Large-scale transport projects: tools to transform qualitative into quantitative assessment

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Abstract. Decision-making tools for large-scale transport projects are the subject of research in this paper. The purpose of this paper is to improve decision-making techniques for loosely structured problems and to demonstrate the results of experimental calculations on the example of a large-scale transport project. The methods of the research are the methods of system analysis: expert technologies that are being improved in the course of the research; method of scenarios; for construction of problem hierarchy, goal tree; criteria priorities; and criteria of decision-making theory (Wald, Savage, Hurwicz, Bayes, Laplace). The study has established three criteria for assessing the effectiveness of the Barentskomur railway project (the project of the railway connecting Indiga port and Surgut); it has revealed the priorities of the criteria for assessing the effectiveness of the project in three different scenarios of external environment development: optimistic, pessimistic, and the most probable in a quantitative scale. The survey of experts was carried out. A new approach to the significance of the general goal of the project has been proposed. The quantitative estimations of significance of two different alternatives of realization of the project in various scenarios are received. The results have led to the conclusion that the Barentskomur 2 project should be implemented, because there is a high degree of uncertainty in the world, and in this case the most "cautious" Wald criterion should be used. Not only do we need to con-sider scenarios and immerse alternatives in those scenarios, but in the case of large-scale transport projects we also need to consider the impact that the project has on the scenario, due to its scale.

1 Introduction

Introductory remarks. System analysis is used in this paper to apply it to complex decision making in poorly structured problem situations. A typical situation in this sense is when a decision is made to implement a large-scale transport project of strate-gic importance to the state in the long term. The problem of the situation is that the significance of competing

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projects of this type at the initial stage of their life cycle is described mainly verbally, the results and costs are roughly and tentatively described by analogues, and the time parameters of the projects are ambiguous. The desired completion dates are stated more or less clearly, from which the expected duration of the life cycles of the projects naturally follows. The financial and commercial aspects are analysed in terms of the investment intentions of the project initiators; in project practise, the relevant phase of the project life cycle is called pre-investment phase.

From a scientific point of view, this creates uncertainties that cause uncertainty about how to evaluate and select the most suitable project alternative [1]. Unfortunately, neither the researchers of operations in the past nor the current generation of authors of econometric methods and models have so far proposed constructive approaches to solving this problem in the general case. Deterministic models do not solve the prob-lem, even if they have been developed by outstanding mathematicians and economists. In these models, as J. Kornai [2], they have worked out specific mathematical and eco-nomic problems and solved some applied problems. However, attempts to generalise the results obtained for more general cases where it is necessary to solve so-called undefined problems have so far proved to be unsuccessful [3].

At the same time, economic practise, both domestic and foreign, responding to the challenges of technological and social progress, is forced to make decisions on the implementation of an increasing number of large-scale projects (in the western terminology - mega-projects), without relying on the relevant theory and reliable methodological tool.

As a consequence, the expected results are not achieved and the costs are negligible. Here is an illustrative Russian example. In 2007, the Russian Federation's Government approved the project to build the Kuragino-Kyzyl railroad line in conjunction with the development of the base of mineral and raw materials of the Tyva Republic. In 2021, it also ordered the construction to be postponed for 5 years, until 2026. By the time this decision was made, 1 (one!) km of the 410 km railway had been built. Consequently, it took 14 years to unravel the uncertainties of the project in terms of: total cost; sources of financing; composition and content of the original version; identification of the customer; the general designer; and construction contractors. And when this uncer-tainty was resolved, the decision was made to stop the project without any reason.

In the history of Russian railway construction, unfortunately, this is not an isolated case. In 1953 construction of the Circumpolar Railway, nowadays sluggishly contin-ued under the name of Northern Latitudinal Railway (NLR) was stopped [4]. Construc-tion began but was halted on the mainland-Sakhalin project. For more than 40 years, the North Siberian Railway (Severosib) project has been under discussion with partial-ly completed surveys.

In fairness, there are two positive examples. First of all, it is the project of the Trans-Siberian Railway, the idea of construction of which began to be discussed back in 1832. The project turned out to be socially effective under tsarism, developed social-ism and state capitalism, which replaced each other in Russia for the last hundred years [5]. Another positive example is the Baikal-Amur Mainline (BAM) construction project, which was once declared the most inefficient project of "developed" social-ism. Times have changed and the Baikal-Amur Mainline has turned out to be a strate-gically needed communication link for transporting Russian products and resources to the Asia-Pacific region. Today, BAM is being actively reconstructed and completed in order to increase the throughput and carrying capacity of the mainline by 2-3 times [6].

With this in mind, the objectives of this paper are defined as follows.

1. to describe the proposed methodology, methodology and computer means for their mapping as a system of large-scale transport projects at the pre-investment stage of their life cycles.
2. to propose a logical-heuristic model (LHM system) of evaluation and selection based on expert information and the rules of decision-making theory under conditions of risk and radical uncertainty.

2 Materials and methods

Problem statement. In order to achieve the formulated objectives, an integrative ap-proach is further applied, when elements of methodological constructs, methodologi-cal techniques and computer (hardware) means to achieve the goals are assembled into a complete decision-making system. Generally, the proposed approach can be inter-preted as engineering programming using specialized computer products and organiza-tional procedures. The element of novelty in this paper is the synthesis of verbal anal-ysis tools of logical-heuristic model (LHM) and economic-mathematical model (EMM), which results in a hybrid system of evaluation and selection of the most pref-erable large-scale project.

As a tool, a tree of objectives is used similar to the tree used in the analytical hierarchy method (AHM) [7-13], but with a modification, which is that the objective tree is built for different scenarios, that is, in each scenario will be different priorities of im-portance of each local and global criteria [14]. In addition, since the projects in ques-tion are in the class of large-scale projects, their implementation has an impact on the economic environment in which they themselves are implemented. This is due to the large-scale procurement of raw materials, materials and components. Furthermore, the implementation of this class of projects generates demand for manpower, which leads to higher wages. While implementation of this class of projects leads to improvement of global supply chains and reduces delivery costs of transported products. As a result of such changes there are changes in inter-industry links. Thus, this leads to the fact that the very scenarios in which projects are implemented are also changing [15].

Let us outline the proposed approach step by step on the example of large-scale rail-way projects Indiga - Surgut (hereinafter referred to as Brentskomur) with two differ-ent variants of this project implementation. The reason for choosing this particular example was the instruction of the President of the Russian Federation. The Russian Government to submit proposals on the creation of a railway route from Sosnogorsk to the ice-free bay of the Barents Sea near the existing settlement of Indiga. The article presents a hypothetical view of the authors of the article in the framework of a model experiment: how the experts should use the proposed methodology in order to com-pare the Barentskomur project (in which the Indiga-Sosnogorsk section is only a local fragment) with the North Siberian project, taking into account its strategic advantages.

3 Results

Barentskomur projects as objects of assessment and selection of the most preferable of them, being large-scale, are characterized by uncertainty in the parameters of the pro-jects themselves and the external environment of their implementation [16]. Moreo-ver, the uncertainty in the pre-investment phase of the life cycles of these projects is, by conjecture, maximum, which creates conditions for making erroneous decisions, which cannot be corrected at the investment and operational stages.

We will evaluate the social efficiency of projects, in a classical interpretation of the term, as a ratio of potentially useful project results to resources spent by society on their realisation. In the pre-investment analysis phase, the 'instrumentalisation' of this verbalised target is carried out using the objective tree, the main tool of system analy-sis designed to unlock the uncertainty of the objectives of large-scale and complex projects (Figure 1).

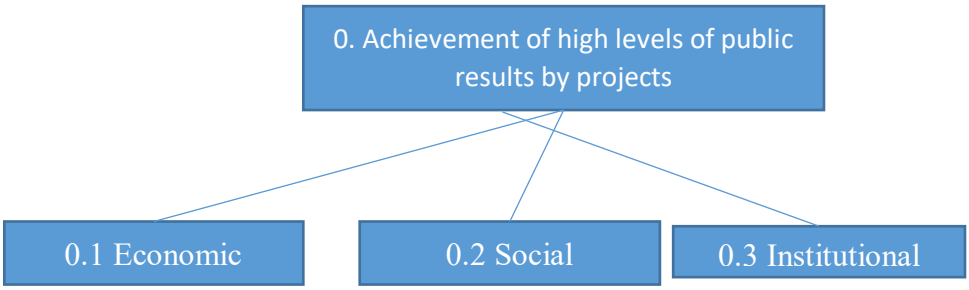

Fig. 1. Barentskomur project target tree with access to the NorthSib.

Both projects are comparable in their indicative parameters (as known from many years of discussions on project designs), represented by the so-called triple constraint: "time - scope of work - budget" [17] are comparable. Namely, time of railway lines construction in both cases is 6 years, amount of works mainly defined by length of lines under construction - about 2000 km each, projects budget is approximately the same and estimated as 1.5 trillion rubles in 2019 prices.

Under these assumptions, i.e., if the cost component of the projects is the same, the most preferable project is identified based on the maximum of the objective function derived from the quantification of the objective tree in Figure 1.

Quantification of the objective tree is carried out by a group of experts in stages. First, the structure of the objective tree, the general objective of rank 0, and the composition of the objectives of the so-called criterion slice of the tree are determined by brain-storming. Fig. 2. three subgoals of rank 1 form the criterion slice: 0.1. Economic; 0.2. Social; and 0.3. Institutional (connectivity of territories through which the projected railways pass). All other strategic goals (environmental, defense, etc.) are set as con-straints by default and all strategies under all scenarios satisfy these constraints. The resulting structure is invariant in all contrast scenarios. This simplification reduces the complexity of the original problem, but transforms it into a problem that can realisti-cally be solved numerically, taking into account the uncertainty factor.

Subgoals 0.1, 0.2, 0.3 are then ranked in order of importance to achieve the general objective of rank 0. Ranking on an ordinal scale is performed three times under the assumption that the evaluated projects may be implemented in three scenarios-contrasts of external environment development: optimistic, pessimistic, and most probable.

The expert rankings are processed by the ORDEX computer product. The program accepts expert rankings in the dialog mode, builds a matrix of pairwise comparisons, finds its main eigenvector, and normalizes it by dividing it by the sum of the coordi-nates. The procedure of expert evaluation of objects (in our case, subgoals 0.1, 0.2, 0.3 which we'll apply below (see [18; 19] for more details) consists in that each expert orders the objects by a given criterion (importance for achieving the general objective 0). The result of expert's work can be represented as an ordered list of all objects con-nected by signs "more" (the preceding object is better than the following one) or "equal" (the preceding object is equivalent to the following one).

Let us suppose that mij experts prefer the facility i to facility j, and nij the experts con-sider these objects to be of equal value. The evaluation procedure can be interpreted as a

"tournament between objects", in which the number of rounds equals the number of experts and the object i gets aij = mij + 0,5nij points against the object j. It is clear that aji = m – aij, where m is a number of experts. After completing these procedures, the quantified objective tree and scenario contrasts 1 - optimistic, 2 - pessimistic and 3 - most likely are presented in Fig. 2.

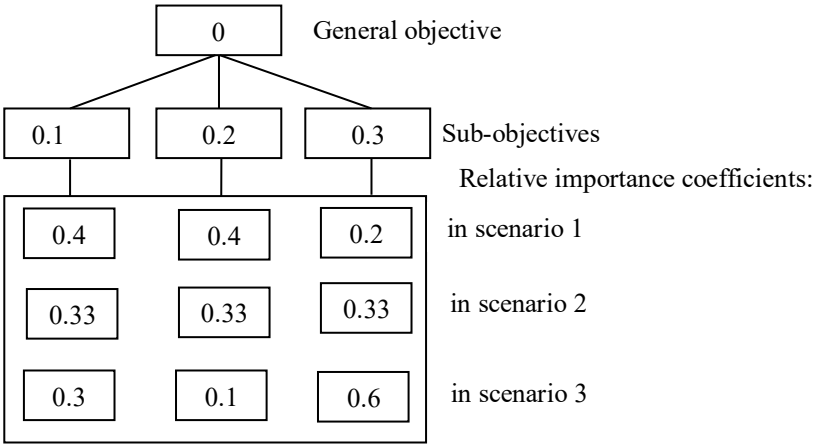

Fig. 2. Quantified objective tree of Barentscomr projects.

Now the experts assess the degree of achievement of each sub-objective pro-vided by the project + scenario system (we will call this system a 'combination'). As the degree of achievement of each sub-objective depends on the combination, the ex-perts rank the 6 possible combinations (see Table 1) according to the non-increasing degree of achievement of each sub-objective of rank 1 in Figure 2 and place the re-spective rankings in the "Rank" columns of the Table 2.

Table 1. Combinations and their composition.

Combination	Combination composition
Combination I	Barentskomur 1 + scenario 1
Combination II	Barentskomur 1 + scenario 2
Combination III	Barentskomur 1 + scenario 3
Combination IV	Barentskomur 2 + scenario 1
Combination V	Barentskomur 2 + scenario 2
Combination VI	Barentskomur 2 + scenario 3

After processing the orderings presented in Table 2 (the "Rank" columns) with the ORDEX program, we normalize the obtained vectors by dividing their components by the value of the largest component. The values of the normalised vectors are placed in the column "Normalised degrees of goal achievement" in the Table 2.

Table 2. Results of the expert judgement survey and their processing.

Project+scenario combinations	Sub-objectives of the general objective								
	0.1 Economic			0.2 Social			0. 3 Institutional		
	Rank	ORDEX	Normalised degrees of goal achievement	Rank	ORDEX	Normalised degrees of achievementи я	Rank	ORDEX	Normalised degrees of goal achievement
I	2	0.2392	0.6933	1	0.3450	1	3	0.1658	0.4806
II	1	0.3450	1	6	0.0553	0.1603	6	0.0553	0.1603
III	3	0.1658	0.4806	2	0.2392	0.6933	5	0.0797	0.2310
IV	4	0.1150	0.3333	3	0.1658	0.4806	4	0.1150	0.3333
V	5	0.0797	0.2310	4	0.1150	0.3333	2	0.2392	0.6933
VI	6	0.0553	0.1603	5	0.0797	0.2310	1	0.3450	1
Total	–	**1**	–	–	1	–	–	**1**	–

In the next step, the normalised degrees of achievement of the objectives in Table 2 are multiplied by the relative importance coefficients of the sub-objectives of rank 1 of the quantified objective tree (see Figure 3), having previously written them in the form of a column matrix. In this way we obtain the degrees of achievement of the gen-eral objective 0. The obtained result is presented in the form of an evaluation matrix in Table 3.

Table 3. Evaluation matrix for large-scale railway projects.

Projects	Scenarios		
	Scenario 1 Optimistic	Scenario 2 pessimistic	Scenario 3 most likely
Barentskomur-1	0.7734	0.4401	0.3521
Barentskomur-2	0.3824	0.4192	0.6712

Table 3, analysed using decision theory criteria in a situation of uncertainty, yielded the results shown in Table 3 4.

Table 4. Choosing a strategy according to decision-making theory criteria.

Project	Criteria					
	Maximin (Wald)	Maximax	Savage	Hurwicz	Bayes	Laplace
Barentskomur 1		+	+	+		+
Barentskomur 2	+				+	

4 Discussion

The purpose of the study was to improve the methodology for evaluating the efficien-cy of large-scale transport projects. The study makes it possible to draw some interest-ing conclusions. In general, the use of systems analysis methodology offers significant

advantages for the comprehensive assessment of project efficiency in terms of societal effectiveness and project relevance. During the research it was discovered that com-paring different projects through analytical hierarchy method doesn't give full picture of effectiveness, because, firstly, this method doesn't consider development scenarios of external environment, secondly, external environment has changed under influence of project implementation, particularly demand for materials, raw materials and com-ponents necessary for project implementation has changed, which leads to price in-crease, demand for man power in proper regions and other aspects. Thus, the environ-ment scenario itself is changing. A case study has been selected for the Barentskomur transport project. For this project, an objective tree with three criteria was generated: economic, social and institutional. The analysis showed that using these criteria would ensure comparative effectiveness between the different options for implementing the project. Typically, an evaluation based on only one criterion would cause significant harm to the public utility. Giving the decision-maker only economic efficiency is de-liberately misleading as it may underestimate the effectiveness of other projects that might have been chosen [20]. In the study, the ordinal scale was transformed into a quantitative scale. In this way, each scenario was prioritized (coefficients of relative importance). In addition, priorities were set for each project-scenario combination; setting quantitative priorities allows the decision-maker to make an informed and cor-rect choice in favour of one project or another. In addition, the quantitative priority values allow the use of the payment matrix for further choices using decision theory criteria (Wald, Maxime, Savage, Hurwitz, Bayes, Laplace).

5 Conclusions

In Russia, there are many large-scale transport projects that could make a significant contribution to the development of global supply chains and economies. A methodol-ogy has been developed to assess the effectiveness of large-scale transport projects, based on 3 criteria selected by experts. Despite significant cost overruns in several previous projects, the relevance of large-scale projects, and the evaluation of their efficiency, remains scientifically and practically relevant. The shortcomings of previ-ous cost-effectiveness methodologies, which use a comparative scale, have been ad-dressed. The most significant shortcoming is the lack of consideration of the impact of the alternative on the scenario, a situation that arises when a large-scale project is evaluated because of its macroeconomic impact; it affects the external environment in ways that also change the scenarios, so a systematic analysis of effectiveness evalua-tion of the project-scenario combination is needed.

6 Acknowledgements

The article was prepared within the framework of the state assignment for project 5.6.1.5. (0260–2021–0002) «Integration and interaction of mesoeconomic systems and markets in Russia and its eastern regions: methodology, analysis, forecasting».

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