENT THEORY OF COMPLEX OBJECT STRUCTURAL DYNAMICS

To date, various methods and models are used to describe and solve the problems of structural dynamics control of the CO. In this case, we can distinguish the traditional description based on the representation of the considered tasks as network planning and management tasks, as well as the previously proposed options for dynamic interpretation of these tasks. However, the implementation of these approaches in practice raises a number of algorithmic and computational problems associated with large dimension, nonlinearity, unsteadiness and uncertainty of the corresponding control models.

The paper presents a modified version of the dynamic interpretation of proactive management processes of complex operations, describing the functioning of CO. In this case, the nonlinear technological constraints are not set in the right-hand side of the differential equations, but in the field of permissible control actions. At the same time, using the method of local sections, it was possible to explicitly obtain Lagrange multipliers, with which these restrictions are taken into account in the models of proactive management. In addition, within the proposed formalization of CO control processes it is possible to move from the initial class of admissible controls to the

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extended class, in which the conditions of the relativity of control actions are replaced by interval restrictions. Despite this, because of the linearity of differential equations and the convexity of the region of permissible controls, the control actions themselves take boolean values. This feature allows to solve various problems of CO management (including the job scheduling theory problems) to widely use the fundamental scientific results of modern control theory. The theoretical provisions under consideration were implemented in the development of the applied theory of proactive control of small-mass-size spacecraft (SMSS)

While developing the foundations of the theory of proactive management of CO its authors were based on two fundamental concepts and technologies of modern system-cybernetic research. The first concept and the corresponding technology is the concept of complex (system) modeling of CO, which assumes development and implementation of the new principles, approaches to polymodel description of the considered space means, and also development and combined application of methods, algorithms and techniques of the multi-criteria analysis, synthesis and the choice of the most preferred management decisions (including the ones connected with their reconfiguration) connected with creation of CO, use and development of the regarded objects in various conditions of dynamically changing external and internal environments.

To implement this concept the developed model-algorithmic software for each experimental prototype of the software module, original model descriptions were proposed, as well as combined methods and algorithms for manipulating these descriptions in solving specific application problems of calculation, evaluation and analysis of reliability and survivability of the CO in normal and specified conditions.

The second basic concept was the concept and technology of proactive management of CO, which include, among others, the SMSS and ground control complex (GSS) (the latter is used to expand the capabilities for proactive management of the SMSS in the event of emergency). Proactive management, in contrast to the traditionally used reactive management of CO is focused on operational response and subsequent prevention of incidents through the creation of fundamentally new predictive and proactive capabilities in the formation and implementation of control actions based on the methodology and technologies of system (complex) modeling [1–3].

Based on these concepts, the authors proposed the following generalized procedure of proactive management of CO, which includes **two main stages**.

In accordance with the developed generalized procedure for solving this problem the first stage should include the formation (generation) of acceptable variants of multi-structural macrosstates of CO or in other words, thestructural and functional synthesis of a new image of CO, corresponding to the emerging (projected) situation, is necessary. In this situation, the problems solved in the first phase are reduced to the problems of structural and functional synthesis of CO.

In the second stage of the study the problem of selecting optimal programs for proactive structural dynamics management (PSDM) of CO whole set of specific problems of multi-level and multi-stage optimization has to be solved.

One of the main advantages of the proposed method of searching for optimal programs of PSDM is that during the formation of the program controls space at the final moment of time, along with the optimal plan, we simultaneously obtain the desired multi-structural macro-state, in which CO will be able to perform its tasks in the emerging (predictable) environment with the required degree of stability.

As a result of the research, combined methods and algorithms for solving the problems of choosing the optimal programs of CO PSDM in the centralized and decentralized operation modes were developed. As a basic combined method it is proposed to use a combination of the branch and boundary methods and the method of successive approximations. The theoretical justification of this method is based on the proven theorem on the properties of the relaxed problem of choosing the optimal program of CO. The features of the proposed combined method implementation are illustrated by solving an example [4–5].

In the course of the research the classification and analysis of disturbing factors affecting the functioning of the complex technical system, proposed ways to take into account disturbing factors in the models of PSDM were performed. The most promising way to take into account the uncertainty factors (perturbing factors) in the models is the way in which all adequate methods and forms of presentation of these factors are used in a complex way. At the same time, a comprehensive study of the capabilities of CO management, with a fairly broad interpretation, includes both an assessment of the functioning of CO in normal modes, and an assessment of the possible behavior of the system in extreme situations, including the assessment of the "opportunities" of the emergence of disturbing effects that destroy the system. In this case, the CO operation study should include the following steps [4–5]:

(a) identification of all possible scenarios for the change in the external environment in which CO can be used, including extreme situations and impacts that could cause catastrophic consequences associated with these situations;

b) analysis of CO behavior under normal conditions of functioning on the basis of a priori probabilistic information (if any), simulation, expert information processing using the theory of subjective information and the theory of fuzzy sets;

c) the same actions as in "b" for all major extreme situations, finding guaranteed estimates of the CO performance in these situations;

(d) finding generalized (integral) estimates of the effectiveness of CO structural dynamics management.

In the study of the problem 2, algorithms of parametric and structural adaptation of CO SDSU models based on fuzzy clustering and hierarchy analysis methods, analytical and simulation methods were proposed.

## III. Conclusion

Currently, the theory of proactive monitoring and control of CO considered in the paper is experiencing its formation. The scientific novelty of the results obtained by the authors is based on the original dynamic interpretation of CO management processes, which provided increased flexibility and adaptability of these processes. The main aspects of the developed applied theory are illustrated by the example of solving the problem of operational planning of space assets and reconfiguration of their structures.

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