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Logistics of Low-Tonnage LNG

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ABSTRACT

In recent years, there has been an increasing interest in liquefied natural gas (LNG) as a bunker fuel for ships. This is due to a number of reasons of environmental (reduction of sulfur emissions by vessels in accordance with MARPOL 73/78 international convention), economic (lower price of LNG compared to distillate fuels meeting MARPOL 73/78 requirements), technical and economic (reduction of maintenance costs of vessels and an increase in service life) character. These conclusions regarding LNG are applicable to vessels of various types intended for sea and river navigation.

At the same time, the transition of river ships and coastal vessels to LNG bunkering is currently being restrained, including in Russia, by a number of reasons, one of which is weak logistics support for LNG delivery from production sites to vessel bunkering points. As a result, the development of LNG vessel bunkering market requires improvement of logistics for delivery of low-tonnage LNG, which can be carried out using several modes of transport.

The objective of the study is to develop a practical algorithm for estimating the cost of LNG transportation for vessel bunkering, taking into account the characteristics of intermodal logistics. The research methodology is based on an analytical method based on a system-structural approach.

At the example of Russia, an algorithm has been developed for choosing the optimal transport and technological scheme (TTS) for delivering low-tonnage LNG and operational and economic models for calculating the unit cost of transportation, storage and transshipment of LNG.

Testing the models on the calculated routes allowed to estimate the cost of LNG transportation according to the options of transport and technological schemes for bulk and container delivery methods and draw conclusions. Moreover, the methodology used is to a large extent universal and allows using the proposed approaches for development of TTS in relation to other countries.

Keywords: *transportation, river and sea vessels, inland water transport, LNG, logistics, transport and technological scheme, delivery price, operational and economic model, bunkering, tank, tank container, tariff.*

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Introduction. The interest in liquefied natural gas (LNG) as a bunker fuel for vessels has increased significantly in recent years for many reasons:

• the use of LNG will make it possible to fulfill the requirements of MARPOL 73/78 Annex VI to the International Convention on Reduction of Sulfur Emission by Ships (from January 1, 2020, the sulfur content in marine fuel in all regions of the world should not exceed 0,5 % by weight);

• lower cost of LNG compared to distillate fuels satisfying the requirements of the Convention;

• the presence of a number of technical factors that reduce the costs of maintaining vessels in operation: the absence of the need for purification of waste gases from SO_x due to the absence of sulfur in LNG, a significant reduction in the content of NO_x in the exhaust gases of power plants, and the almost complete absence of solid particles in the exhaust gases. This allows to avoid installation of selective catalytic reaction reactors and of traps to collect soot on the vessel. In general, there is an increase in the motor resource of piston engines and a decrease in carbon formation in them.

At the same time, the transition of vessels to LNG bunkering is currently constrained by a number of reasons, including the weak logistics of LNG delivery from production sites to vessel bunkering points. For a wide conversion of vessels to LNG, it is necessary that the bunkering process of LNG vessels does not cause serious problems for shipowners.

This issue is particularly relevant for the gas fuelled fleet used for navigation in coastal waters and on inland waterways.

The *objective* of the study was to develop a practical algorithm for estimating the cost of LNG transportation for bunkering of river vessels, taking into account the features of intermodal logistics.

The research *methodology* is based on an analytical method applied through a system-structural approach. For testing, empirical and forecast data were used in relation to the Russian Federation.

Results

The achievement of the research objective was carried out in the following sequence.

1. Research on the geography of location of points of liquid oil fuel bunkering operations of inland vessels

Based on the data from the Register of Bunkering Fuel Suppliers [1] and the Russian Association of Sea and River Bunkering Companies [2], a list of ports of river ships bunkering has been compiled.

Following the results of the study, the most demanded currently ports of bunkering river vessels with liquid oil fuel were identified.

Currently, bunkering of river vessels is carried out at points located on the rivers of the Single Deepwater System of the European part of Russia, the rivers of Siberia and the Far East. Most bunkering companies operate in the river ports of Cherepovets, Yaroslavl, Nizhny Novgorod, Kazan, Samara, Volgograd.

2. Research on the geography of location of natural gas liquefaction complexes

Natural gas liquefaction complexes (NGLC) depending on the annual volume of production are divided into large-capacity, medium-capacity and small-capacity ones.

The existing large-capacity plants (for example, the gas liquefaction plant within Yamal-LNG project is located in the port of Sabetta) are focused only on export of LNG using large-capacity gas carriers (Christophe de Margerie type of the project Yamalmax with a capacity of 170 thousand m^3) [3]. Promising projects, such as Arctic LNG-2, Vladivostok LNG, and NGLC in Ust-Luga (former Baltic LNG) [4–6], suggest the possibility of bunkering of sea vessels.

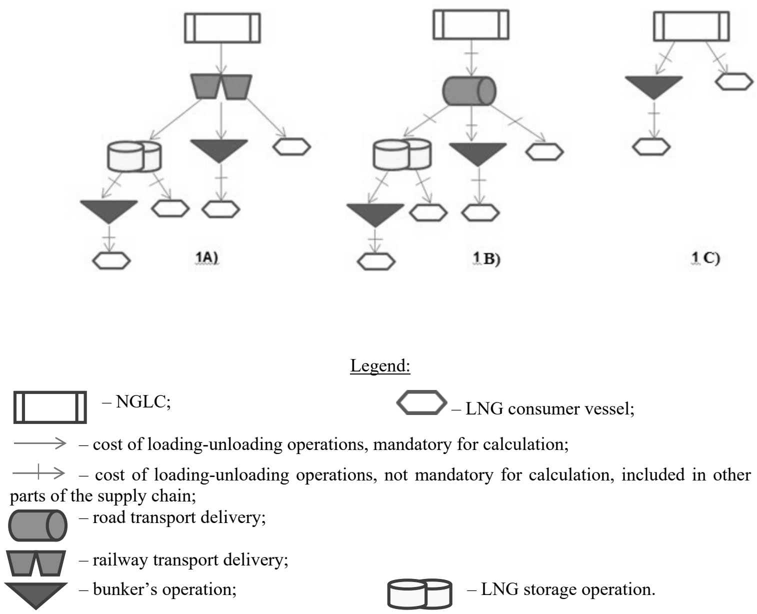
Starting in 2019, medium-tonnage LNG production will be deployed mainly in the North-West of Russia. This is Cryogas-Vysotsk project with a capacity of 660 thousand tons of LNG per year [7] and LNG terminal of PJSC Gazprom in the vicinity of Portovaya compressor station with a capacity of 1,5 million tons of LNG per year [8].

Thirteen small-capacity production sites operate in Russia: six are concentrated in the North-West economic region, three in the Urals, two in the West Siberian region and two in the Far East. In the coming years, four more plants are scheduled to be launched.

For the purpose of this study, and to explore LNG delivery routes we consider existing small-capacity facilities.

3. Development of potential routes for delivery of low-tonnage LNG from places of production to bunkering points of river vessels

When forming gas delivery routes, the following parameters were taken into account: distance between LNG production sites and bunkering port points, the load (demand) of bunkering port points, the capacity and loading



Pic. 1. Options of LNG delivery in tanks.

of LNG production complexes, and availability of roads and railways.

Given the above factors, the following LNG delivery routes (hereinafter referred to as «calculated») were determined for the calculations:

1. NGLC Petergof (St. Petersburg) → Ust-Slavyanka;
2. NGLC Kingisepp (Kingisepp) → Cherepovets;
3. NGLC Razvilka (Moscow) → Yaroslavl;
4. NGLC Kanyusyata (Perm) → Kazan;
5. NGLC GRS-4 Yekaterinburg (Yekaterinburg) → Samara;
6. NGLC Mitino (Novokuznetsk) → Barnaul.

4. Analysis of possible methods of LNG transportation with development of logistics operation chains for the selected routes

There are two ways to deliver gas from manufacturers to bunkering points: gas delivery in bulk and in tank containers.

When delivering gas in bulk, the options shown in Pic. 1 are available.

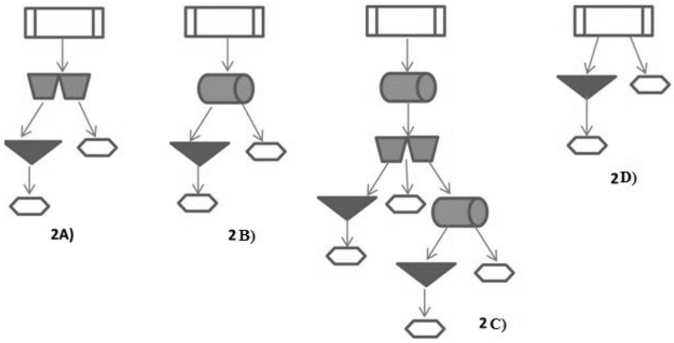
A method of transporting gas in bulk is common, but it should be borne in mind that storing LNG in tanks is unsafe and not economically viable. Downtime of railway and automobile tanks significantly increases the cost of cargo delivery, so LNG is loaded into the tank before departure, and immediately after delivery it is unloaded by transferring it to the storage tank or by bunkering «from the wheels», which requires a comparable amount of delivered and bunkered fuel and coordinated work of different modes of transport. According to VRD39-1.10-064-2002 [9], when transporting LNG, the number and time of parking should be avoided or minimized.

LNG transportation in specialized tanks requires additional processing and transshipment, which increases product losses and the risk of accidents [10–12]. Thus, transshipment from road to railway transport and vice versa, subject to the relevant rules, is theoretically possible, but should be economically justified.

When delivering LNG in tank containers, the options shown in Pic. 2 are considered.

Tank containers are used on fuelled vessels in the mode of interchangeable modules delivered «from the shore» and from a bunkering vessel, which can be a container ship. A tank container is a container consisting of a frame (frame elements) and a tank equipped with drain valves and devices for unloading.

The key advantage of transporting LNG in tank containers is the ability to transport it by several modes of transport and the absence of the need to build special expensive facilities for reception, storage and distribution of LNG. Tank containers are loaded and unloaded using a crane or a reach stacker. The accumulation



Pic. 2. Options of LNG delivery in tank containers (legend is the same as in Pic. 1).

of tank containers at specialized storage sites is possible. Since a tank container is both a vehicle and a transport container, there are no cargo losses during loading and unloading operations. But mass of a transported product in a tank container is usually less than in a tank.

5. Calculation assumptions

After analyzing the technology of transportation and transshipment of LNG, as well as the terms of payment for the logistics services of participating companies, the following *assumptions* were made for subsequent calculations:

• for LNG delivery in bulk:

– cost of LNG when leaving manufacturer's plant includes the cost of loading on the selected mode of transport;

– upon delivery by special motor transport, the cost of loading and unloading operations is included in the cost of delivery;

– when transported by rail, transshipment operations are not included in the tariff, they must be taken into account separately;

– storare operations include costs of loading and unloading operations;

– bunker operation includes its refueling and bunkering of fuelled vessels;

– transportation in mixed road-rail traffic is a combination of schemes 1A and 1B.

• for LNG delivery in tank containers:

– the cost of freight operations is calculated for all segments of LNG supply chain and is not included in the cost of delivery by any single mode of transport;

– reloading of tank containers from a container ship to a LNG consumer ship is performed by port mechanization facilities;

– transportation in mixed road-rail traffic (2C) is a combination of schemes 2A and 2B.

The above LNG transportation schemes for bulk and container delivery methods correspond to the world theory and practices of organizing logistic schemes for supply of motor gas fuel [13–18].

Thus, for each route, with respect to all the conditions, transport and technological schemes (TTS) were developed using possible modes of transport (road, rail, water) and their combinations. A list of necessary freight operations has been compiled for each TTS. For each TTS element, duration of the operation was calculated.

6. Selection criteria for optimal TTS of LNG delivery

As a criterion for choosing the best option for TTS of LNG delivery, the delivery price (Pd) of cargo for the *i*-th calculated route was used:

$$Pd_i = Pt_i + Ps_i + Pco_i, \quad (1)$$

where Pt_i – price of transportation of goods by one or more modes of transport along the *i*-th calculated route;

Ps_i – price of storage of cargo (for the method of delivery in bulk) along the *i*-th calculated route;

Pco_i – price of cargo operations along the *i*-th calculated route.

A TTS option is selected by a minimum LNG delivery price.

For the equal delivery price, the delivery time was used as an additional criterion, and for transportation in tanks the number of transshipment operations was used as the third criterion.

7. Development of operating and economic models for calculating the specific cost of transportation, storage and transshipment of LNG

To calculate the price of LNG delivery by road, an operational and economic model of the transport company operation was developed, with the help of which the cost structure of the transport company and the final cost of LNG delivery for the potential customer were estimated. The developed model takes into account more than 20 cost items, including

Table 1

Calculation of the integrated tariff for LNG delivery in tanks according to TTS options (including VAT)

No.	Departure point	Destination point	Mode of transport	Distance, km	Delivery time	Tariff rate, rub./t • km
1	St. Petersburg, NGLC Petergof	Ust-Slavyanka	road	54	2 h 15 min	4,94
2	Leningrad region, NGLC Kingisepp	Cherepovets port	road	660	9 h	3,66
			road, railway	624	5 day 1 h 15 min	5,09
3	Moscow, MKAD [Moscow Ring Road], 24th km, JSC MGPZ	Yaroslavl port	road	300	6 h 30 min	3,81
			road, railway	353	5 day 1 h 20 min	7,99
			road, vessel	548	1 day 17 h 40 min	8,90
4	Perm region, village Kanyusyata, NGLC Kanyusyata	Kazan port	road	670	9 h 50 min	3,58
			road, railway	652	5 day 2 h 50 min	5,17
			road, vessel	1074	3 day 10 h 40 min	5,57
5	Yekaterinburg, Novosverdlovskaya TPP [termal power plant] industrial zone	Samara port	road	1000	15 h	3,63
			road, railway	1163	6 day 1 h 30 min	3,34
6	Kemerovo region, Novokuznetsk district, NGLC Mitino	Barnaul port	road	360	6 h	3,48
			road, railway	328	4 day 3 h	8,80

Table 2

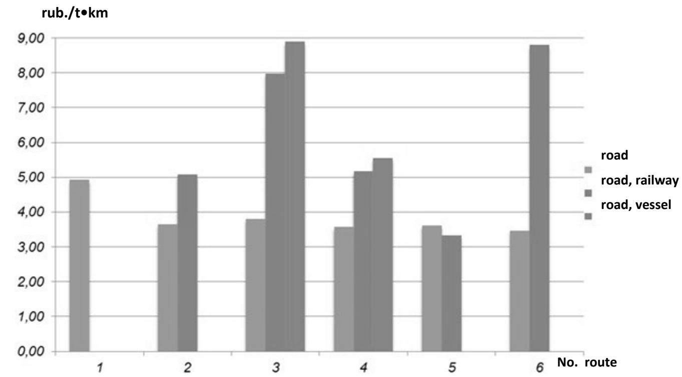
Calculation of the integrated tariff for LNG delivery in tank containers according to TTS options (including VAT)

No.	Departure point	Destination point	Mode of transport	Distance, km	Delivery time	Tariff rate, rub./t • km
1	St. Petersburg, NGLC Petergof	Ust-Slavyanka	road	54	1 h 40 min	7,81
2	Leningrad region, NGLC Kingisepp	Cherepovets port	road	660	8 h 30 min	4,33
			road, railway	647	11 day 1 h 30 min	3,32
3	Moscow, MKAD, 24th km, JSC MGPZ	Yaroslavl port	road	300	6 h	4,81
			road, railway	355	9 day 1 h 50 min	4,92
			road, vessel	548	1 day 17 h 10 min	5,23
4	Perm region, village Kanyusyata, NGLC Kanyusyata	Kazan port	road	670	9 h 20 min	4,21
			road, railway	647	12 day 1 h 50 min	3,49
			road, vessel	1074	3 day 10 h 10 min	3,81
5	Yekaterinburg, Novosverdlovskaya TPP industrial zone	Samara port	road	1000	14 h 30 min	4,18
			road, railway	1168	14 day 1 h	2,40
6	Kemerovo region, Novokuznetsk district, NGLC Mitino	Barnaul port	road	360	5 h 30 min	4,33
			road, railway	340	9 day 2 h	5,12

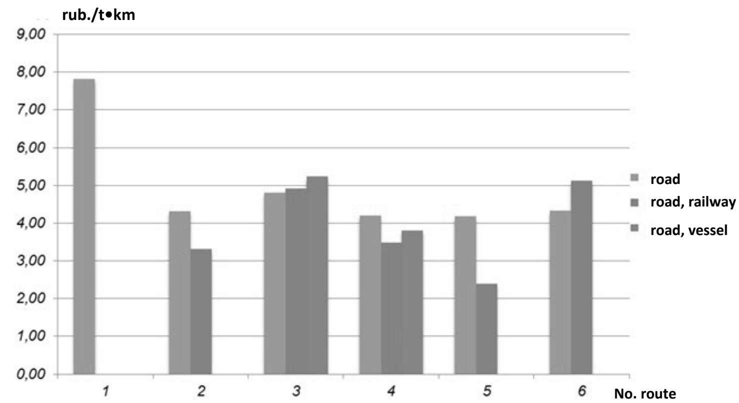
wages, insurance premiums, car fuels, lubricants, maintenance and service repairs, tire wear and tear, depreciation of rolling stock, payment for Platon system [toll road payment, from Russian abridged «payment per ton»] and other expenses.

The cost of delivery by rail was estimated according to existing standards of JSC Russian Railways [19].

In order to estimate the cost of LNG delivery by bunkering vessels of various sizes, large-scale calculations of the vessels' construction cost, its estimated freight rate and operating costs were performed, which were framed in the form of an operational-economic model of the operation of bunkering vessels on the calculated lines of operation.



Pic. 3. Tariff rate for LNG delivery in tanks according to TTS options for calculated routes.



Pic. 4. Tariff rate for LNG delivery in tank containers according to TTS options for calculated routes.

To estimate the cost of LNG storage in a stationary storage tank, we simulated the operation of 1 to 23 cryogenic tanks with a volume of 44 m^3. The calculation of the LNG storage price was carried out using enlarged cost items with a given level of profitability.

The calculation of the price of cargo operations was carried out using the standards applicable in rail and road transport, an analysis of open sources for the cost of renting container trucks with a driver, and information on tariffs for transshipment of containers at specific ports. The data obtained were formalized into an operational and economic model for calculating the unit cost of cargo operations.

8. Calculation of the price of delivery of low-tonnage LNG using different TTS options

To carry out the calculations, the daily bunkering volume of LNG consumer vessels was set, the bunkering mode of operation were selected, and the initial data for all options were prepared. The size of cargo lots is correlated with capacity of bunkers and amounts to 1110 tons for transportation in tanks, 1430 tons for transportation in tank containers. The results are grouped by delivery method: in bulk (Table 1, Pic. 3) and in tank containers (Table 2, Pic. 4). For convenience of analyzing the results, the delivery price is interpreted in the form of an integrated tariff rate, taking into account the cost of delivery and cargo operations. The calculations were made using October 2018 prices.

Calculations show that the high cost of transshipment of railway tanks makes TTS with participation of railway transport impractical if the distance of transportation by railway is less than 1000 km. TTS in mixed road/water traffic is usually more expensive than other TTS options.

Thus, due to the lower cost of cargo operations using a containerized method of delivery, TTS involving railway transport is more economical when LNG is transported by rail over 600 km. LNG delivery by water is competitive with regard to other modes of transport.

For both methods of LNG delivery, according to the criterion of delivery time, TTS using direct road traffic is more advantageous, followed by TTS using water transport. Transportation involving railway transport is most time-consuming.

Conclusions. An algorithm has been developed for choosing an optimal transport and technological scheme for delivery of low-tonnage LNG. Operational and economic models for calculating the unit cost of transportation, storage and transshipment of LNG have been suggested.

As part of the departmental project of the Ministry of Industry and Trade of Russia «Development of gas fuelled fleet for navigation in coastal waters and inland waterways», models were tested on calculated routes. This made it possible to estimate the cost of LNG transportation according to the options of transport and technological schemes for bulk and container delivery methods and to formulate particular conclusions regarding optimality of various schemes according to the criteria of time and cost.

The proposed methodology is largely universal and allows the use of the proposed approaches for development of TTS in relation to other countries.

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