Simulation of optimal control of industrial corporations that produce complex dynamic systems engineering

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Abstract. In the article economic models to improve management efficiency by industrial corporations on the basis of scenario planning, management hierarchies Corporation. The role of business process reengineering in the formation of the integrated structures as a tool for the restructuring of the system of material, financial and information flows, aimed at reforming the organizational structure, optimizing the use of resources, improving the quality of products.

Keywords: management techniques hierarchical structures of industrial corporations, management of hierarchical systems with fuzzy inference, directions of reengineering of business processes.

1. Introduction

An important problem is the development of theoretical and methodological guidelines aimed at creating economic models to improve the effectiveness of management of industrial corporations on the basis of scenario planning, hierarchical structures of corporate governance, based on the generalization of experience of industrial corporations that have adopted new organizational and legal principles of operation. To solve this problem, you must identify the main areas of business process reengineering, to determine the most cost-effective and practically implemented quality criteria for optimal control of the hierarchical system of industrial corporations.

2. Statement of management tasks to create complex dynamic systems

The concept of an active system is used for modeling of complex objects that have a hierarchical structure. At the top level of the hierarchy is the control center. Managed elements are located at the following levels of hierarchy. A similar structure has, for example, holding structures. The control center has its own interests and goals, which it achieves through the organization of activities of lower level. In hierarchical systems, these elements can also have their own goals and have the freedom to achieve them. In this case, the elements are active. If an element of the hierarchical structure selects an action, most fully consistent with the objectives of the center, then in such systems operating principle of benevolence. Another extreme case can be a choice element of the hierarchical structure of the worst in terms of the center of the action. In hierarchical systems, the interests of all operating elements may be consistent [5], and may be inconsistent with one another. The presence of multiple targets in a system leads to a game situation [3]. Questions of optimum control of hierarchical systems are usually considered as part of game-theoretic modeling [3]. The desire to achieve several objectives in a hierarchical system classifies the problem of optimal control of a hierarchical system to the family of multi-criteria optimization problems.

When building of model of management of hierarchical system is necessary to define its constituent elements. Establishing a hierarchical structure of the system implies the establishment of links between elements of the system. By relations are control actions, exchange of information, the rights and duties of elements, as well as the hierarchy of subordination between the elements.

On the object system is given by a set of properties of the object and purpose of each property of the respective variable. The status of system is described by a vector of the variables $\mathbf{x}$, defined on some admissible set X. Each state is dependent on the availability of controlled and uncontrolled factors. Controllable factors to manage the impact of $\mathbf{u}$, as defined in the feasible set U. Uncontrollable factors $\mathbf{a}$ usually refers to the environment. The functioning of a hierarchical system is determined by a set of actions, rules and behavior of participant's algorithms. On set of rules defined by a system of state-dependent:

$$\mathbf{x} = B(\mathbf{u}, \mathbf{a}). \tag{1}$$

The effectiveness of the functioning of the system, from the position of the control center is defined by functionality:

$$F(\mathbf{x}, \mathbf{u}). \tag{2}$$

Management efficiency corresponds to the value of the functional Eq. (2):

$$J(\mathbf{u}) = F(B(\mathbf{u}, \mathbf{a}), \mathbf{u}). \tag{3}$$

The elements of the hierarchical structure also have their own criteria for the behavior described objective function:

$$f_i(\mathbf{x}, \mathbf{a}), \quad i = \overline{1, I}. \tag{4}$$

Rational choice of action elements of the hierarchical structure maximizes (minimizes) the objective functions Eq. (4). The control center selects the control action so that the elements of the hierarchical structure, taking into account their interests and preferences to work towards maximizing (minimizing) the center of the objective functional Eq. (3).

The control center can have full information about the patterns of behavior elements of the hierarchical structure [2]. In this case there is a non-manipulable control mechanism. With incomplete information submitted by the center, say to the manipulated control mechanism.

Scheduling tasks in hierarchical systems involve transmission of information from the elements to the center of the hierarchical structure. Based on the information center of the action plan elements of the hierarchical structure, maximizing the function of the target center. Scheduling problem has the form:

$$\begin{aligned} &J(\mathbf{p}, \mathbf{v}) = F(\mathbf{p}, \mathbf{v}) \to \max, \\ &f_i(\mathbf{x}, \mathbf{v}, \mathbf{a}) \to \max_x, \end{aligned} \tag{5}$$

where $\mathbf{v} = (v_i)$, $i = \overline{1, I}$ – a vector of messages from elements of hierarchical structure to the center.

The problem Eq. (5) can be regarded as multi-criteria optimization problem of the form:

$$Y_j(\mathbf{X}) \to \min, \quad j = \overline{1, m}. \tag{6}$$

3. Model of optimum control of difficult dynamic systems

The considered system is hierarchical, with horizontal and vertical communications. In system are available the managing center with the global purpose and the elements of lower level having the local purposes. For identification of optimum strategy for the long-term period of time it is necessary to construct model of similar production association and to formulate criteria of development.

We will accept that productive activity of elements of hierarchical system is described by production functions of $Y = F(\mathbf{X})$ where Y – output; $\mathbf{X}$ – a vector of the production resources providing production [7].

We assume that as resources are the following properties of the production elements:

x – the amount of fixed assets or capital;

L – the amount of labor resources;

q – the amount of funds allocated for the improvement and modernization of production (funds for scientific and technological progress);

r – the additional resource allocated by the operating center (means of the centralized financial fund).

In the modelled system there are N elements of a hierarchical structure. Funds from implementation of products are allocated for expansion and improvement of production, for consumption and for contributions to centralized fund.

We will present a production function of each ith of an element in the following form:

$$F_i = \varphi(q_i)\psi(r_i)[x_i + P_i(\mathbf{Y})]^{\alpha_i} L^{\beta_i}, \quad i = \overline{1, N}. \tag{7}$$

Products of other elements used in production are determined by expression:

$$P_i(\mathbf{Y}) = \sum_{j=1, j\neq i}^{N} w_{ij} Y_j, \tag{8}$$

where Y_j – the element jth products used in case of production in ith an element; w_{ij} – products utilization rates (horizontal communications between production elements).

The function considering increase in release of machine-building products due to use of funds for scientific and technical progress registers in the form of:

$$\varphi(q_i) = 1 + a_q {q_i}^{\gamma_q} \exp\left(-\frac{E_q}{q_i}\right), \tag{9}$$

where $(a, \gamma, E)_q$ – the coefficients characterizing technological capabilities. For example, the coefficient of E_q characterizes a system capability to innovations. This coefficient is responsible for some threshold of means, after achievement which manifestation of effect of investment of capital in production improvement begins. If to make a physical analogy, then E_q – energy of activation.

A similar view has a function that is responsible for the development of the production of the ith element of the centralized fund:

$$\psi(r_i) = 1 + a_r (\chi(N) r_i)^{\gamma_r} \exp\left(-\frac{E_r}{\chi(N) r_i}\right). \tag{10}$$

By increasing the number of production elements may decrease the effectiveness of control or misuse of the additional resources that takes into account the function:

$$\chi(N) = \frac{1}{1 + a_N N^{\gamma_N}}. \tag{11}$$

Coefficients α_i, β_i are also parameters of the system. The growth of fixed assets or capital of business units is determined by the part of the manufactured products $S_i^1 F_i$. The decrease is related to the depreciation of fixed assets $\mu_i x_i$. Part of the funds from the sale of products $u_i F_i$ sent to the central fund. Another part of the funds spent on the purchase of products from other elements $P_i(\mathbf{Y})$. As a result, we obtain the equation for the growth of capital items in the form of:

$$\frac{dx_i}{dt} = S_i^1 Y_i - \mu_i x_i - P_i(\mathbf{Y}) - u_i Y_i, \quad i = \overline{1, N}. \tag{12}$$

Increase in the volume of funds allocated for the improvement and modernization of production depends on the share of the output $S_i^2 F_i$, aimed at scientific and technological progress:

$$\frac{dq_i}{dt} = S_i^2 Y_i, \quad i = \overline{1, N}. \tag{13}$$

The initial conditions for the Eqs. (12), (13):

$$x_i(0) = x_i^0, \quad q_i(0) = q_i^0, \quad i = \overline{1, N}. \tag{14}$$

Another part of the $S_i^3 F_i$ is directed to the consumption of a given element. As part of the proceeds from the sale of products $u_i F_i$ is sent to the central fund, we have the following condition:

$$\sum_{k=1}^{3} S_i^k + u_i = 1, \quad i = 1, N. \tag{15}$$

Additional resources centralized fund R is distributed between the production elements in such a way that the:

$$\sum_{i=1}^{N} r_i \leq R. \tag{16}$$

As already noted, the purpose of the control center is the growth of the consolidated profit of the hierarchical structure and capitalization in the long term. The following target functionalities can act as criteria of development:

$$\sum_{i=1}^{N} u_i Y_i(T) - \sum_{i=1}^{N} r_i \to \max, \tag{17}$$

$$\sum_{i=1}^{N} x_i(T) \to \max. \tag{18}$$

Each element of a hierarchical structure can have the purposes as matching the purposes of the center for the direction, and opposite. One of criteria of behavior of a production element is the maximum increase in amount of the made products by the end of the considered planning period of time of T:

$$Y_i(T) \to \max, \quad i = 1, N. \tag{19}$$

Other criteria can be a maximum of consumption at the time of T:

$$S_i^3 Y_i(T) \to \max, \quad i = 1, N, \tag{20}$$

or the maximum mean-for this time of consumption:

$$\int_0^T S_i^3 Y_i(t)dt \to \max, \quad i = \overline{1, N}. \tag{21}$$

The operating center at the order has two sets of managing directors of influences. One group corresponds to "whip", the other – the "cake". "Cake" is understood as allocation of elements of hierarchical structure of means of "yyy" from the centralized fund (condition Eq. (16)). Second hand center takes the business units of the funds from the sale of products (control u_i, $i = \overline{1, N}$). This center can set the same for all elements of the hierarchical structure of rates $u_i = const$, and maybe a differentiated approach to each element. In this case there can be elements – "donors" and subsidized elements. Another control parameter is a center mounted them volume centralized fund R.

Business Unit to achieve their goals share the manufactured product into three parts. The first part of the S_i^1, $i = \overline{1, N}$ is the expansion of production facilities, the second part of the S_i^2, $i = \overline{1, N}$ is directed to the improvement of production (technological progress), the last part of the S_i^3, $i = \overline{1, N}$ is given to the consumption of the condition Eq. (15).

Therefore, we have the following multiple objective task of optimum control of hierarchical structure. The path of development of system is described by differential Eq. (12), (13) with the phase variables:

$$X = (x_i, q_i), \quad i = \overline{1, N}, \tag{22}$$

and with boundary conditions Eq. (14). Production processes are described by functions Eqs. (7)-(11).

The choice of control actions:

$$U = (r_i, u_i, S_i^1, S_i^2, S_i^3, R), \tag{23}$$

when performing conditions Eqs. (15), (16) there is an optimum trajectory of development providing achievement of the objectives of the center (criteria Eqs. (17), (18)) and respect for interests of elements of hierarchical structure in the form of maximizing criteria Eqs. (19), (21).

To solve this problem, we introduce a differential grid in time $t^k = k\tau$, $k = \overline{0, K}$, $\tau = T/K$ [7]. The phase variables Eq. (7) X^k are the numerical solution of Eqs. (6, 7, 14) for the explicit Euler scheme with recalculation. Control actions are taken as constant throughout the planning period of time $t \in [0, T]$. The multiextreme problem of optimization is solved with the help of a genetic algorithm capable to solve problems of multiextremeness of objective functions.

4. Development of model of management of creation of difficult dynamic systems based on hierarchical systems with fuzzy inference

Multipurpose optimal control problem for a hierarchical structure consisting of N production elements and control center, described by a system of differential equations.

If the value of the state order $Y_i^{S0}(t) = G$ is not a given function of time, then there is uncertainty associated with the external environment. A probabilistic representation of the value of the state order requires the specification of a probability distribution. Set any statistics in this area is not practically feasible. Therefore, the situation must be described using the theory of capacity, based on the concept of fuzzy sets [1, 4]. Theory features allows you to simultaneously model the imprecision and to quantitatively characterize uncertainty.

The state order will be presented using fuzzy numbers [6]. Values of the state order can be compared the fuzzy numbers with triangular function of membership $G = (G^0; \Delta_l G; \Delta_r G)$. For fuzzy numbers are defined rules of addition, multiplication, and division:

$$G_1 \pm G_2 = (G_1^0 \pm G_2^0; \Delta_l G_1 + \Delta_l G_2; \Delta_r G_1 + \Delta_r G_2),$$
$$G_1 \cdot G_2 = (G_1^0 \cdot G_2^0; \Delta_l G_1 \cdot G_2^0 + \Delta_l G_2 \cdot G_1^0; \Delta_r G_1 \cdot G_2^0 + \Delta_r G_2 \cdot G_1^0),$$
$$G_1 : G_2 = \left(\frac{G_1^0}{G_2^0}; \frac{\Delta_l G_1 \cdot G_2^0 + \Delta_l G_2 \cdot G_1^0}{(G_2^0)^2}; \frac{\Delta_r G_1 \cdot G_2^0 + \Delta_r G_2 \cdot G_1^0}{(G_2^0)^2}\right). \quad (24)$$

For the values of the function of the fuzzy number we define the rule:

$$f(G) = \left(f(G^0); \frac{\partial f(G^0)}{\partial G} \Delta_l G; \frac{\partial f(G^0)}{\partial G} \Delta_r G\right). \quad (25)$$

Suppose, for some $\mathbf{x}$ received limit value $B_i = \phi_i(\mathbf{x})$, calculated according to the rules Eq. (26), as well as the left and right borders $\Delta_l B$, $\Delta_r B$. The degree of inequality is $\psi = 1$ if $B_i + \Delta_r B \leq 0$ and $\psi = 0$ if $B_i - \Delta_l B \geq 0$. A fuzzy set of restrictions defined by the membership function:

$$\psi(\mathbf{x}) = \begin{cases} 0, & |B - \Delta_l B \geq 0, \\ 1 - \dfrac{(B + \Delta_r B)^2}{\Delta_r B(\Delta_l B + \Delta_r B)}, & |B < 0, \\ \dfrac{(B + \Delta_l B)^2}{\Delta_l B(\Delta_l B + \Delta_r B)}, & |B \geq 0, \\ 1, & |B + \Delta_r B \leq 0. \end{cases} \quad (26)$$

In the presence of fuzziness in the coefficients of the optimal control problem arises the problem of achieving fuzzy defined goal. The solution of a problem to achieve of fuzzy defined goal based on the way the Bellman-Zadeh [1]. If some alternative x ensures the achievement of goal with the degree of $\varphi(x)$, and restrictions are performed with a degree of $\psi(x)$, then decision of the task of achieving fuzzy defined goal is the intersection of fuzzy sets goals and constraints with membership function:

$$\mu(x) = \min[\varphi(x), \psi(x)]. \quad (27)$$

In our case, the alternatives are understood by the possible values of the control parameters. To control actions, include: investments made in the expansion of production; funds allocated for the improvement and modernization of production; funds of consumption; funds for marketing consumer products. Control of production development is also exercised of the choice of credit policy of the entity, i.e. sizes of the credits. The center exercises control through the size of contributions to centralized fund and through the centralized credits.

If we make the normalization of the objective function, then normalized function can be regarded as a function of fuzzy set goal:

$$\varphi(\mathbf{x}) = \frac{F(\mathbf{x})}{F^{\max}(\mathbf{x})}. \quad (28)$$

The value function $\varphi(\mathbf{x})$ determines the degree of achievement of goal when choosing alternatives. In accordance with the principle of achieving fuzzy defined goals Bellman-Zadeh objective function for fuzzy programming problem takes the form of:

$$\Phi(\mathbf{x}) = \max_x \min[\varphi(\mathbf{x}), \psi_i(\mathbf{x})]. \quad (29)$$

For comparison, the objective function – fuzzy number contained in accurate via centroid method. For the triangular type membership functions to bring the fuzzy number

$z = (z^0; \Delta_l z; \Delta_r z)$ to accurate in the following manner:

$$\hat{z} = z^0 - \Delta_l z + \sqrt{\frac{\Delta_l z(\Delta_l z + \Delta_r z)}{2}}. \quad (30)$$

Formulated fuzzy problem of optimal control is solved numerically using the above algorithm.

5. Conclusions

The role of business process reengineering in the formation of the integrated structures as a tool for the restructuring of the system of material, financial and information flows, aimed at reforming the organizational structure, optimizing the use of resources, improving the quality of products. It is shown that in a business reengineering of fundamental importance is the coherence, complementarity and interdependence.

The model of corporate governance as a hierarchical system with a dominant center, establishing control actions so that the elements of the system, taking into account their interests and preferences acted in the direction of an extremum of target functionality of the center. Installed versions of the interaction of elements of the corporate system with the control center in order to achieve parity of interests.

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