

Models and Management Structure for the Development and Implementation of Innovative Technologies in Railway Transportation. I. Mechanisms of Priority Projects Selection and Resource Allocation

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Abstract—This paper consists of two parts. In the first part, organizational approaches to manage the development and implementation of complex projects on the creation of innovative products and technologies for energy-saving railway transport are proposed. Some methods for estimating and classifying projects by the degree of implementability and effectiveness are considered. A resource planning model and a corresponding algorithm for a set of projects are presented.

Keywords: classification, maturity level of developments, saving energy, allocation of funds, control, management, organization

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1. INTRODUCTION

A major problem of large production associations, such as, e.g., JSC Russian Railways (RZhD, further referred to as the organization), is to adopt innovative products and technologies in their business activities for improving their energy-saving characteristics. The solution of this problem requires significant investments of financial, material, intellectual, and labor resources. These resources have limited volumes, and the current scientific and technological achievements, as well as the expected effectiveness of innovative products and technologies, are at different levels of readiness (maturity). Due to the factors mentioned above, immediate questions are to select priority projects and determine the degree of organization's participation in the further development of these projects as well as the degree of participation in bringing some of them to a maturity level at which pilot production and subsequent implementation are possible. For this purpose, the idea is to divide the current scientific and technological achievements into classes that characterize the level of their development (maturity and assessed prospects from implementing into serial operation). Such a classification procedure (the division into three layers of projects) was proposed when analyzing the interconnection of complex projects in [4]. Four classes of developments will be considered below as follows:

—the class of projects that are at the level of fundamental research;

- the class of projects that are at the level of research and development (R&D);
- the class of developments for which experimental samples of products and technologies have been created;
- the class of ideas and developments with underinvestigated or doubtful prospects.

In world practice, classification of developments by maturity is determined by the Technology Readiness Level (TRL) standards [25, 27, 30]. According to these standards, projects are assigned 9 readiness levels. The four classes considered in the first part of this paper and TRLs have the following relations:

—The class of ideas and developments with underinvestigated or doubtful prospects corresponds to TRL1 and TRL2.

—The class of projects that are at the level of fundamental research corresponds to TRL3 and TRL4.

—The class of projects that are at the level of R&D corresponds to TRL5–TRL7.

—The class of developments for which experimental samples of products and technologies have been created corresponds to TRL8 and TRL9.

The first part of the paper describes a method to classify projects by analyzing the level of completeness and prospects of research and developments in terms of the set of heterogeneous indicators using a refined version of an integrated assessment methodology. Note that the foundations of this methodology were laid in [2, 3]. The method to assign projects to different classes is illustrated by the example of projects on the development and implementation of innovative energy-saving products and technologies, including the use of alternative types of energy for the propulsion of trains.

Depending on the class to which a certain development belongs, different alternatives for the organization's participation in its support and financing are proposed. To solve this problem, an allocation mechanism of financial resources for a complex of projects is introduced.

Participation in the support and financing of developments from different classes requires an appropriate modernization of the management system of the scientific and technical complex of the organization. From these positions, the capabilities of improving the management structure of the scientific and technical activities are investigated.

The past studies in this field of research were surveyed in the paper [20] and also in the books [22, 26, 28, 29].

2. INTEGRATED ASSESSMENT OF PROJECTS AND THEIR CLASSIFICATION

2.1. Basic Principles for Constructing Integrated Assessment System for Innovative Projects

The integrated assessment system for innovative projects under consideration includes the following blocks of activities.

The first block of activities consists in the formation of a most complete list of projects related to the area of products and technologies under consideration.

The second block of activities is to compile a list of indicators characterizing the projects under consideration. These indicators determine the diverse and possibly heterogeneous features of the projects that are assumed significant for assessment. It is necessary that the set of indicators fully reflect the goals of the organization. A common recommendation is that this set include the following characteristics: the volume of works performed; the volume of works in progress; the planned energy costs of the designed product; the presence of open (unexplored) problems; the current level of foreign research in the field; the availability of experimental data on the use of

the product's prototype; environmental effect; the level of safety; the estimated time to obtain prototypes and also the estimated time before the start of possible serial production; finally, the estimated time to cover the project's costs. The exact set of indicators may differ for various application domains of projects.

In the sequel, as an example of an application domain, the development and implementation of innovative energy-saving products and technologies, in particular, the use of alternative types of energy for the propulsion of trains, will be considered. For this example, a possible list of such indicators will be presented. Note that the indicators should reflect not only energy cost reduction but also other aspects related to the effectiveness of the transportation process and its customer focus according to the goals of the organization.

In *the third block* of activities, measurement scales are formed for each indicator from the list selected. Since the indicators are significantly heterogeneous, it seems rational to measure them in discrete scales, e.g., in the form of the grades "poor," "satisfactory," "good," and "excellent"; or, e.g., according to the colors of the traffic light ("red," "yellow," and "green"). In the absence of sufficiently accurate quantitative values of the indicators or in the case of their qualitative nature, the scales are formed using expertise.

In *the fourth block* of activities, the pairwise convolution of different indicators in the form of a convolution tree is determined. Whenever possible, it is recommended to form meaningful characteristics of intermediate indicators when choosing indicators for pairwise convolution.

Finally, in *the fifth block* of activities, the values of the convolution matrices corresponding to the vertices of the constructed tree are filled.

2.2. Example of Integrated Assessment System and Classification of Projects

Consider the application of this integrated assessment system for classifying projects on an example of the use of alternative types of energy for the propulsion of trains.

Currently, JSC RZhD uses two types of locomotives: electric locomotives with traction motors that receive energy from a contact electric network and diesel locomotives with diesel engines. Replacing hydrocarbon fuel with alternative sources is one of the most important directions for improving the energy-saving characteristics of transportation [10, 17, 24, 31].

Block 1. List of projects

A review of the existing capabilities of using other types of fuel for the propulsion of locomotives reveals the following alternatives: synthetic liquid fuel, natural gas, solid fuel, hydrogen fuel cells, and locomotives with a nuclear propulsion system. This list should also include promising innovative transport technologies, such as magneto-levitation and vacuum-levitation.

Briefly describe the current scientific and technical achievements in this field and also the problems that need to be solved during the implementation of projects for the use of alternative fuels.

Synthetic liquid fuel. This refers to the use of all kinds of synthetic liquid fuels obtained from plant materials [6, 8, 13, 18, 19]. The studies conducted [6, 8, 13] demonstrated the possibility of using these types of fuel in the propulsion systems of locomotives. The main disadvantage of synthetic fuels is lower calorific value in comparison with diesel fuel and, as a result, higher fuel consumption. The problem is the development and implementation of fuel synthesis technologies and the provision of raw materials for production.

Natural gas. Can be used in compressed and liquefied conditions.

A sample of TEM18G, a shunting gas and diesel locomotive on compressed natural gas, was built and tested at Bryansk Machine Works. The tests showed that the length of run of this locomotive is considerably restricted by the size of its fuel tanks. In other words, compressed gas can be used on

locomotives with a limited radius of action [6]. The operation of liquefied gas locomotives requires the provision of gas stations with powerful compressor units.

The use of liquefied natural for a traction rolling stock is promising.

GT1h-001 (2009) and GT1h-002 trunk gas turbine locomotives and also TEM19 shunting gas and diesel locomotive [7] were created and put into trial operation at The All-Russian Research, Design and Technological Institute of Rolling Stock (VNIKTI).

The main problems associated with the use of liquefied gas are associated with the operation of cryogenic equipment as well as with the organization of production and supply of liquefied gas to railway transport in the required volumes.

Solid fuel. There is experience in creating gas-generating diesel locomotives and their operation on the railways of the former USSR and the People's Republic of China. Coal gasification on transport gas generators is less efficient than in stationary conditions, which is due to the size and weight limits of locomotives [6].

The operation of a gas turbine locomotive on solid fuel can be carried out in two ways, namely, on generator gas (similar to gas-generating locomotives) and using the pulverized coal combustion method [6].

A gas-generator gas turbine locomotive requires a gas generator of greater productivity than diesel locomotives.

For a gas turbine locomotive on pulverized coal fuel, the problem of improving the quality and completeness of solid fuel combustion is relevant. It can be solved when implementing the following combustion methods:

- the burning of coal dust in a cyclone furnace;
- the two-stage combustion of coal in the furnace of a steam boiler, i.e., gasification in the layer with a lack of air and subsequent combustion of the gas mixture;
- the burning of coal dust in a fluidized layer at a temperature of about 850°C, like in the case of stationary steam generators.

A gas-turbine locomotive propulsion system on pulverized coal requires the preliminary preparation of pulverized coal in stationary conditions or on the locomotive itself.

The combustion of pulverized coal is accompanied by intense wear of the turbine blades.

The main problems of using solid fuel for locomotive propulsion systems are related to the need for improving the efficiency of engines, ensuring the reliability and service life of the gas generator and turbines, reducing additional costs for products and storage operations, the preliminary preparation of coal, and its loading.

Fuel cell locomotive. A prototype of a hydrogen fuel cell train was developed in Japan. The train can reach a speed of 120 km/h, and its length of run is about 300–400 km. A prototype of a locomotive powered by hydrogen fuel cells with a capacity of 2 thousand hp was developed in the United States. A hydrogen train in Denmark runs 59 km along the route, which is due to the capacity of its hydrogen tanks [8, 13].

A number of projects to create hydrogen-powered rolling stock (handcar, railbus, railcar, power train and locomotive) were carried out at The All-Russian Research Institute of Railway Transport (VNIIZhT) [12]. Currently, a power plant car is being developed for track equipment operating in tunnels.

Hydrogen fuel cell engines have many advantages. However, for their use on locomotives, it is necessary to solve a number of complex problems:

- the development of hydrogen storage technology;
- the development of numerous standards (safety, storage, transportation, use, etc.);
- the creation of an appropriate hydrogen infrastructure.

Locomotive with nuclear propulsion system (NPS). The design of a locomotive with a nuclear propulsion system (atomic carrier) with a fast neutron reactor of the BOR-60V type was developed in 1983–1985 by the All-Russian Research Institute of Diesel Locomotives (VNITI) jointly with Kolomensky Works and the participation of other organizations [1]. Possible layouts of the nuclear propulsion system, which can be used as a locomotive (gas turbine) or a mobile power station, were worked out. However, further works were terminated.

The creation and use of locomotives with nuclear propulsion systems require solving a large number of problems, primarily related to the safety of their operation, maintenance and repair, their considerable dimensions and weight, variable operation modes of the locomotive, and many other problems to ensure the tightness, reliability and strength of pipelines and connections, environmental measures, and the creation of service infrastructure.

Promising transport technologies. The studies carried out to date demonstrate good prospects of using magneto-levitation and vacuum-levitation transport technologies. However, their creation requires solving a number of fundamental problems.

For the transport technology based on a linear electric motor and magnetic suspension (magneto-levitation technology) [10], it is necessary:

- to create materials for high temperature superconductivity;
- to create electromagnets, motors, high-voltage switches, inductive-type electric energy storage devices with elements of high-temperature superconductivity;
- to develop structural composite materials using nanotechnologies and also technologies for the manufacture of products from such materials;
- to develop autonomous energy sources of high power and energy intensity for on-board power sources, including hydrogen fuel cells and small nuclear installations;
- to develop high-voltage semiconductor converters and other high-power electronic components, etc.

For vacuum-levitation transport [10, 23, 32], it is necessary to solve the following problems:

- to study the aerodynamic characteristics of vacuum-levitation transport in a rarefied medium;
- to determine the parameters and design solutions for ensuring a vacuum environment, in view of cost optimization;
- to study the dynamics of motion (stability of vehicles, load, overload during maneuvers, etc.);
- to study the passive and active methods of stabilization and control of rolling stock during motion;
- to study and calculate mechanical stresses arising on the surface of a moving capsule and pipe;
- to determine the parameters and design solutions for ensuring a vacuum environment;
- to determine the limiting temperatures of the design and equipment of vacuum-levitation transport as well as the capability of the thermoregulation system of vacuum-levitation transport to maintain thermal conditions in a given range;
- to study heat transfer problems during vehicle movement in a vacuum environment, etc.

High costs will be required to create transport infrastructure. It is also necessary to develop an integrated safety system based on continuous diagnostics and protection of passengers and cargo from the influence of negative factors (magnetic radiation, overloads during acceleration and braking, pressure and temperature differentials, etc.).

Blocks 2 and 3. Indicators and their measurement scales

The set of indicators used to classify different projects is selected by analyzing the organization's strategic goals and assessing the impact of the expected effectiveness of the projects (in terms of

Table 1. List of indicators and their measurement scales

No.	Indicator	Measurement scale
1	Expected reduction in specific energy costs per unit of cargo carried and unit of distance	1, 2, 3, 4
2	Stage of works	1, 2, 3
3	Safety of product or technology	1, 2, 3
4	Expected payback period	1, 2, 3
5	Capital investments	1, 2, 3, 4
6	Risk of failure	1, 2, 3
7	Implementation period	1, 2, 3
8	Discounted reduction in energy costs over life cycle of technology	1, 2, 3, 4

Table 2. Ratings of projects: example

No.	Name of project	Ratings of project							
		1	2	3	4	5	6	7	8
1	Synthetic liquid fuel	2	3	3	2	3	3	3	2
2	Natural gas in compressed condition	3	3	3	2	3	3	3	3
3	Natural gas in liquified condition	4	3	3	3	4	3	3	4
4	Solid fuel	3	3	3	3	3	3	3	4
5	Fuel cells	4	2	3	3	3	3	3	3
6	Nuclear propulsion system	3	1	1	2	1	1	1	2
7	Magneto-levitation technology	3	3	3	2	3	3	2	3
8	Vacuum-levitation technology	4	2	2	3	3	2	2	4

saving energy) on these indicators. For clarity and interpretability of the classification system, if possible, it is desirable to use a finite number of indicators. An example below involves 8 indicators.

The first indicator determines the expected specific effectiveness of an energy-saving project. The scale (rating system) for this indicator has 4 ratings: 1—poor effectiveness, the project is excluded from consideration; 2—inclusion of the project is possible, provided that other indicators of the project have good ratings; 3—satisfactory value of the indicator; 4—good value of the indicator.

The second indicator characterizes at which stage of research or production the project currently is. Three ratings are established for this indicator as follows: 1—the project is at the stage of research and conceptual development; 2—the project is mainly at the stage of experimental development; 3—prototypes have been created for the project.

The third indicator determines the degree of safety of the technology being developed. Three ratings are established for this indicator as follows: 1—safety issues are not settled; 2—a generally satisfactory level of safety and environmental impact, but there are deviations that can be eliminated without significant costs; 3—the product or technology for the project in question agrees with the safety requirements and environmental measures.

The fourth indicator characterizes the payback period after the anticipated start of the industrial operation of a product or technology. Three ratings are established for this indicator as follows: 1—the payback is more than 15 years; 2—the payback is no more than 10 years; 3—the payback is less than 5 years.

The fifth indicator characterizes the degree of costs for creating an industrial sample and all necessary infrastructure for the operation of a product or technology. Four ratings are established for this indicator as follows: 1—the amount of costs significantly exceeding the ability of the organization and interested structures to finance the project; 2—the project requires significant investments by the organization and interested investment structures; 3—the project can be implemented at

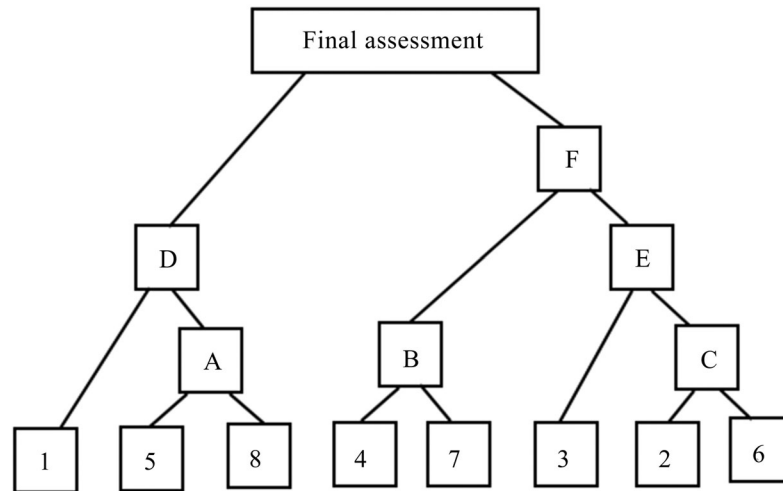


Fig. 1. Convolution tree for indicators.

the expense of rather big, albeit acceptable financial investments; 4—the project does not require big investments for implementation.

The sixth indicator characterizes the risks of project failure due to external and internal adverse conditions and insufficient justification of the project's reliability. Three ratings are established for this indicator as follows: 1—the risk of non-implementation is very high; 2—the risk of non-implementation is conditionally acceptable; 3—the risk of non-implementation is acceptable.

The seventh indicator determines the estimated period for the implementation of a technology. Three ratings are established for this indicator as follows: 1—an unacceptably long period; 2—a conditionally acceptable period; 3—an acceptable period.

The eighth indicator determines the energy-saving characteristics of a product or technology during their life cycle, taking into consideration the income discounting effects. Four ratings are established for this indicator as follows: 1—small reduction of costs; 2—a satisfactory reduction of costs comparable with financial investments in the implementation of the project; 3—good energy-saving potential; 4—the reduction of energy costs significantly exceeds the costs of the implementation and adoption of project results.

As the above description of indicators shows, they should be assessed with the assistance of experts.

Each of the given indicators can, in turn, be calculated using a convolution of the corresponding set of sub-indicators.

Note that for all indicators, these ratings of a project are not quantitative, but qualitative in nature; they are implemented before the development of the financial model of a project. The financial model of a project is developed after the decision to consider it in detail.

Block 4. Structure of convolution tree for indicators

The structure of the convolution tree is established by experts, including users of the integrated assessment system for projects; see Fig. 1. To obtain an intermediate indicator, it is advisable to convolute indicators that are close in content. For example, a convolution of the fifth and eighth indicators (see Table 1) characterizes the profitability of the project being assessed.

Block 5. Description of convolution matrices

The following is an example of constructing convolution matrices; see Fig. 2. Here the rows (from bottom to top) correspond to the ratings of a first indicator entering the input of a convolution block, and the columns (from right to left) to the ratings of a second indicator. The values of

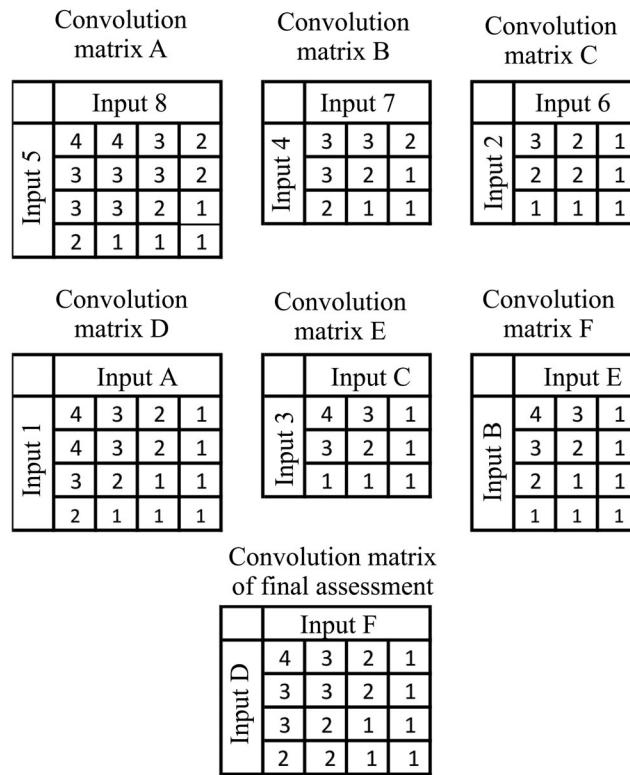


Fig. 2. Convolution matrices of indicators.

convolution matrix elements are established by expertise when tuning the integrated assessment system for a given application domain (in the example under consideration, when assessing the prospects of projects to create products and technologies for using new types of energy for the propulsion of trains).

2.3. Forms of Organization’s Participation in Projects Depending on Their Classification

The table below shows the calculated ratings for the projects under consideration. The final rating can be used to divide the projects into classes describing their prospects. Also, it can be used for choosing the form of participation of the organization in the development of projects.

For example, regarding projects nos. 1 and 6, the organization may decide not to participate in their development. For project no. 2, participation in the form of research grants may be considered

Table 3. Calculation of intermediate and final ratings of projects: example

No.	Name of project	Intermediate and final ratings of project						Final rating
		A	B	C	D	E	F	
1	Synthetic liquid fuel	3	1	3	2	4	1	1
2	Natural gas in compressed condition	3	3	3	2	4	3	2
3	Natural gas in liquified condition	4	3	3	4	4	4	4
4	Solid fuel	3	3	3	3	4	4	3
5	Fuel cells	3	3	2	3	3	3	3
6	Nuclear propulsion system	2	1	1	2	1	1	1
7	Magneto-levitation technology	3	2	3	3	4	3	3
8	Vacuum-levitation technology	3	2	3	3	4	3	3

if new breakthrough ideas appear. For projects nos. 4, 5, 7, and 8, it is possible to provide subsidies for works on individual parts of the projects jointly with other interested organizations. For project no. 3, the organization may actively participate in financing.

Note that this preliminary selection procedure for projects can serve as a decision support system only, with the use and further processing of expert appraisals. The final decision on the degree of the organization's participation in the investment of any projects should be considered on the basis of financial models and business plans of the most promising projects, using the techniques presented in the organization's standards and administrative documents, including [14–16].

The most promising projects of a certain class can be identified using the classification procedure illustrated above for prioritizing projects within this class. For this purpose, by analogy with the technique presented in the example, a new list of original indicators, a new structure and new convolution matrices have to be formed.

3. ALLOCATION MECHANISMS OF FINANCIAL RESOURCES FOR COMPLEX PROJECTS

The preliminary assessment procedure described above allows selecting a group of priority projects. The highest priority is assigned to the projects falling into the group with final rating 4; next, to the ones falling into the group with final rating 3, and so forth.

Consider the problem of forming an investment program based on the preliminary assessment of projects. As it has been underlined above, projects can be at different stages of research or production (the stage of research and development, the stage of experimental development, the stage of mass production, etc.). Obviously, a certain innovative potential is needed at each stage. The volumes of financing to support the potential of developments at each stage will be determined using expertise. For this purpose, the mechanism of consent can be applied [5, 11].

In accordance with this mechanism, two expert commissions are formed. The first commission reports an assessment s_1 of the relative financing of stage 1 projects compared to the financing of stage 3 ones. The second commission also reports an assessment s_2 of the relative financing of stage 2 projects compared to the financing of stage 3 projects. These assessments are then used for calculating the financing of separate stages:

$$\begin{aligned}x_1 &= \frac{Rs_1}{(1 + s_1 + s_2)}, \\x_2 &= \frac{Rs_2}{(1 + s_1 + s_2)}, \\x_3 &= \frac{R}{(1 + s_1 + s_2)},\end{aligned}$$

where R is the value of investment fund. The following result was established in the theory of active systems [5]: under the hypothesis of sufficient interest, each expert commission benefits from reporting the true opinion expressing the consensus of its members. For satisfying the hypothesis of sufficient interest, it is necessary to include in each commission the experts who are interested in supporting both the potential of serial models and the potential of developments of a corresponding stage.

After determining the volume of financing for each stage, an innovative program is formed. This problem is solved independently for the projects of each stage. First, for each stage, the projects with final rating 4 are considered.

If the resources allocated for a corresponding stage are sufficient for all projects with final rating 4, then projects with final rating 3, etc., are considered. This is done in accordance with the forms of participation in projects described above.

Consider algorithms for forming an investment program for each separate stage.

Suppose that the set $N = \{1, 2, \dots, n\}$ of activities (projects) is fixed and, for each of them, the costs x_i and income y_i from implementation are known. The project's effectiveness is defined as the ratio of its income to costs. Propose a mechanism for finding a portfolio of projects (a subset of the set N) with the maximum total income from implementation, provided that the total costs of implementing all portfolio projects do not exceed the available fund R .

Study the case of indivisible and independent projects, in which the projects can be implemented independently and the effectiveness of projects is independent of the final list of projects selected. In this case, the implementation of the mechanism includes solving the NP -hard knapsack problem. Practical problems of this class are solved using heuristic algorithms, e.g., the greedy algorithm. In accordance with this algorithm and cost-effectiveness analysis [9], the optimal investment program is formed in the following way: the projects are arranged in the descending order of their effectiveness; starting from the first project (having maximum effectiveness), the projects are sequentially included in the portfolio until all available resources are exhausted. This selection procedure will result in the complete implementation of a certain number of projects and, possibly, an incomplete implementation of exactly one project. For the continuous problem, this will give an optimal solution. For the case of indivisible projects, it is necessary to consider the list of still unselected projects, ordered by their effectiveness, and find a project for which the residual budget is enough. Whenever such a project exists, it is selected, and the residual budget is reduced accordingly. The procedure is repeated until there are no projects for which the residual budget is sufficient.

The procedure described above is based on the independent implementation of projects and also on the independent effectiveness of projects. In practice, however, these conditions may be violated: for example, some project can be implemented only if other projects are completed beforehand; if some projects are implemented jointly, their effectiveness will change due to the synergy effect.

Consider a complex project containing a set of interconnected projects in which the result of some projects may depend on the results of other projects.

Let the set $I = \{1, 2, \dots, n\}$ of activities (projects) and also the volume R of available resources be fixed. For each project $i \in I$, the following numerical parameters are given:

- the result y_i ;
- the costs x_i to implement the project (to achieve the result).

The problem is to select the set M of projects by maximizing the total effect of their implementation subject to two constraints as follows. First, the total volume of resources allocated to all projects does not exceed R . Second, the existing interconnections of projects can be represented as one or more trees in which it is easy to identify all projects dependent on a given project (i.e., the projects that cannot be completed without it).

The idea of a heuristic algorithm intended for this problem is to solve sequentially a series of problems with a monotonically decreasing number of projects. For each problem, the most effective project (or group of projects) is selected, and the resources are allocated to it. If this project (or group of projects) is completely implemented, it is excluded from further consideration, and the same problem is then solved for a smaller volume of resources and a smaller number of projects.

Input data of algorithm:

- the set N of projects;
- the fund R of available resources;
- the interconnections of projects in the set I .

Output data of algorithm:

- the set m of selected projects.

Algorithm

1. Introduce the following notations:
 - (a) t as the number of current problem being solved;
 - (b) N^t as the set of projects available for selection in problem t ;
 - (c) R^t as the volume of available resources in problem t ;
 - (d) J^t as the set of previously selected projects in problem t ;
 - (e) $J(k, M)$ as the procedure that, for each pair “project k , the set of projects M ,” outputs a set of projects such that:
 - 1) project k depends on them;
 - 2) they belong to the set M .
2. Perform initialization:
 - (a) The first problem being solved has number 1 ($t = 1$).
 - (b) The set of available projects in the first problem being solved coincides with the set of all projects ($N^1 = N$).
 - (c) The available resources in the first problem being solved coincide with the fund ($R^1 = R$).
 - (d) There are no previously selected projects in the first problem being solved (J^1 is an empty set).
3. If there are no available projects (N^t is empty), then pass to the last step of the algorithm (step 12) for completion.
4. For each project j belonging to the set N^t , calculate the value of its effectiveness

$$k_j^t = \frac{\sum_{i \in J(j, N^t)} y_i}{\sum_{i \in J(j, N^t)} x_i}.$$

5. Select any of the projects with maximum effectiveness; let its number be d .
6. Check if the residual resources are sufficient for the full implementation of all projects on which project d depends. If the residual resources are enough, check if it will be enough to fully complete project d . Otherwise, allocate as much as necessary for the implementation of all projects on which project d depends; for project d itself, allocate the residual resources (if any).
 - (a) Add into the set J^1 of previously selected projects project d and those projects available for selection on which it depends; pass to the last step of the algorithm (step 12) for completion.
7. Check if the residual resources are sufficient for the full implementation of project d . If they are not enough and, moreover, these resources are also not enough for the full implementation of all projects on which project d depends, then:
 - (a) Obtain the set N^{t+1} of projects available for selection in problem $t + 1$ by eliminating project d from the set N^t of projects available for selection in the current problem t .
 - (b) Let the available resources R^{t+1} in problem $t + 1$ be the same as the available resources R^t in problem t .
 - (c) Let the set J^{t+1} of previously selected projects in problem $t + 1$ be the same as the set J^1 of previously selected projects in problem t .
 - (d) Increase the number of current problem by 1 (let $t := t + 1$).
 - (e) Pass to step 3 for solving the next problem.

8. Check if the residual resources are enough for the full implementation of project d . If the implementation of project d requires the implementation of projects that have not yet been implemented, it is necessary to take into account the costs of their implementation. If the resources are enough, form the input data for the next problem. Assign number $t + 1$ to it. The set J^{t+1} of selected projects in this problem will consist of the set J^t of selected projects in problem t , project d , and the set of all projects on which project d depends. Form the input data for the following problem:
 - (a) The available resources R^{t+1} in problem $t + 1$ are determined as follows. The required volume of resources for implementing project d is subtracted from the resources R^t available in problem t . If the implementation of project d requires executing some projects still not implemented, the costs of these projects are also subtracted.
 - (b) Obtain the set N^{t+1} of projects available for selection in problem $t + 1$ from the set N^t of projects available for selection in the current problem t , excluding the element with number d and all projects on which it depends.
9. Increase the number of current problem by 1 (let $t := t + 1$).
10. Pass to step 3 for solving the next problem.
11. Finish the algorithm. The set J^t gives the list of selected projects ($m = J^t$); at the same time, some projects selected may have insufficient resources.

This algorithm for selecting priority projects and allocating financial resources among them is an extension of cost-effectiveness analysis [9] to the case of a complex of interconnected projects.

Like cost-effectiveness analysis [9], which is actually an analog of the greedy algorithm for the approximate solution of the knapsack problem, for a complex of independent projects this algorithm yields an approximate solution of the resource allocation problem with a given tree of interconnections of the projects. The conditions of its optimality, as well as the deviations of the resulting solutions from the optimal solution in terms of effectiveness, require further research.

The application of the mechanisms described above can be written as the following chain of actions:

—The set of potential projects for consideration is formed, and these projects are then divided into 4 classes.

—Financial resources are allocated among the classes of projects using the mechanism of consent.

—The projects from each class are divided into a system of sub-projects that have independent value. An interconnection tree of sub-projects that characterizes the order of their implementation is constructed. In other words, the chains of sequentially executed sub-projects are determined, and the possibilities for their parallel execution are assessed.

—For each sub-project and also for each set of interconnected sub-projects within each class, the effects and the financial resources required are estimated in accordance with the constructed interconnection tree.

—The resource allocation algorithm proposed above is used to determine budgets for projects in each class, i.e., to find the investment program.

4. CONCLUSIONS

In the first part of the paper, the assessment, classification, and selection of priority projects have been studied. As an example the development of products and technologies for using alternative types of energy for the propulsion of trains has been considered. This example has illustrated the authors' methodology for the preliminary selection and ranking of projects by their priority.

The original indicators for the selection of projects have been proposed in accordance with the main principles of the goal structure for managing the innovative and scientific complex of

the organization. The list of these indicators, together with the integrated assessment procedure described above, can be adopted as a system of key performance indicators (KPIs) for the scientific complex of the organization.

The original structure for assessing and classifying different projects can be a tool for the expertise and scientific-technological support (monitoring) of complex scientific-technical projects and long-term strategic scientific and innovative programs.

The resource allocation mechanism described in the first part of the paper can be used in the formation of investment programs of the innovative and scientific complex of the organization.

The second part of the paper will be dedicated to the incentive models for implementing energy-saving projects within a multi-project structure. Also, some opportunities to form the individual elements of a management structure for the scientific and technical complex of the organization will be presented.

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