Modeling of Crisis Management of an Economic Object in a Crisis Associated with Risks

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Abstract. The model of management of an economic object in a crisis is developed. Limitations and quality criteria are formed. General scheme of solving the task of minimax program crisis management at an enterprise is detected. The algorithm of the solution of the problem of crisis management of an enterprise taking into account the risks is offered. The main method for solving the problem is the method of detecting the reachable areas. Using this method, we work out the scenario of optimal crisis management in the presence of risks. The proposed algorithm allows to create effective numerous methods for implementing a computer simulation of solution of the problem of risk`s influencing. Simulated tools allow the reducing the risks at information system of crisis management of an enterprise. It opens the perspective of developing computer information systems for support of making effective crisis management decisions in the conditions of uncertainty and lack of information for increasing information security.

Keywords: Crises Management of Enterprise, Optimal Crisis Management, Economic Object, Program Crisis Management, Reducing the Risks.

1 Introduction

The term "crisis management" in the conditions has not yet been established. The reason for the terminological differences is the lack of strong scientific traditions and practical experience in crisis management. The need for crisis management is determined by the objectives of the development of economic systems and the existence of the danger of a crisis [2]. However, the ambiguity and diversity of the content of the crisis give different reasons for the classification of management in crisis situations [5], [6].

We will consider the concept of managing an economic object in a crisis as a series of measures to reduce all sorts of risks associated with the development of the studied object or process [1]. Anti-crisis management is a microeconomic category that reflects production relations in relation to a particular enterprise [8]. At the enterprise level, they are formed as a combination of forms and methods for implementing anti-crisis procedures. Economic activity - this is all kinds of activities of people that allow society to supply themselves with material resources for existence [17]. The set of problems associated with the life of the enterprise in a crisis, leads to various types of risks [11], [20]. An effective solution to these problems is carried out on the basis of solving the problem of optimizing the management of an economic object (enterprise) in the presence of risks [13].

An analysis of literature on modeling in crisis management of an economic objects in a crisis has shown that there are difficulties associated with the dynamics of a model [23]. This is due to the parameters changing over time, as well as to complexity of the nature of relationship between the components of the model (including existence of delays and "feedback") [14].

Realization of the problems, associated with modeling of crisis management in practice contributed to scientific development and widespread application of hybrid models based on a combination of formal and informal text, verbal and special graphic approaches. These tools offer simplified models and in many cases involve graphic interpretation of [7]. As a result, most models of crisis management were implemented by descriptive means or represented fragmentarily, with insufficient analytical formalization [21]. Some of them are characterized by lack of practical focus, integrity, and complexity in crisis management [5], they simplify obtaining knowledge and offer opportunity to experiment with crisis management. In this case, there is no possibility to assess the impact and consequences of different variants for crisis management in the prospects of minimization of risks of crisis while making managerial decisions [15]. Thus, crisis management with the use of simulation remains an unresolved problem for researchers [18]. In addition, existing models may have a limited availability and must be adapted to conditions of activity of specific enterprises.

The problem of modeling of crisis management was most fundamentally studied in [3]. The general problems of risk`s reduction at an enterprise’s crisis management system were examined, which have a common effect on the functionality of the enterprise and in critical infrastructures as a whole.

2 Model of Crisis Management of an Economic Object on Example of an Enterprise

2.1 Structural and Functional Model of Solving the Task of Dynamic Optimization of the Program Crisis Management of an Enterprises in a Crisis

Consider the current economic and mathematical model of crisis management at an enterprises (CME) associated with risks. On a given integer time interval

$\overline{0,T} = \{0,1,\ldots,T\}$ $(T > 0)$ we consider multistage dynamic management system, which consists of a single management object (enterprise), the movement of which is described by a linear discrete recurrent vector equation (dynamic model) [5]. Here and further for simplification of mathematical calculations we will consider the following equation:

$$x(t+1) = A(t)x(t) + B(t)u(t) + C(t)v(t), \quad x(0) = \{x_0, I_0\} \tag{1}$$

where $t \in \overline{0,T-1} = \{0,1,\ldots,T-1\}$ $(T > 0)$; $x(t) \in \mathbf{R}^n$ – phase vector (vector of phase variables) – a set of basic parameters describing the state of the system of CME at time *t*; $\mathbf{R}^n$ − dimensional Euclidean space of column vectors, $n \in \mathbf{N}$ – the set of natural numbers; $u(t) \in \mathbf{R}^p$ – vector of management (management action) that satisfies a given restriction:

$$u(t) \in U_1 \subset \mathbf{R}^p, \tag{2}$$

where U_1 is a finite set of vectors (plurality alternatives to management actions), that is a finite set of vectors $\mathbf{R}^p$, that determine all possible implementations of different management scenarios at time *t*; $p \in \mathbf{N}$;

$v(t) \in \mathbf{R}^q$ – vector of risks affecting the implementation process CME that meet the specified limit:

$$v(t) \in V_1 \subset \mathbf{R}^q, \tag{3}$$

V_1 – convex, closed and bounded polyhedron of space $\mathbf{R}^q$, that is, a set that restricts the possible values of the realization of the risk vector at the time *t*; $q \in \mathbf{N}$;

A(*t*), *B*(*t*) i *C*(*t*) are matrices of dimensions($n\times n$), ($n\times p$) i ($n\times q$), respectively, determining the dynamics CME.

We describe the information capabilities the subject of management in the process management of IP in a discrete dynamic system (1)-(3).

We assume that in the course of the implementation of CME and a fixed natural number $s >> T > 0$ each time $t \in \overline{1,T}$ the subject of management has such information capabilities corresponding to the implementation of the phase vector of the system, management influence and risk vector on the integer period of time $\overline{-s,t}$, preceding the considered process of IP management:

1) the history of realization of the phase vector of the system is known $x_t(\cdot) = (x_1(\cdot)_t, x_2(\cdot)_t, \ldots, x_n(\cdot)_t) = \{(x_1(\tau), x_2(\tau), \ldots, x_n(\tau))\}_{\tau \in \overline{-s,t}} = \{x(\tau)\}_{\tau \in \overline{-s,t}}$;

2) known history of implementation the management influence of the system $u_t(\cdot) = (u_1(\cdot)_t, u_2(\cdot)_t, \ldots, u_p(\cdot)_t) = \{(u_1(\tau), u_2(\tau), \ldots, u_p(\tau))\}_{\tau \in \overline{-s, t-1}} = \{u(\tau)\}_{\tau \in \overline{-s, t-1}}$;

3) the history of the implementation of the risk vector of the system is known $v_t(\cdot) = (v_1(\cdot)_t, v_2(\cdot)_t, \ldots, v_q(\cdot)_t) = \{(v_1(\tau), v_2(\tau), \ldots, v_q(\tau))\}_{\tau \in \overline{-s, t-1}} = \{v(\tau)\}_{\tau \in \overline{-s, t-1}}$.

Note that on the basis of these data it is possible to solve the task of a posteriori identification (discussed in the following sections) of all the main elements of a discrete dynamic system [3], [4], i.e. to determine the elements of matrices $A(t)$, $B(t)$ and $C(t)$. We assume that the subject of management also known equations (1) and constraints (2), (3).

The management process under consideration is estimated by the value of the convex functional $\gamma: \mathbf{R}^n \rightarrow \mathbf{R}^1$ defined on possible realizations of the phase vector $x(T) \in \mathbf{R}^n$ of the system at the final time *T*.

Then for the system (1)-(3) the purpose of minimax program crisis management of an enterprise from the point of view of the subject management can be formulated as follows: on a given period of time $\overline{0,T}$ it is necessary that the subject of management formed such management $u^{(e)}(\cdot) = \{u^{(e)}(t)\}_{t \in \overline{0,T-1}}$ (for all $t \in \overline{0,T-1}: u(t) \in U_1$) that there was a minimum value of the convex functional defined on implementation of the vector $x(T) \in \mathbf{R}^n$ (where $x(T)$ (where there is an implementation of the phase vector of the system at the time *T*, the corresponding management of IP $u(\cdot)$) at the worst (that maximize the value of the functional γ) possible implementations of the risk vector $v(\cdot) = \{v(t)\}_{t \in \overline{0,T-1}}$ (for all $t \in \overline{0,T-1}: v(t) \in V_1$).

2.2 Formulation of the Task of Minimax Program Crisis Management of at the Enterprises

Based on restrictions (2) and (3)

$$\boldsymbol{U}(\overline{0, T}) = \left\{u(\cdot) : u(\cdot) = \{u(t)\}_{t \in \overline{0,T-1}}, \forall t \in \overline{0, T-1},\ u(t) \in U_1\right\} \tag{4}$$

there are many alternatives to all possible implementations of $u(\cdot)$ program managements (all possible scenarios of Crisis management implementation) on the integer time interval $\overline{0,T}$, which is a set of finite;

$$\boldsymbol{V}(\overline{0, T}) = \left\{v(\cdot) : v(\cdot) = \{v(t)\}_{t \in \overline{0,T-1}}, \forall t \in \overline{0, T-1},\ v(t) \in V_1\right\} \tag{5}$$

there is a set of all admissible implementations of the risk vector $v(\cdot)$ (all admissible scenarios of implementation of the risk vector) on the integer interval of time $v(\cdot)$.

Consider for fixed and possible implementations of program crisis management of an enterprise and the risk vector, $v(\cdot) \in \boldsymbol{V}(\overline{0,T})$, $x_{\overline{0,T}}(T; x_0, I_0, u(\cdot), v(\cdot))$ the final state (state at time *T*) of the process trajectories generated by the system (1)-(3) and corresponds to the set $(x_0, I_0, u(\cdot), v(\cdot))$.

Let's choose a specific program crisis management $u^*(\cdot) = \{u^*(t)\}_{t \in \overline{0,T-1}} \in U(\overline{0,T})$, with a finite set $\boldsymbol{U}(\overline{0,T})$ of alternatives to all possible program crisis managements $u(\cdot)$ over a period of time $\overline{0,T}$.

Then, during the implementation of the fixed program crisis management $u^*(\cdot) = \{u^*(t)\}_{t \in \overline{0,T-1}}$ and on the basis of the multistep equation (1) will be implemented such a trajectory of the system and (1) will go into a system of this type:

$$x^*(t+1) = A(t)^*(t+1) + B(t)u^*(t) + C(t)v(t), \quad x^*(0) = \{x_0, I_0\}, \ \forall t \in \overline{0,T-1}, \tag{6}$$

where the final state will be denoted by $x^*(T) = x_{\overline{0,T}}(T; x_0, I_0, u^*(\cdot), v(\cdot))$, which is the state at the time *t* of the trajectory of the management process of the IP generated by the system (1)-(3) (with a fixed implementation of the risk vector $v(\cdot) \in V(\overline{0,T})$).

For all valid implementations of sets – $(x_0, I_0, u(\cdot), v(\cdot))$, $x(0)=\{x_0, I_0\}$, $u(\cdot) \in \boldsymbol{U}(\overline{0,T})$ and $v(\cdot) \in \boldsymbol{V}(\overline{0,T})$ the quality of the management process in the system (1)-(3), describing the CME, we propose to evaluate the terminal functional $\Phi(u(\cdot))$, the value of which evaluates the quality of the management process of the IP, determine the following ratio:

$$\tilde{\Phi} = \tilde{\Phi}(x_0, I_0, u(\cdot), v(\cdot)) = \Phi(x(T)) = \Phi(x_{\overline{0,T}}(T; x_0, I_0, u(\cdot), v(\cdot))), \tag{7}$$

where $\Phi: \mathbf{R}^n \to \mathbf{R}^1$ is functionality; $x(T) = x_{\overline{0,T}}(T; x_0, I_0, u_T(\cdot), v_T(\cdot))$.

It should be noted that with the help of the functional Φ based on the ratio (7), which determines its value, it is also possible to assess the impact of damage that is possible in the implementation of a specific risk vector $v_T(\cdot) \in \boldsymbol{V}(\overline{0,T})$.

Then for each fixed program crisis management of an enterprise $u(\cdot) \in U(\overline{0,T})$ from the solution of the optimization task we can find the value of the selected functional:

$$\tilde{\Phi}^{(e)}_{u(\cdot)} = \max_{v(\cdot) \in V(\overline{0,T})} \tilde{\Phi}(x_0, I_0, u(\cdot), v(\cdot)), \tag{8}$$

where $v(\cdot) \in V(\overline{0,T})$ introduced above, the set of all admissible realizations of the vector of risks on an integer interval $\overline{0,T}$.

Let's proceed to the formulation of the task of minimax program crisis management of an enterprise with the presence of risks.

Next, we consider the task of minimax program CME.

Task 1. It is necessary to find the program minimax management $u^{(e)}(\cdot) \in U(\overline{0,T})$ satisfying the minimax condition:

$$\begin{aligned} \tilde{\Phi}^{(e)} &= \max_{v(\cdot)\in V(\overline{0,T})} \tilde{\Phi}(x_0, I_0, u^{(e)}(\cdot), v(\cdot)) = \min_{u(\cdot)\in U(\overline{0,T})} \max_{v(\cdot)\in V(\overline{0,T})} \tilde{\Phi}(x_0, I_0, u(\cdot), v(\cdot)) = \\ &= \min_{u(\cdot)\in U(\overline{0,T})} \tilde{\Phi}^{(e)}_{u(\cdot)} = \min_{u(\cdot)\in U(\overline{0,T})} \max_{v(\cdot)\in V(\overline{0,T})} \Phi(x_{\overline{0,T}}(T; x_0, I_0, u(\cdot), v(\cdot))) = \\ &= \max_{v(\cdot)\in V(\overline{0,T})} \Phi(x_{\overline{0,T}}(T; x_0, I_0, u^{(e)}(\cdot), v(\cdot))) = \Phi^{(e)} . \end{aligned} \tag{9}$$

Note that given the limitation and finiteness of the set of possible program managements $U(\overline{0,T})$ and (9), we show that the solution of this task is reduced to the solution of a finite number of optimization problems with a convex functional of the process quality [12], [19].

3 General Scheme of Solving the Task of Minimax Program Crisis Management of an Enterprise

Consider a fixed time interval ($\overline{\tau,\vartheta} \subseteq \overline{0,T}$ ($\tau < \vartheta$) and a set $(X(\tau), u_{\overline{\tau,\vartheta}}(\cdot)) \in \mathbf{2}^{\mathbf{R}^n} \times \boldsymbol{U}(\overline{\tau,\vartheta})$ where $X(\tau) \subset \mathbf{R}^n$ ($X(0)=\{x_0, I_0\}$) is a convex closed and bounded polyhedron (with a finite number of vertices) in space; $\mathbf{2}^{\mathbf{R}^n}$ is the set of all subsets of space $\mathbf{R}^n$; $u_{\overline{\tau,\vartheta}}(\cdot) \in$ $\boldsymbol{U}(\overline{\tau,\vartheta})$ − possible program crisis management on the time interval $\overline{\tau,\vartheta}$.

On the basis of (1)-(3) we introduce a lot:

$$\begin{gathered} X^{(+)}_{u_{\overline{\tau,\vartheta}}(\cdot)}(\tau,\, X(\tau),\, \vartheta, V(\overline{\tau,\vartheta})) = \{x(\vartheta) : x(\vartheta) \in \mathbf{R}^n, \\ x(t+1) = A(t)x(t) + B(t)u(t) + C(t)v(t),\ \forall\, t \in \overline{\tau,\vartheta-1},\, v(t) \in V_1, \\ u_{\overline{\tau,\vartheta}}(\cdot) = \{u(t)\}_{t\in\overline{\tau,\vartheta-1}} ,\, v(\cdot) = \{v(t)\}_{t\in\overline{\tau,\vartheta-1}} \in V(\overline{\tau,\vartheta}))\} \end{gathered} \tag{10}$$

and will call the domain of reach or the predicted set of [10] phase States of the system (1)-(3) at the time , which corresponds to the set $(X(\tau), u_{\overline{\tau,\vartheta}}(\cdot))$.

Given the linearity of the recurrent dynamical system (8) and the introduced set condition V_1, which is a convex, closed and bounded polyhedron in space $\mathbf{R}^q$, it can be shown that for the following properties of the introduced set $u_{\overline{\tau,\vartheta}}(\cdot)=\{u(t)\}_{t\in\overline{\tau,\vartheta-1}} \in \boldsymbol{U}(\overline{\tau,\vartheta})$ are valid for the fixed program crisis management [8]:

1) $\boldsymbol{X}^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(\tau, X(\tau), t, \boldsymbol{V}(\overline{\tau,t})) = X^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(t)$ for all there is $t\in\overline{\tau+1,\vartheta}$ a non-empty, convex, closed and bounded polyhedron (with a finite number of vertices) in space $\mathbf{R}^n$ $u_{\overline{\tau,t}}(\cdot)=\{u(t)\}_{t\in\overline{\tau,t-1}}$ (see, for example, [9]);

2) for all $t\in\overline{\tau,\vartheta-1}$ and $X^{(+)}_{u_{\overline{0,\tau}}(\cdot)}(\tau)=X(\tau)$ fair recurrence ratio:

$$\begin{aligned}&\boldsymbol{X}^{(+)}_{u_{\overline{\tau,t+1}}(\cdot)}(\tau, X(\tau), t+1, \boldsymbol{V}(\overline{\tau,t+1})) = \\ &\boldsymbol{X}^{(+)}_{u_{\overline{t,t+1}}(\cdot)}\left(t, X^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(t), t+1, \boldsymbol{V}(\overline{t,t+1})\right) = \\ &= \boldsymbol{X}^{(+)}_{u(t)}(t, X^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(t), t+1, V_1)\ .\end{aligned} \tag{11}$$

Then it follows from the relation (11) that the multistep task of constructing the reachability domain $\boldsymbol{X}^{(+)}_{u_{\overline{\tau,\vartheta}}(\cdot)}(\tau, X(\tau), \vartheta, \boldsymbol{V}(\overline{\tau,\vartheta}))$ is reduced to the solution of a finite recurrent sequence of only one-step problems of constructing the following reachability domains, respectively:

$$X^{(+)}_{u_{\overline{\tau,t+1}}(\cdot)}(t+1) = \boldsymbol{X}^{(+)}_{u_{\overline{t,t+1}}(\cdot)}(t, X^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(t), t+1, \boldsymbol{V}(\overline{t,t+1})) = \boldsymbol{X}^{(+)}_{u(t)}(t, X^{(+)}_{u_{\overline{\tau,t}}(\cdot)}(t), t+1, V_1)\ ,$$
$$t\in\overline{\tau,\vartheta-1}\ ,\ X^{(+)}_{u_{\overline{\tau,\tau}}(\cdot)}(\tau) = X(\tau)\ . \tag{12}$$

Based on these properties, the General scheme of solving the Task 1 for a dynamic system (1)- (3), (8) it can be described as the implementation of the following sequence of actions [9].

1. Lets sort by increasing the natural index *j* a finite set $\boldsymbol{U}(\overline{0,T})$ consisting of N_u possible program managements $u_T^{(j)}(\cdot)=\{u^{(j)}(t)\}_{t\in\overline{0,T\text{-}1}} \in \boldsymbol{U}(\overline{0,T})$ over a period of time $\overline{0,T}$, that is, we have $\boldsymbol{U}(\overline{0,T})=\{u_T^{(j)}(\cdot)\}_{j\in\overline{1,N_u}}$.

2. For fixed and possible program crisis management (for ex., from a set of alternatives of possible management actions) $u_T^{(j)}(\cdot)\in\boldsymbol{U}(\overline{0,T})$ ($j\in\overline{1,N_u}$), taking into account the above property, the area of reach $\boldsymbol{X}^{(+)}_{u_T^{(j)}(\cdot)}(0, X(0), T, \boldsymbol{V}(\overline{0,T}))$ considered dynamic system (1)-(3) at the final time *t*, which corresponds to fixed set $(\{x_0, I_0, \}, u^{(j)}_{\overline{0,T}}(\cdot)) = (X(0), u^{(j)}_{\overline{0,T}}(\cdot)) \in 2^{\mathbf{R}^n}\times U(\overline{0,T})$, are convex, closed and a bounded polyhedron (with a finite number of vertices) of the space $\mathbf{R}^n$ that we build on the

basis of the recurrent formulas (11), (12) by implementing the construction of T single-step domains of reach, namely:

$$\boldsymbol{X}^{(+)}_{u^{(j)}_{t+1}(\cdot)}(0, X(0), t+1, \boldsymbol{V}(\overline{0,t+1})) = \boldsymbol{X}^{(+)}_{u^{(j)}_{\overline{t,t+1}}(\cdot)}(t, X^{(+)}_{u^{(j)}_t(\cdot)}(t), t+1, \boldsymbol{V}(\overline{t,t+1})) =$$

$$= \boldsymbol{X}^{(+)}_{u^{(j)}(t)}(t, X^{(+)}_{u^{(j)}_t(\cdot)}(t), t+1, V_1), \ \forall t \in \overline{0, T-1}, \tag{13}$$

where $X(0)=\{x_0, I_0\}$; $X^{(+)}_{u^{(j)}_t(\cdot)}(t) = X^{(+)}_{u^{(j)}_t(\cdot)}(0, X(0), t, \boldsymbol{V}(\overline{0,t}))$.

3. For the selected fixed program crisis management $u^{(j)}_{\overline{0,T}}(\cdot) \in U(\overline{0,T})$ ($j \in \overline{1, N_u}$) and the range of reach constructed in accordance with it $\boldsymbol{X}^{(+)}_{u^{(j)}_{\overline{0,T}}(\cdot)}(0, X(0), T, \boldsymbol{V}(\overline{0,T}))$ which is a convex, closed and bounded polyhedron (with a finite number of vertices) of space $\mathbf{R}^n$, with a solution of the convex mathematical program task with a convex terminal functional Φ and linear constraints, describes the area reach $\boldsymbol{X}^{(+)}_{u^{(j)}_{\overline{0,T}}(\cdot)}(0, X(0), T, \boldsymbol{V}(\overline{0,T}))$ (see, for example, [5]) in accordance with (6), (7), (9), we find the following value of the quality functional Φ :

$$\Phi^{(e)}_{u^{(j)}_{\overline{0,T}}(\cdot)} = \max_{x(T)) \in X^{(+)}_{u^{(j)}_{\overline{0,T}}(\cdot)}(0, \{x_0, I_0\}, T, V(\overline{0,T}))} \Phi(x(T)) . \tag{14}$$

It should be noted that for solving the problem, one can use the Zeytendeik method [13].

4. With the decoupling of the following discrete optimization problem, we find the program crisis management $\hat{u}^{(e)}_{\overline{0,T}}(\cdot) \in U(\overline{0,T})$ and the numerical value $\hat{\Phi}^{(e)}$:

$$\min_{u_{\overline{0,T}}(\cdot) \in U(\overline{0,T})} \Phi^{(e)}_{u_{\overline{0,T}}(\cdot)} = \min_{i \in \overline{1,N_u}} \Phi^{(e)}_{u^{(j)}_{\overline{0,T}}(\cdot)} = \Phi^{(e)}_{\hat{u}^{(i)}_{\overline{0,T}}(\cdot)} = \hat{\Phi}^{(e)} . \tag{15}$$

Based on relations (11)-(13) and (41)-(15), it can be shown that the following equalities hold:

$$u^{(e)}(\cdot) = u^{(e)}_{\overline{0,T}}(\cdot) = \hat{u}^{(e)}_{\overline{0,T}}(\cdot) \in U(\overline{0,T}) , \ \Phi^{(e)} = \hat{\Phi}^{(e)} , \tag{16}$$

which show that as a result of the implementation of the proposed general scheme, a complete solution of task 1 was found [2].

Note that the procedure for constructing one-step reach $X^{(+)}_{u^{(i)}(t)}(t, X^{(+)}_{u^{(i)}_{\overline{0,t}}(\cdot)}(t), t+1, V_1)$, $\forall t \in \overline{0, T-1}$, areas appearing in formula (16) can be implemented similarly to a computational algorithm [4], which reduces the solutions of this task in the implementation of solutions of a finite number of tasks of linear mathematical programming.

3.1 The Algorithm of the Solution of the Problem of Management of Innovation Processes at an Enterprise Taking into Account the Risks

1. Form the set of alternatives of possible IP management. The components of the first group of control vectors from this set represent the volumes of production of new products over a period of time (according to the corresponding IP) (the first level of management).

2. Based on the values of the first group of management vectors of the IP, we build a plurality of material, labor and investment resources (second level of management).

3. Determine the set of permissible risks with appropriate constraints.

4. We consistently capture the management of the IP with the corresponding vector of replenishment of material and labor resources, investment resources and "take away" all the risks from the set of permissible. We construct the corresponding predictable sets of reach regions G for the final vectors $x(T)$ of the PMIP state at the moment T.

5. On the sets of reach domains, we solve the discrete optimization problem with the help of minimax and find the rational software control of the IP, which provides a guaranteed result of the solution of the CME problem under the influence of any risks from the set of permissible.

4 Conclusion

Thus, for organization of minimax crisis management at an enterprise in the selected class of permissible strategies for adaptive management, the model of adaptive management was developed. The proposed recurrent algorithm reduces an original multi-step problem to implementation of the ultimate sequence of problems of minimax software crisis management at an enterprise. In turn, solution of each of these problems is reduced to implementation of the finite sequence of only one-step optimization operations in the form of solutions of linear and convex mathematical programming and discrete optimization. Then it is possible to obtain a solution of the considered model of adaptive crisis management at an enterprise in the face of risks. Solution is reduced to implementation of solution of a finite sequence of problems of linear convex mathematical programming and discrete optimization.

Presented results can be used for economic-mathematical modeling and solution of other problems of management processes optimization. Economic-mathematical models for such problems are presented, for example, in papers [12], [16], [19], [22]. Prospects of the conducted research are associated with possibility of introduction of parameters of the vector of non-determined risks into a model of crisis management at an enterprise.

The developed models are an effective tool of modeling of optimization of the guaranteed outcome of crisis management associated with risk factors for enterprises. The results obtained can be used for economic-mathematical modeling and solution of other problems of optimization of processes of data forecasting and management. This takes into consideration conditions of information deficit and uncertainty in the face of risks. The developed mathematical apparatus can be used for implementation of the relevant program-technical complexes for supporting effective managerial decision making in practice.

Developed tools of modeling in crisis management at an enterprise make it possible to solve the problems of reducing the risks of management of processes at an enterprise.

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