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RESEARCH PRINCIPLES OF MATHEMATICAL THEORY OF SOCIO-TECHNICAL SYSTEMS CONTROL

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Abstract: The general research principles of mathematical theory of socio-technical systems (STS) control are considered. These principles - rationality, coordination and decomposition reflect the specifics of STS as control objects with a complex structure (logical, cause-and-effect, process, etc.), requiring coordination of the life cycles of their elements and including subjects demonstrating active behavior.

Key words: scientific laws and principles, control theory, socio-technical systems.

1 Introduction

Работа посвящена выделению и систематизации общих исследовательских принципов теории управления организационно-техническими системами, на сегодняшний день включающей, в т.ч., такие направлений теории управления, как теория активных систем (ТАС) [5, 10] и теория управления организационными системами (ТУОС) [15].

2 Research principles

Let us consider a hierarchy of scientific *laws* (the law is a statement of an order or relation of a phenomenon that as far as is known is invariable under the given conditions -) and *principles* (the principle is a comprehensive and fundamental law, doctrine, or assumption) (Novikov 2016 [14]): philosophical laws are the most general; logical and other general scientific laws and principles are more “specific”; laws, rules, and principles of concrete sciences follow those.

Two classes of principles might be distinguished: those that describe the structure and operations of certain classes of systems (these *"entity-based" principles* are an outcome of scientific studies of these systems), and internal *principles* (conventionally speaking, *"epistemological,"* research ones), used within the framework of a relevant science (its fundamental provisions, paradigms, and research methodology: approaches, general methods of study, etc.).

As a science, *control theory*, on the one hand, has its own laws and principles; on the other hand, it uses the laws and principles of other sciences related to the corresponding controlled system.

As applied to *sociotechnical systems* (STSs), “entity-based” principles include general laws of control and principles of complex systems organization and operation, as well as principles of organizational control, which can be supplemented, with an appropriate adaptation, with principles of operations of living systems and social systems (Novikov 2013 [15], Novikov 2016 [17]). This should also include all the knowledge (in a generalized form - laws, regularities and principles) that is available regarding the subject of control in the STS - a person and / or a technical system controlled by a person (the corresponding knowledge can be gleaned from related sciences, studying, firstly, the subject of management - for example, mechanics; secondly - the sciences that study the laws of creating artificial systems - the general *theory of systems* and *systems engineering* [1, 8, 20].

Let us consider the general "epistemological" principles of the *theory of control in organizations* (TCOr) [15], the subject-matter of which is control of organizational systems and STSs. These principles (see Fig. 1) – rationality, coordination, and decomposition – reflect the specifics of organizational system as controlled entities that have a complicated *structure* (logical, cause-effect, process, etc. [2]), require coordination of the *lifecycles* (LCs) of their elements [3], and include actors implementing *active behavior* (independent goal-setting, active choice, and decision-making).

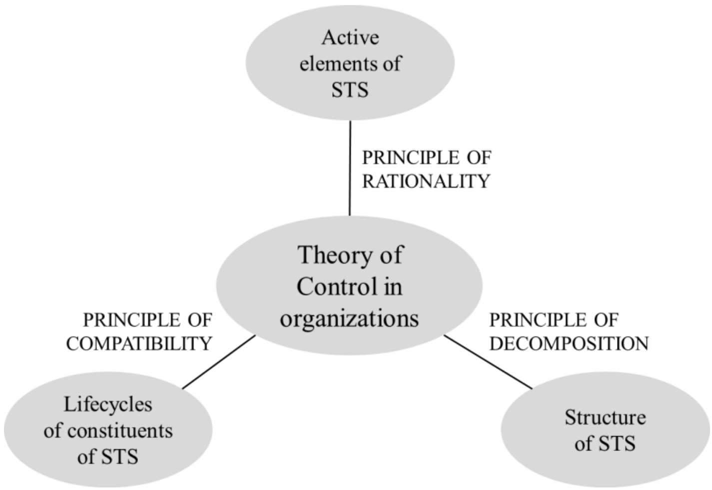

Figure 1. *Research principles of theory of control in organizations*

2.1 The principle of rationality

The principle of rationality consists of the need to take into account and constructively model *the active behavior* of controlled and controlling actors of an STS, carried out in interaction with the environment and other active elements of the STS. This research principle includes a number of hypotheses.

The basic *hypothesis of rational behavior* is that an actor, taking into account all the *information* available to them, chooses actions that lead to an *output* of activity that they prefer most (Novikov 2013 [15]). Decision theory, choice theory, and other related fields of science provide an apparatus to model and study such a choice. If an actor chooses solutions that are not optimal (the best among the feasible ones; the most effective one) but are rational (with an efficiency no less than a given one or differing from the maximum by no more than a given value), it is a case of *bounded rationality* (Simon 1969 [9, 19]), which takes into account time spent on decision-making, as well as the cognitive capabilities of the actor.

If the output of an actor's activity depends not only on his/her actions but also on other factors, maybe uncertain ones, then, when making decisions, he or she must *eliminate uncertainty* (we distinguish between so-called *natural uncertainty* – related to environmental factors – and *game uncertainty*, dealing with the behavior of other actors).

The *determinism hypothesis* is that an actor seeks to eliminate (with all the information available to them taken into account) the existing uncertainty and to make decisions being fully aware (in other words, the final criterion that guides a decision-maker should not contain uncertain parameters) (Novikov 2013 [15]).

In the case of game uncertainty studied by the apparatus of *game theory*, the *equilibrium principle* is used, according to which a combination of actions chosen by actors is effective and/or stable in one sense or another. In *hierarchical games*, the equilibrium actions by controlled actors depend on the actions of controlling actors (Germeier 1986 [7]). In *reflexive games*, the equilibrium actions by actors also depend on their mutual awareness of natural uncertainty and on principles of behavior with regard to each other (Novikov and Chkhartishvili 2014 [16]).

The use of the principle of rationality allows one to create a *model of controlled actors* to describe the dependence of their behavior on control parameters. With this model, it is possible to solve the *control problem* – the search for such feasible control actions that would ensure such a behavior of actors, controlled by a controlling actor, which is desired from the point of view of the latter.

2.2 The principle of compatibility

Since both controlling and controlled actors are active, then, by virtue of the hypothesis of rational behavior, each of them strives to achieve the best output for themselves. But, since their interests do not generally coincide, the *principle of compatibility* requires a compromise (taking into account the asymmetry of the roles of actors), i.e., *coordination of interests* (Burkov 1969 [5], Novikov 2013 [15]), and, in the general case, compatibility of the lifecycles of all constituents of STS (including conditions, resources, preferences, and interests) [3]. [4, 10, 15, 18]

The *principle of compensation* states that (in the case of a transferable utility, i.e., in an active system with side payments) an actor must be compensated by other actors for losses in productivity (gains, etc.) due to the fact that he or she chooses the actions according to the interests of other actors but not the best action for himself or herself (Novikov 2013 [15]).

In incentive problems, the *principle of compatible control* states that a controlling actor can predict that a controlled actor choses only such actions that are profitable (with the control taken into account) for the latter (Burkov 1969 [5]). The principle of compatible control allows one to guarantee a required behavior (within a certain range) of controlled actors (the coincidence of actions or results by controlled actors with *plans* – desirable from the point of view of the controlling actor), reducing the complicated game-theoretic problem to a simple optimization problem – one of *incentive-compatible planning*, i.e., the choice by a controlling actor of such coordinated states of actors, controlled by him/her, that are the most favorable to him/her.

In planning problems (when a principal makes decisions based on information reported by controlled agents), the *open control principle* (synonyms: *fair play principle* (Burkov 1969 [5]) or *revelation principle* [13]) directs a controlling actor (to ensure the accuracy of the information they receive) to make decisions that are the most beneficial to controlled actors by believing that information communicated by the latter is true.

In *systems with distributed control* (multiple controlling principals), the *principle of compromise* states that a stable outcome of the interaction of controlling actors is either a *Pareto-effective* situation for them or a "monopolization" of the subordinate actor by one of them [15].

If the coordination principle allows solving control problems in an STS with a sufficiently simple, *basic* structure (one controlling actor and multiple weakly coupled controlled actors), then the next class of research principles makes it possible to reduce complex problems of control of STSs to a set of basic ones.

2.3 The decomposition principle

The decomposition principle assumes that a control impact on a separate actor should be based on his or her observable actions and/or outputs of activity. Such control should provide him or her with a beneficial choice of actions desired by the controlling actor, regardless of other factors, namely:

- actions and outputs of activity of other actors (*principle of decomposition of agents' game*);
- a prehistory (*principle of decomposition of periods of functioning*);
- the technology of interaction of STS participants (*principle of technology decomposition*);
- a multilevel structure of organizational subordination (*principle of hierarchical decomposition*).

The possibility of such a decomposition is justified in [3] for all of the above factors simultaneously.

Thus, the principle of decomposition makes it possible to reduce the problem of control of a multi-element, multi-level, dynamic STS to a set of interconnected basic control problems.

3. Conclusion

Joint implementation of the above classes of research principles (rationality, compatibility, and decomposition) – see Fig. 1 and Table 1 - is a universal tool for the definition and solution of STS control problems, taking into account the dynamics, the multiplicity of interrelated actors, the multilevel hierarchy, distributed control, uncertainty, technological constraints of cooperative activity, information exchange, and other factors.

Indeed, all known STS models are based on general research principles (see Table 1). Moreover, when considering these models, certain assumptions with respect to the properties of a researched STS are introduced.

Table 1. Research principles of mathematical theory of socio-technical systems control

General principles	**Special hypothesis and principles**
Rationality principle	Rational behavior hypothesis
	Determinism hypothesis
	Equilibrium principle
Compatibility principle	Principle of compensation
	Principle of coordinated control
	Principle of open control
	Principle of compromise
Decomposition Principle	Principle of decomposition of agents' game
	Principle of decomposition of periods

	Principle of technology decomposition
	Principle of hierarchy decomposition

A **researcher** executes the following **general algorithm**:

1) Describe the composition and structure of the STS (an aggregate of controlling and controlled actors and relationships among them);

2) Describe an aggregate of feasible actions of the participants;

3) Describe the awareness of the participants, including that about uncertain parameters, as well as the causal-temporal order (a sequence of information exchange and decision-making operations);

4) Within the framework of the principle of rationality, describe procedures of decision-making by participants by setting their preferences (assuming the validity of the rational behavior hypothesis) and procedures for uncertainty elimination (the determinism hypothesis), taking into account the interaction with each other (the equilibrium principle);

5) For all the feasible *planned trajectories* of vectors of actions or those of outputs by controlled actors, find the most desired actions for the controlling actor. These control actions should encourage (the compensation principle) the controlled actors to choose such planned actions or achieve such planned outputs that are the equilibrium of their game (the principle of equilibrium), regardless of their interaction, dynamics, and organizational structure (the decomposition principle). The result of this step is a set of pairs – compatible plans and "expenses" of the controlling actor for the implementation of this plan;

6) Solve the problem of optimal compatible planning (the principle of compatible control) – choose compatible plans which are optimal from the point of view of the controlling actor.

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