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TOPICAL ISSUE

Optimization and Simulation Approach to Determining Critical Combinations of Company Parameters

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Abstract—We propose an optimization-simulation method for determining combinations of influences that make it possible to remove an organizational and technical system from a potentially unfavorable state. We demonstrate the solution using the example of the inverse problem of stress testing mature companies in traditional industries of the real sector. A condition for a company to be in a potentially unfavorable state is a projected negative cash balance. To determine changes that improve the forecast, mathematical programming methods solve the problem of maximizing the benefits from such changes — the difference between the predicted cash balance and the costs of changes. The results obtained can be applied when solving issues of stabilization under risk conditions: pandemics, economic sanctions, natural disasters, etc. A model example is given.

Keywords: critical combination of events, unfavorable system state, stress testing, cash balance, crisis

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1. INTRODUCTION

Currently, massive sanctions pressure is pushing companies from various sectors of the economy into potentially unfavorable conditions. A number of such states can be considered pre-bankruptcy, when bankruptcy can be predicted, but there are resources to avoid it. The relatively small and inexpensive interventions that can be made using these resources can be seen as nudging the system toward states that are relatively safe or desired by the researcher. This consideration echoes the well-known theory of nudging, based on the works of D. Kahneman and A. Tversky [1, 2] and further by R. Theiler and K. Sunstein, [3–5]. In domestic works, this direction is also not ignored [6, 7].

However, we consider these ideas not only in the context of influencing human behavior, but also to influence the states and behavior of organizational and technical systems as a whole. Another key point we put forward is that individual impacts should be individually relatively small-scale and inexpensive. The thesis is that the strength and effectiveness of nudges is determined not so much by the amount of resources expended, but by the selection of a specific combination in which these resources will be used. Such combinations can be considered in a certain sense as critical, and the achievement of certain values by the corresponding parameters — as critical combinations of events [8–10]. The task of determining critical combinations is far from trivial; its solution will require both mathematical methods and algorithms, as well as experiments that must be carried out with mathematical models.

As a result, the required control actions for this should be aimed at synthesizing a new (updated) structure and parameters of the company. Updates may involve changing suppliers, consumers, logistics and other activities carried out by the company itself. In conditions of risks and limited resources, such activities require preliminary modeling. If the modeling results show that one's own resources are not enough, government assistance is required in the form of loans and subsidies. For the expedient distribution of such assistance, planning its type and volume, the solution of complexes of optimization and modeling problems is also required. As a result of solving these problems, recommendations are formed on the appropriate use of their resources by companies, their groups and industries to possibly reduce potential losses and, if necessary, on the method and amount of government assistance.

Due to the fact that the systems under study are of a hybrid nature, large and complex, to solve the identified problems it turns out to be necessary to use heterogeneous sets of models, including not only analytical ones, but also presented partly in the form of algorithms, rules, and heuristics. Modern information technology capabilities make it possible to quickly carry out both analytical and simulation calculations in these complexes. This approach constitutes a modern optimization and simulation paradigm [11, 12]. It seems to us that in conditions of increasing turbulence of the systems under study, in some cases it is advisable to go beyond the traditional plane in the direction of involving models of different natures in solving the same subtask, presenting the final results after their comparison and processing also in the form of data complexes.

In the optimization-simulation paradigm, both large-scale systems (industrial complex [13], region [14]) and individual enterprises [15] are studied. Moreover, in times of crises, the importance of the approach increases due to the new uncertainties and challenges introduced by transition processes [16]. Combined optimization and simulation models are used to analyze the possibilities of optimizing the activities of enterprises in the processes of mergers and acquisitions [17], and removing unprofitable enterprises from companies [18].

Researchers also note the insufficiency of using rigid mathematical models that do not follow an interdisciplinary approach to solve the problems identified to solve problems of managing large and complex systems [9]. Thus, a number of authors propose to predict the bankruptcy of companies using models based on deep learning [20], hybrid methods of particle swarm and support vector machines [21, 22]. Such models are designed to take into account, among other things, various legal, behavioral and economic issues in a financial crisis.

Below we propose a statement of the problem of determining a combination of scenarios that will allow us to bring the company out of a state that is unfavorable in terms of a given performance indicator, and an approach to solving this problem using a set of simulation problems and mathematical programming problems.

2. FORMAL STATEMENT OF THE PROBLEM

Let us assume that the value S is considered as a criterion for the efficiency of a company's activities for a certain period, the forecast value of which $S(X)$ at the end of the period under consideration can be determined using a well-known algorithm applied to a set of parameters and structure X.

For example, the balance of funds in the company's account at the end of this period can be considered as such an indicator. This value reflects the solvency of the organization, which is especially important in a difficult macroeconomic situation. Let the predicted value of $S(X)$ not satisfy the decision maker, for example, the predicted cash balance is negative.

It is required to determine scenarios for changing the parameters and structure of the system to increase the value of S. It is taken into account that changes in the parameters and structure of the system from X to X' will require certain costs, denoted as $R(X, X')$. Therefore, the possibility and feasibility of carrying out measures depends on whether such costs are allowed by the existing restrictions and how much the corresponding increase in S will exceed these costs. Thus, it is required to find such a structure of the system and values of parameters X' for which

$$S(X') - R(X, X') \longrightarrow \max, \tag{1}$$

where $S(X'), R(X, X')$ are analytically or algorithmically specified functionals: forecast of the value of S for a system with parameters and structure X' and costs of measures to change the structure and parameters of the company from X to X' respectively. Problem limitations:

$$R(X, X') \leqslant R, \tag{2}$$

$$y_i(X) = 0, \quad i \in I, \tag{3}$$

$$S(X') - R(X, X') > 0, \tag{4}$$

where R is the quantity that limits resources for changing the parameters and structure of the system, $y_i(X)$ is the relationship between the parameters and the structure of X, specified in analytical or algorithmic form, and the condition (4) means the feasibility of the required measures.

3. MATHEMATICAL MODEL FOR SOLVING THE PROBLEM

Let, as a result of a system analysis of the scheme for calculating the financial and economic indicators of a company, a set of control parameters $X_1, \ldots, X_n$ has been identified that determine S – the forecast of the company's target performance indicator:

$$S = F(X_1, \ldots, X_n), \tag{5}$$

where $F(X_1, \ldots, X_n)$ expresses the forecast value of the cash balance.

Let us further assume that the parameters $X_1, \ldots, X_n$ are available for change with coefficients in the intervals $K_1, \ldots, K_n$. We assume that these intervals are sufficiently small, so the corresponding changes can be carried out almost simultaneously; the influence of the time that will be required in the current state of the system for these changes is insignificant.

We are exploring the possibility of improving (hereinafter we will say increasing, as in the case of the cash balance) S by changing $X_1, \ldots, X_n$ in the specified intervals. In particular, if the predicted value of S is negative, then measures must be taken to prevent potential bankruptcy. Let us denote by $X_1^*, \ldots, X_n^*$ the changed values of the indicators $X_1, \ldots, X_n$. We denote the predicted value of the cash balance indicator by S^* and present it in the form

$$S^* = S + Z(X_1^*, \ldots, X_n^*) - R(X_1^*, \ldots, X_n^*), \tag{6}$$

where S is the initial predicted value of the target indicator, and the functions $Z(X_1^*, \ldots, X_n^*)$ and $R(X_1^*, \ldots, X_n^*)$ express its increase due to the adopted changes and the costs associated with these changes.

Let's represent the changed values in the form $X_i^* = k_i X_i$, $i = 1, \ldots, n$. If $k_i > 1$, then the value of X_i increases by $100(k_i - 1)$ percent as a result of the measures taken, if $k_i < 1$, then the value of X_i decreases by $100(1 - k_i)$ percent. When $k_i = 1$, the value of X_i does not change. Further, the quantities $k_1, \ldots, k_n$ will be considered as variables of the optimization problem, and the arguments of the functions Z and R will be written as $(X_1, \ldots, X_n, k_1, \ldots, k_n)$.

It is required to determine such admissible values of $k_1, \ldots, k_n$ that the value of S^*, determined by (6), will exceed the current value of S and will be maximum at given restrictions, which means maximum benefit from the measures taken. We will consider as critical combinations such subsets of the set of parameters $X_1, \ldots, X_n$, the coefficients of change of which in the solutions found will be different from 1.

In essence, the problem can be formulated as follows. Let's say that in the process of operation the company has entered a state that is potentially unfavorable from the point of view of the decision maker (for example, a negative cash balance in its account is predicted, which leads to bankruptcy of the organization). It is necessary to take measures to transfer the company to another, more favorable state, while maximizing the benefit criterion, taking into account the existing restrictions.

The problem under consideration can be posed and solved as a mathematical programming problem [22, 23] with non-negative variables $k_1, \ldots, k_n$. In the notation introduced above, it is required for given $X_1, \ldots, X_n$, $S = F(X_1, \ldots, X_n)$, functions $Z(X_1, \ldots, X_n, k_1, \ldots, k_n)$, $R(X_1, \ldots, X_n, k_1, \ldots, k_n)$ find the maximum of a function

$$S^* = S + Z(X_1, \ldots, X_n, k_1, \ldots, k_n) - R(X_1, \ldots, X_n, k_1, \ldots, k_n) \longrightarrow \max, \tag{7}$$

under restrictions

$$Z(X_1, \ldots, X_n, k_1, \ldots, k_n) - R(X_1, \ldots, X_n \leqslant 0, \tag{8}$$

$$k_i \in K_i, \tag{9}$$

$i = 1, \ldots, n$, and the condition of connection between changes

$$Y(k_1, \ldots, k_n), \tag{10}$$

where $Y(k_1, \ldots, k_n)$ – a predicate expressing possible dependencies between the desired changes and determined by the composition, structure and resources of the system under study.

Remark 1. In fact, we are solving the problem of increasing the projected cash balance. In this case, we highlight the following options:

— $S < 0$, $S^* \leqslant 0$ – we determine changes in parameters that will allow us to predict the most profitable positive balance;

— $S < 0$, $S^* < 0$ – given the existing restrictions, we do not find measures to achieve a positive forecast of the cash balance, however, it is possible to determine changes in parameters that will allow us to predict minimal losses, assess the "scale of the disaster" and the amount of necessary subsidies, subject to the implementation of such measures;

— $S > 0$, $S^* > 0$ – a negative cash balance is not initially predicted, but it is advisable to determine possible measures to increase it under the existing restrictions.

Remark 2. The solution to the problem (7)–(10) will not exist if the conditions of the problem are incompatible with each other, i.e. the set of admissible plans is empty. In this case, for further use of the proposed DM results, it is advisable to change the set of considered parameters $X_1, \ldots, X_n$ or the problem constraints.

If a solution to the problem (7)–(10) exists, but is not unique, then it is expected to select an implementable option for changing parameters using additional criteria, expert opinions and considerations of transparency, explainability of measures that will be taken to this version of changes. In this case, the selected solutions can be checked for stability and, if necessary, regularization [24–27].

4. APPROACH TO SOLVING THE PROBLEM

The suggested approach is to do the following:

1) Analysis of the state of the enterprise and identification of reserves for changing the parameters and structure of X. The result of this stage should be a list of control parameters $x_1, \ldots, x_n$ that influence the value of S, and relationships connecting these parameters in addition to their inclusion in the algorithm for determining S.

2) Determination of the boundaries of possible changes in the parameters under consideration based on the results of computational experiments, taking into account established connections and conditions (2)–(4).

3) Solution of the optimization problem (1)–(4).

4) Determination of possible scenarios for the changes identified as a result of the previous paragraph, taking into account historical data and expert opinions. Analysis of the possibility of combining scenarios corresponding to solutions for various subsets of $X_1, \ldots, X_n$, to achieve a maximum (1) on all parameters and structures from X.

5) Transfer of information to the decision maker about the obtained solutions to the original problem or the absence of such solutions under the given conditions.

5. PROPOSED SOLUTION ALGORITHM

The algorithm for determining critical combinations of changes is as follows.

1) Select $X_1, \ldots, X_m$ – company parameters available for change that affect the forecast values in the form (1) and the method for determining the forecast value of the target indicator S from the values $X_1, \ldots, X_m$, determine the value of S.

2) Determine $K_1, \ldots, K_n$ – sets of possible values of coefficients $k_1, \ldots, k_n$ of changes in parameters $X_1, \ldots, X_m$. The upper bound of K_i is generally estimated as a result of simulation modeling of possible measures that increase the value of X_i, taking into account the condition (2), the lower bound of K_i is similar to measures that reduce Xi.

3) Define the function $Z(X_1, \ldots, X_n, k_1, \ldots, k_n) - R(X_1, \ldots, X_n)$, which allows us to obtain a new predicted value of the target indicator using the formula (6).

4) Solve the problem of finding the maximum of the objective function (7) from variables $k_1, \ldots, k_n$ under restrictions (7)–(10) using mathematical programming methods. For each such solution, we will consider a subset of variables $X_1, \ldots, X_m$ with corresponding non-unit coefficients as one of the variants of the desired critical combination of parameters.

5) Transmit information to the decision maker about all critical combinations found or that no solution was found under the given conditions. The proposed approach to determining the critical combination of parameters for solving the inverse problem of stress testing a company assumes that the decision maker has algorithms or preferences for selecting a critical combination of parameter changes in the event that solving the problem gives several options for such combinations. Such a criterion can be the number of single values in some part of the desired set $k_1^*, \ldots, k_n^*$, if it is desirable to change the minimum number of indicators in this part, etc. It is also assumed that the decision maker has the ability to determine sets of measures to implement selected changes in the parameters of the enterprise.

The application of the proposed approach will be illustrated with an example.

6. MODEL EXAMPLE

Let's move on to a more specific formulation and solution of the problem using the example of one of the manufacturing enterprises, hereinafter referred to as the Factory. The reporting forecast and calculations for stress testing were formed on the assumption that the forecast and actual revenues for 2021 were equal. Note that this study was formed on the basis of the Plant's reporting, is of a model nature, and is not directly related to the internal program of anti-crisis measures.

The time variable is omitted below, since in the example we are considering one-step control.

To determine the magnitude and cost of changes in company parameters, we use publications based on a set of consulting works on the development of Russian organizations [28–30], which show that almost all organizations have development opportunities with high performance.

To form the expression on the left side of the condition (7) and then (8) we use the results from [31]. In this work, for mature, established organizations, a financial condition forecasting model is proposed, which allows us to write the expression on the left side (7) for organizations with the possibility of quickly restructuring production as

$$\begin{aligned} S = S_0 + (V(1-v) - FC - r_D D)(1-k_\tau)(1-k_u) \\ - (\Delta FA + \Delta Inv + \Delta AR - \Delta AP) + \Delta D, \end{aligned} \tag{11}$$

where S is the projected cash balance at the end of the period, S_0 is the cash balance at the beginning of the period, V is revenue, v is the share of variable costs, FC – fixed costs without interest, r_D – percentage of debt payable, D – amount of company debt, k_τ – income tax rate, k_u – share net profit on consumption (dividends), ΔFA, ΔInv, ΔAR, ΔAP, ΔD – increase in non-current assets, inventories, receivables, payables and the company's debt accordingly. The values are considered at the time of forecasting the value of the target indicator at the end of the period under consideration.

Next, if we introduce the notation $k_{\tau u} = (1-k_\tau)(1-k_u)$, $l_{TC1} = l_{Inv} - l_{AP}$, $l_{TC} = k_{Inv} l_{Inv} = k_{AP} l_{AP}$, ratio (6) can be represented in the form

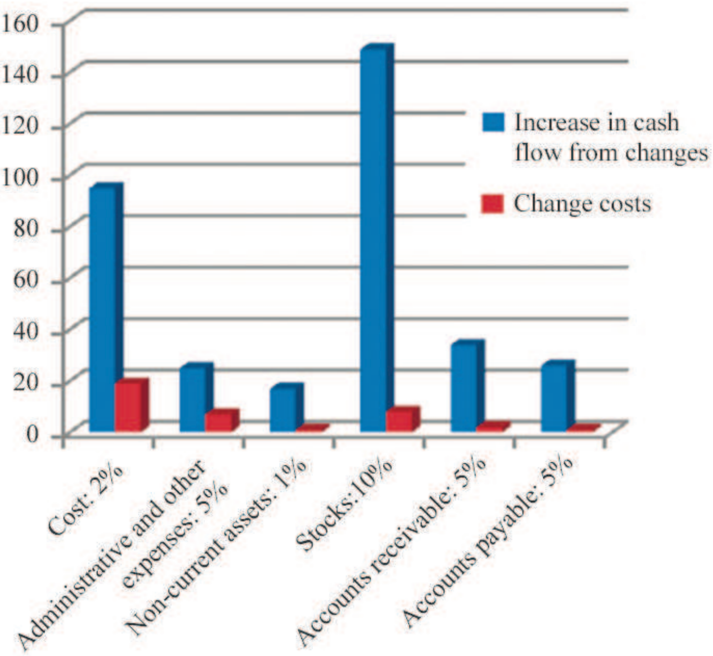
$$\begin{aligned} S^* = S + (k_D - 1)D - k_{FA} FA + V(k_{\tau u} - k_{AR} l_{AR} - l_{TC} v) \\ -(k_{FC} FC + k_D r_D D) r_{\tau u} - l_{TC} FC + l_{AR} V + l_{TC1} TC, \end{aligned} \tag{12}$$

where TC is total costs (without interest on loans), VC is semi-variable costs, FC is semi-fixed costs, l_{Inv} is inventory turnover period (Inventory), k_v – coefficient of change in variable expenses, k_{Inv} – coefficient of change in inventories, k_{AR} – coefficient of change in accounts receivable (Accounts Receivable), l_{AR} – turnover period of accounts receivable, k_{AP} – coefficient of change in accounts payable (Accounts Payable), l_{AR} – turnover period of accounts payable.

To clarify the optimization problem, we determine the parameters that can be subject to changes and the possible boundaries of these changes (condition (9)). Parameters that may be appropriate to change: revenue, cost, administrative and commercial expenses, non-current assets, inventories, receivables and payables. Let us take the considered range of changes in all these parameters to be equal to 10 percent. The solution to the optimization problem shows that within these limits changes can be selected, the costs of which are quite small compared to the positive effect of them, figure. In this figure, the increase from changes and the costs of them are plotted along the vertical axis and are expressed in million rubles. After the name of each variable, its change obtained when solving the optimization problem is indicated.

The resulting solution allows us to give a positive forecast of the cash balance according to the model constructed in [31], subject to the implementation of measures for the specified changes. As calculations show, the value of the objective function in the example under consideration before applying changes in measures will be $S = 21$ million rubles, and after applying these measures the new value will be $S^* = 455$ million rubles.

Thus, the possibility of using the proposed approach to determine measures to bring the company's projected cash balance into the area of positive values is shown. Note that when considering significant dependencies between possible changes in parameters, the proposed approach



Costs and effect of changing enterprise parameters.

may encounter problems of nonlinear, including non-convex, optimization. This may be due to the limitation of its application due to the limitations of the methods developed to solve such problems.

7. CONCLUSION

We are exploring the issue of determining relatively small changes in parameters that make it possible to transfer an organizational and technical system from a potentially unfavorable state to an area where the indicators in question have a favorable prognosis. The proposed approach to solving the problem allows us to identify a subset of such parameters (a critical combination of parameters) and the required volume of their change. In this case, the option that is most appropriate in terms of the costs of the desired changes is selected. To use the approach, the functional dependence of the forecast of the indicator of interest to us on the set of parameters under consideration must be known. In this case, the problem is reduced to a mathematical programming problem. In the example under consideration, the company's cash balance is taken as a forecast indicator. The proposed approach allows us to determine relatively small acceptable changes in the company's parameters, which will increase the projected cash balance in the company's account, and, in particular, bring the company to a larger value of this value. In particular, to a positive value if bankruptcy was predicted. In this case, the necessary measures are sought for considerations of maximum benefit, taking into account costs.

The obtained results of solving the inverse problem of stress testing are intended in the future for periodic use on time intervals of various durations with correction of conditions and assumptions at each of them. To this end, in the continuation of the study, basic provisions will be developed for extending the proposed approach to management in several steps. In addition, the issue of organizing an appropriate sequence of changes deserves attention.

Controls for such changes generally depend on data from past periods and from desired or expected data from future periods.

As a perspective for research, we note that the inverse stress testing problem considered in the example can be solved simultaneously for many companies and corporations in various industries. Such a solution can be used to identify companies whose government support in the context of a pandemic, turbulence and international sanctions is most appropriate for maintaining the stable operation of these industries. At the same time, the required volumes of such support will be determined.

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