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Methods to Forecast Transport Systems Development under Modern Conditions

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ABSTRACT

The objective of the work is to study methods for forecasting transport systems development and determine their suitability under economic instability conditions.

The modern methodology for forecasting the development of regional transport systems includes expert and formal methods, methods of active and passive forecasting.

The use of expert systems, scenario forecasting and strategic planning can be mentioned as promising areas.

Scenario planning is more adapted to non-linear transformations in the economy than traditional linear planning. In traditional planning, the past explains the present, in scenario planning, the future is the meaning of the present, the future is created.

The variety and instability of statistical indicators encourages creation of hybrid systems of forecasting models. They are based on regression models, as well as on intelligent models, including artificial neural networks, analytical networks, etc., which are complemented by scenario forecasting.

The identification of the main factors that determine the functioning of the transport network of the European and Ural Arctic facilitated the choice of methods for forecasting its development. The main factors negatively affecting the development of the transport network of the region under the study are the insufficiency of freight flows in the ports; insufficient capacity of seaports' access roads; political, social, natural-climatic, and other risks.

The example of the Northern Sea Route (NSR) illustrates the use of a hybrid system of forecasting models to obtain possible values of traffic volumes. Based on the analysis of regression models and the study of the possibility of achieving the target traffic volume by 2024, it was concluded that this model is basically acceptable for forecasting the volume of goods transported along the NSR.

Keywords: transport system, forecasting methods, European and Ural Arctic, regression models, intelligent models, scenario forecasting, hybrid forecasting models.

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INTRODUCTION

Transport, being a sector of the economy and a provider of services, ensures the prerequisites for revitalisation of economic activity in a particular territory, and development of transport infrastructure should be ahead of the curve [1] in relation to material production. Therefore, it is necessary to identify trends and indicators that make it possible to forecast development of transport systems both in the short and long term.

Throughout its history, humanity has tried to look into the future and find out what lies ahead. Martin van Creveld [2] tells from the point of view of a historian the story about the emergence of various methods of prediction, the principles and beliefs that underlie them. Today, scientists strive to make predictions using the latest computer technology.

The analysis of various forecasting methodologies, including those applied to transport systems, was carried out by A. M. Andronov, A. N. Kiselenko, E. V. Mostivenko [3, pp. 26–41]. Under the conditions of a planned economy (from the beginning of the 1970s to 1991), methods based on probability theory, mathematical statistics, and regression theory were widely used in forecasting traffic volumes.

The *objective* of this work is to determine the applicability of these and a number of promising methods for forecasting the development of transport systems in today's economic environment, characterised by a high degree of uncertainty.

RESULTS

Methodology

Forecasting Development of Transport Systems and Scientific Methods

The authors [3] have developed a modern methodology for forecasting the development of regional transport systems, which includes expert and formal methods, active and passive forecasting methods, *bottom-up* and *top-down* methods, individual and group models.

Expert methods are methods for making forecasts based on expert assumptions. Among them are Delphi Method, brainstorming, morphological method, etc.

With *passive forecasting* methods, the value of an indicator of interest is predicted without specifying how it will be achieved, for example, when extrapolating time series.

With *active forecasting*, the mechanism for formation of the indicator in question is accurately described. In foreign literature, such methods are also called *normative*, and passive methods are called *search* methods.

Forecasts have different time signs (over five years, five years, year, quarter, month, etc.).

Transport facilities have a certain hierarchy according to belonging to various departments, regions, enterprises of various forms of ownership. A necessary condition for quality of forecasts developed for transport facilities (forecasts of different levels) is their correspondence to each other.

Also, when predicting the development of transport systems, *individual and group models* are applicable. An individual forecasting model is based on considering each object separately (for example, a transport company); a group model is based on considering a certain set of objects at the same time (airports, etc.)

To analyse and forecast the development of transport systems, the methods of multivariate linear regression are often used.

Suitability of Forecasting Methods under Economic Instability Conditions

Classical forecasting methods

The authors of [4] note that «with all the noted constraints, the methods based on statistical dependencies remain the most used methods in economic research for forecasting demand for infrastructure services at the regional level. The reasons are associated with availability of statistical information and ease of implementation, when the task of achieving economic growth, both in general and in terms of components, is brought to the fore».

The turbulence of the economy actualises the development of methods for obtaining predictive values of socio-economic indicators with unstable time series. As promising areas, one can name the use of expert systems in forecasting [5; 6], scenario forecasting and strategic planning [7–9], which makes it possible to use both expert and formalised methods when building scenarios.

Scenario planning is more adapted to non-linear transformations in the economy than traditional linear planning. In traditional planning, the past explains the present, in scenario planning, the future is the meaning of the present, the future is created.

T. Saaty and K. Kearns offer the following definition of a scenario: in its most general form,

Table 1

Correlation of scenario, forecast, vision [11]

Scenario	Forecast	Vision
Possible, most probable options of the future	Probable options of the future	Desired option of the future
Based on uncertainty	Based on certain relationships	Based on the value
Shows risks	Hides risks	Hides risks
Qualitative or quantitative	Quantitative	Usually qualitative
Needed to know what decision to make	Needed to dare to make a decision	Encourages action
Rarely used	Daily used	Relatively often used
Effective in the medium long term and under medium to high uncertainty	Effective in the short term and under low uncertainty	Acts as a trigger for conscious change

a scenario is a hypothetical outcome that is determined using some assumptions about current and future trends [10, p. 144].

M. Lindgren and H. Bandhold noted that «the scenario is not a forecast, that is, a description of a relatively predictable development of events in the present. Nor is it a vision, a desired future. A script is a carefully crafted answer to the question, «What is supposed to happen?» or «What happens if...?» [11]. The ratio (difference) of the scenario, forecast and vision, as suggested in that work, is shown in Table 1.

B. V. Artamonov notes that «the purpose of writing a scenario is not so much to predict the future, but to identify the main patterns and trends in the development of the object in question over time, to provide a higher probability of developing an effective solution in situations where it is possible, and to reduce the expected losses to a minimum in situations where they are unavoidable» [12].

In the monograph [13, p. 187] it is noted that scenario analysis has been actively used since the 1970s. It should be «considered as a forecasting tool complementing traditional quantitative forecasting and simulation methods, as a means of strategic planning», since «the main goal of scenario analysis is not to predict the future state of the economic system, but to reduce the uncertainty of its development».

In addition, the authors of [10; 13] distinguish the following classes of scenarios: *research scenarios* (based on the study of cause-and-effect relationships between the current state of the system and options for its future development); *anticipatory scenarios* (based on the study of cause-and-effect relationships in the opposite direction – from the desired future state of the system to the current one by identifying development strategies that will ensure the desired transition); scenarios based on quantitative mathematical models and simulations. There is no single approach to the methodology of scenario analysis, each method has «its own advantages and disadvantages, its constraints regarding applicability».

Regarding transport support for development of the Russian Arctic, the monograph [13, pp. 63–64] states that «it is necessary to substantiate the calculated options for the scenario conditions for formation and development of energy and transport systems in the Arctic territories ... in interaction with the processes of development of the productive forces of the base region».

The need to obtain predictive values under the conditions of instability of time series and uncertainty promotes the use of multiprocessor architectures that would approach the capabilities of the human brain in terms of performance, such as, for example, *artificial neural networks* (ANN) [14].

ANN is «composed of many individual processors, which we call data processing units» (DPU), «just like neural networks are formed in living biological systems» [15, pp. 465–466].

DPU includes several inputs (i), each of which is assigned with a certain weight (w_i). Weight can be either positive (excitatory effect) or negative (inhibitory effect). Variables (x_i) that take the values «0» or «1» are received at the inputs of DPU.

The weighted sum of the actual inputs S is called the effective input and is defined as a multiple linear regression:

$$S = \sum_{i=1}^{n} x_i \cdot w_i + \theta,$$

where θ – shift parameter. If it is not specified, then $\theta = 0$.

The value of the effective input is compared with the specified threshold value P. If $S > P$, the output of DPU is «1», otherwise the output is «0».

Determining the weight coefficients of ANN DPU is similar to the search for the weight coefficients when using the analytical hierarchy process [16, pp. 64–66; 17].

Table 2

Comparison of forecast estimates of traffic volumes along the NSR with actual values for 2020 and 2021 (million tons) [18]

No.	System objects	Actual cargo flows	Forecast estimates						
			Pessimistic scenario			Optimistic scenario			
		2020	2021	2020	2025	2030	2020	2025	2030
1	NSR	32,98	34,85	19,7	39,8	39,0	23,2	68,6	71,1
2	Transit	1,28	2,04	1,5	2,0	3,0	2,0	4,0	8,0

In addition to those listed, *patent research* (promising vehicles) can be attributed to methods for predicting the development of transport systems. «Another aspect of time is the speed of innovation» [11], including in transport.

Below we consider the application of the above approaches to forecasting the development of the transport network of the European and Ural Arctic (EaUA).

The Main Factors Determining the Functioning of the Transport Network of the European and Ural Arctic

The EaUA transport network, which includes railways, road, air routes, waterways and a pipeline system, operates in the following land areas of the Russian Arctic and adjacent waterways, including the Northern Sea Route (NSR): Murmansk region, Nenets Autonomous District, parts of the territories of the Yamalo-Nenets Autonomous District (two urban districts and two municipal districts), of the Republics of Karelia (five municipal districts and an urban district) and Komi (three urban districts and a municipal district), Arkhangelsk region (three urban districts and four municipal districts).

The main factors influencing freight traffic in the Russian Arctic are listed in [18, p. 89]. They are «divided into two groups: exogenous (natural and climatic conditions, the state of global commodity markets, geopolitical and geoeconomic relations, strategies of global corporations and companies) and endogenous (state economic policy regarding mining, state policy in the field of regulation of Arctic shipping, the state of the port and transport infrastructure, the state of the merchant and icebreaker fleets, organisational and economic infrastructure)».

The authors of [18] obtained predictive estimates of the volume of traffic along the NSR for two scenarios. Let's compare them with the actual cargo flows in 2020 and 2021 (Table 2).

The comparison shows that the actual values of traffic along the NSR in 2020 turned out to be higher than the forecast estimates, even under its optimistic scenario. At the same time, the volume of transit in 2020 turned out to be lower than forecast estimates, but quite close to the forecast value in the pessimistic scenario.

In our opinion, the main factors negatively affecting the development of the EaUA transport network are:

• Insufficient cargo flows in the ports [19].

• Insufficient capacity of access roads to seaports[1] [20].

• Political, social, natural-climatic, and other risks [21].

The impact of external and internal factors is complex and constantly changing. When forecasting the volumes of EaUA traffic for 2021, the main groups of factors in terms of significance could be arranged in the following sequence: sufficiency (or insufficiency) of the cargo flows in the seaports; the impact of Covid restrictions (it is with this that the slowdown in the growth rate of traffic along the NSR in 2019–2021 can be linked). It is possible to expect that in 2022 Covid restrictions will gradually decrease, but probably other constraints will come to the fore.

Hybrid Model for Forecasting the Development of the Transport Network of the European and Ural Arctic

B. V. Artamonov notes: «Under the conditions of high uncertainty and rapid changes in economic and market conditions, when developing a strategy for any business entity, it makes sense to use scenario forecasting, during which, taking into account the simultaneous change in many factors, the possibility of various situations in which studied subject may turn out to be» [22].

[1] Mikhailov, A. Murmansk ports are faced with a lack of capacity (in Russian). Internet portal «Rossiyskaya Gazeta». [Electronic resource]: https://rg.ru/2021/11/30/reg-szfo/murmanskie-porty-stolknulis-s-nehvatkoj-propusknoj-sposobnosti.html. Last accessed 27.05.2022.

E. O. Demidova distinguishes three enlarged stages of scenario forecasting and planning: pre-scenario, scenario, and stage of scenario implementation [23, p. 3].

At the pre-scenario stage, the goals of scenario forecasting should be determined, and a working group should be constituted.

The main task of the scenario stage is to identify the key factors that determine the development of production systems (in our case, of transport system). This is followed by immediate work on formation of scenarios, during which « key driving forces with weak correlation are identified and a range of their possible values is outlined for scenarios». With reference to foreign researchers, the author notes that «scenarios in the amount of more than four begin to blur and lose their important differences for decision-making» [24, p. 238].

It would be more correct to call the last stage the «scenario implementation stage». During its implementation, it is necessary to pay due attention to each scenario, monitor them and analyse feedbacks.

The author of the work [23, p. 3] also notes: «The scenario method is quite expensive and resource-intensive. However, with the proper use of scenarios in strategic planning, the costs pay off many times over, as they give a great economic effect due to more efficient use of emerging opportunities and countering threats».

B. V. Artamonov says [22] that «a set of scenario options forms a cone of scenario forecasting, the boundaries of which are» optimistic and pessimistic scenarios.

The forecasted development of the system is determined by the vector (trajectory) of scenario development, which is located inside the forecasting cone.

The location of this vector close to the boundaries of the contour (to optimistic or pessimistic scenarios) in both cases carries risks to the functioning of the system; therefore, for development of the system, it will be optimal to choose a *base scenario* that will allow rational use of system resources to achieve the target result. At the same time, based on the data of continuous monitoring, the scenarios are adjusted.

One of the possible algorithms for scenario management of regional development, which can also be applied to the management of the development of transport systems, is presented in the work of T. V. Solovyova and S. G. Chefranov [25]. Conventionally, four stages of implementation of this algorithm can be distinguished:

«At the first (initial) stage, the following occurs: formation of the goal of scenario synthesis; determining the time horizon of the scenario; formation of a set of targets; identification of the current state.

Next, the synthesis of scenario conditions is carried out (the second stage). A check is made to see if a complete group of events has been formed. In the case of a successful check, the probability of occurrence of events that determine the scenario conditions is estimated; quality indicators of a set of scenario conditions are calculated; it is checked whether the best performance has been achieved. When the best indicators are achieved, a system of control actions is formed for various scenario conditions.

At the third stage, after synthesising a set of indicators of scenario conditions, monitoring the state of the controlled object and the environment, the implementation of scenario conditions is checked.

At the final stage, the implementation of control measures for the most probable scenarios (as mentioned above three or four) is carried out».

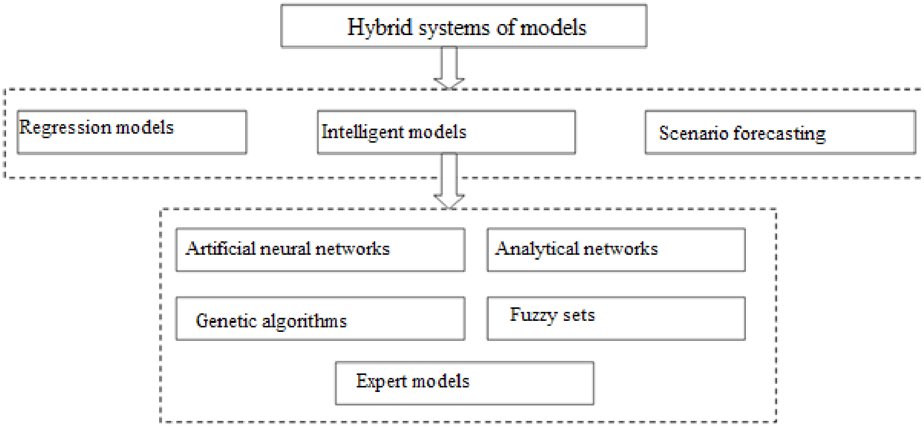
N. M. Bukharov suggests using combinations of different approaches in forecasting and calls them «hybrid» appraoches: «If the outcome of the hybrid is successful, a synergistic effect is expected, which means a significant improvement in its performance» [26].

According to the authors of [27, pp. 130–131], a hybrid system of forecasting models consists of a complex of regression models and a set of intelligent models, including artificial neural networks, analytical networks, etc. (Pic. 1).

This system is open and allows us to include new models and indicators, it can have a modular architecture, which gives additional stability.

Using a Hybrid System of Models: an Example of Obtaining Predictive Values of Traffic Volumes along the Northern Sea Route

The number of indicators characterising the rate of passenger and cargo transportation used in various problems of forecasting and planning the operation of the EaUA transport is very large. To date, there are more than 150 forecasting methods and models. They are usually based on stable time series of indicators, mathematical statistics, and programming [1, pp. 16–17].



Pic. 1. Hybrid system of forecasting models [27].

Table 3

Volume of cargo transported along the Northern Sea Route in 2011–2021 (thousand tons) [[29; 30] and based on the analytical data of the NSR Directorate of Rosatom State Corporation*]

	Year										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Traffic volumes along the NSR	3111,0	3752,0	3930,0	3982,0	5392,0	7256,0	10691,0	20180,2	31531,2	32978,9	3487,9
including transit	824,0	1212,0	1355,9	274,3	39,6	210,0	214,5	491,3	697,3	1281,0	2041,3

* Volume of transportation of goods within the basin of the Northern Sea Route (in Russian). [Electronic resource]: https://www.fedstat.ru/indicator/51479. Last accessed 28.05.2022.

An important indicator of the functioning of the EaUA transport system is the volume of freight traffic along the NSR, which is of exceptional importance, first, for ensuring the security of the Arctic zone of the Russian Federation. Its target value is stipulated as 80 mln tons by 2024[2]. Such a target setting activates two possible scenarios for development of the Arctic transport system and of the EaUA transport network as of its component: *optimistic* (the specified traffic volume will be achieved) and *pessimistic* one (the specified traffic volume will not be achieved). Which of them will develop is determined by economic, political, natural and other risks [28, p. 53].

Between 2011 and 2019 there was a steady increase in the volume of freight traffic along the NSR due to an increase in the volume of hydrocarbon production in the EaUA and their export transportation, which made it possible to develop quite adequate models for their forecasting with regression analysis.

Data on traffic volumes along the NSR in 2011−2021 are given in Table 3.

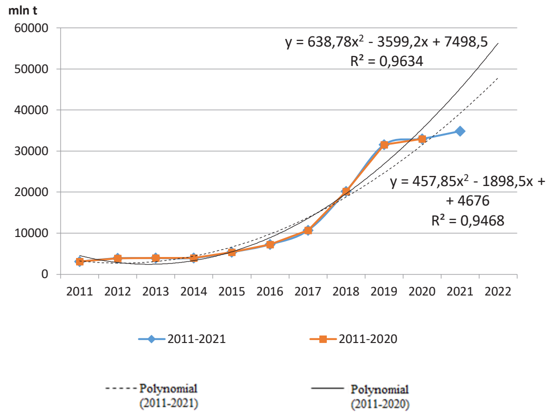
A certain contribution to this growth was made by transit transportation of goods from the Asia-Pacific region to Europe, however, their volumes are insignificant.

Based on the available values, regression models were built for the time series of 2011−2020 and 2011−2021 (Pic. 2).

For the time series 2011−2020 the forecast value obtained from ten actual values using a quadratic model for 2021 amounted to 45199,7 thousand tons, which significantly exceeds the real value of 34850,0 thousand tons. The estimate of traffic volumes in 2022 according to this model is 56292,4 thousand tons, further continuation of the trend line confirms the achievability of the target in 2024.

For the time series 2011−2021 the value of traffic volumes along the NSR for 2022 (based on 11 actual values) is 47824,4 thousand tons, while

[2] Plan for development of infrastructure of the NSR till 2035 has been approved (in Russian). [Electronic resource]: http://government.ru/docs/38714/. Website of state programs of the Russian Federation. [Electronic resource]: https://programs.gov.ru/Portal/pilot_program/24/elements. Last accessed 27.05.2022.



Pic. 2. Extrapolation of time series 2011–2020 and 2011–2021 in terms of traffic volumes along the NSR using regression models [compiled by the authors].

regression analysis does not exclude development according to the pessimistic scenario as well, including slower growth pace by 2024.

Thus, according to the results of the regression analysis, it is possible to make certain assumptions about the achievability or unattainability of the target indicator in the presence of stable time series. The scheme of such studies is directed «from the past to the future» [31, p. 18].

Therewith, it is necessary to consider great dependence of the regression analysis on the current changes in the dynamics of indices achieved, including temporary fluctuations, which reduce the accuracy of the forecast.

In the case of ANN, research is directed «from the future to the present», i.e., first, the main factors that may affect the functioning of the system in the future are determined, and then several scenarios for the current development are developed.

Below is a basic example of a model of building the elements of ANN, which determines the probability of achieving the target indicator of traffic volumes along the NSR by 2024.

Building a basic DPU

Considering the initial data, the input and output variables were determined, preliminary weights were set for the inputs (Table 4), and the threshold value $P = 0{,}4$ was also set. It is to bear in mind that preliminary groups of considered constraints, their composition (including decomposition into the single lines), and relevant weights, that were determined by expert method, are not strictly set and in that case represent an illustrative example only. While implementing acting model they should be determined through large expert survey.

The generated basic DPU is shown in Pic. 3.

Using the software implementation of ANN – the Flux.jl package (machine learning library[3], written with the Julia programming language[4], and for it), the weight coefficients were recalculated, a new threshold value $P' = 0{,}2$ was set, new data were entered into DPU_2 (Pic. 4).

To analyse the sufficiency of the cargo flows intended for transportation along the NSR, ANN developed DPU_1, the table of initial data of which is presented in Pic. 5.

The output variable DPU_1 goes to the input DPU_2, which, in addition to the sufficiency of the cargo flows, analyses the impact of other external factors (Pic. 6).

The initial data were read from an Excel file into Julia using XLSX.jl package, which made it easy to correct the data (variable weights) depending on the declared volumes of cargo

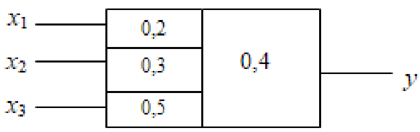
[3] Flux: The Julia Machine Learning Library. [Electronic resource]: https://fluxml.ai/Flux.jl/stable/. Last accessed 27.05.2022.

[4] The Julia Programming Language. [Electronic resource]: https://julialang.org/. Last accessed 27.05.2022.

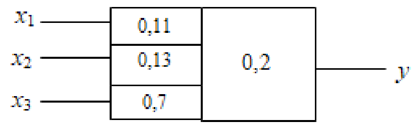
Table 4

Input and output variables and their weights for the basic DPU [compiled by the authors]

Variable notation	The meaning of the variables x_i	«Weight» of the variable w_i
x_1	External constraints (economic, environmental, etc.)	0,2
x_2	Covid-restrictions	0,3
x_3	Insufficient cargo flow	0,5
y	Target indicator is achieved / is not achieved	



Pic. 3. Basic DPU for the stated forecasting goal.



Pic. 4. Changed DPU_2.

	Semantic meaning of variables (conditional name of a project)	Variable notation	Variable's weight (transported volume within the project, mln t), W_{3i}
1	New port	$X_{3,1}$	**5,56**
2	Vostok Oil	$X_{3,2}$	**30,00**
3	Ymal LNG	$X_{3,3}$	**19,70**
4	Arctic LNG2	$X_{3,4}$	**12,60**
5	Obsky GCHC	$X_{3,5}$	**0,60**
6	Norilsky Nickel	$X_{3,6}$	**0,96**
7	Syradasayskoe deposit	$X_{3,7}$	**3,50**
8	Other projects	$X_{3,8}$	**0,31**
9	Procurement goods, «Northern delivery», transit	$X_{3,9}$	**16,78**
	Shift	Θ_3	**-10,01**
	Insufficient cargo flows	$\mathbf{X_3}$	
	P=	**80**	

Pic. 5. Table of initial data DPU_1 for the analysis of the sufficiency of the cargo flows along the NSR [compiled by the authors based on the Decree of the Government of the Russian Federation dated 01.08.2022 No. 2115-p «On approval of the Plan for development of the Northern Sea Route for the period till 2035». Consultant Plus reference and legal information system].

flows (Pic. 5). The results of all calculations were also exported to an Excel file.

Depending on the objectives of the study, it is possible to replace the inputs of the network elements with new DPU, thereby increasing the number of ANN layers, or the number of DPU in any layer.

As a result of assessing the current and future volumes of cargo transportation along the NSR, it is possible to conclude that there are risks associated with achievement by 2024 the directive and forecast value of the cargo turnover of 80 million tons along it. One of the obstacles, in addition to the above, is the limited capacity of the existing railway access roads to the seaports of EaUA (Murmansk and Arkhangelsk) and the lack of such for Sabetta and the promising port of Indiga.

The quality of any forecast depends on the accuracy of input data, in that case, on the list of factors considered and on weights attributed by experts. Therefore, the forecast could not be considered under existing dynamically changing conditions as a finally achieved.

Thus, the first half of 2022 showed that a group of foreign countries was going to renounce[5] to Russian oil, gas and coal, despite the fact that in 2021 this group of countries had provided more than half of the proceeds from energy exports (about 100 out of 191,5 billion dollars). This might negatively affect the problem of insufficient freight flows in the Arctic seaports and, consequently, provoke the decrease in the volumes of cargo transported along the NSR.

On the other hand, the forecast regarding the set 2024 indicator has not been reduced, the target indicator is maintained at 80 mln t[6]. The exportation of oil and gas is redirected to the promising markets of other groups of countries (it refers also to implementation of rail, pipeline, port infrastructure projects and to provision of demand for energy resources in the internal

[5] It has been ordered to accelerate the turn to the East: the path of energy resources to Asia will be thorny (in Russian). [Electronic resource]: https://eadaily.com/ ru/news/2022/04/15/povorot-na-vostok-prikazano-uskorit-put-energoresursov-v-aziyu-budet-ternist. Last accessed 27.05.2022.

[6] Russia will deliver 80 mln t along Northern Sea Route by 2024. *Izvestiya*, 05.05.2022 (in Russian). [Electronic resource]: https://iz.ru/1329712/2022-05-04/rossiia-dostavit-po-sevmorputi-80-mln-t-gruzov-k-2024-godu. Last accessed 27.05.2022.

Variable notation	Variable weight w_i	The meaning of variables
x_1	0,11	External factor 1
x_2	0,13	External factor 2
x_3	0,7	External factor 3 (insufficient cargo flows)
…	…	…
y		Target indicator will not be achieved
P=	0,2	

Pic. 6. Example of a table of initial data DPU_2 for forecasting the achievement of the target indicator of the volume of freight traffic along the NSR [compiled by the authors].

market). Therefore, to determine priority of oil and gas projects and of implementation there-of it is necessary to use forecasted values of high validity.

In general, this task is due not only to the situation developing at a certain time period but has a long-term nature.

CONCLUSION

«The complexity of the problems of economic forecasting, in particular, of development of the transport network of the European and Ural Arctic determines the need for an interdisciplinary approach to their solution, the expansion and integration of existing methods» [32].

The variety and instability of statistical indicators encourages the creation of hybrid systems of forecasting models. They are based on regression models, intelligent models, including artificial neural networks, analytical networks, etc., which are complemented by scenario forecasting.

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