THE ESSENCE, ATTRIBUTES, AND DESCRIPTION PRINCIPLE OF ORGANIZATIONAL SYSTEMS

G. A. Ougolnitsky

Southern Federal University, Rostov-on-Don, Russia

✉ gaugolnickiy@sfedu.ru

Abstract. The concept and essence of an organizational system are discussed. A general characterization of this concept is provided within the theory of control in organizational systems. Several attributes are indicated to classify a given system as an organizational one (the description principle of organizational systems). A mathematical model of a general organizational system is described, with an illustrative example based on the Cournot duopoly. Extended examples of some classes of organizational systems specified using this principle are presented. Such classes include special-purpose organizational and technical systems, queuing organizational systems, and ecological-economic organizational systems. Typical representatives of each class are described within the general model proposed. This paper has a methodological focus and is intended to define a standard description of organizational systems.

Keywords: organizational systems, game-theoretic models, control in active systems.

INTRODUCTION

The topicality of organizational control problems is beyond doubt: the quality of this control determines labor productivity, economic growth, and thus government capabilities and the welfare of the population.

The Philosophical Encyclopedic Dictionary gives the following definition of *organization*: 1) internal orderliness, the consistency of interaction between more or less differentiated and autonomous parts of a whole, conditioned by its structure; 2) a totality of processes or actions leading to the formation and improvement of interrelations between the parts of a whole; 3) an association of people jointly implementing some program or goal and acting based on certain procedures and rules [1]. The totality of these procedures and rules is called a *mechanism of functioning*. The third meaning of the term “organization” is the definition of an *organizational system*. Methodology uses a similar definition [2]: *organization* is a complex activity with the goal of creating internal orderliness, the consistency of interaction of more or less differentiated and autonomous elements of the subject of this activity (in particular, by forming and maintaining interrelations with specified characteristics between these elements).

Formal models of organization control are provided by the theories of active systems and control in organizational systems (OSs) [3, 4], the information theory of hierarchical systems [5–8], contract theory and mechanism design [9], and the theory of sustainable management of active systems [10–12]. The possibilities of using artificial neural networks in the study of hierarchical organizational systems were shown in [13]. To a large extent, we agree with the author’s opinion [13] that multistage hierarchical games of many persons represent the **LANGUAGE** of organizational systems control, although models of this control theory involve other mathematical constructs as well. According to the fundamental monograph on the theory of control in organizations (TCO) [4], the object of research is OSs, the subject of research is control mechanisms, and the main method of research is mathematical modeling. Following this approach, the main attention in [4] was paid to control problems and control mechanisms, namely, control of the staff and structure of OSs, institutional control of activity constraints and norms, motivational control of interests and preferences, informational control, and control of the order of functioning (the sequence of acquiring information and choosing strategies by agents). Finally, the OS model is defined by specifying its staff (a set of OS participants), structure (a set of various relations between OS participants), a set of feasible strategies of OS participants, their preferences, awareness, and the order of functioning.

Meanwhile, where is the watershed between the approaches of management and TCO? This issue remains unsettled. Another question deserving a clear answer is: what kind of system can be considered an organizational system? Indeed, many complex systems of the real world are not such.

This paper has the following contribution:

- The essence of organizational systems is described, and their mathematical formalization defining the TCO approach is proposed.
- Several attributes are indicated to classify a given system as an organizational one (the description principle of organizational systems).
- In accordance with this principle, some classes of organizational systems are identified and characterized in detail.

In Section 1, we describe the essence of organizational systems as well as their attributes and general mathematical model. In Section 2, the description principle of classes of organizational systems is considered. Section 3 gives extended examples of some classes of organizational systems obtained by applying this principle. The results and perspectives are discussed in the Conclusions.

1. THE ESSENCE AND ATTRIBUTES OF ORGANIZATIONAL SYSTEMS

The following definition was given in the remarkable book [14]: a social system is a dynamic set of autonomous individuals pursuing their goals in interaction with an environment. This definition is quite close to what should be understood by an OS. However, since any complex concept is a synthesis of many definitions, it seems more convenient to define an OS in a detailed way through its mathematical model. This model synthesizes the description from [3, 4] (see the Introduction) and the active network model from [15], with some essential refinements and additions. We suppose that an OS consists of a control (active) subsystem and a controlled subsystem. (Note that such a structure includes organizational and technical systems as well.) The OS model has the form

$$\left\langle N,\ A,\ X,\ I,\ U,\ S,\ F,\ J, R\right\rangle \tag{1.1}$$

with the following notation:

$N = \{0,\ 1,\dots,\ n\}$ is the set of active agents, which form the staff of the OS control subsystem. The number 0 is associated with a selected agent (Principal), representing a single agent for the time being.

$A = \{(i,\ j)\}$ is the set of different-type links between active agents $i, j \in N$. A directed graph $D = (N,\ A)$ defines the structure of OS links, which are defined by subordination relations as well as substance, energy, and information flows.

X is the state set of the controlled subsystem of the OS (a subset of some topological vector space).

$I = I_0 \times I_1 \times \ldots \times I_n$, where I_i is the information available to agent *i* about the OS and its environment. Since the deterministic model (1.1) is considered, in contrast to [16], this information contains the agent's beliefs about the actions of other agents and their payoff functions as well as about the controlled subsystem's state. All agents, including the Principal, strive to maximize their payoffs; in the presence of ambiguity, they are guided by the principle of guaranteed result [8].

$U = U_0 \times U_1 \times \ldots \times U_n$, where U_i is the set of feasible actions of agent *i* (a subset of some finite-dimensional space [8]).

$S = S_0 \times S_1 \times \ldots \times S_n$, where S_i is the set of feasible strategies of agent *i*. A feasible strategy $s_i \in S_i$ is a mapping $s_i : I_i \to U_i$ that determines the choice of a feasible action by agent *i* depending on the information available to him/her.

F is a rule of changing the states under the actions of active agents. It can be a system of algebraic, differential or difference equations, or an algorithm that explicitly defines the transitions between the controlled subsystem's states. This rule can be treated as a generalized operator acting in the state space.

$J = (J_0, J_1, \ldots, J_n)$ is the set of payoff functionals of active agents. A mapping $J_i : U \times X \to \mathbb{R}$ defines the payoff of agent *i* depending on the actions of all agents and the current state of the controlled subsystem. An efficiency criterion of the entire organization is the value of a Principal's payoff functional, which generally depends on the actions of all agents and the state of the controlled subsystem.

R is an order of functioning of the OS, which algorithmically determines the sequence of choosing strategies by active agents, the possible transmission of information to other agents, and changes in the state of the controlled subsystem.

Accordingly, we distinguish the following attributes of an OS.

1. *The activeness of agents*. Each agent has an individual payoff functional J_i and independently chooses a feasible strategy $s_i \in S_i$. Within the model, the optimization of the payoff functional completely determines the agent's interests and preferences. In

particular, agents may deliberately distort the information transmitted to other agents in their own interests (the so-called *manipulation* problem of decision procedures [17]). Other manifestations of activity include the *far-sighted* behavior of agents [18] and *reflexion* regarding their activity and the activity of other agents [16].

2. *Goal-setting*. An organizational system has a certain goal, which is established independently or set from the outside (e.g., by society or a superior organization). In the general case, this goal, expressed in the form of a constraint, consists at least in fulfilling the viability condition $X \subseteq X^*$ of the organization. (In other words, the values of all its essential indicators belong to a given range.) Technically, it is possible to incorporate the viability requirement into the Principal's payoff functional J_0 via a penalty function $\rho(X, X^*)$: the latter is 0 when the viability condition holds and takes an infinitely large value when it is violated. In the absence of any viability condition, the goal of the OS is only to maximize the functional J_0 without penalties.

3. *Organization*. An organizational system (an extended active system) is formed by a control subsystem consisting of active agents, including the Principal, and a controlled subsystem. A controlled subsystem does not contain active agents: it includes technical, economic, and other components controlled by active agents. The interaction between active agents is established by an order of functioning R and determines the dynamics of the controlled subsystem (the change of its state $x \in X$ over time by a rule F) and the payoffs J_i of agents.

2. THE DESCRIPTION PRINCIPLE OF ORGANIZATIONAL SYSTEMS. AN ILLUSTRATIVE EXAMPLE

Some system is called organizational if and only if it has all the three features of OSs listed above: the activeness of agents, goal-setting, and a control mechanism. Then it is possible to build model (1.1) of this OS and specify the values of its components. In particular cases, some components can be empty sets or take trivial values.

Consider the following simplified illustrative example, known as the Germeier game (the inverse Stackelberg game) Γ_2 in a Cournot duopoly [8]. Here, $N = \{0, 1\}$ in the expression (1.1). The organization consists of two active elements, namely, a Principal and an agent; $A = \{(0, 1)\}$. The Principal makes the first move by formulating the "rules of play" for the agent.

The Principal knows U_0, U_1, J_0, and J_1, will have information about the choice $u_1 \in U_1$, and is aware that the agent chooses an appropriate strategy by maximizing his/her own payoff. In other words, the Principal's strategy (control mechanism) is a mapping of the set U_1 into U_0. The agent knows U_1 and J_1. Given the agent's known strategy, the Principal seeks to maximize his/her own payoff J_0. Under an ambiguous choice of the agent, the Principal is guided by Germeier's generalized principle of guaranteed result [5, 6, 8]. Let

$$J_0 = \left(a - c_1 - u_1 - u_2\right)u_1,$$

$$J_1 = \left(a - c_2 - u_1 - u_2\right)u_2,$$

$$c_1 < c_2 < a,$$

where $U_0 = U_1 = [0, 1]$, $s_0 : U_1 \to U_0$, $s_1 \equiv u_1$. The model is static and contains no controlled subsystem, i.e., the set X and the rule F are not considered. The goal of the organization is to maximize the Principal's payoff J_0.

The Principal makes the first move by choosing the strategy

$$u_0(u_1) = \begin{cases} (a - c_1)/2, \ u_1 = 0, \\ a - c_1 - u_1, \ u_1 > 0, \end{cases}$$

and reports it to the agent. The agent's unique optimal response is $u_1 = 0$, resulting in $J_0 = (a - c_1)^2/4$, $J_1 = 0$ (otherwise, $J_1 < 0$). A possible practical interpretation of the Cournot duopoly is as follows: firm 0 offers firm 1 some terms, becoming the duopoly's leader. Say firm 0 can offer firm 1 a side payment for a higher price in a tender involving firm 0. This situation is more precisely described by the Bertrand duopoly [7], but Cournot's quantity competition is suitable as well.

3. EXTENDED EXAMPLES

Here are some examples to demonstrate the description approach to OSs. In each subsection below, we provide a general characterization of some class of OSs, with its further specification to particular OSs within the class.

3.1 Special-Purpose Organizational and Technical Systems

The first extended example of OSs is special-purpose organizational and technical systems (OTSs). Here, we consider surveillance and interception systems for opponent's aircraft and missiles. Such systems and their several examples were characterized in [19]. In the general case, a special-purpose OTS has the following components:

N is the group of surveillance agents. The Principal is the group commander. Note that active agents also represent the opponent's side. They are not included in the OS (being its environment); however, their actions can be considered in the OS model, particularly when determining the state of its controlled subsystem and describing other aspects, e.g., active confrontation.

A is the set of links between agents. They are determined by the need for operational interaction during surveillance and interception.

I_i is the information available to agent i about the actions of other agents, the Principal, and the opponent as well as about the state of the controlled system.

U_i is the set of feasible actions of agent i (position choice, targeting parameters of anti-aircraft mounts).

S_i is the set of strategies of agent i depending on the opponent's actions. Since these actions affect the system state, closed-loop strategies are generally used; they depend not only on time but also on the system state.

$x = (x_1,..., x_m) \in X$ is the system state vector (the coordinates and velocities of objects under surveillance).

F is the general rule of changing the system state. This rule is determined by the mechanical and geometrical conditions as well as the regularities of system operation.

J_i is the payoff functional of agent i. It is determined by the accuracy of target detection.

R is the order of decision-making in the special-purpose OTS. This order is determined by the rules of some Germeier game [8] in which the Principal acts as the leader whereas surveillance agents and opponent agents as followers with simultaneously chosen actions.

Let us take the triangulation measurement system (TMS) [19] as a particular example of special-purpose OTSs. In this case, the set N (agents) is formed by TMS operators, each associated with a separate measuring point. The set A is given by pairwise bilateral links between the agents and the Principal. Using these links, the agents transmit information about their actions and the state of the controlled system to the Principal and the Principal informs the agents of his/her strategies chosen. Each agent knows the set of his/her actions and the payoff functional, which define the set I_i. We consider the control problem in a static formulation, so the state vector x and the rule F are omitted.

Let $\{P_n\}_{n=1}^{N} = \left\{[x_n^p,\ y_n^p]\right\}_{n=1}^{N}$ be the measuring points of the TMS and $\{S_m\}_{m=1}^{M} = \left\{[x_m^s,\ y_m^s]\right\}_{m=1}^{M}$ be the points of a deception jamming system. Here, N is the total number of measuring points, M is the total number of jamming points, and x and y are the 2D coordinates of points. The superscripts p and s indicate measuring and jamming points, respectively; the subscripts n and m, the point numbers. The surveillance agent's problem can be written as follows:

$$J(u_p, u_s) = |N - K| \to \max_{u_p},$$
$$K < \lfloor N/2 \rfloor + 1,$$
$$\forall i, j \in \{1,..., N\} : \| P_i - P_j \| > B_{\min},$$
$$\forall i, j, k \in \{1,..., N\} : \frac{y_k^p - y_i^p}{y_j^p - y_i^p} \neq \frac{x_k^p - x_i^p}{x_j^p - x_i^p},$$

where K is the number of measuring points in the jamming zone; $u_p = [P_1 ... P_N]$ and $u_s = [\alpha_1, S_1 ..., \alpha_M, S_M]$; $\lfloor \cdot \rfloor$ denotes the integer part of numbers; $\|\cdot\|$ means the Euclidean norm; α_m is the angle of rotation for the jamming sector of point m. Here, the condition $K < \lfloor N/2 \rfloor + 1$ reflects the number of working measuring points necessary for normal TMS operation (more than half of their total number). The other two constraints express requirements for the TMS topology: $B_{\min}$ is the minimum allowable distance between TMS points; no three TMS points should lie on the same straight line. Thus, the set of feasible actions U_i has been defined; for the sake of simplicity, by assumption [19], the strategies S_i coincide with the actions.

The value of the goal function $J(u_p, u_s)$ represents the number of working measuring points. The surveillance agent maximizes this number under the above constraints. On the other hand, the opponent seeks to minimize it over u_s:

$$J(u_p, u_s) = |N - K| \to \min_{u_s},$$
$$K \geq \lfloor N/2 \rfloor + 1.$$

Thus, the payoff functionals $J = J_1 = -J_2$ define an antagonistic game between the surveillance agent and the opponent. According to the condition $K \geq \lfloor N/2 \rfloor + 1$, for the value minimizing the goal function, the number of TMS points jammed exceeds half of their total number. (Only in this case the TMS becomes inoperable.)

The decision order R is as follows: each agent chooses its feasible actions and reports them to the Principal. The Principal analyzes the whole situation and approves the actions proposed by the agents or corrects them by a command; after that, the set N can be treated as a single player. The opponent acts similarly, thereby determining the outcome (value) of the antagonistic game and the players' payoffs [19].

3.2 Queuing Organizational Systems

As the second extended example of an OS, we select queuing organizational systems (QOSs). This class of OSs was introduced in a series of papers [20–24]. Here:

N is the set of active agents who serve an incoming flow of requests. The Principal is the management of the service organization.

A is the set of links between agents arising in the service process.

I_i is the information available to agent i about the goals and capabilities of other agents (especially the Principal) and the principles of their decision-making.

U_i is the set of feasible actions of agent i related to the service process (the values of service intensity and quality).

The Principal assigns a service discipline and determines the capacity of service units (e.g., through expenditures for their purchase and maintenance), the staff, structure, and skill levels of agents, as well as the numerical parameters of administrative and economic mechanisms for managing agents.

S_i is the set of strategies of agent i. As in the case of special-purpose OTSs, the Principal's strategies are control mechanisms with feedback by agents' actions. However, degenerate control mechanisms without feedback are also possible, e.g., normative regulations. The strategies of the other agents can either coincide with their actions (open-loop strategies) or depend on the state of the controlled system (closed-loop strategies) or on the actions of other agents (strategies with control feedback).

$x = (x_1,\ldots, x_m) \in X$ is the state vector of the QOS, which includes as main variables the time interval between successively arriving requests and the service time of one request; m is the number of all state variables under consideration. These variables may differ for particular service units. The derived variables are the waiting time for a request and the idle time of the service units. It is also possible to introduce additional variables reflecting the specifics of a particular QOS.

F is a general rule of changing the QOS state. It is defined by the distribution laws of the above random variables and their parameters.

J_i is the payoff functional of agent i (the difference between his/her income and the cost of labor effort and skill development). The Principal's main goal in the QOS is to keep a balance between the waiting time of a request in the queue and the idle time of the service equipment, which determines the viability of the system.

R is the order of decision-making in the QOS. Here, the key role is played by the mechanisms of administrative and economic management of the Principal; knowing them, service agents make their decisions.

Now consider the "railway station–marine port" QOS [20–24]. Figure 3.1 shows the structural diagram of such a QOS. The control authority (Principal) is represented by the Ministry of Transport of the Russian Federation, regional ministries of transport, or another body capable of coordinating the work of given railway station and marine port, by order of the government or by voluntary agreement of economic entities. Active subsystems (agents) are the management and personnel of the railway station and marine ports, which define the set N. The set A is demonstrated in Fig. 3.1.

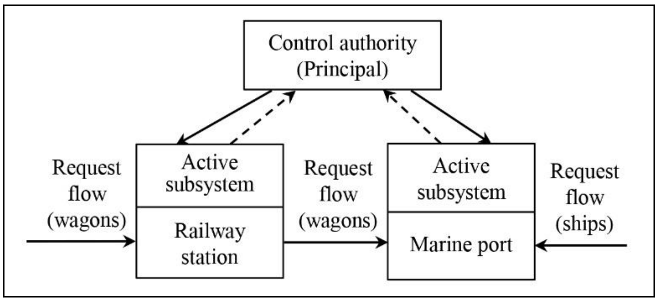

Fig. 3.1. The "railway station–marine port" QOS [24].

According to Fig. 3.1, this QOS contains two queuing subsystems: "wagon–port" (the left part of the figure) and "ship–port" (the right part of the figure). Let us begin with the "wagon–port" subsystem. Each wagon will be characterized by a set $w = \langle y, g, s, j, m, b, \omega \rangle$,

$y \in Y,\ g \in G,\ s \in S,\ j \in J,\ m \geq 0,\ b \in B,\ \omega \in \Omega,$

with the following notation: y is the wagon type from a set Y of different wagon types described by this model; g is the cargo kind from a set G of cargo kinds; s is the cargo type from a set S of cargo types; j is the batch number from a set J of batch numbers; m is the net weight of cargo in a wagon (if the wagon arrives for unloading) or the net weight of cargo required for loading (if an empty wagon arrives for loading); b is the attribute indicating the type of cargo operation with a given wagon (1—loading and 0—unloading, i.e., $B = \{0, 1\}$); ω is the train type of the wagon arrived, from a set Ω of train types under consideration.

The requests of the second ("ship–port") subsystem are the ships arriving at the port for cargo operations. Service units for these requests are berths with loading and unloading equipment.

We introduce the following set of characteristics for each ship:

$$\eta = \langle \tilde{G}, \tilde{S}, \tilde{J}, \Phi, l \rangle .$$

Here, $\tilde{G} \subset G$ is a set of transported cargo kinds; $\tilde{S} \subset S$ is a set of transported cargo types; $\tilde{J} \subset J$ is a set of cargo batch numbers; l is the ship length; $\Phi : \tilde{G} \times \tilde{S} \times \tilde{J} \to \mathbb{R}^{+} \times B \times \mathbb{N}$ is a mapping that specifies the ship loading structure, i.e., for each triple (g, s, j) is assigns a triple (m, b, d), where $m \in \mathbb{R}^{+}$ is the weight of cargo of the gth kind and the sth type in the jth batch on the ship to be unloaded (loaded), $b \in B$ is the type of cargo operation (loading or unloading), and $d \in \mathbb{N}$ is the natural number specifying the order of cargo operation with the given cargo. The state variables x and their change rule F were described in detail in [20–23].

The dynamic hierarchical control model of the QOS has the following form [21–23]:

$$H(s_1, s_2) = \int_0^T \Big[k_1 s_1(t) V\big(y_1(t)\big) + k_2 s_2(t) y_2(t) - d s_1^{\gamma}(t) - d s_2^{\gamma}(t) \Big] dt, \tag{3.1}$$

$$C_1(y_1, s_1) = \int_0^T \Big[c_1 y_1^{\frac{1}{\alpha}}(t) - k_1 s_1(t) V\big(y_1(t)\big) - c_3 x_1(t) p_1 - P \Big] dt, \tag{3.2}$$

$$C_2(y_1, s_1) = \int_0^T \Big[c_2 y_2^{\frac{1}{\beta}}(t) - k_2 s_2(t) y_2(t) - c_4 x_1(t) p_2 - k_3 Q\big(y_2(t)\big) \Big] dt, \tag{3.3}$$

$$s_1 = \big(s_1(t_0),\ s_1(t_1), \ldots,\ s_1(T)\big), \quad s_2 = \big(s_2(t_0),\ s_2(t_1), \ldots,\ s_2(T)\big), \tag{3.4}$$

$$c_1 = \big(c_1(t_0),\ c_1(t_1), \ldots,\ c_1(T)\big), \quad c_2 = \big(c_2(t_0),\ c_2(t_1), \ldots,\ c_2(T)\big), \tag{3.5}$$

$$s_1^{\min}(t) \leq s_1(t) \leq s_1^{\max}(t), \quad y_1^{\min}(t) \leq y_1(t) \leq y_1^{\max}(t), \tag{3.6}$$

$$s_2^{\min}(t) \le s_2(t) \le s_2^{\max}(t),$$
$$y_2^{\min}(t) \le y_2(t) \le y_2^{\max}(t), \qquad (3.7)$$

$$x_1(t) = x_1(t-1) + y_1^{\max}(t) - y_2(t), \qquad (3.8)$$

$$x_2(t) = x_2(t-1) + y_1(t) - y_2(t-1)\,; \qquad (3.9)$$

$$V(y_1(t)) = \begin{cases} \dfrac{y_1(t)}{w_1}, & \mathrm{mod}(y_1, w_1) = 0 \\ \dfrac{y_1(t)}{w_1} + 1, & \mathrm{mod}(y_1, w_1) > 0, \end{cases} \qquad (3.10)$$

$$Q(y_2(t)) = \begin{cases} \dfrac{y_2(t)}{w_2}, & \mathrm{mod}(y_2, w_2) = 0 \\ \dfrac{y_2(t)}{w_2} + 1, & \mathrm{mod}(y_2, w_2) > 0. \end{cases} \qquad (3.11)$$

Here, H , and C_1, C_2 are the profit functions of the Principal and agents for time *t*; $s_1(t)$ is the Principal's control action for agent 1 (a railway transport company) at time *t* (i.e., the price of renting a docking place for railway customers); $s_2(t)$ is the Principal's control action for agent 2 (port) at time *t* (i.e., the port fee paid when transporting goods); $y_1(t)$ is the control action of agent 1 (i.e., the amount of goods sent from the company's warehouse to the port); $y_2(t)$ is the control action of agent 2 (i.e., the amount of products sent as delivery from the port warehouse); $x_i(t)$ is the amount of cargo not delivered to the final consumer by agent *i*; $c_i(t)$ is a penalty coefficient; p_1, p_2 are price coefficients; P is additional costs; α, β, γ are tuning parameters; finally, k_1, k_2, k_3 are coefficients for dimensionality matching [20–22].

Model (3.1)–(3.11) describes the elements J_i and U_i of the general model (1.1). The order of functioning R is as follows. The Principal selects its control actions $s_1(t), s_2(t)$ and reports them to the agents. Knowing the Principal's control actions, the agents simultaneously and independently choose the values of their control actions $y_1(t), y_2(t)$, respectively. Thus, the strategies of the agents and the Principal coincide with their actions (the dynamic Germeier game Γ_{1t}) ; the mutual awareness I_i of the players has been described as well.

3.3 Ecological-Economic Organizational Systems

The third extended example of a class of OSs is ecological-economic organizational systems (EEOSs). Control mechanisms for EEOSs with the specifics of their controlled subsystems were described in the monographs [25, 26] and papers [27–30]. In general, the components of EEOSs can be characterized as follows.

N is the set of agents (exploiters of natural resources) associated with an ecosystem forming the environmental basis of the ecological-economic system under consideration. These include enterprises of manufacturing, agriculture, recreation, transportation, and other economic sectors located in the territory of the ecosystem (or adjacent to its water area) as well as the local population. The Principal is the public administration of the territory.

A is the set of transport, economic, and administrative links between agents.

I_i is the information available to agent *i* about the actions and payoff functions of the other agents (especially the Principal).

U_i is the set of feasible actions of agent *i*. The Principal assigns permissible quotas for the exploitation of natural resources (fishing, logging, mining, etc.) and maximum permissible concentrations (emissions) of pollutants in the environment, as well as the numerical parameters of economic regulation mechanisms (taxes, fines, benefits, or subsidies). Economic agents choose production outputs, product prices, and the parameters of environmental protection measures.

S_i is the set of strategies of agent *i*. As a rule, the Principal's strategies are control mechanisms with feedback by the actions of agents. In particular, when considering opportunistic behavior, the control system has a feedback loop by the amount of agents' bribes, paid to the Principal, e.g., to relax environmental requirements or allocate additional resources. However, control mechanisms without feedback are also possible, such as legislative regulations. The strategies of other agents can either coincide with their actions (open-loop strategies) or depend on the state of the controlled system (closed-loop strategies) or on the actions of other agents (strategies with control feedback).

$x = (x_1, ..., x_m) \in X$ is the state vector of the ecological-economic system. It seems natural to divide its components into two subsets describing the ecological and economic subsystems of the EEOS, respectively.

F is a general rule of changing the EEOS state. In fact, it also consists of two parts: first, material balances and production functions describing economic activity; second, the rules of changing the values of ecological indicators. In turn, the second part is subdivided into the description of the natural dynamics of the environment and its anthropogenic change (pollution, exploitation of natural resources, environmental protection, etc.).

J_i is the payoff functional of agent *i*. Here, as active agents, we consider economic entities: their payoff is profit after the deduction of environmental protection costs and possible ecological penalties. The Principal has two criteria: economic growth in the territory and compliance with ecological requirements.

R is the order of decision-making in the EEOS. The main role here is played by the Principal's mechanisms of administrative and economic control, reported to the agents. Knowing these mechanisms, economic agents make their decisions.

Now we take an EEOS arising in fishery management [31]. Here, active agents are fishing enterprises and the Principal is an environmental authority. The links are limited by the Principal's impact on the agents. The latter maximize the goal functionals

$$J_i = \int_0^T e^{-\rho t}\{av_i(t)P(t) - s_i(t)M[P(t)-P^*]^2\}dt \qquad (3.12)$$
$$-e^{-\rho T}s_i(T)M[P(T)-P^*] \to \max$$

under their control constraints (the permissible actions of agents)

$$q_i(t) \le u_i(t) \le r_i\ ,\ i = 1,\ldots,\ N, \qquad (3.13)$$

due to the bioresource dynamics equations

$$\frac{dP}{dt} = [\varepsilon - \beta P(t) + \alpha(\sum_i u_i(t))^\gamma$$
$$-\sum_i \alpha_i(r_i - u_i(t))^{\gamma_i}]P(t), \qquad (3.14)$$
$$P(0) = P_0,\ i = 1,\ldots,\ N$$

(the rule F of changing the scalar state variable $x = P$). Here, P_0, $P(t)$ are the initial and current values of the bioresource (fish population biomass), and P^* is its ideal value fully satisfying the population viability requirements. When violating the viability condition, the agents are penalized with a coefficient $M >> 1$; a is the unit price of fish biomass; ε is the natural growth coefficient of the fish population; β is the self-limiting coefficient; ρ is the discount factor; finally, α, γ are tuning parameters of the model.

A simplified linear version of model (3.12)–(3.14) was also considered in [31].

By assumption, each agent allocates his/her resource between social and private interests. Therefore, his/her payoff is made up of two components, namely, the income from the private activity and the share of damage from the social evil that the agents jointly fight against. Agents (fishing enterprises) $i = 1,\ldots,\ N$ maximize the income from fishing considering a possible penalty for violating the viability condition of the fish population. The viability condition (the Principal's control goal) is written as $\forall t\ P(t) = P^*$ or, in a weaker form, as $\forall t\ [P(t) - P^*]^2 \le \delta$.

The agent's control action $u_i(t)$ is the share of the resource r_i allocated to social needs. (Then $r_i - u_i(t)$ is the share of the resource allocated to the private activity.) In this model, $r_i - u_i(t)$ is the investment in increasing the fishing effort; then the share of fish caught by enterprise i is calculated as a function of the fishing effort: $v_i(t) = h_i(r_i - u_i(t))$. Without essential loss of generality, let $v_i(t) = k_i(r_i - u_i(t))^{p_i}$, $0 < p_i < 1$, where k_i, p_i are tuning parameters of the model. The value $u_i(t)$ is the allocations to improve sustainable fishery and fish farming.

Model (3.12)–(3.14) is an N-player differential game with the viability conditions incorporated into the goal functionals via the penalties $M[P(t) - P^*]^2$. The variables $s(t) = \{s_i(t)\}_{i=1}^N \in S$ are naturally interpreted as economic controls (impulsion) of the Principal as a top-level state control authority (e.g., the Fisheries Service) such that

$$0 \le s_i(t) \le 1,\ \sum_{i=1}^N s_i = 1;\ t \ge 0,\ i = 1,\ldots,N\ . \qquad (3.15)$$

The Principal can also use administrative control (compulsion) $q(t) = \{q_i(t)\}_{i=1}^N \in Q = \{0 \le q_i(t) \le r_i,\ t \ge 0\}$, selecting the values of the variables $q_i(t)$ from the condition

$$0 \le q_i(t) \le r_i,\ \ t \ge 0,\ \ i = 1,\ldots,\ N. \qquad (3.16)$$

The Principal's interests are supposed to be described by maximization of the following functional (the utilitarian social welfare function):

$$J = \sum_{i=1}^N J_i \to \max. \qquad (3.17)$$

Then model (3.12)–(3.17) is a hierarchical differential game between the Principal and several active agents of the lower control level. We make several assumptions concerning the order R of such a game: all players use open-loop strategies; the Principal chooses the economic (3.15) or administrative (3.16) control actions (functions of time only or those of time and the agents' control actions); in particular, the Principal assigns penalties; under known Principal's strategies, the agents simultaneously and independently choose their actions, which leads to a Nash equilibrium in the normal-form game of the agents [31]. All players, including the Principal, know their strategy sets and payoff functionals; the awareness of players regarding the strategy sets and payoff functionals of other players is determined by the rules of some Germeier game [6–8].

CONCLUSIONS

Traditional management as a science and TCO have the same object, i.e., control of organizations. However, the subject of management is organizational-economic and socio-psychological relations and control methods, and the subject of TCO is mathematical models, information technologies, and methods of their application in control of organizations. We emphasize that mathematical models in TCO are used exclusively as tools for solving control problems (building and improving control mechanisms) and not as abstract formal-logical constructs of pure mathematics to be studied. By the way, in the classifier of the State Commission for Academic Degrees and Titles of Russia (VAK RF), the first direction corresponds to specialty 5.2.6 "Management (economic sciences)" whereas the second to specialty 2.3.4 "Control in organizational systems (engineering)."

This paper has proposed a general mathematical model describing an organizational system from the standpoint of TCO. The construction of such a model and its application to the analysis and control of a particular organization or class of organizations allows referring this study to TCO (the description principle of OSs). Extended examples of some classes of OSs (special-purpose OSs, queuing OSs, and ecological-economic OSs) and their particular representatives have been provided and described in terms of the mathematical model proposed. Of course, the range of currently known control models of OSs (with active agents and a controlled subsystem of a certain nature) is much wider. In this context, we should mention production systems [32, 33], organizational and technical systems [33], project management [33], military operations [34], and others.

For the sake of simplicity, the model has been given in a deterministic formulation. The functioning of real OSs is inevitably accompanied by significant uncertain factors. In view of the problems addressed above, the consideration of uncertainty will only complicate the understanding. However, it undoubtedly forms the first important direction of further research.

The second natural direction of refining the model is to consider the bounded rationality of active agents (H. Simon, R. Heiner, R. Selten, D. Kahneman, A. Tversky, etc.).

The third direction is the study of OSs with multiple Principals (the case of distributed control) as well as multilevel OSs.

Note that the controlled subsystem of an OS can be of technical, biological, economic, or other nature. Considering the specifics of the controlled subsystem, determined by the characterization of its state, the rule of state change, and other elements of the model, is essential when designing and implementing control mechanisms for OSs. Despite the general character of the regularities of control processes and the structure of control mechanisms, in practice, it is impossible to control an OS successfully without understanding its technical and economic specifics. Therefore, the model description of the controlled subsystem dynamics and its viability conditions is crucial in TCO along with the consideration and coordination of interests of its active agents.

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REFERENCES

1. *Filosofskii entsiklopedicheskii slovar'* (Philosophical Encyclopedic Dictionary), Moscow: Sovetskaya entsiklopediya, 1983. (In Russian.)
2. Belov, M.V. and Novikov, D.A., *Methodology of Complex Activity: Foundations of Understanding and Modelling*, Cham: Springer, 2020.
3. Burkov, V.N. and Novikov, D.A., *Teoriya aktivnykh sistem: sostoyanie i perspektivy* (Theory of Active Systems: State-of-the-Art and Prospects), Moscow: SINTEG, 1999. (In Russian.)
4. Novikov, D., *Theory of Control in Organizations*, New York: Nova Science, 2013.
5. Germeier, Yu.B., *Vvedenie v teoriyu issledovaniya operatsii* (Introduction to the Theory of Operations Research), Moscow: Nauka, 1971. (In Russian.)
6. Germeier, Yu., *Non-antagonistic Games*, Dordrecht: D. Reidel Publishing, 1986.
7. Kukushkin, N.S. and Morozov, V.V., *Teoriya neantagonisticheskikh igr* (Theory of Nonantagonistic Games), Moscow: Moscow State University, 1984. (In Russian.)
8. Gorelik, V.A., Gorelov, M.A., and Kononenko, A.F., *Analiz konfliktnykh situatsii v sistemakh upravleniya* (Analysis of Conflict Situations in Control Systems), Moscow: Radio i Svyaz', 1991. (In Russian.)
9. Laffont, J.-J. and Martimort, D., *The Theory of Incentives: The Principal-Agent Model*, Princeton: Princeton University Press, 2002.
10. Ougolnitsky, G.A., *Upravlenie ustoichivym razvitiem aktivnykh sistem* (Sustainable Management of Active Systems), Rostov-on-Don: Southern Federal University, 2016. (In Russian.)
11. Ougolnitsky, G.A., Methodology and Applied Problems of the Sustainable Management in Active Systems, *Control Sciences*, 2019, no. 2, pp. 19–29. (In Russian.)
12. Ougolnitsky, G., Gorbaneva, O., Usov, A., et al., Theory of Sustainable Management in Active Systems, *Large-Scale Systems Control*, 2020, no. 84, pp. 89–113. (In Russian.)
13. Ereshko, F.I., Application of Hierarchical Games to Control Organizational Systems, *Trudy 14-go Vserossiiskogo soveshchaniya po problemam upravleniya* (Proceedings of the 14th All-Russian Meeting on Control Problems), Novikov, D.A., Ed., Moscow: Trapeznikov Institute of Control Sciences RAS, 2024, pp. 3314–3318. (In Russian.)
14. Slovokhotov, Yu.L., *Fizika obshchestva: Primenenie fizicheskikh modelei v opisanii obshchestvennykh yavlenii* (The Physics of Society: Application of Physical Models to the Description of Social Phenomena), Moscow: LENAND, 2024. (In Russian.)
15. Ougolnitsky, G. and Gorbaneva, O., Sustainable Management in Active Networks, *Mathematics*, 2022, vol. 10, no. 16, art. no. 2848.
16. Novikov, D.A. and Chkhartishvili, A.G., *Reflexion and Control: Mathematical Models*, Leiden: CRC Press, 2014.
17. Burkov, V.N., Enaleev, A.K., and Korgin, N.A., Incentive Compatibility and Strategy-Proofness of Mechanisms of Organizational Behavior Control: Retrospective, State of the Art, and Prospects of Theoretical Research, *Automation and Remote Control*, 2021, vol. 82, no. 7, pp. 1119–1143.
18. Shchepkin, A.V., Dynamic Active Systems with Far-sighted Elements. I. The Dynamic Model of an Active System, *Avtom. Telemekh.*, 1986, no. 10, pp. 89–94. (In Russian.)
19. Ugolnickiy, G.A. and Chepel, E.N., Game-Theoretic Approach to Managing the Composition and Structure of a Bearing-Only Measurement System in Conditions of A Priori Uncertainty, *Journal of Computer and Systems Sciences International*, 2024, vol. 63, no. 2, pp. 343–356.
20. Agiev, Kh.R., Model of Queuing in the System of Logistic Interaction of the Railway with the Seaport, *Engineering Journal of Don*, 2022, no. 6. URL: http://ivdon.ru/ru/magazine/archive/n6y2022/7733. (In Russian.)
21. Demenskiy, V.I., Malsagov, M.K., and Agiev, K.R., A Model of Interaction between Two Types of Transport in Multimodal

Transport, *Engineering Journal of Don*, 2023, no. 7. URL: http://ivdon.ru/ru/magazine/archive/n7y2023/8528. (In Russian.)

22. Agiev, Kh.R., Malsagov, M.Kh., Ougolnitsky, G.A., Dynamic Models of the Coordination of Interests of the Active Participants of Logistic Interactions. Part 1, *Sistemy Upravleniya i Informatsionnye Tekhnologii*, 2024, no. 1 (95), P. 31–36. (In Russian.)
23. Agiev, Kh.R., Malsagov, M.Kh., Ougolnitsky, G.A. Dynamic Models of the Coordination of Interests of the Active Participants of Logistic Interactions. Part 2, *Sistemy Upravleniya i Informatsionnye Tekhnologii*, 2024, no. 3 (97), pp. 30–34. (In Russian.)
24. Agiev, Kh.R., Queuing Organizational System “Railway - Marine Port,” *Engineering Journal of Don*, 2025, no. 4. URL: http://www.ivdon.ru/ru/magazine/archive/n4y2025/10019. (In Russian.)
25. Burkov, V.N., Novikov, D.A., and Shchepkin, A.V., *Control Mechanisms for Ecological-Economic Systems*, Cham: Springer, 2015.
26. Ugol’nitskii, G.A., *Upravlenie ekologo-ekonomicheskimi sistemami* (Control of Ecological-Economic Systems), Moscow: Vuzovskaya Kniga, 1999. (In Russian.)
27. Mazalov, V.V., Rettieva, A.N. Asymmetry in a Cooperative Bioresource Management Problem, *Large-Scale Systems Control*, 2015, no. 55, pp. 280–325.
28. Rettieva, A., Cooperation Maintenance in Dynamic Discrete-Time Multicriteria Games with Application to Bioresource Management Problem, *J. of Computational and Applied Mathematics*, 2024, vol. 441, no. 8, art. no. 115699.
29. Grune, L., Kato, M., and Semmler, W., Solving Ecological Management Problems Using Dynamic Programming, *J. of Economic Behavior and Organization*, 2005, vol. 57, no. 4, pp. 448–473.
30. Fanokoa, P.S., Telahigue, I., and Zaccour, G., Buying Cooperation in an Asymmetric Environmental Differential Game, *J. of Economic Dynamics and Control*, 2011, vol. 35, no. 6, pp. 935–946.
31. Sukhinov, A.I, Ougolnitsky, G.A., and Usov, A.B., Methods of Solving the Theoretic Game Models for Coordinating Interests in Regulating the Fishery Industry, *Mathematical Models and Computer Simulations*, 2020, vol. 12, pp. 176–184.
32. Burkov, V.N., Goubko, M.V., Kondrat’ev, V.V., Korgin, N.A., and Novikov, D.A., *Mechanism Design and Management: Mathematical Methods for Smart Organizations*, New York: Nova Science, 2013.
33. Belov, M.V. and Novikov, D.A., *Optimal Enterprise: Structures, Processes and Mathematics of Knowledge, Technology and Human Capital*, Boca Raton: CRC Press, 2021.
34. *Modeli voennykh, boevykh i spetsial’nykh deistvii* (Models of Military, Combat, and Special Operations), Novikov, D.A., Ed., Moscow: Lenand, 2025. (In Russian.)

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Author information

Ougolnitsky, Gennady Anatol’evich. Dr. Sci. (Phys.–Math.), Southern Federal University, Rostov-on-Don, Russia
✉ gaugolnickiy@sfedu.ru
ORCID iD: https://orcid.org/0000-0001-5085-5144

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Translated into English by *Alexander Yu. Mazurov*,
Cand. Sci. (Phys.–Math.),
Trapeznikov Institute of Control Sciences,
Russian Academy of Sciences, Moscow, Russia
✉ alexander.mazurov08@gmail.com