Comparison of international transport corridors in the Arctic based on the autoregressive distributed lag model

D F Skripnuk, K N Kikkas, A S Safonova and E B Volodarskaya
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

djamilyas@mail.ru, xekikkas@gmail.com

Abstract. This article examines the modeling of international transport corridors using the autoregressive distributed lag (ARDL) model. The modeling of international transport corridors makes allowance for the potential capacity to develop the Arctic transport environment in the context of polar ice melting and increasing time of navigation on the seas of the Arctic Ocean. The authors build models for the Northern Sea Route, the Trans-Siberian Railway (TSR), the Southern Sea Route (transport corridor of the Suez Canal), the Northwest Passage, and analyze the natural, organizational, technological, and economic factors that affect the endogenous variable of the international transport corridor model. When building the transport corridor models, the authors take the volume of transit traffic via the international corridor in time t as the endogenous variable for all corridors. Exogenous variables are selected according to the variables that have the highest impact on the volume of traffic via each transport corridor and feature most prominently in the literature reviewed in this article. For the Northern Sea Route, these variables include Russia’s GDP, the number of ships passing through the route, the number of nuclear icebreakers, the average tariff, and the minimum ice coverage in the Arctic. For the Southern Sea Route (transport corridor of the Suez Canal) – EU’s GDP, the number of ships passing through the route, the average tariff, and the volume of commercial transit cargo. The methodology for determining the parameters of the model includes the following procedures: flux balance analysis, analysis of the autocorrelation between endogenous and exogenous variables, multicollinearity analysis.

1. Introduction
The transport potential of the Arctic attracts global attention, particularly from the countries of the Arctic region. Arctic routes are interesting because they offer the shortest sea route for delivering cargo from Europe to Asia, reducing flight time from America to Asia through cross-polar routes.

Improvement of transport capacity increases opportunities for the industrial development of the Arctic, which involves exploitation of both hydrocarbon and biological resources, leading to the development of the Arctic transport infrastructure and traffic flows.

This article presents the results of an interdisciplinary study aimed at developing a procedure for the modeling of international transport corridors under various operating conditions. The modeling of transport corridors involves consistent steps to substantiate the selection of a model for the formal description of the economic substance of the transport corridor and consideration of natural, organizational, technological, and economic operating conditions of transport corridors.

2. Analysis of studies on the transport and logistics capacity of the Arctic
Analysis of publications on the subject of this study demonstrates the broad range of the addressed problems. These problems are associated with the assessment and development of the transport capacity of individual regions and countries, analysis of the state of major transport corridors in the context of sustainable territorial development, comparison of major transport corridors from the perspective of assessment of the volume of transported goods, and the relationship between domestic and international transport corridors. These are also problems of modeling of the transportation of goods via different routes: sea, railway, road, etc.

Researchers address the issues of assessment and development of the transport capacity of individual regions and countries from the perspective of examination of development factors or application of statistical and mathematical tools.

D. Guerrero & J.-P. Rodrigue [1] propose to make allowance for the development cycles of global container ports (Kondratieff wave) in the assessment of the transport capacity of individual regions. Evidence from the global container port system suggests five main successive waves of containerization with a shift of the momentum from advanced economies to developing economies, but also within specific regions.

N. Hong [2] discusses potential new transport routes emerging due to Arctic ice melting. The shrinking of Arctic ice triggers a new round of competition and dispute in this region between traditional Arctic states and non-Arctic actors. Like its East Asian neighbors, China sees the melting Arctic Ocean as a unique opportunity for itself and international trade generally.

Bayerz M. [3], Jean-Paul Rodrigue [4] analyze Canada's economic development of the adjacent Arctic shelf. They postulate that the Northwest Passage is of paramount importance to Canada due to the increasing time of navigation as a result of ice melting. If released from the ice, the passage could rival the economic appeal of the Northern Sea Route (NSR) around the Arctic coast of Russia.

A wide range of problems associated with the development of the Northern Sea Route are addressed in the articles of the implementing parties of the Russian Science Foundation Grant "Results-based management of comprehensive development of the Arctic zone of the Russian Federation" [5],[6],[7],[8], [9],[10],[11],[12]. These studies focus on the issues of logistics, namely: logistics costs and their management, problems of cost estimation, route planning, raw material transportation schemes, key indicators of efficient logistics, coordination of goods distribution in the Arctic and other regions.

The issues of using the ARDL model in interdisciplinary research are addressed by J. Hong & V. N. Shankar, T. Wang & Y. Yu, N. Didenko [13,14,15].

Didenko, N.I., Cherenkov, V.I. [7] consider the Northern Sea Route as a target subspace within the Arctic space and distinguish seven types of target Arctic subspaces. They propose a results-based form of organization and management of subspace development with the purpose of achieving a synergetic effect: base cities; mobile camps; mineral and raw material resources extraction sites; recreational territories; fishing territories; the Northern Sea Route; security infrastructure, with different attributes, development functions and goals.

J. Verny and C. Grigentin [16] develop a techno-economic model of container traffic via the Northern Sea Route (NSR). By adopting a model schedule between Shanghai and Hamburg, they analyze the relative costs of various axes in the Asia–Europe transport network, including the NSR. While shipping through the Suez Canal is still by far the least expensive option, the NSR and Trans-Siberian Railway are represented as equivalent second-tier alternatives.

M. B. Regmi & S Hanaoka [17] propose a model of intermodal transport corridors in the Northeast and Central Asia. It utilizes a time–cost-distance approach to assess and compare the performance of intermodal transport corridors. There are few studies that analyze the status of intermodal transport corridors as well as assess their performance.

E. Twrdy & M. Batista [18] propose dynamic models for predicting the traffic capacity of ports in the northern Adriatic Sea. This study presents dynamic models to forecast container throughput in the North Adriatic ports of Koper, Trieste, Venice, Ravenna, and Rijeka. The models are prepared based
on available data; they are the Markov-chain annual growth rate model, a time-series trend model, a
time-series trend model with periodical terms, and the gray system model.

M. Lupi, A. Farina, D. Orsi & A. Pratelli [19] perform a quantitative analysis of the
competitiveness of intermodal transport based on sea motorways compared with road transport. The
authors identify the major factors of competitiveness of sea motorways. According to the results of the
analysis, the choice of intermodal transport is affected by several elements: the costs, time, and
reliability of sea motorway.

C. Clott & B. C. Hartman [20] present a model of a concentrated freight corridor. The model
allows planning cargo transportation within regional and international transport networks.

L. Tavasszy et al. [21] develop a model reflecting the relationship between the capacity of sea ports
and the volume of transported cargo in the context of the development of the Trans-Siberian Railway
and the Northern Sea Route. The model includes import, export and transshipment flows of containers
at ports, as well as hinterland flows. The model is calibrated against observed data and is able to
reproduce port throughput statistics rather accurately.

O. Vaněk et al. [22] present an agent-based model of maritime traffic through the lens of strategies
of interested participants.

Dudarev G., Boltramovich S., Filippov P., Hernesniemi H. [23], Rūnno Lumiste, Gunnar Prause
[24] compare the Northern transport corridor with the Trans-Siberian Railway and the transport
corridor of the Suez Canal. The authors believe that maritime transport in polar regions is the only
viable alternative and the most efficient way of delivering machinery and production equipment,
energy carriers, industrial goods, and food supplies required for the operation of territorial production
complexes in the coastal zone of the Arctic seas.

It can be added that the technological complexity of organizing transport operations in the Arctic
climate along with certain legislative aspects of the Arctic states dictate the need for international
cooperation in the field of transport. In this regard, it is necessary to analyze the Northern Air Bridge
project intended to provide air routes from Asia to North America across the Arctic. Air routes can be
used most notably by the countries of Southeast Asia. Depending on the route, the time of flight from
these countries to North America can be decreased by 2 to 5 hours.

Analysis of studies dedicated to the development of Arctic territories is dominated by the
conclusion that efficient development of the Arctic by Russia is impossible without a proper transport
infrastructure. The Northern Sea Route is expected to play a key role in its development. It is the
shortest sea route that connects Russia's western and eastern regions, European and Asian ports. In the
long term, this transport corridor is poised to become the shortest connection between the Asia-Pacific
region and Europe.

Analysis of published works emphasizes the need to make allowance for the factors and conditions
that reflect the full range of functioning of transport corridors and sea ports in the modeling of
transport corridors.

3. Characteristics of the Northern transport corridor and alternative corridors

Northern transport corridor (Northern Sea Route). The main goal of the project is to create the most
favorable conditions for the development of maritime and intermodal (i.e. using different modes of
transport) transport through the northern ports of Norway and Russia, and to establish an integrated
maritime transport system in northern Europe. This should contribute to increasing the volume of sea
transport between European ports and the northern Russian ports. Apart from that, one of the major
driving factors is the development of the oil and gas sector and implementation of large-scale projects
in this field. Using the Northern Sea Route to transport oil and gas equipment is the essence of the
project. At the same time, establishment of a regular connection will attract the attention of cargo
owners that are already transporting goods to and from Russia through the ports in the Gulf of Finland.

As is known, the Northern Sea Route begins in Europe at Novaya Zemlya (Cape Zhelaniya) and
ends in the Bering Strait in Asia. Goods can be transported along the Northern Sea Route via two
distinct shipping lanes: high-latitude (2,200 nautical miles long) and coastal (2,990 nautical miles).
Potential alternatives to the Northern Sea Route include the Northwest Passage, Trans-Siberian Railway, and the Southern Maritime Corridor.

Northwest Passage. The Northwest Sea Passage is a network of several sea routes through the Canadian Arctic Archipelago, which comprises around 19 thousand islands, many hazardous rocks and reefs. With the rapid climate change as a result of global warming and due to the fact that, by some estimates, 25 percent of the world’s oil and gas reserves are concentrated here, the shipping lines of the Arctic Ocean are becoming increasingly congested. However, by connecting the Atlantic and Pacific oceans, the Northwest Sea Passage reduces the length of transport routes and thus saves time and money spent on commercial trade, while ice melting in the Arctic Ocean reduces reliance on the Panama and Suez canals.

Trans-Siberian Railway (TSR). The TSR, historically named the Great Siberian Route, is a railroad network that runs across the Eurasian continent, connecting the European part of Russia comprising its largest industrial areas and capital with its central (Siberia) and eastern (Far East) regions. With a length of 9,288.2 kilometers, it is the longest railway in the world. It was fully electrified in 2002.

Southern Sea Route (transport corridor of the Suez Canal). The Suez Canal is the key element of this route. The legal status of the Suez Canal is currently regulated by the Convention of Constantinople relating to free passage through the Suez Canal. The most important principles of navigation through the Canal established by the Convention of Constantinople include (1) the freedom to use the Canal for ships from any country; (2) the equality of all countries in their use of the Canal; (3) the principle of neutrality, implying a prohibition on blockading the Suez Canal.

4. Modeling of transport corridors

The process of modeling of transport corridors includes the following steps.

4.1. Model selection

The autoregressive distributed lag (ARDL) model is selected for the formalized description of the economic substance of the transport corridors. The model shows both the effects of changes in the endogenous indicator in previous periods on the indicator value in the current period and the effects of other exogenous variables.

The ADL model \((p, q, k)\) has the form:

\[
y_t = a_0 + \sum_{i=1}^{n} a_i y_{t-i} + \sum_{j=0}^{q} b_j x_{t-j} + \ldots + \sum_{j=0}^{k} b_j x_{t-j} + E_t \quad (1)
\]

\(k\) is the number of exogenous variables;
\(q\) is the number of lags;
\(n\) is the variable lag depth;
\(E_t\) are the residues that constitute the white noise process.

Important stages in the modeling of international transport corridors include selection of the lags of the endogenous variable that affect its current value; analysis of the stationarity/non-stationarity of the time series of data used in the model; finding the numerical values of the model equation coefficients; selection of the exogenous variables with the most significant impact on the endogenous variable.

4.2. Data collection and analysis

Data on the Northern Sea Route are obtained from World Bank databases.

Data on the Southern Sea Route are obtained from the following databases:
http://data.worldbank.org/indicator/NY.GDP.MKTP.CD; http://www.pancanal.com/esp/plan/estudios/0284.pdf; http://www.suezcanal.gov.eg/TRstat.aspx?reportId=4.

Data on the Trans-Siberian railway are obtained from the following databases:
http://data.worldbank.org/indicator/NY.GDP.MKTP.CD; http://www.ati.su/Media/News.aspx?HeadingID=1&ID=12792; http://ria.ru/spravka/20130621/944936776.html; http://www.rg.ru/2011/11/10/reg-
4.3. **Substantiation of the endogenous and exogenous variables used in the model**

Models are built for the Northern Sea Route, the Trans-Siberian Railway, the transport corridor of the Suez Canal, and the Northwest Passage. When building the transport corridor models, the authors take the volume of transit traffic via the international transport corridor in time $t$ as the endogenous variable for all corridors. Exogenous variables are selected individually for each model according to the number of the variables with the highest impact on the volume of traffic and feature most prominently in the literature reviewed in this article. The equation coefficients are determined on the basis of data for 1990-2016.

In the modeling of the **Northern Sea Route**, the following variables are analyzed: $X_1$ - Russia's GDP, billions of US dollars per year; $X_2$ - number of ships passing through the route, thousands of units; $X_3$ - number of nuclear icebreakers, units; $X_4$ - average tariff, US dollars/ton; $X_5$ - minimum ice coverage in the Arctic, millions of square kilometers; $X_6$ - population of the major hubs, thousands of people.

In the modeling of the **Southern Sea Route** (transport corridor of the Suez Canal), the following variables are analyzed: $X_1$ - EU’s GDP, US dollars per year; $X_2$ - number of ships passing through the route, thousands of units; $X_3$ - number of voyages, times; $X_4$ - average tariff, US dollars/ton; $X_5$ - volume of commercial transit cargo, millions of tons; $X_6$ - population of the major hubs, thousands of people.

In the initial stage of modeling of the **Trans-Siberian Railway**, the following variables are analyzed: $X_1$ - Russia's GDP, US dollars per year; $X_2$ - import, US dollars per year; $X_3$ - export, US dollars per year; $X_4$ - average tariff, US dollars/ton; $X_5$ - transport capacity, millions of tons; $X_6$ - traffic flows, millions of tons; $X_7$ - train speed, km/h; $X_8$ - transit, millions of tons; $X_9$ - Russian Railways rate, US dollars/ton; $X_{10}$ - maritime freight rate.

In the initial stage of modeling of the **Northwest Passage**, the following variables are analyzed: $X_1$ - Canada's GDP, billions of US dollars per year; $X_2$ - USA's GDP, billions of US dollars per year; $X_3$ - number of ships/trains involved in transportation, units; $X_4$ - number of voyages, times; $X_5$ - average tariff, US dollars/ton; $X_6$ - transport capacity, millions of tons; $X_7$ - traffic flows, millions of tons; $X_8$ - volume of commercial transit cargo, millions of tons; $X_9$ - insurance fees, US dollars/ton; $X_{10}$ - time of receipt, hours; $X_{11}$ - average haul, km; $X_{12}$ - container traffic, millions of tons; $X_{13}$ - time of transportation, hours; $X_{14}$ - packaged goods, millions of tons; $X_{15}$ - capacity of oil harbors, number of ships/rail cars per day; $X_{16}$ - capacity of dry harbors, number of ships/rail cars per day; $X_{17}$ - cost of transit traffic, US dollars/ton; $X_{18}$ - average arrival/departure time, hours.

According to the results of the primary data analysis, the number of indicators for the Trans-Siberian Railway and the Northwest Passage is significantly reduced, and only the following are left:

For the **Northern Sea Route**: Russia's GDP ($X_1$); number of ships passing through the route ($X_2$); average cost of passage ($X_3$). For the **Southern Sea Route**: EU's GDP ($X_1$); number of ships passing through the route ($X_2$); average cost of passage ($X_3$). For the **Trans-Siberian Railway**: Russia's GDP ($X_1$); number of containers passing through the Trans-Siberian Railway ($X_2$); average cost of transit
through the Trans-Siberian Railway ($x^3_1$). For the Northwest Passage: Canada's GDP ($x^1_1$); number of ships passing through the route ($x^2_1$); average cost of passage ($x^3_1$).

4.4. Stationarity analysis
The time series analysis is performed using the Dickey-Fuller test. The analysis shows that all time series have a unit root; therefore, the first differences form a stationary time series.

4.5. Autocorrelation analysis of the endogenous and exogenous variables
Autocorrelation coefficients are calculated in order to determine the lags for the exogenous variables in the autoregressive model. Lags that are statistically significant are included in the model.

In the model for the Northern Sea Route: the endogenous variable is included with lag $t-1$ ($y_{t-1}$); two exogenous variables are included with lags $t-1$ and $t-2$ ($x^1_{t-1}, x^2_{t-2}$ and $x^3_{t-1}, x^3_{t-2}$). In the model for the Southern Sea Route: the endogenous variable is included with lags $t-1$ and $t-2$ ($y_{t-1}, y_{t-2}$); two exogenous variables are included with lags $t-1$ and $t-2$ ($x^1_{t-1}, x^1_{t-2}$ and $x^2_{t-1}, x^2_{t-2}$). In the model for the Trans-Siberian Railway: the endogenous variable is included with lags $t-1$ and $t-2$ ($y_{t-1}, y_{t-2}$); two exogenous variables are included with lags $t-1$ and $t-2$ ($x^1_{t-1}, x^1_{t-2}$ and $x^2_{t-1}, x^2_{t-2}$). In the model for the Northwest Passage: the endogenous variable is included without a lag due to a small correlation coefficient between $y$ and $y_{t-1}$; two variables are included with lag $t-2$ ($x^1_{t-1}$ and $x^2_{t-2}$). The significance is tested using the standard error and Q-Box-Pearson criteria.

4.6. Multicollinearity analysis
The correlation coefficients between the endogenous and exogenous variables in all corridors show a close relationship between the volume of transported goods and GDP ($r = 0.89$; $0.82$; $0.69$ at $r = 0.9$). The correlation coefficients between the volume of transported goods and the average cost of passage through the route are drastically different: $-0.0967$ for the Southern Sea Route, $-0.0076$ for the Trans-Siberian Railway, $-0.215$ for the Northern Sea Route, and $-0.88$ for the Northwest Passage. Multicollinearity analysis shows no significant correlation ($r \geq 0.9$) between the pairs of factors.

4.7. Calculation of regression equation coefficients
Below is an example of a regression equation with the remaining variables:

$$y_t = a_0 + a_1 \cdot y_{t-1} + a_2 \cdot y_{t-2} + b_1 \cdot x^1_{t-1} + b_2 \cdot x^1_{t-2} + c_1 x^3_{t-1} + c_2 x^2_{t-2} \quad (2)$$

Equation coefficients for each corridor are determined using the regression analysis module of the SPSS program; Student's t-test is used to assess the statistical significance of the regression equation coefficients.

5. Model forms
The equation for the Northern Sea Route has the following form:

$$y_t = 2.415 + 0.01y_{t-1} - 0.05x^1_{t-1} + 0.07x^1_{t-2} + 0.007x^3_{t-1} - 0.045x^2_{t-2} - 0.13x^3_{t-2}$$

The significance of the coefficients with the variables $x^1_{t-2}, x^3_{t-1}$ $\alpha = 0.696$ and 0.864 respectively, i.e. these variables can be removed from the equation.

The equation for the Southern Maritime Corridor has the following form:
\[ y_t = 733.477 + 0.069y_{t-3} + 0.016y_{t-2} - 0.026x^1_{t-1} - 0.025x^1_{t-2} + 95.192x^2_{t-1} + 13.198x^2_{t-2} - 0.017x^3_{t-2} \]

The significance of the coefficient with the variable \( x^2_{t-2} \) \( \alpha = 0.794 \), i.e. this variable can be removed from the equation.

The equation for the Trans-Siberian Railway has the following form:

\[ y_t = 642457.687 + 80.743y_{t-4} + 0.169y_{t-2} - 0.214x^1_{t-1} - 1.076x^1_{t-2} + 259.061x^2_{t-1} + 45.211x^2_{t-2} - 3.01x^3_{t-1} \]

The significance of the coefficient with the variable \( x^2_{t-2} \) \( \alpha = 0.873 \), i.e. this variable can be removed from the equation.

The equation for the Northwest Passage has the following form:

\[ y_t = 0.261 - 0.017x^1_{t-2} - 0.143x^2_{t-2} \]

The significance of the coefficient with the remaining variables \( \alpha = 0.99 \).

6. Conclusion

Climate change in the northern regions leads to a greater availability of most sea routes in the Arctic Ocean for passage in terms of the number of days. This trend indicates that the number of ships travelling via the Northern Sea Route and the Northwest Passage will increase, as will, consequently, the volumes of transported goods. The Northern Sea Route (NSR) is the shortest path and the shortest sea transit corridor between Northern Europe and the Asia-Pacific region, which runs through the seas of the Arctic Ocean (the Barents, Kara, Laptev, East Siberian, and Chukchi Seas) and a part of the Pacific Ocean (Bering Sea).

The Northern Sea Route and the Northwest Passage can become cost-effective due to the emergence of large-scale transportation, further development of the territory and a reduction in transportation costs.

The models of transport corridors allow the volume of traffic to be estimated depending on various factors that characterize different operating conditions of transport corridors, including natural, organizational, technological, and economic factors. The results of the study presented in this article show that at present the largest limitation to the full-scale operational modelling of the corridors is the lack of information on many indicators. This means that with the development of the Arctic regions, it is necessary to compile databases required for analysis and forecasting.

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