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OPTIMIZATION OF INFRASTRUCTURE PROJECTS PARAMETERS IN THE PROGRAM

The object of research is infrastructure projects as part of the program. The products of infrastructure projects are various infrastructural objects that together provide a certain value for stakeholders, for example, a certain bandwidth of the transport network or the capacity of a port, channel, etc. Identification of the parameters of project products is carried out at the stage of program development. For most projects, these parameters allow for variability within certain limits. The interconnection of infrastructure projects is determined not only by general financing and management, but, above all, by the consistency of the properties of goods. Therefore, the optimization of the parameters of the products of such projects is carried out integrally, within a single model. Coordination of the parameters of the products of infrastructure projects as part of the program requires formalized methods that allow them to be optimized taking into account both local constraints for each project and the global conditions for implementing the program. As a result of the study, a concept has been formed and an appropriate model has been developed, which allows setting the optimal parameters of the products of infrastructure projects as part of the program. Modeling is based on the ability to vary the parameters of project products and their relationship with the characteristics of projects and the program as a whole, such as value, costs, and the magnitude of risks. Since the program and the projects included in it can be of a non-commercial nature, therefore, the main criterion of optimality for the parameters of the products of projects and programs is a universal category – value, and it is considered for all stakeholders. The use of this model in the development of the program and the infrastructure projects included in it ensures the optimization of the required result while meeting certain requirements and limiting conditions. The model belongs to the class of nonlinear models and is developed for a situation where a so-called «main» project (or their combination) can be distinguished, which form(s) the requirements for the products of other projects interconnected with it, which is typical for infrastructure programs.

Keywords: *stakeholders of infrastructure projects, project value, optimization of the program composition, infrastructure facility, project risks.*

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1. Introduction

Infrastructure projects are quite often implemented as part of programs of various sizes, the products of which are various infrastructure facilities. These objects in the complex provide, for example, a certain capacity of the transport network or the capacity of a port, canal, etc. (for programs for the development of maritime transport infrastructure), which is the essence of the corresponding programs. The product of each project is characterized by a certain set of parameters (for example, the depth, width and length of the canal, the length of the railway track, etc.) These parameters, in turn, determine the cost of the project, its duration, risks, etc. That is, the characteristics of the project depend on the parameters of its product, which, as a consequence, determines similar characteristics for the program.

The identification of the parameters of project products is carried out at the stage of program development. For most projects, these parameters allow for variability within certain limits. Coordination of the parameters of the products of infrastructure projects as part of the program requires formalized methods that allow them to be optimized taking into account both local constraints for each project and the global conditions for implementing the program.

Infrastructure projects are the subject of many modern studies, first of all, because the number and scale of implemented infrastructure projects is growing every year [1]. At the same time, their specificity requires the adaptation of existing theoretical provisions and the development of appropriate methods and models for managing these projects, taking into account their specificity as much as possible. The modern methodology for managing infrastructure projects is described in many works. So, the value of these projects and programs in terms of the development of socio-economic systems is identified in [2–4]. The need to use a proactive approach is justified in [5], the identification of the specifics of the project methodology in the context of this category of projects is carried out in [6, 7].

Much of the research on infrastructure projects *deals with three main questions*:

1) financing [8];
2) budget distribution [9];
3) monitoring and management of changes [10].

A special category of projects is made up of information platforms related to infrastructure facilities and their development, which is considered, for example, in [11, 12].

Nevertheless, the problem of optimizing the parameters of the products of infrastructure projects, both at the level of an individual project and at the level of infrastructure programs, is practically not considered. It should be noted that the idea of varying the parameters of a project product at the stage of its development in order to maximize the value of the project and minimize risks was expressed in [13, 14], where projects were considered in general form without reference to specific specifics. This idea can be developed in terms of infrastructure projects with their integral consideration within the program.

Thus, *the object of research* is selected infrastructure projects as part of the program. *The subject of research* is the parameters of the products of infrastructure projects as part of the program, which maximize the value of stakeholders. *The aim of research* is to develop a model for optimizing the parameters of products of infrastructure projects as part of the program.

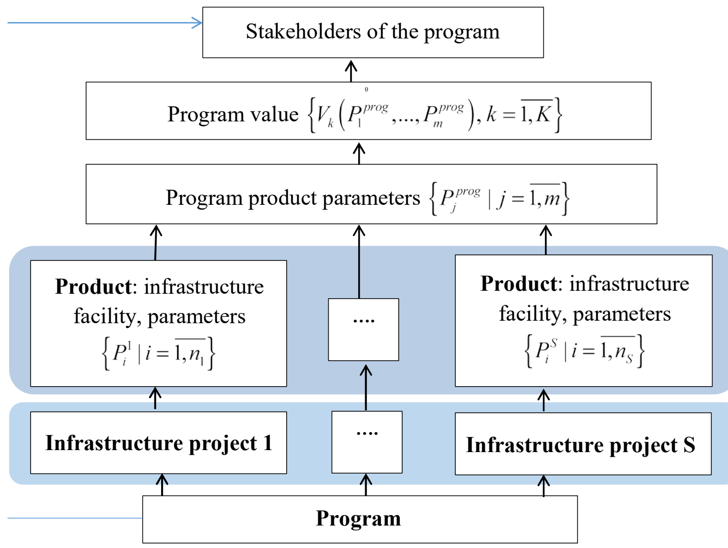

Fig. 1. Influence of the parameters of products of infrastructure projects as part of the program on its value for stakeholders

2. Methods of research

Methods of research are system analysis, functional analysis, operations research. System analysis was used to establish the relationships between the products of infrastructure projects as part of the program and to form a conceptual model for optimizing the parameters of the products of infrastructure projects as part of the program. Functional analysis made it possible to determine the fundamental form of dependences of various indicators and characteristics of projects and programs on the parameters of project products. Operations research, in particular nonlinear optimization, was used to develop a mathematical model.

3. Research results and discussion

As previously stated, the parameters of an infrastructure project product determine its cost and duration of work. When an infrastructure project is included in the program, then its product is interconnected and interdependent with the products of other projects included in the program (Fig. 1).

So, if the program is related to the development of *the transport system of the region*, and involves the implementation of several infrastructure projects, then, for example, the place and length of the ferry crossing determine the length of roads leading to/from it. Another example: a certain depth of the approach channel to the port forms the requirements for the ships for which this channel is accessible, and, accordingly, determines the necessary transshipment equipment in the port, etc. Thus, the program may include one or more infrastructure projects, or the whole program is a set of interrelated infrastructure projects.

In this situation, for each project $s=\overline{1,S}$ of the program, a product is formed, the parameters of which $\left\{P_i^s \mid i=\overline{1,n_s}\right\}$ n_s, where – the number of selected parameters of the s-th project. Moreover, these products are generally interrelated. As a rule, among infrastructure projects one can distinguish a «fundamental» project or a set of «fundamental» projects, whose product parameters determine the parameters of the products of other program projects (for example, as the situation with dredging works at the approach channel in the port was previously considered). At the same time, the logic of distinguishing such a fundamental project/projects of the program is based on *the product and value* of the program. For example, if *the product of the program* is a transport network of a region with a certain bandwidth, then the fundamental project will be the one whose product forms *the main restriction* for the parameters of the program product. Thus, the situation takes place as in Fig. 2.

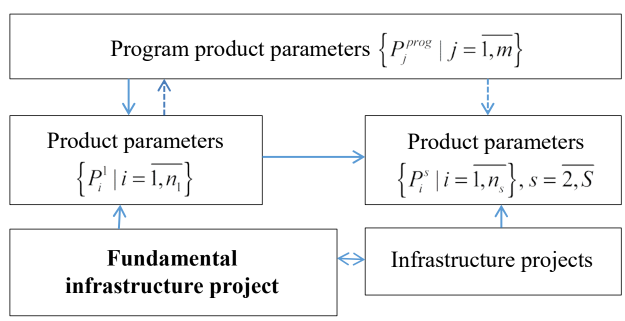

Fig. 2. The relationship of the parameters of the products of projects within the program

The required parameters of the program product determine the requirements for the product parameters of the underlying project(s). This, in turn, determines the requirements for the parameters of the products of the remaining projects of the program. Thus, if to assume that the first project is fundamental in the program, then:

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$$P_i^s = P_i^s(P_1^1,...,P_{n_1}^1), i=\overline{1,n_s}, s=\overline{2,S}, \quad (1)$$

that is, the parameters of its product determine the parameters of the products of other program projects.

As for the program product: on the one hand, it is natural that the parameters of the program product are formed depending on the parameters of the projects included in it, that is:

$$P_j^{prog} = P_j^{prog}(P_1^1,...,P_{n_1}^1,...,P_1^S,...,P_{n_S}^S), j=\overline{1,m}, \quad (2)$$

or, in the event that all parameters of the products of the program projects are determined only by the parameters of the products of the underlying project:

$$P_j^{prog} = P_j^{prog}(P_1^1,...,P_{n_1}^1), j=\overline{1,m}. \quad (3)$$

On the other hand, the given parameters of the program product $P_j^{prog}, j=\overline{1,m}$ form the parameters, first of all, of the fundamental infrastructure project P_i^1, $i=\overline{1,n_1};$, and then, taking into account its parameters, the parameters of the products of other projects:

$$P_i^1 = P_i^1(P_1^{prog},...,P_m^{prog}), i=\overline{1,n_1}; \quad (4)$$

$$P_i^s = P_i^s(P_1^1(P_1^{prog},...,P_m^{prog}),...,P_{n_1}^1(P_1^{prog},...,P_m^{prog}),P_1^{prog},...,P_m^{prog}), \; i=\overline{1,n_s}; s=\overline{2,S}. \quad (5)$$

Let's note that (5) formalizes the relationship of the parameters of the products of the program projects (not fundamental), taking into account the fact that their parameters may depend directly on the parameters of the program. Transforms can allow transforming (5) as follows:

$$P_i^s = P_i^s(P_1^{prog},...,P_m^{prog}), i=\overline{1,n_s}; s=\overline{2,S}. \quad (6)$$

Thus, depending on the situation, the definition of the parameters of the program and the corresponding projects can be carried out in two directions – from the program to projects and vice versa. This is, for example, relevant when certain limitations of a natural nature (features of geography) *set the limiting boundaries of the fundamental project*, and the parameters of the program and other projects are determined taking this into account by formulas (2), (3). In another situation, the program product and its parameters are the primary information for determining the parameters of the program projects' products. In this case, formulas (4), (6) are used.

So, the interconnection of infrastructure projects is determined not only by general financing and management, but, above all, by the consistency of product parameters. Therefore, the optimization of the parameters of the products of such projects is carried out integrally, within a single model.

Let the program (subprogram) include S infrastructure projects. The parameters of the project products will be denoted as $P_1^s, P_2^s,...,P_{n_s}^s, s=\overline{1,S}$, where n_S – the number of product parameters of the *s*-th project.

For each project, there are restrictions associated with the permissible levels of product parameters. These restrictions can be both natural (features of the area, soil, existing infrastructure, etc.), and the requirements of the program initiators:

$$P_i^{s\min} \le P_i^s \le P_i^{s\max}, s=\overline{1,S}, i=\overline{1,n_s}. \quad (7)$$

Earlier it was found that on the basis of the requirements of the program from the point of view of its product $P_1^{prog},...,P_m^{prog}$, the parameters of *the fundamental project* (conditionally – the first in numbering) are formed and on its basis the rest. Let's note that the program product (more precisely, its parameters) are also subject to optimization and allow for a certain variation (at the stage of program development):

$$P_j^{prog\min} \le P_j^{prog} \le P_j^{prog\max}, j=\overline{1,m}, \quad (8)$$

where $P_\mu^{prog\min}, P_\mu^{prog\max}$ – respectively, the lower and upper limits of the admissible values of the program product parameters. A conceptual model for optimizing the parameters of the products of infrastructure projects as part of the program is shown in Fig. 3. This conceptual model reflects the following properties of projects within the program:

1) the presence of the relationship between the parameters of the products of various projects of the program and their compliance with the parameters of the program product;

2) the need for a certain level of investment for each project and the presence of corresponding risks (expressed in monetary terms), which is determined by the parameters of the project product;

3) limited investment in the development and implementation of the program, with the existence of certain restrictions on the minimum acceptable risks and the value of the program from the perspective of stakeholders.

At the same time, the main criterion for optimizing the parameters of infrastructure projects as part of the program is to maximize value for the "main" stakeholder. This is true, since in the case of a multi-criteria approach and maximization of values for all stakeholders, as a rule, the task comes down to the formation of a system of restrictions on values for stakeholders. In this case, only one main criterion stands out; restrictions on other values have already been taken into account (paragraph 3).

The diagram in Fig. 3 as a result of taking into account all of the above in the development and application of the optimization model, the optimal values of the parameters of infrastructure projects in the program are used. These parameters correspond to a set of requirements and the specifics of the influence of project parameters on the characteristics of both projects and programs as a whole.

Thus, Fig. 3 displays the basic structure and control parameters of the optimization model presented below.

Let's note that this conceptual model is the basis and can be supplemented with restrictions both at the level of an individual project and the entire program. For example, these may be restrictions on specific types of resources (not financial), which is determined by their physical availability and availability for use. It may also be time constraints for the implementation of projects and the program as a whole, which is associated, for example, with weather conditions, certain events, etc.

This conceptual model was used as the basis for the further development of the mathematical model.

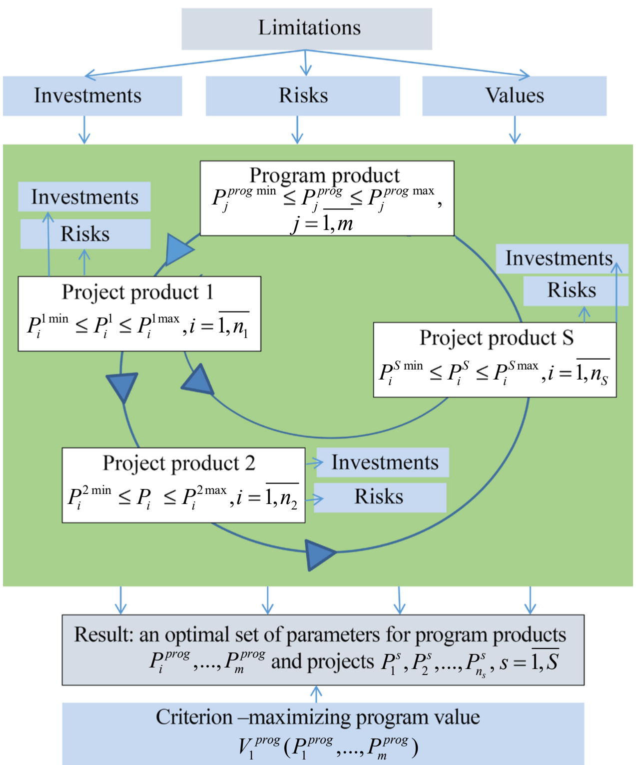

Fig. 3. Conceptual model of optimization of parameters of products of infrastructure projects as part of the program

Let's note that the program and the projects included in it (all or some) may be non-commercial in nature. Therefore, the main criterion of optimality for the parameters of project products and programs is *value* as a universal category. As described above, an infrastructure project can be part of a program of both regional and national scale. Depending on the hierarchy of goals set by the program, the main goal can be identified, the achievement of which is the main value [15]. If the program affects several levels/sectors, etc., then a whole set of values is formed $C_k^{prog}, k=\overline{1,K}$, where K – the number of program values under consideration.

Thus, for a situation where there is a fundamental project (conditionally one and the first), the criterion for optimizing the parameters of project products is to maximize the value of the program (its main component):

$$V_1^{prog}(P_1^{prog}(P_1^1,...,P_{n_1}^1),...,P_m^{prog}(P_1^1,...,P_{n_1}^1)) \to \max_{P_1^1,...,P_{n_1}^1}. \qquad (9)$$

The rest of the program value components can be used as constraints when setting their minimum (maximum) admissible boundaries $V_k^{prog\,min}, k=\overline{2,K}$:

$$V_k^{prog}(P_1^{prog}(P_1^1,...,P_{n_1}^1),...,P_m^{prog}(P_1^1,...,P_{n_1}^1)) \ge V_k^{prog\,min},$$
$$k=\overline{2,K}. \qquad (10)$$

The program and the projects included in it are limited in funding, and in addition to the general restriction on the program, as a rule, the budgets of each project are also limited separately, thus:

$$R^{prog}(P_1^1,...,P_{n_1}^1) \le R^{prog\,max}, \qquad (11)$$

$$R^s(P_1^1,...,P_{n_1}^1) \le R^{s\,max}, s=\overline{1,S}, \qquad (12)$$

where $R^{prog}, R^s, s=\overline{1,S}$ – respectively, the costs of the program and projects; $R^{prog\,max}, R^{s\,max}, s=\overline{1,S}$ – the maximum allowable costs for the program and projects. Note that (11), (12) takes into account the transformation of program and project costs depending on the parameters of their products in dependence on the parameters of the product of the underlying project, that is:

$$R^{prog}(P_1^{prog}(P_1^1,...,P_{n_1}^1),...,P_m^{prog}(P_1^1,...,P_{n_1}^1)) =$$
$$= R^{prog}(P_1^1,...,P_{n_1}^1), \qquad (13)$$

$$R^s(P_1^s(P_1^1,...,P_{n_1}^1),...,P_{n_s}^s(P_1^1,...,P_{n_1}^1)) =$$
$$= R^s(P_1^1,...,P_{n_1}^1), s=\overline{2,S}. \qquad (14)$$

It should also be noted that in (11) it is not necessary:

$$R^{prog}(P_1^1,...,P_{n_1}^1) = \sum_{s=1}^{S} R^s(P_1^1,...,P_{n_1}^1),$$

taking into account, for example, the synergistic effect [15], it is possible:

$$R^{prog}(P_1^1,...,P_{n_1}^1) < \sum_{s=1}^{S} R^s(P_1^1,...,P_{n_1}^1);$$

or, on the contrary:

$$R^{prog}(P_1^1,...,P_{n_1}^1) > \sum_{s=1}^{S} R^s(P_1^1,...,P_{n_1}^1),$$

if the program as a whole requires the development of special information support for integrated project management. Or certain items of expenditure (including for management and documentation) are not taken into account at the project level in $R^s(P_1^1,...,P_{n_1}^1), s=\overline{1,S}$ and are considered within $R^{prog}(P_1^1,...,P_{n_1}^1)$.

Let's suppose that projects use G types of resources, the availability of which is limited by volume $M_g, g=\overline{1,G}$, then the following should be done:

$$\sum_{s=1}^{S} M_g^s(P_1^1,...,P_{n_1}^1) \le M_g, g=\overline{1,G}, \qquad (15)$$

where $M_g^s(P_1^1,...,P_{n_1}^1)$ reflects the amount of resources of the g-type required for the implementation of the project with the corresponding parameters of its product.

Let's bote that this study does not take into account the dynamics of the project implementation processes, which can be done within the framework of a separate study and, at the same time, the availability of resources for individual time periods can be considered.

As a rule, infrastructure projects can be interconnected by means of their products and in time (that is, the order

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of obtaining the products of projects is important, some of which can be carried out sequentially, and some – in parallel). Thus, taking into account information about this procedure, time limits for the implementation of projects can be formed to ensure the implementation of the program within a certain time frame:

$$T^s(P_1^1,...,P_{n_1}^1) \le T_s^{\max}, s = \overline{1,S}, \quad (16)$$

where $T^s(P_1^1,...,P_{n_1}^1)$ – project implementation time depending on the parameters of its product; $T_s^{\max}$ – the maximum possible time frame for project implementation, taking into account the interest of the entire program.

As a measure of risks, it is proposed to use a possible increase in costs (in excess of those taken as acceptable) or delays in implementation time. Regardless of the essence of the accepted risk assessment of the program $Risk^{prog}$ and each project $Risk^s$ separately, it certainly depends on the parameters of the project products, that is, it is fair:

$$Risk^{prog}(P_1^1,...,P_{n_1}^1) \le Risk^{prog\max}, \quad (17)$$

$$Risk^s(P_1^1,...,P_{n_1}^1) \le Risk^{s\max}, s = \overline{1,S}. \quad (18)$$

The restrictions on the parameters of the products of projects and the program as a whole, formulated above in (7), (8), taking into account the dependence of the parameters of the products of the underlying project and other projects and programs (1), (3), complement the formation of the optimization model.

Thus, a model (1), (3), (7)–(12), (15)–(18) has been developed, which belongs to the class of nonlinear models, which allows to set the optimal values of the parameters of the products of infrastructure projects as part of the program. This model has been developed for a situation where a so-called "fundamental" project (or their combination) can be distinguished, which forms the requirements for the products of other projects interconnected with it. Let's note that it was justified above that this situation is typical for infrastructure programs.

4. Conclusions

As a research result, a concept has been formed and an appropriate model has been developed, which allows setting the optimal parameters of the products of infrastructure projects as part of the program. Modeling is based on the ability to vary the parameters of project products and their relationship with the characteristics of projects, and the program as a whole, such as value, investment, resources, time, and the magnitude of risks. The use of this model in the development of the program and the infrastructure projects included in it ensures the optimization of the required result while meeting certain requirements and limiting conditions.

The development of the proposed result can be:

a) statistically establishing a specific type of dependence of the characteristics of infrastructure projects on their products and using them in the proposed model;

b) transformation of the model (its addition) for specific conditions not considered in this research.

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