Dyomina O. A. Candidate of Pedagogy, Associate Professor
Head of Foreign Languages Department
Siberian State University of Railway Engineering
Novosibirsk, Russia

Kibalov Ye. B. Doctor of Economics, Professor
Chief Research Officer
Institute of Economics and Industrial Engineering
Siberian Branch of Russian Academy of Sciences
Novosibirsk, Russia

Khutoretskii A. B. Doctor of Economics, Professor
Novosibirsk State University
Novosibirsk, Russia

SYSTEM ANALYSIS OF TRANSPORT ALTERNATIVES FOR SUPPORT THE MINING OPERATIONS ON THE RUSSIAN ARCTIC SHELF: PROBLEM STATEMENT AND DATA-ANALYSIS TOOLS

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The subject of this article is the alternative strategies for transport support to using the natural resources of the Russian Arctic Shelf. These strategies, per se, are large-scale complex systems of long-term investment projects. We suggest the approach to defining the comparative effectiveness of strategic alternatives in qualitative-quantitative terms and to choosing the most preferable ones under radical uncertainty.

Historical reference

The construction of the Polar Railroad (fig. 1), currently known as “dead railroad” has been started in USSR just after the ending of the World War II. The reason was that the attempts of Hitler’s Kriegsmarine to block the Northern Sea Waterway in the summer 1942 to stop the allies’ convoys with military and industrial cargoes from the East, across the Kara Sea into the Barents Sea, were fresh in the memory.

The heavy cruiser “Fleet Admiral Sheer”, participating in the “Wonderland” operation, sank the old Soviet icebreaker “Sibiryakov”, attacked the port of Dickson, and was ready to land troops to occupy this significant communication point in the Polar Region. Fortunately, this poorly prepared military operation came to nothing: frightened of heavy retaliatory fire of Russian 152-mm guns deployed at the port of Dickson moorage, the cruiser ran away back to starting point, the Norwegian port of Narvic. Thereby the aim of the cruiser – total destruction of Soviet infrastructure from the port of Dickson up to the Chukchi Peninsula – was not attained, the operation “Wonderland” had failed.

The Wehrmacht global military plans for deep penetration into the Soviet rear, using the Siberian rivers Ob, Yenisei, Lena, and Kolyma, was at the bottom of this failed attempt to paralyze cargo delivery from the East to the railroad stations at the ports of Murmansk and Arkhangelsk. In the period of “friendship” between fascist Germany and the USSR and even during the war between them, the Germans built shelters and filling stations for the submarines in the mouths of the mentioned rivers. Moreover, according to one of the “Ost” plan versions, 20,000 German soldiers would make a landing in the city of Novosibirsk to block the Trans-Siberian Railroad [1], and Fascists had a good chance, because the river network from the Gulf of Ob to the city of Novosibirsk was defenseless from the military point of view. If it had been so, the Great Patriotic War could have ended with other results [1].

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[1] A. Muravliov. Plan that failed. (In Russian). // Altaiskaia pravda. No. 165–167. June 10, 2005 г. – URL: http://www.ap.altairegion.ru/165-05/2.html (reference date 21.07.2014).

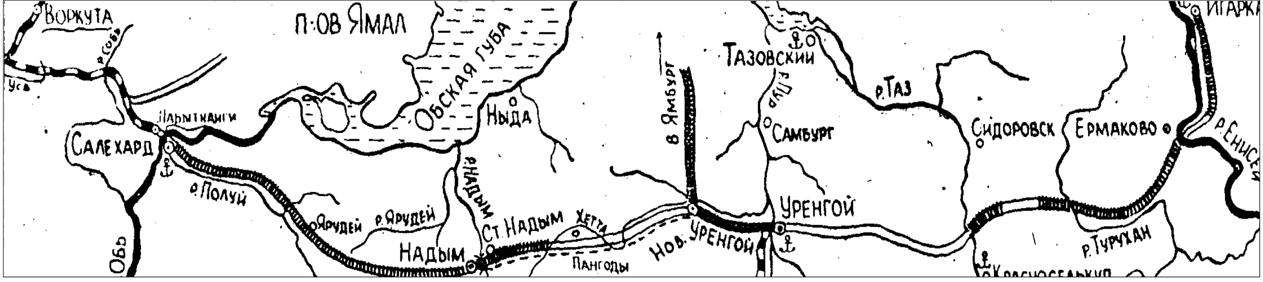

***Fig.* 1. *Salekhard-Igarka railway plan, 1949* [1]**

Comment: In the future, it was planned to extend this main line farther to the East, through the valleys of the rivers Lower Tunguska, Vilyui, Aldan, Indigirka, and then via Kolyma to Chukotka. Thereby, the line Salekhard - Igarka was considered the first stage of the Great Polar Main Line.

This situation have taught a lesson to the Germans: despite their bold strategic plan they met with failure as a result of poor information on Russian reality at all and, particularly, on the conditions of Polar navigation. To the point, owing to bad ice patrol, the cruiser “Fleet Admiral Sheer” only accidentally have avoided ice trap in the Kara Sea and inevitable extermination by the allies forces.

It is quite obvious that Soviet experts took into account the pre-war experience of working under extreme climatic conditions of Arctic region when adopting the decision to construct the Polar Railroad. They also have taken into consideration the wartime experience of operations under the severe climate conditions. The principal reason for this decision was the clear understanding that the Russian Arctic, from the military point of view, is a poorly defended coastal area with islands, and it would be rather difficult to defend these territories only by navy, even using the Northern Sea Waterway naval bases and heavy icebreakers. It followed from the experience, that an overland lateral railroad parallel to the frontal line passing via the Arctic Ocean water area should be constructed. Only such road with the ports at the mouths of Siberian rivers could ensure a safe rear for the fighting navy forces and support the latitudinal transportation of different resources, being carried by Siberian rivers from the industrial areas situated along the Trans-Siberian Railroad. The Polar Railroad (from Salekhard to Igarka) has been planned and constructed to achieve these goals. This road worked according to temporary scheme and could be used for development of the Arctic areas during more than half a century, but was abandoned after 1953. Particularly, according to the present-day calculations, the cost if commercial development of the West-Siberian oil and gas deposits might be decreased by six trillion rubles if oil and gas industry were supported by reconstructed Polar Railroad [2].

Problem statement

The modern situation in the Arctic is shown by fig. 2. One can see, that the states having outlet to Arctic Ocean claim both the resources of 250-mile coastal zone and the sectors of water areas in the meridians bounds. The main claimants shown in the illustration are: the Russian Federation, the USA, Canada, Denmark, and Norway. Besides these, still 14 states claim the Arctic resources: Belgium, the UK, Germany, Ireland, Iceland, Latvia, Lithuania, the Netherlands, Poland, Finland, Sweden, Estonia, and Japan.

[2] “Abandoned road” Salekhard–Igarka. “Project 501/503”. (In Russian). URL: history.rzd.ru/history/public/ru?STRUCTURE_ID=5164 (reference date 15.08.2014).

“Kuzma’s mother”. The outcomes. A dead road. / Documentary. (In Russian). 2012 // TV channel “Russia 1”, 11.12. 2012. URL: http://russia.tv/brand/show/brand_id/35266 (reference date: 31.08.2014).

***Fig.* 2.**The situation in the Arctic [2] and the supposed line of the Polar Railroad (red chain line)

Information warfare for the Arctic has started, and the experts cannot rule out, that it could result in the World War III in a not-so-distant future. This paper does not deal with political problems of sharing out the territories in the Arctic. We focus on transport support for the development of those resources which undoubtedly belong to Russia. Nevertheless, the world-wide context of exploring the Arctic is also taken into account due to Russian technological dependence on Western technological systems intended for operating in the extreme climate conditions of this region. This dependence can be overcome by different ways in various scenarios of the Arctic development, but the imperative requirement is the using of the modern high technologies of cargoes and passengers transportation to the Russian Arctic shelf. Only such technologies can make mining operations in the Arctic region efficient from economic, social and ecological point of view.

The problem in question includes formulation of the goals and choice of an expedient strategy for transport support of development of the Russian Arctic, taking account of scenario uncertainty.

At the present stage of understanding the Arctic problems, there isn't sufficient information for making a reasonable decisions concerning the long-term investment, consequences of such decisions are hidden by the “veil of uncertainty”. Selection of the preferred strategy enables experts to keep on resolving uncertainty, collecting and analyzing the information relevant to this very strategy.

The Problem Structuring

The first step is the goals structuring. Let's construct a double-level objectives tree. We formulate the general goal as “effective transport support for mining operations on the Arctic shelf of Russia” and denote it by A.

Let us assume that the most important goals, that have to be attained as a result of solving the mentioned problem, are the following ones: the technological goal, that means reliability of transport support for the strategy; the economic goal, that means the necessity of cost reducing during the strategy life cycle (up to 2030); and the military-strategic goal that means the defense ensuring for the Russian Arctic and preventing the attempts of our neighbors-rivals to occupy this area. We assume that all other strategic goals (social, ecological, etc.) which should be attained in the specified period through realizing the chosen strategy, are set as constraints, and all the strategies in all the scenarios satisfy these constraints. The specified simplifications reduce the initial problem complexity and convert it into a task that can be solved under scenario uncertainty.

Taking into account the above assumptions, the second level of objectives tree should contain three subgoals: "technological reliability of transport support", "economic efficiency of transport support", and "military-strategic efficiency of transport support". Let us denote these subgoals by A_1, A_2, and A_3 respectively.

The second step of system structuring includes formulating the scenarios of changes of the external environment where the chosen strategy will be realized. We shall describe three scenarios named as "Cooperation", "Compromise" and "Confrontation".

The contrast-scenario "**Cooperation**" assumes that the states which are interested in the Arctic development will coordinate their national strategies within some coalition-free cooperative agreement.

On the contrary, the contrast scenario "**Confrontation**" assumes that the parties concerned will fail to adopt an acceptable agreement on development of the Arctic region, and moreover, the states having the outlet to the Arctic Ocean will establish coalition opposing the Russian Federation.

The "**Compromise**" scenario, in conformity with its name, is a combination of the contrast-scenarios.

The third step provides the qualitative (as in case of scenarios) analysis of the alternative strategies for development of the Russian Arctic.

1. In the past, militaristic Germany was at the head of the fourth world industrial setup, leaving behind the USA in some fields. Relying on such technological basis, the Wehrmacht strategists considered the Siberian rivers as transport corridors for infall into remote Russian regions using Arctic as a supporting zone, to block the Trans-Siberian Railroad and occupy the industrial potential around the railroad.

Now, in the postindustrial period, under transition from fifth technological setup to sixth one, on basis of innovative technologies, Siberian rivers can be used as transport corridors for development of the russian Arctic shelf. The flows of cargoes and technical equipment can move out of industrial supporting zone that includes megalopolises of southern Siberian areas – the cities Omsk, Novosibirsk, Krasnoyarsk, and Irkutsk, – in the opposite direction as compared to that specified by the "Ost" military operation for occupying the mentioned cities.

We shall call this strategy **"River"**. This strategy implies formation of the new inland water transport consisting of the ice-breakers, ice-cutters, air-cushion platforms, etc., which would be the main force for the shelf resources development. Using such fleet it would be possible to transport cargoes and passengers along the great Siberian rivers – Ob, Yenisei, Lena, and Indigirka, – which are covered with ice for five or six months a year.

For ships piloting in shallow water, it is necessary to deepen the river bed. If it is impossible, or in case of frost penetration up to the river bottom (e.g. on the river Indigirka), it is necessary to use either vehicles with air-cushion or helistates. The helistates' carrying capacity allows of super-long transportation of super-heavy cargoes, using the river corridors.

Efficient combinations of traditional and innovative technologies for river transportation at low winter temperatures should be defined by ad hoc projects taking account of weather forecasts, distinctive features of concrete river corridor and the types of cargoes being transported out of the southern supporting zone to the Arctic shelf. The most promising are, possibly, the ice-breakers equipped with laser gun, which can cut ice layer of more than 3.5 m thick [4], and the "frozen" in 1980s and resumed now project of ice-breaker with air-cushion [3].

2. Alternative is the strategy of developing the Arctic shelf "from the sea". This strategy assumes that the powerful ice-breaker fleet will support the piloting of water crafts (of general purpose and special-purpose, including warships) along the transport corridor of Northern Sea Waterwayt. The *support zone* for this strategy will include all the floats of ice-breakers. These floats are located in Arctic and near-Arctic waters of the Barents Sea and White Sea, so the strategy, seemingly, will demand higher costs. We shall call this strategy "**Sea**". This strategy implies that transport developing of the shelf resources will be provided by ice-breaker fleet. As the existing ice-breakers will be written off the more powerful innovative fleet will be created. It

is expected that such a decision will assure the whole-year piloting of vessels with cargoes and manpower to places of extraction of hydrocarbons and other mineral resources. Besides, the effective ice-breaker fleet, based in the properly equipped ports at the mouths of Siberian rivers, will provide profitable whole-year domestic and foreign transit along the Northern Sea Waterway. In this case, the foreign transit would compete with shipping through the Suez Canal.

3. The **"Sea - River"** compromise strategy is defined as a combination of mentioned above alternative strategies.

The described strategies are the great and complex systems of long-term investment projects. Evaluating the comparative efficiency of these strategies under scenario uncertainty cannot be executed by exact methods. Neither existing statistics nor publications in opened sources allow quantitative comparison of the results and costs for such large-scale transport strategies. But the comparisons are necessary because there are examples of rather controversial and expensive strategic decisions in the field of transport in the West (the Eurotunnel under the English Channel) and in Russia (the Bridge to the Russky Island across the Eastern Bosporus Strait). Therefore, we are to use expert technologies for strategies comparison. In this case, verification of the obtained results includes checking the comparison procedures consistency and by juxtaposition of the results derived by different evaluation methods.

We shall prove below that methodology of system analysis, methods of decision making theory methods, and the expert technologies, using specially developed data-analysis tools allow to compare the above mentioned strategies in qualitative-quantitative terms and obtain the consistent conclusion about the preferable strategies under the radical non-stochastic uncertainty.

The suggested approach to the problem of transport support for development of the Russian Arctic shelf combines some new ideas with elements of well-known methods: PATTERN, cost-effectiveness method [3], analytic hierarchy process [4]. We believe that our approach gives an adequate instrument for strategic choice under scenario uncertainty.

Strategies evaluation

In the subsequent investigation we will employ the procedure of objects evaluation by experts (see more detailed descriptions in [5, p. 64–70], [6, p. 320–326]). The procedure begins with ordering the objects by each expert according to the given criterion. The result of each expert's work can be presented as an ordered list of all the objects combined by signs "more" (the previous object is better than the next one), or "equal" (the previous object is equivalent to the next one).

Let us assume that m_{ij} experts prefer object i to the object j, and n_{ij} experts consider that these objects are of equal worth. The evaluation procedure may be interpreted as a "tournament between objects", where the number of rounds is equal to the number of experts, and the object i "gains" $a_{ij} = m_{ij} + 0{,}5n_{ij}$ points against the object j. It is clear that $a_{ji} = m - a_{ij}$, where m is the number of experts.

For $i \neq j$ the amount $s_{ij} = a_{ij} / a_{ji}$ evaluates the quality of object i with respect to object j, if these objects were compared independently of others. If all the experts prefer object i to the object j for some pair of objects i and j, then $a_{ji} = 0$ and the value s_{ij} is not determined. One can get round the problem by two ways: either by replacing $a_{ij} = 0$ onto a small positive number, or by including a fictitious "expert" who consider all the objects equivalent (then each a_{ij} will be increased by 0,5). Let's assume $s_{ii} = 1$ for all i and make the matrix $S = (s_{ij})$.

According to the terminology of [7], S is a matrix of pair-wise comparisons with power calibration. The eigenvector of matrix corresponding to its maximum eigenvalue (*the main eigenvvector*) is proportional to required vector of objects' evaluations [8]. Therefore, the objects' evaluations are the properly normalized coordinates of the main eigenvector. The normalization mode depends on objects' type and evaluation criterion.

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[3] See e.g. Ayres R. U. Technological forecasting and long-range planning. – New York: McGraw-Hill, 1969. (Russian translation – 1971).

[4] See Saaty T. L. The Analytic Hierarchy Process. – New York: Pergamon Press, 1988. (Russian translation – 1989).

We implement the described procedure by ORDEX program [5, p. 141–149], which takes the expert orderings in the dialog mode, constructs a matrix of pair-wise comparisons, finds its main eigenvector, and normalizes this vector (divides it into the sum of coordinates) [5].

Let us revert to the problem under consideration. The structuring described in a previous section makes it possible to form a valuation matrix *U*. Element u_{ij} of this matrix shows to what degree the strategy *i* achieves the general goal at scenario *j*. Using the valuation matrix, one can find a strategy which is preferable in the sense of "efficiency adaptive to scenarios" [9], if efficiency is interpreted as a degree of attainment of the general goal.

The following results of experimental calculations were obtained with participating of the competent experts. For compactness of descriptions, let us number the strategies and scenarios. Strategies: 1 – "Sea", 2 – "Sea – River", 3 – "River"; scenarios: 1 – "Cooperation", 2 – "Compromise", 3 – "Confrontation".

According to the experts' common opinion, the structure of the objectives tree is invariant in all scenarios, but significances of the subgoals of second level (the factors of relative importance for the elements of the criterial set) depend on the scenario. The degrees of the goals attainment will be evaluated by numbers within the interval [0, 1].

At the **first step**, the subgoals A_1, A_2, A_3 (the second level of the objectives tree) were estimated with respect to importance for the goal *A* (general goal) under each scenario (fig. 3). Each expert had sorted the subgoals in order of non-increasing significance, and the obtained orderings were processed by ORDEX program.

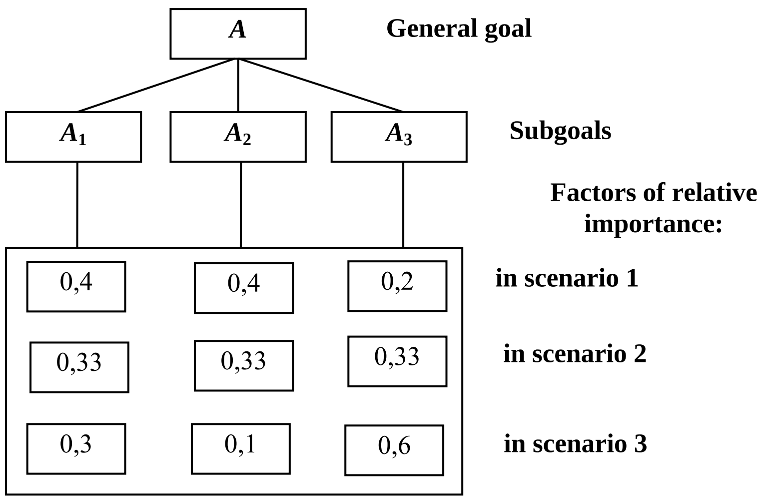

Fig. 3. Objectives tree with the factors of relative importance

Assuming that attainment of the general goal is fully determined by the degrees of subgoals attainment, we normalize the main eigenvector for each scenario so that the sum of valuations equals to unit.

The pair comprised by strategy *i* and scenario *j*, we name "situation (*i*, *j*)". The degree of a subgoal attainment depends on the situation, and at the **second step** we have estimated the degrees of subgoals attainment for all the situations. For any goal of second level, each expert had sorted 9 possible situations according to non-increasing of the degree of the given goal attainment.

For each subgoal A_k, after processing the corresponding expert orderings by the ORDEX program, we obtained the vector v_k of length 9, proportional to the required vector of assessments for degrees of the subgoal attainment in all the situations.

Let's suppose that the sets of strategies and scenarios under consideration cover all the possibilities. Then, in any possible situation, a subgoal cannot be attained to a greater extent, than in the most favorable of the examined situations. Consequently, the evaluation of a subgoal attainment degree in this most favorable situation should be equal to unit. Previous reasoning substantiates normalization of each vector v_k by division into its maximal component. The results are presented in table 1.

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[5] The program is written by A. B. Khutoretskii.

Table 1

Valuations of subgoals attainment degrees

Situation number	Strategy number	Scenario number	Subgoal		
			A_1	A_2	A_3
1	***1***	**1**	0,58	0,81	0,30
2	***1***	**2**	0,35	1,00	0,36
3	***1***	**3**	0,20	0,20	0,20
4	***2***	**1**	0,35	0,66	0,24
5	***2***	**2**	0,24	0,54	0,59
6	***2***	**3**	0,35	0,39	0,45
7	***3***	**1**	0,58	0,30	0,59
8	***3***	**2**	0,81	0,39	0,81
9	***3***	**3**	1,00	0,24	1,00

The final **third step** of the procedure includes construction and analysis of the valuations matrix $U = (u_{ij})$, where u_{ij} is the evaluation of general goal attainment in situation (i, j).

Let a_{kj} be valuation of the subgoal A_k importance in scenario j, b_{ijk} be valuation of the subgoal A_k attainment of by the strategy i in scenario j. The numerical values of a_{kj} and b_{ijk} are presented at fig. 3 and in table 1 correspondingly. The elements of the valuation matrix (see table 2) can be calculated by the following formula

$$u_{ij} = \sum_k a_{kj} b_{ijk}.$$

Table 2

Valuation matrix

Strategy number	Scenario number		
	1	**2**	**3**
1	0,616	0,564	0,2
2	0,452	0,452	0,414
3	0,47	0,663	0,924

For example, to calculate u_{23}, the attainment degree of the general goal by the strategy 2 “Sea – River” in the scenario 3 (Compromise), it is necessary to calculate the scalar product of the vectors $(a_{13}, a_{13}, a_{33}) = (0{,}3, 0{,}1, 0{,}6)$, which is situated in the third row of the table on fig. 3, and $(b_{231}, b_{232}, b_{233}) = (0{,}35, 0{,}39, 0{,}45)$, which corresponds to the situation 6 in the table 1. Consequently, $u_{23} = 0{,}3{\cdot}0{,}35 + 0{,}1{\cdot}0{,}39 + 0{,}6{\cdot}0{,}45 = 0{,}414$.

Obviously, no strategy is dominating; therefore, there is uncertainty, which may be resolved by criteria of Laplace, Wald, and Hurwicz.

In the third row of the matrix, the sum of elements is greater than in all other rows. The same is true for the maximum and minimum elements of this row. Consequently, the strategy “River” is preferable by criteria of Laplace, Wald, Savage and Hurwicz (with any value of parameter $\lambda \in [0, 1]$).

To apply the Savage criterion let us compose a regret matrix (table 3)

Table 3

Regret Matrix

Strategy number	Scenario number		
	1	**2**	**3**
1	0	0,1	0,72
2	0,16	0,21	0,51
3	0,15	0	0

Obviously, the strategy “River” is preferable by this criterion too.

Comment

We have formulated and formalized the problem, assuming that there is no numerical information about the strategies realization costs. Correspondingly, we suppose that the economic goal (denoted by A_2) consists in the costs reducing all over a strategy life cycle. The expert evaluation of the achievement of this goal in situation (i, j) (i. e., by the strategy i under the conditions of scenario j) was denoted by b_{ij2}. This value indicate the proximity of goal attainment in the situation (j, j) to maximum possible level [10], but allows no conclusion about the absolute value of the needed costs.

Conclusion

The obtained result is not a final one. The main goal of this article is to show the possibilities of the suggested approach to evaluation of the strategies of solving the important Russia problem. The approach's main advantages are: the clear structuring of the problem, moderate data requirements (experts are not asked about numerical estimates, they report only the qualitative alternatives comparisons results), and well-grounded processing of expert information.

Our investigation is, in fact, a scientific experiment. The expert group included researchers at the Institute of Economics and Industrial Engineering of Siberian Branch of Russian Academy of Sciences and professors of Novosibirsk universities. Actually, the large-scale problem studied above is of federal level. Therefore federal resources are needed to solve it. In particular, wide expert community should be involved in a real strategical decisions making. It will result in large outlay, but, in our opinion, “the game is worth the candle”, as the failure in exploration and development of the Arctic shelf is inadmissible for Russian Federation.

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