# SYSTEM MODELING OF GOALS AND DIRECTIONS IN PROJECTS OF INNOVATIVE DEVELOPMENT OF HIGH-TECH ENTERPRISE

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*The publication sets and solves the urgent task of forming goals and directions of innovative development of high-tech enterprises. The subject of research is the process of development management. The object of research is project-oriented system development management. Due to the complexity of the problem to be solved, the study is conducted in two stages: systematic decomposition of the goals of innovative development with the assessment of feasibility and costs; choice of the direction of reform in the conditions of limited possibilities. The purpose of the study is to substantiate the goals and choose the direction of innovative development of high-tech enterprise. Modern methods of system analysis are used to substantiate development goals, lexicographic and integer optimization to choose the best direction of development; hierarchical base of precedents for forming decisions to choose goals; agent simulation modeling to assess the dynamics of time, costs and risks of the innovation development project.*

## Introduction

The production of high-tech products, in conditions of increasing competition in the markets, requires a careful analysis of the goals of reforming high-tech enterprises in the short term, taking into account the limited opportunities [1, 2]. Existing methods of strategic planning are focused mainly on the long term in terms of stable inflow of financial resources [3, 4]. Dynamic changes in the market situation associated with the stochastic behavior of markets for high-tech products require new approaches that allow at an early stage of formation of goals of reforming the production system, assess the feasibility of modernization, risks of measures taken in limited opportunities (financial costs, terms of implementation). To manage projects to create high-tech products, it is necessary to improve and create new methods of organization management, based on a process approach, which uses modern methods of project management. [5, 6]. Particular attention is paid to the management of the process of innovative development of the organization because

ensuring competitiveness requires constant improvement not only of production processes but also of project management processes for the creation of modern high-tech products.

World practice indicates a number of possible areas of development, the choice of which is related to the specifics of the sphere of activity of the organization, its capabilities and willingness to reform. Therefore, the topic of the proposed publication is relevant, related to the management of innovative development of high-tech enterprises to ensure its competitiveness. The purpose of the work is to conduct a study to assess the implementation of strategic goals of the enterprise and the choice of direction of innovative development in conditions of disabilities. The following stages for research of innovative development of the high-tech enterprise are allocated:

1. Systematic decomposition of the goals of innovative development with an assessment of feasibility and costs.

2. Choice of the direction of reform in the conditions of limited possibilities.

The global goal of a developing enterprise is analyzed, which is decomposed into sub-goals of lower levels, as a result of which a hierarchical structure of goals is formed. Decomposition of goals is carried out depending on the capabilities of the enterprise. Both ready-made solutions from the experience of production development and new solutions are used to select solutions related to the implementation of the strategic goals of the enterprise. This allows to optimize financial costs and to reduce the time to meet the goals of modernization. To substantiate the choice of the current direction of reform, external experts are involved, who assess many possible areas of development, taking into account the state and level of maturity of the organization, readiness for reforms, existing business process model, financial opportunities for development processes.

Due to the complexity of the research task, modern methods are used in the work: system analysis for decomposition of development goals, project-oriented management of innovative development, lexicographic subordination, integer optimization, agent modeling, hierarchical base of precedents.

# 1. Systematic decomposition of the goals of innovative development with an assessment of feasibility and costs

Given the complexity of the task of reforming a modern enterprise in a dynamic change of environment (economic, political, social, etc.), the global goal associated with the modernization of the production system can be represented as a set of strategic goals that must be decomposed in accordance with the requirements system analysis. The division of the goal into sub-goals at each level of decomposition allows to specify the requirements and tasks for the modernization of production. Theoretical-multiple description of strategic goals and their decomposition can be presented as follows (1):

$$\left\{C_j^u\right\} = \left\{\left\{C_1^{u+1}\right\}, ..., \left\{C_i^{u+1}\right\}, ..., \left\{C_{n_u}^{u+1}\right\}\right\},\tag{1}$$

where $\left\{C_j^u\right\}$ is a subset of the goals of the u-th level of the global goal of decomposition; $\left\{C_j^{u+1}\right\}$ – subset of nested goals (sub goals) u+1-th level of decomposition for the j-th goal; u – decomposition level number; $n_u$ – the number of targets at the u-th level of decomposition.

To achieve each separate goal, it is necessary to assess the relevant resources in the form of costs, terms (time) and the risk of its implementation.

These requirements can be represented as (2):

$$Q_j^u = \left\langle w_j^u, t_j^u, r_j^u \right\rangle,\tag{2}$$

where $Q_j^u$ is a tuple that describes the requirements for the goal $C_j^u$; $w_j^u$ – cost requirements; $t_j^u$ – requirements for terms; $r_j^u$ – risks of fulfilling the goal.

We will use, for the analysis of a tree of the purposes which is formed at reforming of the enterprise, the world and domestic experience which can be presented in the form of base of precedents (BP). In this case, the structure of the global goal of the reforming enterprise will consist of three types of goals:

– goals that were used and have experience of positive solution (GP);

– existing goals that need to be adapted to the selected goals of the modernized enterprise (GM);

– new goals that are missing in the world practice of reforming (GN).

Each precedent (existing decision) can be represented as an element of the BP with a set of requirements for the implementation of the goal $c_j^u$. Let's present the BP to find ready-made reform solutions in the form of a hierarchical base of precedents (HBP), which corresponds to the structure of the global goal of the enterprise and contains many solutions for enterprise modernization.

Requirements for the implementation of any goal can be formed using a tuple $Q_{S_j^u}$, which represents a certain problem situation that needs to be resolved in the process of enterprise modernization. You can solve this problem by searching for ready-made solutions in HBP. To do this, the values available in HBP are compared with the values $Q_{S_j^u}$ (problem situation) taking into account the corresponding level of decomposition of the global goal in HBP.

We will search for "relatives" according to the characteristics of the existing goals at the u-th level of HBP decomposition to fulfill the set goal of modernization. If the solutions found in HBP at the u-th level do not satisfy the management of the enterprise, then the decomposition and transition and search for ready-made solutions at the next (u+1) level of decomposition of the goal.

Thus, to achieve the goals of enterprise modernization, it is necessary to conduct an iterative procedure for finding ready-made solutions in multilevel HBP in the form of a set $M_j^u$. The choice of the constructed decision requires lexicographic subordination of precedents in the set $M_j^u$. Lexicographic subordination is based on sequential optimization and is used in the problem of choosing the best option from a given set (in this case $M_j^u$). In this case, all modernization requirements are set in a linear order of importance, for example:

$$w_j^u, t_j^u, r_j^u,$$

where in the first place are the requirements for costs, in the second - the timing of the goals, in the third - the risks of the goal.

You can use qualitative estimates that can be provided by enterprise development managers in the form of values of linguistic variables, for example [7, 8]:

A is an excellent value,

B is a good value,

C is a satisfactory value,

D is a bad value.

Many precedents with ready-made solutions $M_j^u$, from which the search for the best solution for the modernization of the enterprise can be presented in the form of "words".

For example:

1. B A B.

2. A B A.

3. A A C.

4. A B C.

5. B A C.

By subordinating them (sequential optimization), the best solution can be identified:

3. A A C.

2. A B A.

4. A B C.

1. B A B.

5. B A C.

In this example, the third option corresponds to the best solution for upgrading the enterprise for the goal $C_j^u$.

We present a method of finding solutions to achieve the global goal of the enterprise, which is modernized in the form of the following stages:

1. Zero level of decomposition will represent the global goal of production modernization. At the first level of decomposition, a set of goals for modernization of the enterprise is formed.

2. The search for ready-made solutions (precedents) is carried out in HBP for the first level of decomposition of the global goal (later for the u-th level).

2.1. HBP allocates a set $M_j^u$ with ready-made solutions for each j-th goal.

2.2. Lexicographic subordination of "words" in $M_j^u$ and selection of the best variant of the decision on modernization is carried out.

3. Forecasting the assessment of costs, terms and risks for modernization according to the found ready solution. Taking into account the peculiarities and condition of the enterprise, the requirements are adapted to clarify the estimates of costs, terms and risks.

4. If the obtained values for costs, terms and risks satisfy the managers of the enterprise, then the formation of a list of measures to achieve this $C_j^u$ goal.

5. If the costs, time and terms do not meet the requirements of the enterprise, the goal $C_j^u$ is decomposed into a sub-goal of the lower (u +1) level of the global goal with the search and evaluation of a set of ready-made solutions at the next level of decomposition.

6. Step 2-step 4 are repeated for each goal, taking into account the possible levels of decomposition of the global goal.

7. If the managers of the enterprise do not see the point in the decomposition of a separate goal (sub-goal) $C_j^u$, then the search for ready-made solutions for it (the goal is new and has no analogues) is not carried out. A list of activities related to the implementation of the new goal (sub-goals) is formed.

8. Costs, terms and risks are assessed for the new purpose $C_j^u$. It should be noted that due to the novelty of the goal, the risks for its implementation, costs and terms increase sharply.

9. If the goal is unattainable due to the limited capabilities of the enterprise, it is removed from the list of goals.

Assessment of the feasibility of the target tree built (hierarchy of the structure of the global goal) is based on the values of risks, as well as the possible costs and timing of measures to implement the goals that have been formed.

To do this, it is necessary to proceed to the probable presentation of risks. Each $r_j^u$ risk of the j-th goal (sub-goal) of the u-th level, taking into account the opinion of experts, receives a probabilistic assessment in the form (3):

$$P_j^u = 1 - r_j^u, \tag{3}$$

where $r_j^u$ is presented on a scale $(0 \div 10)$.

Then to assess the feasibility of the R project to modernize the enterprise, taking into account the constructed whole tree, it is necessary (4):

$$R = \prod_{u=1}^{m} \left( \prod_{j=1}^{n_u} \left( 1 - r_j^u \right) \right), \tag{4}$$

where $n_u$ is the number of formed goals (sub-goals) of modernization at the u-th level; m is the number of levels obtained after the decomposition of the global target.

If the value of the global goal is satisfied by the management of the enterprise, then the assessment of the costs W and the timing of the implementation of the modernization project (5-6):

$$W = \sum_{u=1}^{m} \sum_{j=1}^{n_u} w_j^u, \tag{5}$$

$$T = \sum_{u=1}^{m} \sum_{j=1}^{n_u} t_j^u. \tag{6}$$

Taking into account the limited capabilities of the enterprise, the final conclusion is made regarding the realization of the global goal of the developing enterprise, which is associated with the modernization of the enterprise. Then, after assessing the implementation of strategic goals, you can proceed to the choice of direction of enterprise development.

## 2. Choice of the direction of reform in the conditions of limited possibilities

There are a number of areas of development of the organization, which have proven themselves in the practice of project management. These include:

1. Improving management processes.

2. Training (advanced training) of staff.

3. Use of high-tech equipment (robotics, informatization, automation, etc.).

4. Improving business processes.

5. Improving the quality of products.

6. Reducing the life cycle of high-tech projects.

7. Improvement and optimization of logistics processes.

This list can be extended, because modern challenges and threats in the economy lead to the search for new relevant directions of development.

The choice of directions is not necessarily limited to one. It is possible, as often happens, the choice of several areas that can be implemented both sequentially and in parallel. But in most cases, the choice of areas depends on the limited capabilities of the organization (finances, deadlines, the current economic situation, etc.).

To justify the choice of areas of development of the organization, we use the assessments of experts that can be obtained during the external audit of the organization [9, 10]. In this case, each expert will be asked to assess the direction of development (or a list of areas, in the case of choosing several) on a specific scale (for example, $0 \div 10$). The expert assessments are then averaged and entered in the final table. For effective purposeful choice of the direction of development we will use a method of planning of experiments in the form of the plan of full factorial experiment (FFE). In this regard, the number of experiments (in our case, these are conditional experiments that involve expert assessments) is determined by a full set of possible combinations (combinations) of factors. Therefore, if n directions of development are chosen to estimate, the number of possible combinations will be $N=2^n$. In the plan $x_j$ - corresponds to the choice of the j-th direction of development; $\overline{y_i}$ is an average estimates of the i-th combination of directions of development. With

the help of FFE plan and using its calculation formulas, it is possible to obtain the following nonlinear regression dependence (7):

$$y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_{12} \cdot x_1 \cdot x_2 +$$

$$+b_{13} \cdot x_1 \cdot x_3 + + b_{23} \cdot x_2 \cdot x_3 + b_{123} \cdot x_1 \cdot x_2 \cdot x_3. \qquad (7)$$

In this dependence, the coefficient $b_j$ indicates the influence of the $x_j$-th factor (direction of development), as well as $b_{jk}$ and $b_{jke}$ the influence of combinations of factors. Here is an illustrated example of the choice of directions of development, limited to three factors (possible directions of development). Let $x_1$ correspond to the direction associated with improving the quality of products, $x_2$ - reducing the life cycle of high-tech projects, $x_3$ - improving and optimizing logistics processes. After the experts evaluate the possible directions of development, we get the next FFE plan, filled with estimates (on a scale of $0 \div 10$) (fig. 1).

| No. | $x_1$ | $x_2$ | $x_3$ | $x_1\,x_2$ | $x_1\,x_3$ | $x_2 x_3$ | $x_1 x_2 x_3$ | $\overline{y}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | +1 | +1 | +1 | -1 | 1 |
| 2 | -1 | -1 | +1 | +1 | -1 | -1 | +1 | 3 |
| 3 | -1 | +1 | -1 | -1 | +1 | -1 | +1 | 2 |
| 4 | -1 | +1 | +1 | -1 | -1 | +1 | -1 | 5 |
| 5 | +1 | -1 | -1 | -1 | -1 | +1 | +1 | 5 |
| 6 | +1 | -1 | +1 | -1 | +1 | -1 | -1 | 8 |
| 7 | +1 | +1 | -1 | +1 | -1 | -1 | -1 | 7 |
| 8 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | 10 |

**Fig. 1.** FFE Plan with expert assessments of development directions

Let's use the FFE calculation formula and obtain the following regression dependence (8):

$$y = 5{,}125 + 2{,}375 \cdot x_1 + 0{,}875 \cdot x_2 + 1{,}375 \cdot x_3 +$$

$$+0{,}125 \cdot x_1 \cdot x_3 + 0{,}125 \cdot x_2 \cdot x_3 - 0{,}125 \cdot x_1 \cdot x_2 \cdot x_3. \qquad (8)$$

From here it becomes clear that the greatest influence on development of the organization, in this case, has the direction connected with improvement of quality of production.

After choosing the current direction of reforming the organization, it is necessary to assess the resources for the implementation of the development project and further optimize costs.

Systematic presentation of the development project in the form of a sequence of stages leads to a multiplicity of options for selection and justification of resources. Therefore, we will use existing optimization models based on the plurality of solutions and the choice of the optimal among them. Integer (Boolean) linear programming will allow to estimate resource costs both for separate criteria of optimization, and for search of the compromise decision taking into account possible contradiction of criteria. As the main criteria for assessing the reform of the organization we will use: financial costs - W, project implementation time - T, the risk of the reform project - R.

We form a representation of optimization criteria in the form of objective functions:

1. Costs – W (9),

$$W = \sum_{j=1}^{M} \sum_{i=1}^{n_j} w_{ij} \cdot x_{ij}, \qquad (9)$$

where $w_{ij}$ – costs for the i-th option of allocating funds at the j-th stage of the project of reforming the organization; $x_{ij}$ – selection of a possible i-th option for allocating funds for the j-th stage of the reform project; $n_j$ – the number of possible options for allocating funds at the j-th stage of the project; M – number of project stages.

2. Time of implementation of the reform project – T (10),

$$T = \sum_{j=1}^{M} \sum_{i=1}^{n_j} t_{ij} \cdot x_{ij}, \qquad (10)$$

where $t_{ij}$ – the time of implementation of the j-th stage of the reform project for the i-th option of allocating funds.

3. Risks of implementing the reform project – R (11),

$$R = \sum_{j=1}^{M} \sum_{i=1}^{n_j} r_{ij} \cdot x_{ij}, \qquad (11)$$

where $r_{ij}$ – the risk of implementing the j-th stage of the reform project taking into account the i-th option of allocating funds.

The following statement of the problem of resource optimization in the implementation of the reform project is possible:

1. Optimization of individual (local) criteria.

2. Multicriteria optimization to find a compromise solution.

As an example, consider the optimization of financial costs for the implementation of the reform project.

Need to find $\min W$:

$$W = \sum_{j=1}^{M} \sum_{i=1}^{n_j} w_{ij} \cdot x_{ij},$$

when the following conditions (restrictions) are met:

$$T \leq T', \quad T = \sum_{j=1}^{M} \sum_{i=1}^{n_j} t_{ij} \cdot x_{ij},$$

$$R \leq R', \quad R = \sum_{j=1}^{M} \sum_{i=1}^{n_j} r_{ij} \cdot x_{ij},$$

where $\sum_{i=1}^{n_j} x_{ij} = 1$ for all j, which means the obligatory choice of a variant from the set of possible ones; $T'$ – admissible term for implementation of the project of reforming the organization; $R'$ – allowable risk of the reform project.

As a result of local optimization according to separate criteria we will receive optimum values $W^*$, $T^*$, $R^*$ taking into account restrictions $W'$, $T'$, $R'$.

To carry out multicriteria optimization, it is necessary to form a complex criterion K, which receives local criteria W, T, R.

Let us use the additive convolution of criteria (12), which is often used in practice:

$$K = \alpha_W \cdot \overline{W} + \alpha_T \cdot \overline{T} + \alpha_R \cdot \overline{R}, \qquad (12)$$

where $\overline{W}, \overline{T}, \overline{R}$ – normalized value of criteria taking into account the local optimization (13):

$$\overline{W} = \frac{W - W^*}{W' - W^*}, \quad \overline{T} = \frac{T - T^*}{T' - T^*}, \quad \overline{R} = \frac{R - R^*}{R' - R^*}, \qquad (13)$$

where $\alpha_W$, $\alpha_T$, $\alpha_R$ – significance ("weight") of individual criteria, $\sum_{e=1}^{3} \alpha_e = 1$.

When conducting multicriteria optimization minK must be found (14),

$$K = \alpha_W \cdot \frac{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} w_{ij} \cdot x_{ij} - W^*}{W' - W^*} +$$

$$+\alpha_T \cdot \frac{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} t_{ij} \cdot x_{ij} - T^*}{T' - T^*} + \qquad (14)$$

$$+\alpha_R \cdot \frac{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} r_{ij} \cdot x_{ij} - R^*}{R' - R^*}.$$

The final conclusion on the choice of the current direction for the reform of the organization should be made after modeling the reform project, taking into account the allocated resources [11].

Let's use agent simulation modeling, which will allow to simulate project actions taking into account the temporal and spatial representations of the project of reforming the organization.

To do this, you need to form the following set of agents:

1. Agent simulator of the beginning of the reform project.

2. Resource allocation agent for the j-th stage of the project.

3. Time delay agent for the implementation of the j-th stage of the project.

4. Risk assessment agent during the j-th stage of the project.

5. Agent for collecting statistics during the project.

6. Modeling process control agent (system time, event lists).

7. Agent of the description of separate stages of the project.

8. Agent of project implementation results.

Here is a brief description of the modeling process.

First, a description of the reform project is made in the form of a sequence of stages of implementation. The Agent of the description of separate stages of the project is used. Control is then handed over to the modeling process control Agent, who generates the first event related to the initiation of the reform project. The reform project initiation Agent is used for this purpose. Control is then passed to the agents associated with the j-th stage of the project (initially for the first stage). The time delay for the j-th stage is simulated, costs and risks are estimated. The time delay Agent, the resource allocation Agent, and the risk assessment Agent are used for this purpose. Next, the events related to the completion of the j-th stage and the transition to the j + 1 stage are planned. Statistics on resource allocation and project risk are collected.

After the implementation of the last stage of the project, the results are determined in the form of:

– the actual time (term) of the project;

– costs associated with the project;

– the final risk of the project.

The obtained modeling results will allow to forecast the implementation of the reform project, to assess the expected and actual design results, which will allow a more reasonable transition to the planning of deadlines, costs in the implementation of the enterprise reform project.

## Conclusions

The publication solves the problem of forming strategic goals and direction of reforming a developing enterprise. Possible solutions are formed in the form of elements of a hierarchical base of precedents (HBP), which correspond to the tree of strategic goals of the developing enterprise. For each decision to modernize production, an assessment of certain costs, terms and risks of implementation has been done. Purposeful search for ready-made solutions for modernization is carried out using the method of lexicographic subordination of options. In case of absence

of ready decisions on modernization of the enterprise the estimation of expenses and terms of achievement of the new purpose in the conditions of the increased risk is carried out. After constructing the tree of strategic goals, the assessment of feasibility was carried out on the basis of the values of risks of individual goals.

The main directions of reforming related to ensuring the competitiveness of the organization in the market of high-tech products are substantiated.

Purposeful search in the problem of resource optimization is used. The optimization problem is carried out on the basis of integer (Boolean) programming in two views: local and multicriteria optimization. Costs, project terms and the risk of successful project implementation were used as criteria for assessing the allocated resources and the success of the reform project. For multi-criteria optimization, the significance of individual criteria was assessed. A simple additive convolution of local criteria was used as a complex criterion. The agent modeling method was used to assess the correctness of the chosen reform option. A set of agents has been formed, with the help of which all stages of the development project are simulated. This takes into account the time factor, the costs of the organization and the risks of individual stages.

The results of agent modeling will allow to make a final conclusion about the expediency and relevance of the choice of direction of development for the subsequent project management of the reform.

The scientific novelty of the publication is the creation a method by which the goals and directions of innovative development of high-tech enterprises are formed.

The proposed approach allows at the stage of preliminary study of the development of the organization to choose the goals and current direction of reform, taking into account the state of high-tech enterprise, readiness to implement reforms, as well as limited opportunities in the face of challenges and threats in the economy.

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