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MODEL OF ADAPTIVE CONTROL OF COMPLEX ORGANIZATIONAL STRUCTURES

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Abstract: This research work deals with the problem formulation of control of complex organizational structures. The mechanism of functioning of such systems is described by example of a vertically integrated company (VIC). The problems of strategic and operative control of VIC are considered. The methods for solving such problems based on genetic algorithms and neural networks are suggested. A new iterative procedure for coordination of strategic and operative control goals based on the estimation of imbalance between shareholder value and net profit distributed for payment of dividends to shareholders is suggested. The considered system is a double criterion optimization problem with complex multiparameter restrictions.

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1. Introduction

Figure 1 presents the general classification of existing control systems of complex organizational structures (corporate systems).

As a rule, for corporate systems there are four levels of managerial decisions and levels of relevant systems:

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Structure and composition of the corporate control system

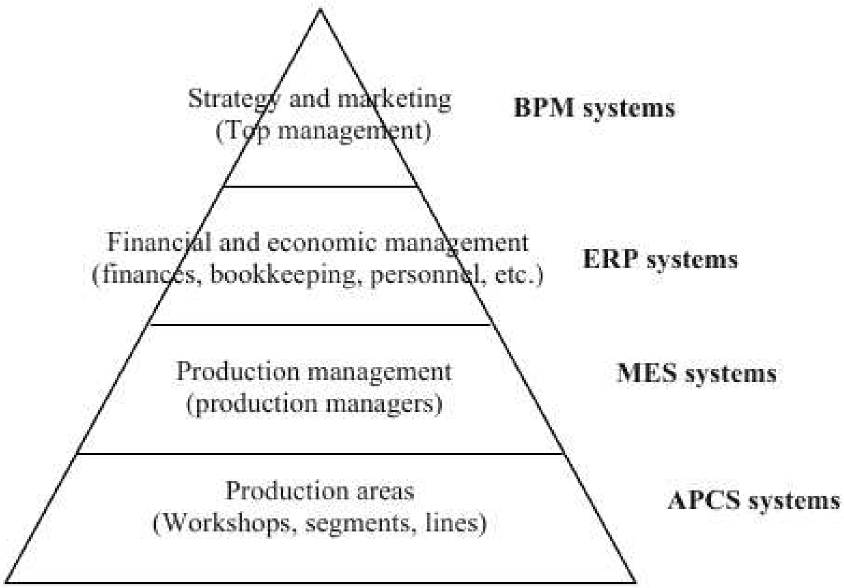

Figure 1: General classification of existing corporate control systems

- APCS (Automatic Process Control Systems) – collecting and processing of primary technological information;
- *MES systems* (manufacturing execution systems) – operative production (process) management;
- *ERP-systems* – operative financial and administrative management;
- *BPM-systems* – strategic forward planning aimed at increase of business economic efficiency.

An important feature of the corporate control system is the integration of all its subsystems (Figure 1), i.e. for the formation of high-level strategic decisions the knowledge of data from all low levels is needed. Consequently there arises an intricate problem of controlling a very large pool of data flows including all units of an organizational structure. Solving this problem requires the construction of corporate data warehouse integrated with computer models of system units and the development of the required integration software.

The upper level of the system hierarchy is taken by *BPM systems*. Such systems allow to solve the most important strategic problems of the company, e.g. to maximize its shareholder value by various restrictions and scenario conditions.

It should be noted that the main difficulties for complex organizational structures are connected with the development of *BPM system*. To ensure functioning of such systems the aggregated data from the set of separate low-level data sources (APCS, MES, ERP and others) are needed. And with it an important feature of *BPM systems* is that as a rule they *are intelligent systems* and can include developed system-dynamic simulated models of company units integrated with genetic optimization algorithms, neural networks and multidimensional data warehouse for decision support ([1]-[4]).

It should be noted, for instance, that for oil companies *BPM systems* are developed by subdivisions of largest service companies such as Schlumberger Information Solutions (Merak Peep, Merak Volts, Merak Capital Planning, Merak FloMatic and others). Therewith the up-to-date methods of computer simulation are used. For instance, the well known project strategic management system of an oil company Merak Capital Planning uses *Monte Carlo* methods and the technology of *genetic algorithms*[1] for the optimization of portfolio of investment projects by various scenarios. As an example the certain software products of Landmark Graphics Corporation (a subdivision of the Halliburton Company) can also be taken. As a subsystem of dynamic simulation for ensuring the efficient scenario planning they use information solutions *Powersim Studio*[2].

The initial data for BPM systems are downloaded into the data warehouse from various low-level systems (Figure 1): MES systems, ERP systems, APCS. Therewith to extract data from sources and to download them into warehouse the *ETL* technology is used (Extract, Transform and Load). The *ETL* applications extract the information from the initial database, convert it into the required format supported by the database and then download the converted information into it.

The necessity of the data warehouse is stipulated by the very large dimension of problems solved by complex organizational structures (e.g., to make efficient investment decisions a large oil company must analyze several thousands of alternative investment projects by hundreds of oilfields, thousands of wells, etc.).

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[1] http://www.slb.com/content/services/software/valuerisk/campaign_portfolio_management_faq.asp?#j

[2] http://www.powersimsolutions.com/LandmarkGraphics.aspx

Besides, the support of operative managerial decision requires the presence of more detailed qualitative initial information (e.g., daily data of oil production for each well) as therewith the problems of monitoring and control of production equipment operating practices can be solved.

It should be noted that the preparation of strategic decisions and their realization is more inertial and long-dated (e.g., as a rule large companies form their investment and finance plans once a year and it concerns the planning horizon of 5 - 20 years). Therewith the characteristics influenced by the made strategic decisions are also more inertial (e.g., the process configuration of an oil refinery will not be changed more frequently than once a year). Thus, the strategic decisions are oriented to the support of the mechanism of the company‘s long-term development, for example, to the maximization of its shareholder value due to efficient investment capital management.

In contrast to the strategic decisions the operative ones are less inertial and short-dated (e.g., the values of equipment operating practices can vary during the day at the month production plan). However du to the execution of level limits of VIC units the smaller persistence of operative control parameters does not lead to the destabilization of system functioning and to its transition into qualitatively different state. Thus, the persistence principle remains. The operative decisions are oriented to the support of the mechanism of the company‘s short-term and medium-term development, for example, to the maximization of its annual profit due to efficient control of production characteristics.

It should be noted that the problems of operative control can be in conflict with the problems of strategic control. In particular, it is well known that for a short-term interval the complete distribution of net profit for payment of dividends to shareholders without reinvestments into basic capital and postponement of payment for external loans is more beneficial. However, in the longer term (3 - 5 years) such a strategy results in reduction of profitability of the company’s assets and decline of the shareholder value.

It should be noted that the persistence principle in both problems is not applied, but the strategic choice must be harmonized wit the operative one and there must be no large mismatch between goals of strategic and operative control.

It should be also mentioned that the problems of strategic and operative control are interrelated. The operative control is realized within the internal faster time. The results of strategic planning are input indexes (particularly, parameters of restrictions) in the problem of strategic control. In its turn the results of operative control specify a new initial state for the problem of strategic control. Consequently the strategy of an organizational structure can be corrected.

As mentioned above the strategic control is focused on the solution of the most important problem on an organizational structure, such as shareholder value maximization, essential market share increase, assets expansion, etc. The solution of such problems for large systems is connected with certain difficulties, mainly they are computing problems. Therewith there is a class of heuristic algorithms, in particular, *genetic algorithms* ensuring an efficient procedure of solution search in such problems. The advantage of genetic algorithms for problems of strategic control is the possibility of controlled selection of efficient strategic decisions by means of their iterative recombination. The genetic algorithm allows to make approximate solutions meeting goals of strategic control, e.g. to maximize the company's shareholder value evaluated at extended planning horizon. Therewith the essential part of initial data is as a rule negligible. For instance, for long-term planning under unstable and unpredictable macroeconomic circumstances the aggregated demand structure, the final production value and the investment policy are considerably more influential than the efficiency of company calculations, the tax policy and operative production decisions. It should be noted that the use of genetic algorithms can result in solutions leading to fundamental changes of the system state: For instance, asset restructuring, redistribution of financial and material flows between system units, etc. Such solutions leading to qualitative system change can be implemented just by strategic control (i.e. at extended planning horizon). An important note is that as a rule the application of genetic algorithm does not require the collection of whole historical data array. Of course, for long-term predictions of goal factors (such as the company's shareholder value) the historical data is used for the prediction of influential characteristics (e.g., production volume and prices for products). However the work of genetic algorithm does not depend on the retrospective information as during the search for solutions the data are used only within simulated time (i.e., horizon of strategic planning). In fact such data can also be received by expertise. It is especially urgent at extended planning horizons (over 15 years) when the fundamental change of environment and system state is possible.

In contrast to the strategic control the operative one is focused on the solution of essentially larger group of non-key problems (e.g., control of operating practices, control of financial flows, daily logistics, etc.) but the important ones for ensuring the stability of system functioning. The complexity is that during the operative control it is necessary to process very large pools of data flows describing the actual system state and to make decisions quite quickly (operative). And with it the inadequate decisions are too expensive, e.g., the role of production risks increases. Therefore it is necessary to use more precise algorithms supporting the mechanism of efficient object control. In particular, such algorithms are *artificial neural networks* providing the possibility of nonlinear dynamics simulation of object behavior. The advantage of neural networks for problems of operative control is the possibility of their self-regulation (adaptive learning) for processing of the whole initial information array (both useful and ”white noise”) with practically “instantaneous” (i.e., during one iteration) formation of response functions, particularly, in the form of parameters of operative managerial decisions. As a result the preparation of operative decisions requires minimum timing budgets (under the stipulation that the neural network is previously taught, e.g., by using the reference simulation model) and is implemented without initial information loss (i.e., the neural network performs the “filter” function). It should be noted that as a rule the use of neural networks does not lead to the solutions fundamentally changing the system state. The neural network can be tuned to the soft correction of system sate, e.g., in the line of minimization of actual value deviation error of annual profit from the relevant planned value. The neural network can autonomously ”study” static and dynamic properties of the controlled object on the basis of measurement results performed in the past and then act in such a way to make a better decision at an unknown environment state. For the operative control an important problem is the problem of *control* of dynamic characteristics of organizational structure (e.g., budgetary control, tax control, etc.) and the choice of optimal correction actions. Therewith the neural network can perform the function of *neural controller* in the control system of a real object, in particular, it can signal about exceeding of limit values for observed characteristics and form correction actions under various external conditions.

An important feature of complex organizational structures is their rigidity (resistance) in relation to control actions. For instance, changing of the company's organizational structure (particularly, connected with shutdown of notpaying businesses) can be connected with social restrictions and consequently with the impossibility of quick implementation of planned changes. Under such conditions the development of precise mathematical models and algorithms of decision making proves to be unreasonable. And with it the artificial neural network can be taught in such a way to take into account similar latent system features when making operative decisions.

The combination of usage of genetic algorithms [7], [8] and neural networks [11], [12] as well as methods of system dynamics [6] during designing of intelligent control systems allows to support efficient strategic and operative managerial decisions.

Hereunder the problem of strategic control will be considered by example of a vertically integrated company (VIC).

2. Problem of Control of Complex Organizational Structures

At the beginning let's describe the problem of *control of complex organizational structures*. One of the most important problems of complex organizational structures is the problem of maximization of net discounted cash flow which as a rule characterizes the estimated (non-marketable) volume of the shareholder value, in the first place, due to efficient investment capital management. For large companies the investment portfolio as well as the value added activity depending on it has a complex structure characterized by the presence of considerable number of shareholder value "drivers". Therefore the problem of the shareholder value maximization belongs to the class of very large dimension and is characterized by the problem of uncertainty in choice of efficient control parameters. In its turn it leads to the necessity to choose system units of the highest priority and their elements for the primary extended evaluation of organization performance and aggregated system control. For instance, in works ([1]-[4]) an extended model of the shareholder value evaluation of a vertically integrated oil company with the separation of oil production section was developed. This model allowed, by using the *Monte Carlo* method [9] and live data of an oil company, from the preliminary list of factors (formed with account of exclusion of the multicollinearity and heteroscedasticity problem) to reveal dominant factors essentially influencing the results of activity and to reduce hereby the initial dimension of the problem. Nevertheless even for identified directions the large dimension of the problem remains during the subsequent system decomposition. For instance, to optimize the portfolio of projects only of the oil production section by N- oilfields the exhaustion 2^N of variants of the formation of investment projects portfolio should be performed completely (as a rule, values $N$are in the range from 300 to 3000). The additional complexities arise in consequence of the necessity of accounting of project interdependences. Therewith for the system consisting of units the group of the very important control variables $\gamma^t_{i_{j_k},j_k,k} \in \{1;0\}$**- matrix elements of investment projects cutoffs**, where t- time (by years), $t = 1, 2, ..., T$; k- index of a unit of a vertically integrated company, $k = 1, 2, ..., K$; j_k - index of enterprises being a part of the structure of k-unit a vertically integrated company, $j_k = 1, 2, ..., J_k$; i_{j_k}- index of investment project of j_k-enterprise, $i_{j_k} = 1, 2, ..., N_{j_k}$can be marked out. Thus, the total amount of projects in the portfolio makes$\hat{\vartheta} = \sum_{k=1}^{K} \sum_{j_k=1}^{J_k} N_{j_k}$.

It should be noted that hereinafter the roman bold type will indicate control parameters in considered problems and models of VIC units, the bold italics will indicate parameters whose values are calculated in other problems and models in relation to the considered one.

Let's consider a very important problem of VIC for the maximization of its shareholder value described in detail in the work [1].

Problem I. *It is necessary to build up a group of control parameters* $\{\gamma^t_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)}$ *by which the maximum value of the shareholder value of VIC is assured*

$$DCF \to \max_{\{\gamma^t_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)}}, \tag{1}$$

and the execution of the system of VIC level limits.

Here DCF is the shareholder value of VIC.

The problem solution consists in searching such variants of the formation of investment portfolio by which the volume of VIC shareholder value will be maximal.

It can be shown that the considered problem belongs to the class of *NP-hard problems* of combinatorial optimization. For this purpose it is enough to prove that the problem comes to it for the polynomial time whose NP-completeness is already proved, in particular, one may state that the problem of maximization of VIC shareholder value is close to the well known NP-hard one-dimensional optimal packing problem or to the knapsack problem [5].

As Problem I also belongs to the class of NP-hard problems of high dimensional discrete optimization the application of precise methods of solution searching is impossible. For such problems the approximate solution methods should be applied, in particular, genetic algorithms, ant colony algorithm, greedy algorithms, etc. The feature of the considered problem is that there is a system of competitive limits described in detail in the work [1] (e.g., minimal oil production plan, limit of investment costs, etc.) which work both on the level of the system in whole and on the level of units as well as there are nonlinear feedback links between characteristics of system units. This leads to that the considered problem of the optimization of values of control parameters $\{\gamma^t_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)}$ can not be divided into sub-problems so that the sequence of locally optimal choices would give a globally optimal solution. Hereupon, for the approximate solution of this problem the optimization algorithms of the class of "greedy algorithms", dynamic programming, branch and bounds method proves to be less efficient (because of the nonlinear interdependency of projects related to different VIC units and the very large dimension of the problem). The neural networks are also inapplicable as under the lack of the statistic database for previously implemented projects it is impossible to assure the procedure of efficient network teaching. Therefore the most efficient solution is using of genetic algorithms. Such algorithms are intended for searching of solutions in very large and complicated search spaces. The feature of genetic algorithm (GA) is the emphasis on the use of crossing-over operator performing the operation of recombination of candidate solutions whose role is similar to the crossing-over role in wildlife. In works ([1]-[3]) it is shown that under conditions of the very large dimension of the problem the modification of classic GA, the application of dedicated rules of fading selection, as well as parallelizing of calculations for search efficiency increase is required. Therewith a special attention should be paid to the problem of GA stability and convergence. It should be mentioned that for the first time the genetic algorithm was suggested by J. Holland [8] in 1975 and developed by other scientists [1], [7], [10], etc. later on.

3. Model of Adaptive Control of Complex Organizational Structures

The developed model of adaptive control of complex organizational structures, in particular, vertically integrated companies (VIC) is based on two important aspects:

- the procedure of strategic control;
- the procedure of operative control;

as well as two important assumptions.

For the strategic control the first assumption is used - this is a *hypothesis about persistence of processing and resource characteristics*. When forming the company's investment strategy this allows to specify exogenously the dynamics of production and sales characteristics and to use econometric methods for the prediction of values of such characteristics. A common example is the accounting of predictable oil production volume which can be calculated for 15 - 20 years ahead on the basis of oil reserves data in certain oilfields and wells. The long-term dynamics of demand and prices for oil and oil products as well as average prices can also be predicted on the basis of macroeconomic data. When forming the investment strategy the different scenarios of development of macroeconomic circumstances can be taken into account. As a rule the number of such scenarios is small (conditionally 3 - 4 scenarios).

The goal of the procedure of VIC strategic control is the shareholder value maximization due to efficient investment capital management.

And with it when using the econometric approach for long-term prediction of processing and resource characteristics the facilities of VIC in reaching the better internal efficiency due to optimal control of operative parameters within internal (fast) time are not taken into account. This happens because within the standard econometric models it is difficult to take into account the complex system of internal feedback links and the activity of system elements particularly expressed as a weakly controlled aspiration of organization's management for profits even to the prejudice of strategic development.

The goal of the procedure of VIC operative control is the maximization of annual net profit distributed for payment of dividends to shareholders due to efficient control of resource, processing and pricing characteristics.

For the operative control the second assumption is used - this is the *principle of coordination of strategic and operative control goals*.

Such system requires coordination of the choice of short-term strategy of resource and processing control (focused on the maximization of annual net profit distributed for payment of dividends to shareholders) and long-term strategy of investment development (focused on the share capital maximization).

A common example of balancing feedback links in such a system ensuring the possibility of transfer to coordinated state is the reinvestment into basic capital and technologies of VIC from annual net profit. The increase of reinvestment part in net profit leads to the reduction of the rest of net profit directed to payment of dividends to shareholders. On the other hand such an increase can lead to the increase of resource base (fixed assets, human resources, market share, etc.) what will allow to increase profits of future periods and accordingly the shareholder value. The mechanism of transfer to coordinated state in such a system is only assured under the presence of appropriate control actions of decision makers (e.g., shareholders) and taking into account that the feedback link between reinvestments and profit of future periods is strictly positive (i.e. current investments result in the increase of profit for the next time periods).

It should be noted that within such coordinated system the feedback link between results of long-term development investment strategy and short-term strategy of resource and processing control is of nonlinear cyclic nature. The redistribution of cash flows from investment activity results in changes of requirements to characteristics of operative control system. On the other hand the correction of values of operative control parameters leads to the necessity of investment strategy reappraisal as certain predetermined (i.e. previously specified for the first cycle iteration) values of resource and processing characteristics are changing.

The following groups of control parameter can be marked out in the considered system:

- the group of strategic control parameters (e.g., annual investments, capital structure, reinvestment part in profit, etc.). Such parameters realize the high-level (strategic) control mechanism; in particular, they can maximize the shareholder value of VIC. Therewith the strategic control model has the most inertial temporal granularity (as a rule, by years).
- the group of operative control parameters (e.g., operating practices of raw material extraction and processing plants, daily prices for products and others). Such parameters realize the low-level (operative) control mechanism; in particular, they can maximize the net profit of VIC distributed for payment of dividends to shareholders. The operative control model is realized within the internal faster time (as a rule, by days).

It should be noted that as a rule in such systems the algorithm of *multistage (cyclic) optimization*, in particular, at the beginning (at the first cycle iteration) by certain predetermined values of characteristics of low-level (operative) VIC units, as well as by a certain predetermined value of reinvestment part of profit into VIC projects the company's shareholder value is maximized and the optimal values of the group of high-level (strategic) control parameters becoming exogenic parameters for the low (operative) level at the next step. At the next cycle iteration realized within the internal faster time and by fixed values of high-level (strategic) parameters the search for optimal values of the group of operative control parameters at the whole strategic planning horizon is performed which provide the maximization of annual profit distributed for payment of dividends to shareholders.

Thereafter the imbalance between shareholder value and net profit distributed for payment of dividends to shareholders is estimated. To coordinate the short-term strategy of resource and processing control and the long-term strategy of investment development the value of reinvestment part of net profit into VIC projects (Figure 2) is recalculated in the line of elimination of this imbalance.

Then, at the next step, the received optimal values of operative control parameters and the new value of reinvestment part of profit are transferred to the high (strategic) level.

The procedure of iterative calculations continues until the state of complete concordance between the current annual profit distributed for payment of dividends to shareholders and the shareholder value formed by the cash flow of

Optimization in the control system of VIC

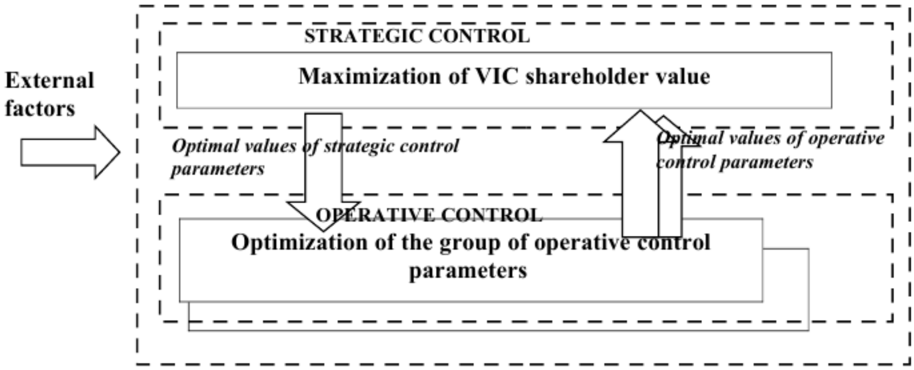

Figure 2: General chart of multistage optimization in the control system of VIC

future periods is reached. The criterion of algorithm stop can be the achievement of the sufficiently small value of imbalance evaluation between strategic and operative control strategies.

It should be noted that the considered system is essentially influenced by the so-called external (macroeconomic) factors most of which as a rule are non-stationary. For instance, the sharp oil price fall can lead to investment capital deficit for VIC and, consequently, it requires the redistribution of material and financial flows at the level of system units.

The considered system is a double criterion optimization problem with complex multiparameter restrictions.

So, the designed control system of VIC (Figure 2) consists of two interacting subsystems:

1. the subsystem of strategic control providing the solution of strategic control problem;

2. the subsystem of operative control providing the solution of operative control problem.

Subsystem of Strategic Control

At the initial instant of time t_0 for long-term planning horizon T ($T \gg 1$ year) by a certain predetermined value of reinvestment part of profit $\{\alpha^t\}$ at output of *the subsystem of strategic control* the optimal values of investment portfolio are formed which are the input values for the subsystem of operative control:

- $\{\hat{\gamma}^t_{i_{j_k},j_k,k}\}^{(t_0+T)}_{t=t_0}$ – optimal values of investment portfolio, $\hat{\gamma}^t_{i_{j_k},j_k,k} \in \{0;1\}$, by $\hat{\gamma}^t_{i_{j_k},j_k,k} = 0$- investments into i_{j_k}- project of j_k- enterprises of k-unit are excluded, and by $\hat{\gamma}^t_{i_{j_k},j_k,k} = 1$ - investments are made.

Here, t is slow time (by years) $t = t_0, t_0+1, ..., t_0+T$; T is planning horizon; $k$is index of a unit of a vertically integrated company, $k = 1, 2, ..., K$; j_k is index of an enterprise being a part of the structure of k-unit of a vertically integrated company $j_k = 1, 2, ..., J_k$; $i_{j_k}$is index of investment project of j_k-enterprise, $i_{j_k} = 1, 2, ..., N_{j_k}$

Subsystem of Operative Control

At each instant of internal fast time τ_t, $t = t_0, ..., t_0 + T$ at output of *the subsystem of operative control* the optimal values of three groups of operative control parameters $\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}$, $\hat{I}^{\tau_t}_{i_{j_k},k}$, $\hat{p}^{\tau_t}_{g_{j_k},k}$ are formed. Here, z_{j_k} is the list of operative control parameters of j_k-enterprises of k-units of VIC; $\tau_t$is fast (internal) time, $\tau_t = 1, 2, ..., st$, $(st = 365\text{days})$; $c = 1, 2, 3$ are categories of operative control parameters (=1 – technological parameters, = 2 – pricing parameters, = 3 – resource parameters); $g_{j_k} = 1, 2, ..., G_{j_k}$are product indexes of j_k-enterprises of k-units of VIC.

- $\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,1}\}^{st}_{\tau_t=1}$ – daily technological operative control parameters (operating practices of production, plant configurations, etc.) influencing the output of g_{j_k}-products in k-units of VIC;

- $\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,2}\}^{st}_{\tau_t=1}$ – daily pricing operative control parameters (prices of raw materials and intermediate product, manufacturing and human resources, etc.) for g_{j_k}-products in k-units of VIC;

- $\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,3}\}^{st}_{\tau_t=1}$– daily resource operative control parameters (number of employees, fixed assets, etc.) influencing the output of g_{j_k}-products in k-units of VIC;

- $\{\hat{I}^{\tau_t}_{i_{j_k},k}\}^{st}_{\tau_t=1}$– daily investments into i_{j_k}-projects of j_k-enterprises of k-units;

- $\{\hat{p}^{\tau_t}_{g_k,k}\}^{st}_{\tau_t=1}$ – daily price of g_{j_k}-end products at output of j_k-enterprises of k-units of VIC.

Coordination of Strategic and Operative Control Goals

At each instant of time $t = t_0, ..., t_0 + T$ after solving the problems of strategic and operative control the imbalance between shareholder value and profit distributed for payment of dividends to shareholders is estimated. Thereafter the value of reinvestment part of profit is recalculated.

$$\alpha^{t,q} = \alpha^{t,q-1} - \beta D^{t,q-1},$$

where $D^{t,q-1}$ is the imbalance between shareholder value and profit distributed for payment of dividends to shareholders; β is a sufficiently small number, $q = 1, 2, ...Q$is the iteration index; $Q = [1/\beta]$ is the number of iterations - (where [] means an integral part of the number).

Thereafter it comes back to the high-level (strategic) control problem with transfer of new values $\{\alpha^{t,q}\}_{t=t_0}^{(t_0+T)}$ and $\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}$, $\{\hat{I}^{\tau_t}_{i_{j_k},k}\}^{st}_{\tau_t=1}$, $\{\hat{p}^{\tau_t}_{g_{j_k},k}\}^{st}_{\tau_t=1}$ as exogenic parameters.

Hereunder the problems of strategic and operative control of complex organizational structures will be considered by example of a vertically integrated company.

3.1. Problem of Strategic Control

The problem of strategic control of VIC is to choose such a structure of investment portfolio which allows to reach the maximal value of VIC shareholder value.

Suppose the source of investment capital of VIC is only made up by own funds (a part of profit from the prior period distributed for projects of VIC units).

It should be noted that to solve the strategic problem of VIC the values of optimal control parameters should be predetermined; they are calculated by using algorithm of "finding" of equilibrium between the choice of short-term and long-term development strategy. Such an algorithm is realized by means of special computational procedure ensuring the transfer to the state of constrained equilibrium between current shareholders' dividends and the company's shareholder value. At the first step of this algorithm the values of operative control parameters are predetermined and they are determined by econometric methods under the hypothesis of their persistence. At the next iterations they become endogenic.

Let's give a more formalized formulation of this problem.

Further the variables calculated as a result of solving the problem of operative control of VIC will be highlighted with bold italics. The variables for the problem of strategic control of VIC will be highlighted with bold upright font.

The important control parameter of the system $\{\alpha^{t,q}\}_{t=t_0}^{(t_0+T)}$ (reinvestment level of profit) by means of which the coordination of strategic and operative control goals occurs should be marked out separately.

It should be noted that the values of operative control parameters

$$\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}, \quad \{\hat{I}_{i_{j_k},k}\}^{st}_{\tau_t=1}, \quad \{\hat{p}^{\tau_t}_{g_{j_k},k}\}^{st}_{\tau_t=1}$$

are predetermined (by calculated standard statistical methods) for the first (initial) cycle iteration ($q = 0$) and they are formed at the previous step for all subsequent cycle iterations (by $q > 1$) at output of the subsystem of low-level (operative) control.

Further the following signs will be used:

π^t_k is annual profit of k-unit of VIC (before taxes and interests on credits) depending both on strategic and operative control parameters accordingly;

$\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}$ are three groups ($c = 1, 2, 3$) of operative control parameters;

$\{\hat{I}^{\tau_t}_{i_{j_k},k}\}^{st}_{\tau_t=1}$ are daily investments into i_{j_k}-projects of j_k-enterprises of k-units, $\sum\limits_{\tau_t=1}^{st}\sum\limits_{k=1}^{K}\hat{I}^{\tau_t}_{i_{j_k},k} = \alpha^{t,q}\sum\limits_{k=1}^{K}\pi^{t-1}_k + I^t_{out}$, where $\alpha^{t,q}$is a factor of net profit reinvestments $0 \le \alpha^{t,q} \le 1$, $q = 1, 2, ..., Q$; $I^t_{out}$are external investments – *exogene*;

$\{\hat{p}^{\tau_t}_{g_{j_k},k}\}^{st}_{\tau_t=1}$ are prices for end products of j_k-enterprises of k-units;

DCF_k is a discounted cash flow (shareholder value) of k-unit of VIC;

I^t_k, $?^t_k$, O^t_k, P^t_k, V^t_k are key (calculated) characteristics of k- units of VIC. investments, operating expense, cash flow from operations, profit, production volume of conditional product;

$\bar{?}^t$, $\underline{O}^t$, $\underline{DCF}$, $\underline{P}^t$, $\underline{V}^t$ are parameters of corporate limits (maximum permissible values of investments, operating expense and minimum permissible values of cash flow from operations, discounted cash flow, profit and production volume of conditional product) – *exogene*;

$\bar{I}^t$ is a limit of investment costs equal to the amount of net profit reinvestments and external investments I^t_{out} being exogenic (because of *i nvestment capital deficit* the maximum possible amount of finance available on the foreign market for this VIC is obtained).

$h^t_{i_{j_k},j_k,k}$ are investments into i_{j_k}-projects of j_k-enterprises of k-units of VIC – *exogene*;

$r*$ is a discount rate – *exogene;*
r_{out} is interest rate for external investment mobilization – *exogene;*
$t = t_0, t_0 + 1, ..., t_0 + T$ is slow time (by years);
$\tau_t \in \{1, 2, .., st\}$ is fast time (by days), $st = 365$ days of the year.

Problem I. *At each initial instant of time t_0 for planning horizon T it is necessary to build up a group of strategic control parameters $\{\gamma^t_{i_{j_k},j_k,k}\}^{(t_0+T)}_{t=t_0}$ by which the maximum value of VIC shareholder value is assured.*

$$\sum_{k=1}^{K} DCF_k \to \max_{\{\gamma^t_{i_{j_k},j_k,k}\}^{(t_0+T)}_{t=t_0}}, \tag{2}$$

where

$$\left(DCF_k = \begin{array}{l} \sum\limits_{t=t_0}^{t_0+T} \frac{[\pi^t_k(\{\gamma^t_{i_{j_k},j_k,k}\}^{(t_0+T)}_{t=t_0}, \{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}, \{\hat{I}^{\tau_t}_{i_{j_k},k}}{\tau_t=1^{st}, \{\hat{p}^{\tau_t}_{g_{j_k},k}\}^{st}_{\tau_t=1})]} (1+r*)^t - \\ - \sum\limits_{t=t_0}^{t_0+T} \frac{\sum_{j_k=1}^{J_k} \sum_{i_{j_k}}^{N_{j_k}} \gamma^t_{i_{j_k},j_k,k} h^t_{i_{j_k},j_k,k}}{(1+r*)^t} - \sum\limits_{t=t_0}^{t_0+T} \frac{I^t_{out} r_{out}}{(1+r*)^t} \end{array} \right), \tag{3}$$

$$t = t_0, 2, ..., t_0 + T, \quad c = 1, 2, 3, \quad k = 1, 2, ..., K, \quad \tau_t \in \{1, 2, .., st\},$$
$$j_k = 1, 2, ..., J_k, \quad i_{j_k} = 1, 2, ..., N_{j_k}, \quad g_{j_k} = 1, 2, ..., G_{j_k}$$

by execution of the following corporate limits at each instant of time $t \in \{t_0, 2, .., t_0 + T\}$:

balance of investment costs:

$$\sum_{k=1}^{K} I^t_k = \sum_{k=1}^{K} \left[\sum\nolimits_{j_k=1}^{J_k} \sum\nolimits_{i_{j_k}}^{N_{j_k}} \gamma^t_{i_{j_k},j_k,k} h^t_{i_{j_k},j_k,k} \right] = \bar{I}^t; \tag{4}$$

$$\bar{I}^t = \alpha^{t,q} \sum_{k=1}^{K} \pi^{t-1}_k + I^t_{out}, \tag{5}$$

limit of operating expense:

$$\sum_{k=1}^{K} C^t_k \leq \bar{?}^t; \tag{6}$$

minimum required level of cash flow from operations:

$$\sum_{k=1}^{K} O^t_k \geq \underline{O}^t; \tag{7}$$

minimum level of net discounted cash flow:

$$\sum_{k=1}^{K} DCF_k^t \geq \underline{DCF} \quad ; \tag{8}$$

minimum level of profit (before taxes):

$$\sum_{k=1}^{K} \pi_k^t \geq \underline{P}^t; \tag{9}$$

minimum production volume of conditional product:

$$\sum_{k=1}^{K} V_k^t \geq \underline{V}^t; \tag{10}$$

and all limits of relevant units of VIC determined in the problem of operative control.

Here the parameters of corporate limits$\bar{I}^t$, $\bar{?}^t$, $\underline{O}^t$, $\underline{DCF}$, $\underline{P}^t$, $\underline{V}^t$ are exogenic and the rest of characteristics is calculated in the relevant models of VIC units for k-units.

It should be noted that $\{\hat{\lambda}^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}$, $\{\hat{I}^{\tau_t}_{i_{j_k},k}\}^{st}_{\tau_t=1}$, $\{\hat{p}^{\tau_t}_{g_{j_k},k}\}^{st}_{\tau_t=1}$ are optimal values of three groups of operative control parameters determined *by means of solving Problem II* which will be considered hereunder. These parameters are predetermined for the problem of strategic control, i.e. their prior values are calculated by econometric methods and then they are recalculated during the transfer to the system equilibrium state.

The feature of the considered problem is that characteristics of all VIOC units influencing on the shareholder value are calculated simultaneously at every point of simulated time$t \in \{t_0, .., t_0 + T\}$. In particular, the parameters of such characteristics in an oil company are: oil production volume, total transportation costs and supply structure, oil production volumes by types, demand and prices for oil products, etc. The most calculated characteristics and control parameters are multidimensional, i.e. they have regional, product and other dimensions depending on VIC unit they refer to.

3.2. Problem of Operative Control

The problem of operative control of VIC is to choose such operative control parameters (within internal fast time) by which the maximum annual profit of VIC is assured.

It should be noted that the variables calculated as a result of solving the problem of strategic control of VIC will be highlighted with bold italics. The variables for the problem of operative control of VIC will be highlighted with bold upright font.

It should be noted that the values of operative control parameters

$$\{\hat{\gamma}^{t}_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)}$$

are formed at the previous step, at output of the subsystem of strategic control.

Problem II. *For all periods of external (slow) time* $t \in \{t_0, ..., t_0+T\}$ *it is necessary to build up three groups of operative control parameters*

$$\{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}_{\tau_t=1}^{st}, \quad \{I^{\tau_t}_{i_{j_k},k}\}_{\tau_t=1}^{st}, \quad \{p^{\tau_t}_{g_{j_k},k}\}_{\tau_t=1}^{st}$$

by which the maximum value of annual profit of VIC distributed for payment of dividends to shareholders is assured

$$\sum_{\tau_t=1}^{st}\sum_{k=1}^{K}(1-\alpha^{t,q})\pi_k^{\tau_t} \to \max_{\{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,c}\}_{\tau_t=1}^{st},\ \{I^{\tau_t}_{i_{j_k},k}\}_{\tau_t=1}^{st},\ \{p^{\tau_t}_{g_{j_k},k}\}_{\tau_t=1}^{st}}, \tag{11}$$

$$\left(\begin{array}{l} \pi_k^{\tau_t} = \sum\limits_{j_k=1}^{J_k}\sum\limits_{g_{j_k}=1}^{G_{j_k}} {}^{\tau_t}v_{k,g_{j_k}}\left(\begin{array}{l}\{\hat{\gamma}^{t}_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)},\{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,1}\}_{\tau_t=1}^{st},\\ \{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,3}\}_{\tau_t=1}^{st},\{I^{\tau_t}_{i_{j_k}}\}_{\tau_t=1}^{st}\end{array}\right)p^{\tau_t}_{g_{j_k},k} - \\ -\sum\limits_{j_k}^{J_k} c^{\tau_t}_{j_k}(\{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,2}\}_{\tau_t=1}^{st},\{\lambda^{\tau_t}_{z_{j_k},g_{j_k},k,3}\}_{\tau_t=1}^{st} \end{array}\right., \tag{12}$$

$$\left.\pi_k^{t} = \sum_{\tau_t=1}^{st}\pi_k^{\tau_t} \text{ is anual profit of } k\text{-unit VIC}\right), \tag{13}$$

by execution of limits of level of VIC units at each instant of time $\tau_t \in \{1, 2, .., st\}$ *:*

limit of production volume of end products:

$${}^{\tau_t}v_{k,g_{j_k}}(\{\hat{\gamma}^{t}_{i_{j_k},j_k,k}\}_{t=t_0}^{(t_0+T)},\{\lambda^{\tau_t}_{k,z_{j_k},1}\}_{\tau_t=1}^{st},\{\lambda^{\tau_t}_{k,z_{j_k},3}\}_{\tau_t=1}^{st},\{I^{\tau_t}_{i_{j_k}}\}_{\tau_t=1}^{st}) \le x^{\tau_t}_{k,g_{j_k}}(p^{\tau_t-1}_{g_{j_k},k}); \tag{14}$$

limit of investment costs:

$$\sum_{\tau_t=1}^{st}\sum_{j_k}^{J_k}\sum_{i_{j_k}=1}^{N_{j_k}} I^{\tau_t}_{i_{j_k}} \le I_k^t; \tag{15}$$

minimum production volume of conditional product:

$$\sum_{\tau_t=1}^{st}\sum_{g_{j_k}}^{G_{j_k}} v_{k,g_{j_k}}^{\tau_t} \geq V_k^t; \tag{16}$$

limit of operating expense:

$$\sum_{\tau_t=1}^{st}\sum_{j_k}^{J_k} c_{j_k}^{\tau_t}(\lambda_{k,z_{j_k},2}^{\tau_t}, \lambda_{k,z_{j_k},3}^{\tau_t}) \leq C_k^t; \tag{17}$$

$$k = 1, 2, ..., K, \quad t = 1, 2, ..., T, \quad \tau = 1, 2, ..., st.$$

and other limits of level of VIC units at each instant of time having intelligible physical meaning and determined in relevant components of the designed system.

Here:

$\sum\limits_{\tau_t=1}^{st}\sum\limits_{k=1}^{K}(1-\alpha^{t,q})\pi_k^{\tau_t}$ are dividends of VIC shareholders, $0 \leq \alpha^{t,q} \leq 1$, $q = 1, 2, ..., Q$;

$v_{k,g_{j_k}}^{\tau_t}$ is daily production volume of g-products at j-enterprises of k-units;

$x_{k,g_{j_k}}^{\tau_t}(p_{k,g_{kj}}^{\tau_t-1})$ is demand for end products of g-products of j-enterprises of k-units depending on previous prices $p_{k,g_{kj}}^{\tau-1}$;

$\{\hat{\gamma}_{i_{j_k},j_k,k}^{t}\}_{t=t_0}^{(t_0+T)}$ are optimal values of investment portfolio calculated by solving Problem I.

From the formulation of Problems I-II it follows that there is an obvious cyclic dependence between subsystems of strategic and operative control. An with it, according to the formulation of Problem II the solutions received during the operative control must be coordinated with the previously formed strategic solutions, to be more precise they should not be worse. If as a result of operative control the better aggregated values of VIC performance factors are received the problem of strategic control is solved anew to gain more adequate evaluation of the shareholder value.

It should be noted that Problem II belongs to the class of NP-hard problems of very high dimensionality. But due to the temporal granularity it is necessary simultaneously to consider the aggregate of decisions at horizon of 360 steps of fast internal time. Therefore to solve the problems of such class the special algorithms should be applied which support the mechanism of adaptive control based on the neural network.

Problem II also belongs to the class of NP-hard problems of very high dimensionality and is solved by using the special class of genetic algorithms.

3.3. General Computational Procedure of Coordination of Strategic and Operative Control Goals

As mentioned above when solving the problems of strategic and operative control there should be the coordination of the choice of short-term strategy of resource and processing control (focused on the maximization of annual net profit distributed for payment of dividends to shareholders) and long-term strategy of investment development (focused on the share capital maximization).

For this purpose a special computational procedure ensuring the possibility of solution of Problem I - II as a result of transfer to coordinated state by reinvestment part characteristic of net profit $\alpha^{t,q}$ was developed.

It should be noted that within the developed procedure for solving problems of strategic and operative control the special algorithms of the class of genetic algorithms (GA) and artificial neural networks (ANN) should be applied accordingly. It should be recalled that the application of GA for the solution of the considered problem of strategic control is stipulated by the very large dimension of the problem and the presence of complex nonlinear dependences between characteristics of VIC units. The application of ANN for the solution of the operative control problem is also stipulated by the larger dimension of the problem (because of internal fast time) and the presence of considerable number of non-homogenous control parameters with complex non-stationary dynamics.

Let's describe this procedure formally.

General Procedure of Coordination of Strategic and Operative Control Goals

1. Let's define the number of iterations - $Q = [1/\beta]$ (where [] means an integral part of the number, $\beta$is a sufficiently small number), iteration index - $q = 1, 2, ...Q$.

2. For each instant of time τ_t for planning horizon st for all periods of external (slow) time $t \in \{t_0, ..., t_0 + T\}$ three groups of operative control parameters$\{\lambda^{\tau_t,q=1}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}$,$\{I^{\tau_t,q=1}_{i_{j_k},k}\}^{st}_{\tau_t=1}$, $\{p^{\tau_t,q=1}_{g_{j_k},k}\}^{st}_{\tau_t=1}$should be formed

by using the standard econometric methods.

3. For each instant of time t at planning horizon T the initial values of operative control parameters $\{\gamma^{t,q=1}_{i_{j_k},j_k,k}\}^{(t_0+T)}_{t=t_0}$ should be formed by using standard methods of efficiency estimation of investment projects (e.g., by setting $\gamma^{t,q=1}_{i_{j_k},j_k,k} = 0$ if net present value of the project $NPV^t_{i_{j_k},j_k,k} \leq 0$; and with it the initial reinvestment part in profit $\alpha^{t,q=1} = \alpha^{t-1}$).

4. By using the algorithms of the class of genetic optimization algorithms, Problem I is solved for the determination of *optimal strategic control parameters* $\{\hat{\gamma}^{t,q=1}_{i_{j_k},j_k,k}\}$ *by which the maximum value of VIOC shareholder value* $DCF^{q=1} = \sum\limits_{k=1}^{K} DCF^{q=1}_k$ *is assured.*

5. By using the algorithms of the class of neural networks, Problem II is solved for the *determination of optimal values of operative control parameters*$\{\hat{\lambda}^{\tau_t,q=1}_{z_{j_k},g_{j_k},k,c}\}^{st}_{\tau_t=1}, \{\hat{I}^{\tau_t,q=1}_{i_{j_k},k}\}^{st}_{\tau_t=1}, \{\hat{p}^{\tau_t,q=1}_{g_{j_k},k}\}^{st}_{\tau_t=1}$ *by which the maximum value of profit distributed for payment of dividends to shareholders* $(1-\alpha^{t,q=1})\sum\limits_{k=1}^{K}\pi^{t,q=1}_k$ *is assured.*

6. Calculate the initial value of imbalance evaluation between strategic and operative control: $D^{t,q} = a_1 DCF^{q=1} - a_2(1-\alpha^{t,q=1})\sum\limits_{k=1}^{K}\pi^{t,q=1}_k$, where$a_1$, a_2 are normalization coefficients of values of shareholder value and net profit (exogenic), $a_1 > 0$, $a_2 > 0$, $a_2 >> a_1$.

7. Start the iterative procedure $q = 2, 3, ..., Q$:

8. For each instant of time t t calculate the increment:

$$\Delta\alpha^{t,q-1} = \beta D^{t,q-1}, \quad \alpha^{t,q} = \alpha^{t,q-1} - \Delta\alpha^{t,q-1}.$$

9. For each instant of time t calculate the new evaluation of imbalance: $D^{t,q}_k = a_1 DCF^q - a_2(1-\alpha^{t,q})\sum\limits_{k=1}^{K}\pi^{t,q}_k$, where

$$DCF^q = \sum_{t=t_0}^{t_0+T}\sum_{k=1}^{K}\frac{[\pi^{t,q}_k(\{\alpha^{t,q}\}) - \alpha^{t,q}\pi^{t,q-1}_k]}{(1+r*)^t}.$$

10. Repeat paragraphs 8-10 until $-\xi \leq D^{t,q} \leq \xi$ where ξ is a sufficiently small number$t = t_0, ..., t_0 + T$.

At the first step of this procedure the values of operative and strategic control parameters are predetermined and they are determined by econometric methods under the hypothesis of their persistence. At the next iterations they become endogenic.

It should be noted that in this procedure the number of iterations Q has an exponent not less than days of the year at the whole strategic planning horizon (e.g., 365 days x 10 years) as the values of annual profit calculated within internal faster time at certain instant of time $\tilde{t} \in \{t_0, ..., t_0 + T\}$ depend on investments made at all previous instants of time and accordingly they depend on all values$\{\alpha^{\tilde{t}-1,q}, \alpha^{\tilde{t}-2,q}, ...\alpha^{t_0,q}\}$. Thereat it is obvious that the number of iterations **Q** for good approximation to the quasi-equilibrium state depends on the value ofβ.

It should be noted that the introduced approach to VIC control:

- needs to take into account characteristics of key units of VIC;
- allows to control a very large pool of investment projects influencing the target function, in particular, the shareholder value;
- takes into account the system of competitive limits and preferences including all units of VIC;
- takes into account environmental factors in the mode of fast time und supports the mechanism of fast time system adaptation and it can be attributed to the class of *financial flows* at the level of system units;
- is implemented by using the special algorithms of the class of genetic algorithms (GA) and by using the parallelizing technique of calculations.

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