Innovative Technologies in the Supply Chains of Large-Tonnage Cargo for Nuclear Power Facilities

Irada MAMEDOVA
Russian University of Transport
9b9 Obrazcova St., 127994 Moscow, Russian Federation
irada-mamedowa@mail.ru

Elena PAVLOVA
Russian University of Transport
9b9 Obrazcova St., 127994 Moscow, Russian Federation
elenaivanovna@bk.ru

Evgeniy REUTOV
Russian University of Transport
9b9 Obrazcova St., 127994 Moscow, Russian Federation
reutov.ev@gmail.com

Elena CHERPAKOVA
Russian University of Transport
9b9 Obrazcova St., 127994 Moscow, Russian Federation
cherpakovae@inbox.ru

Natalia YAKUSHINA
Russian University of Transport
9b9 Obrazcova St., 127994 Moscow, Russian Federation
elena-ri@mail.ru

Abstract
The paper addresses the issue of logistics for transportation of large-tonnage loads for nuclear power plants. It presents the analysis of the characteristics of large tonnage load and peculiarities of its transportation. In particular, the authors discuss key principles to be followed when preparing the transportation process and the risks associated with the transportation of large-tonnage cargo for the nuclear power plants. The objective of the research is to identify key aspects of managing delivery of large-tonnage cargo for nuclear power plants and illustrate associated risks and solutions using the case of Russia's State Atomic Energy Corporation "Rosatom". The authors conclude that at any stage of transportation of a large-tonnage load, the safety of load is the priority, and the modern universal transport and logistics solutions aimed at cost minimization should be introduced in day-to-day operations in Russia.

Keywords
Large-tonnage cargo; logistics decisions; Russia; Rosatom; supply chains for nuclear power plants.

Introduction

The growing need for energy resources, globally, stimulates the development of nuclear energy, which is used in 30 countries of the world (194 nuclear power plants in total, with 437 power units operated). The positive dynamics of the development of nuclear technology is associated with a decreasing role of oil in total energy consumption. The distribution of nuclear energy facilities across countries and regions of the world is uneven: while some countries largely rely on nuclear fuel, others constrain from using it or approach the issue with caution for several reasons, primarily because of the associated risks. Therefore, it is very important to ensure safety both at the construction stage and during the operation of nuclear power plants.

Russia is building nuclear power plants (NPPs) not only in its territory but also in other countries. The Russian State Atomic Energy Corporation "Rosatom" has overseas orders for the construction of new NPPs scheduled for up to 2025: the foreign orders portfolio includes 35 units at various implementation stages.

Construction of the floating NPPs is under consideration. This is an entirely new direction in the peaceful uses of nuclear power. Russia was the first country in the world to engage in the construction of floating NPPs. A floating NPP is a very big vessel, comparable in size to the largest ice breakers. Three tows were required to undock such a station from the Baltic Shipyard to move it further to Murmansk for running tests, and then proceed to the city of Pevek for further use. The station will be transported along the Northern Sea Route, with the help of tows but without ice breakers. Such an experience can be scaled up for similar projects in other countries with remote territories, in Canada, Indonesia, etc., and also in the island countries.

The development and implementation of highly effective supply chain management of large-tonnage loads for NPP will allow increasing efficiency of production and logistics activity of the NPP within territorial scale. The objective of this research is to develop scientific approaches to managing delivery chains and to the justification of transport choice and logistics schemes of delivery of large-tonnage loads for the NPPs (using the case of the Russian Federation).

In transport logistics, when considering the transportation of load, it is necessary to distinguish between "in-gauge" and "out-of-gauge" loads. A load with all its parts fitting in loading dimensions (of the platform, the gondola car, the conveyor) is a cargo within a loading range. A load of non-standard weight, dimensions, or size, is called a large-tonnage, in-gauge load. Large-tonnage loads include bulky and super bulky loads with size, dimensions, and weight differing from established standards.

Delivery of large-size load belongs to the specific category of deliveries. It has certain essential distinctions and differs from standard transportation in terms of the complexity of transportation. A distinctive feature of the delivery of large-tonnage loads is that each bulky load transportation requires an individual approach. Options of transportation of each bulky cargo are determined by transport characteristics of

the load, its size, weight, and functionality. Before starting the transportation of out-of-gauge loads, it is necessary to consider various delivery route options, select and find the required handling equipment, the optimum vehicle for delivery, and select the accompanying personnel.

The transportation of large tonnage loads should follow the stages of preparation of the transportation process (Figure 1).

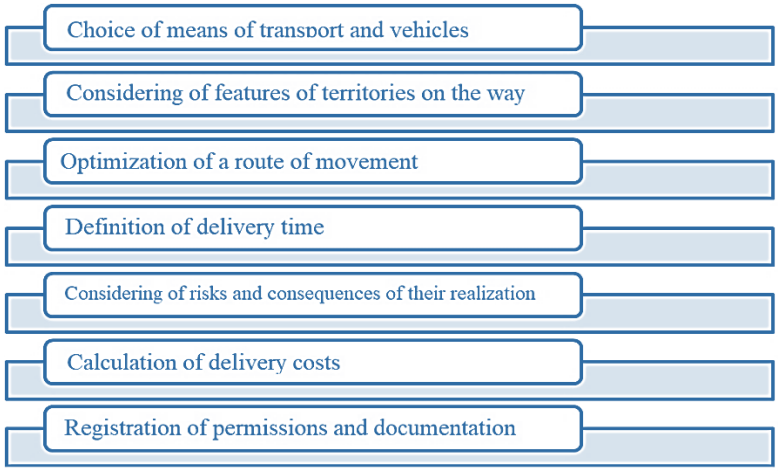

Figure 1. Stages of preparation of transportation process of large-tonnage load

Transportation of such a load by railway or air is expensive, difficult, and highly labor-consuming. Nowadays, transportation of in-gauge loads by the automobile gained popularity due to the availability and affordability of this mode of delivery.

This paper presents the theoretical basis of the organization of the delivery of bulky and super bulky loads relying on the analysis of the characteristics of large-tonnage load and peculiarities of its transportation.

The paper is organized as follows:
1) Overview of the characteristics of large-tonnage loads and the impact of these characteristics on the transportation in terms of observing the principles of profitability and rationality, i.e. reduction of costs and transit time;
2) Analysis of risks associated with transportation of large-tonnage cargo for the NPP;
3) Logistics approaches to the organization of transportations of large-tonnage loads;
4) Criteria for identification of the effective transport and logistics schemes for large-tonnage loads delivery to the nuclear power plants;
5) Case study of the Russian State Atomic Energy Corporation "Rosatom"

Data and method

The analysis is based on the data collected from online sources including previous academic research, and relies on the following theoretical concepts:

- *the material flow*, which represents an object (large-tonnage cargo) moving along the delivery chain between the shipper and the consignee;
- *the information flow*, which comprises the messages necessary for managing and controlling logistics operations and circulating between the logistics system and the external environment. The information flow can exist in the form of paper and electronic documents;
– *the financial flow*, which denotes the targeted movement of financial resources making the material flow move in the direction determined by these financial resources in logistics.

Russian State Atomic Energy Corporation "Rosatom has been chosen as a case illustrating the organization of the logistics of transportation of a large-tonnage load for a nuclear power plant. "Rosatom" is a world-leading company in the market of nuclear power plants construction, but in terms of logistics, it faces the challenge of delivering the accessories to numerous remote objects and has to organize the logistics in the most efficient way to avoid significant economic losses.

Transportation of large-tonnage loads: key principles

The transport process in transit of large-tonnage load is a process of shipment (transportation) of loads, including initial operations in the place of departure and final operations in the destination. Organizing the transport process and providing the required resources should be based on a deep understanding of the most rational technology of load transportation. The technology of load transportation means performing a sequence of selected and rational technological operations which is aimed at achieving the desired outcome.

A market economy encouraged logistics approaching design and implementation of transport process in such a way that it ensures timely and safe delivery of large-tonnage load, with safety standards observed, satisfied customer needs, cost efficiency, and quality of service well considered.

The basic logistics principles of transportation of large-tonnage cargo include:
1. *The principle of efficiency*, which covers:
- searching the shortest or most rational transits;
- reducing the material damage caused by the loss of load and its quality deterioration, including selecting relevant equipment;
- observing the vehicle operating requirements, as well as handling techniques and technologies.
2. *The principle of efficient use of the customer's resources* (least cost principle), which includes searching for a rational way of network transformation, efficient placement of the enterprises, managing inventory, and deciding on the most appropriate cost reduction option.
3. *The principle of safety*, which relates to the need to ensure the safety of cargo and the road (road infrastructure), to organize the traffic rationally, and to provide the equipment with required technical parameters. The transportation of a large-tonnage cargo includes also identification of places of potential risk and considering preventive measures to deal with it. At the same time, it is important to consider the licensing of

the operations and certification of the rolling stock and equipment. Additionally, it is necessary to consider the professional development of workers who are organizing and carrying out transportations of large-tonnage cargo.
4. *The principle of shared responsibility* (responsibility of the firm) refers to the regulation of the behavior of each participant in the general traffic flow, choosing the rational shipment mode corresponding to the characteristics of the traffic flow. It is also necessary to consider the international requirements to the technical condition of the vehicles and the equipment involved in transportation as well as means of reducing the negative impact on the environment.
5. *The principle of active and passive adaptation to the conditions of work* concerns the rational choice of the rolling stock, taking into account the climate of the region of transportation; coordination with the organizations which have their infrastructure objects on the transportation route.
6. *The principle of compensation of the disturbing influences*, or the principle of the "bottleneck" control requires timely replacement of the rolling stock, a container, and the equipment; transformation of the transport network; ensuring safe movement along with the road infrastructure (a railway level crossing, an overpass, etc.); choosing a place for and organizing reloading, etc.

Traditional vs. logistics approaches to the transportation of large-tonnage loads

There are two main approaches to the organization of transportation of large-tonnage loads - traditional and logistics (with an operator of multimodal transportation).

According to the traditional approach, no common function of management is prescribed for the material flow. Little coherence is observed between information flow and financial flow, as there is no coordination of the corresponding actions. The traditional approach, however, covers the whole process of transportation, from initial to a final point (from shipper to consignee), including processes of loading, and observes the principles of safety, storage, and information support of delivery but without centralization of transport and logistics processes.

The difficulties in coordinating the operations led to the emergence of logistics centers implying a logistics approach to the organization of transportation of large-tonnage loads. A logistics center allowed for the centralization of the management of the entire chain of transport operations, due to the implementation of the data analysis and development of suggestions for improvement of traffic load, such as assigning transportation to various means of transport, combining shipments, and ensuring the proper contracting procedure.

The logistics approach to mixed transportation differs in terms of adding another participant to the transport process – one common operator of multimodal transportation.

The technology of reloading plays an important role in the logistics approach. Thus, instead of choosing between different options of material handling, an intermodal technology started to be widely applied for the long-distance transportation of freight

between cities and countries. According to the terminology of the European Conference of the Ministries of Transport, intermodal transportation is the consecutive transportation of cargo in the same cargo unit (container, demountable body, semitrailer, etc.) with its transshipment from one mode of transport to another without reloading the cargo itself. The use of the intermodal technology reduces reloading costs by 4-5 times, reduces container and packing-related costs, reduces the probability of loss and damage of freight in the process of transportation, shortens the time of the shipment. Moreover, the time of transportation depends on numerous factors, including the type of vehicle used for the delivery of the large-tonnage cargo.

Risk assessment

The transportation of large-tonnage load is associated with a range of risks:
- the risk of losing the value and damaging the large-tonnage load during the transportation;
- the risk of damaging a roadbed and road pavement;
- financial risks.

When preparing the transportation of large-tonnage load, it is possible to avoid risks at the stage of planning a route. According to the principles of logistics, at the preparation stage, it is necessary to explore in detail a route, i.e. to examine the transport network to identify the sites where the movement of the vehicle with load can be complicated or impossible due to the size of the vehicle with a load and to the heavy traffic. If no alternative is available, risks can be mitigated by considering the transformation of the transport network (change of its parameters) to avoid these sites.

Worldwide, a systemic approach is applied to the protection of roads against the negative impact of cars. Russia has entered several agreements concerning construction, development, and ensuring the normal service conditions of highways.

The risk situations related to the transportation of large-tonnage load are associated with the following reasons:
- driving along the narrow sections of roads, bridges, tunnels, railway crossings, and power lines;
- specific weather conditions (ice, snowfall);
- the difficulty of fitting into sharp turns and turns of an oversized vehicle;
- junction with oncoming transport;
- bad quality of roads, etc.

Transformation of a network can be considered as a risk reduction measure to be applied together with the calculation of costs to bear to introduce the necessary changes in the parameters of the network.

Transportation of large-tonnage load is carried out in varying and fast-changing environmental conditions which appear challenging for drivers in terms of the tension of work, ability to accurately regulate the actions, the demand of high-quality professional training, and personal qualities of the driver. The driver is connected with

the vehicle, the road, and the entire environment where the process of transportation takes place, thus being included in the "driver- vehicle- road- environment " system.

Transportation of heavy in-gauge load also refers to the area of logistics. As a rule, a heavy in-gauge load represents an especially valuable load, therefore its value is always considered in the cost of the transportation.

Logistics decision-making

The purpose of the logistics decision is to simplify transportation while ensuring full compliance with safety measures and using the possibilities of modern transport infrastructure. Thus, it is necessary to find optimal logistics decisions involving the lowest risks for transportation of large-tonnage load.

The final decision should be well-balanced; a starting point in logistics design is the interests of the consignor. At first, the logistics decision should be economically justified, secondly, geographically correct, thirdly, it should be based on the good knowledge of modern capacities of the existing modes of transport.

The key indicators for comparing options of transportation by different modes of transport are:
- level of operating costs (cost of transportation);
- capital investments;
- speed of the movement and delivery period;
- availability of transportation and throughput capacity;
- maneuverability in providing transportation in various conditions;
- reliability and uninterrupted operation of transportation, regularity;
- guaranteed safety of the transported load and baggage;
- conditions of effective use of vehicles,
- possibilities of mechanization and automation of loading and unloading operations.

The final goal of combining different types of transport in multimodal transportation is to reach optimization of the project in general. From the very beginning of logistics planning, it is necessary to avoid handling using different modes of transport, because it increases the price of the transportation process. It would require developing a scheme of transportation and premeditation of a route so that to minimize the number of overloads.

Summarizing the above, each case of the large-size load transportation should be treated individually, a standard transportation scheme for any large-size load can hardly be offered. Depending on the size, weight, delivery period, location of the recipient and the shipper, one or another mode of transport can appear more suitable for a multimodal shipment.

The case of State Corporation “Rosatom”

In practice, a modern, universal approach to logistics decision-making is rare. The long-existing methods of logistics are still widely applied. Moreover, the legislation

does not allow the Russian economic entities to reduce the size of transport and logistics costs which ultimately affects the final price of products. In this regard, the experience of the State Atomic Energy Corporation «Rosatom» is worth considering.

Construction of the NPP or power units by the Russian company "Atomstroyexport" is planned or is already implemented not only in the European countries – Hungary, Finland, Bulgaria but also in Asian and African countries – Iran, Turkey, India, Egypt, China, and also in other countries of the FSU and beyond. The possibility of construction of a series of NPP in the Republic of South Africa for the sum of $130 billion is considered (Atomenergomash, 2019).

The share of "Rosatom" in the global market of nuclear power plants construction reached 67%. But in terms of logistics, the company faces the challenge of delivering the accessories to numerous remote objects, and associated mistakes can lead to significant economic losses.

A good example is the logistics chain developed for the delivery of the nuclear reactor produced by the Atommash plant in Volgodonsk for the Belarusian nuclear power plant "Ostrovets" (Grodno region). Technical and political factors (the sanctions of the European Union) influenced the design of the route. Technical parameters of road infrastructure, primarily, the paving, made it impossible to use motor transport for transportation. In addition, the power lines over the road bridges and overpasses did not allow for the transportation of the large-tonnage load of the given size and weight. Rail transport was neither suitable because it required extra work including temporary dismounting of traffic lights, signs, and overhead poles. Therefore, it was decided to deliver the freight by water. The waterway started from the city of Volgodonsk, along the Volga river, through Lake Ladoga to the city of Veliky Novgorod. At that point, the reactor was unloaded from the barge and transported to the railroad using the self-propelled modular transporter.

However, the transportation difficulties emerged later when the shielding of the reactor vessel touched the overhead pole of the contact network, during shunting operations at a Belarusian railway station. The vessel was damaged and had to be replaced. This cost the shipment company $400 million.

Another example that shows how challenging it is to design a delivery chain for large-tonnage loads is outlined below. The sequence of activities required for the transportation of the reactor from the city of Vidzhevano (Italy) to the city of Gubakha (Russia, Perm Krai) for the construction of the NPP included:

Step 1: loading of packages on the motor transport in the territory of the consignor;
Step 2: transportation by motor vehicle to the port of departure – Margera and Kyodzha, Italy;
Step 3: reloading from the motor transport to the water transport in the port of departure;
Step 4: transportation by sea from the port of departure to the port of destination – Nizhnekamsk, the Russian Federation;

Step 5: reloading in the port of destination from the marine transport to railway transport (steps 6.1 – 6.3) or internal water transport (steps 7.1 – 7.3);
Step 6.1: transportation by rail from Nizhnekamsk to the railway station of destination;
Step 6.2: reloading at the station of destination from railway transport to automobile transport;
Step 6.3: automobile transportation from the station of destination to the territory of the consignee;
Step 7.1: transportation by water to a temporary Ro-Ro of the mooring near the settlement Verkhnechusovsky Towns;
Step 7.2: unloading from a temporary Ro-Ro to the motor transport;
Step 7.3: automobile transportation from a temporary Ro-Ro of the mooring to the territory of the consignee;
Step 8: unloading in the territory of the consignee.

Obviously, for such complicated transportation, all modes of transport should be integrated considering peculiarities of transportation of large-tonnage loads.

Discussion

The traditional methods of the organization of transportation of large-tonnage loads fail to ensure the quality required by the companies engaged in the construction and operation of the NPPs. At the same time, alternative methods of the organization of delivery chains for large-tonnage and super bulky loads are available and imply the use of different types of transport.

In Russia, "the Union of Haulers of Large-Size, Heavy and Dangerous Loads (SAKTOG) addresses the existing constraints. At the country level, the organization contributes to the emergence of modern logistics systems for the organization of transportation of large-tonnage and super bulky loads, including transportation of freight for the NPP.

In the absence of one common information authority in charge of multimodal transportation, the corresponding role of the integrated logistics operator could be assigned to a coordination and logistics center. Upon its establishment, such a logistics center would keep monitoring traffic load in the direction of the concrete transport hub and apply data processing tools in the online mode. In the long-term perspective, the technologies of information modeling (BIM technologies – Building Information Modeling) would be able to provide the detailed digital description of logistics chains of deliveries allowing to trace the movement of the cargo along its route to the consumer and to confirm the compliance with the established requirements. BIM technology is tested by the JSC "Russian Railways" in selected projects. NPP construction and reconstruction operations depend quite a lot on the timely use of emerging technologies.

To optimize the delivery of large-tonnage loads, a system of integration of transport and logistics service should be introduced and digitization of business processes should be regarded as a must for construction and supply of the NPP while considering minimization of transport and logistics expenses.

When selecting a vehicle ensuring safe transportation of bulky and oversize loads, the weight, size, and dimensions of cargo should be taken into account.

Stage-by-stage implementation of components of improvement of the Party of Social Reforms for an increase in efficiency of transport and logistics operations in relation to large-tonnage and super bulky loads for the NPP is possible.

Conclusions

Exports of nuclear goods and services are a major Russian policy and economic objective. In this regard, efficient logistics for the transportation of large-tonnage loads for NPPs is of primary importance. This paper has addressed the key principles of organizing such logistics, including risk assessment, and decision-making.

At any stage of transportation of large-tonnage load, the safety of load is the priority. The modern universal transport and logistics solutions aimed at cost minimization should be introduced in day-to-day logistics operations in Russia. In Europe, the cost of transportation of large-tonnage load does not exceed 9 - 14% of the cost of the load, whereas in Russia it is 3 times higher. In the European Union countries, there are more than 800 firms that transport heavy and bulky loads.

Use of the railway transport for transportation of large-tonnage load is not always justified and possible (restrictions on dimensions because of bridges and tunnels). Delivery by water transport is the most economically efficient one, because of low operating costs. However, in some cases it requires dredging works for which additional investments are necessary; also, the seasonality factor matters. Construction of the barge fleet can become an alternative to dredging works. Such a solution was used for the construction of the Amur plant of GPP for Sil's gas pipeline of Siberia on the Zeya River which guaranteed a depth is 1.4 m. For ensuring transportation of large-tonnage load to the plant, the barge fleet was used: the load was handled using synchronously working cranes.

Automobile transportation of large-tonnage load requires high-level organization: observance of requirements to the rolling stock, restrictions, and obtaining permissions for transportation of heavy and bulky loads across highways (Bulky cargo…, 2019; Grishagin, 2019). Procedures of obtaining authorization complicate the process - they are labor-consuming and take much time. The government internet portal for registration of services of transportation of large-tonnage and super bulky loads is necessary for simplification of these procedures.

In the course of transportation of large-tonnage loads, any risks can be encountered. The analysis revealed the potential risks connected with loss of value and damage of large-tonnage load in the course of transportation; the risks posing a threat of damage of a roadbed; financial risks.

Key types of risks encountered during the implementation of projects of large-tonnage loads transportation include:

1. Commercial risk: failure of delivery, unavailability of load in time, violation of delivery time, failure to follow financial obligations of the parties in a logistics system;
2. Risk of losing the property because of natural disasters, adverse conditions of transportation;
3 Risk of loss of property because of strikes, turmoil, and military operations;
4. The risks caused by violation of safety measures and fire safety;
5. Risks of plunders;
6. Environmental risks: incidents with loads or packaging-related insufficiencies which can cause damage to the environment;
7. Technical risk: breakage of the vehicle and, as a result, delay of delivery and increased probability of other risks;
8. Risks associated with low qualification of contractors in the logistics system such as negligence, loss of documents, missed deadlines, and other;
9. Risk of civil liability when causing damage to the third parties.

At the same time the analysis showed how the specified risks can be reduced:

1. Commercial risk – by accurate formulation of clauses of the contract with differentiation of responsibilities and definition of penalties;
2. Risk of loss of property because of natural disasters – by the analysis of a situation, use of statistical data during the transportation;
3. Risk of loss of property because of strikes, turmoil, and military operations – by the analysis of the external and internal political situation;
4. The risks caused by violation of safety measures and fire safety – by constant control of actions of personnel, and introducing the check of sheets;
5. Risks of plunders – by insurance;
6. Environmental risks (incidents with loads or packaging-related inefficiencies which can cause damage to the environment) – by controlling the observance of requirements of environmental safety by personnel;
7. Technical risk – by working with the skilled and trusted partners, considering that "the cheapest does not mean the best!";
8. Risks associated with low qualification of contractors in a logistics system - negligence is, loss of documents, missed deadlines, and other – by careful choice of intermediaries in a logistics chain;
9. Risk of civil liability when causing damage to the third parties – by insurance.

The highest damage is linked to accidents on a bridge construction when the destruction can lead to freezing the activity of the whole region, in case the bridge connects the city on both sides of the river. The mathematical apparatus of calculation of the losses connected with transportation of large-tonnage loads is to be applied as described elsewhere (Magomadov, 2019).

Limited availability of specialized equipment in Russia because of the low quality of roads leads to considerable losses and increased repair and maintenance costs, although the situation gradually improves. There is also a risk of vehicle breakage, even when the rolling stock has been in operation only for 2 – 3 years. It happens because the producers of the transport equipment want to reduce the weight of the vehicle (metalwork) to be able to increase its loading capacity.

Technical solutions are developed for the reduction of operating costs, in particular, the use of modular vehicles with electronic control by axes, innovative solutions in the field of the steering system of semi-trailers, etc. The modern equipment is capable to move a load to a vertical and horizontal position, pulling it up and putting it down which allows minimizing the workload on all engineering objects found along the railway.

When international transportation of large-tonnage load is considered in terms of risk management, it is important to assess the impact of force major circumstances on the processes of management of material and information flows regulated by standards of the international and internal law (Pavlova, 2016).

Logistics decisions cannot be implemented without a trans-logistics platform providing the organization of multimodal and intermodal transportation, information communications online, financial, and other business services. Interregional/international cooperation is required for the delivery of large-size products to NPPs (Solovyev, 2015). Logistics outsourcing will allow reducing the time required for designing logistics of large-tonnage loads. Further research illustrating good practices and solutions implemented in the context of Russia will provide more valuable insights into the issue of logistics for the transportation of large-tonnage loads for nuclear power plants.

References

Atomenergomash Group of Companies (2019). *Solutions for Atomic Energy Sector.* http://www.aem-group.ru/static/images/buklety/atomka-rus.pdf.

Bulky cargo: transportation features, permissions, and recommendations (n.d.). Autogear. https://autogear.ru/article/320/149/krupnogabaritnyiy-gruz-osobennosti-perevozki-razresheniya-i-rekomendatsii/

Grishagin, I. (2019). The Russian river system is burdened with oversized cargo. *Transport of the Russian Federation*. http://www.rostransport.com/article/201011/

Magomadov, R. S. (2017). The risk assessment of the transportation of non-standard goods on the example of lifting and transport vehicles. *Don Engineering Engineer*, (1). https://elibrary.ru/download/elibrary_29751749_28798653.pdf

Pavlova, E. (2016). Effect of FORS-major circumstances on modern international logistics. *Proceedings of the Ninth International Conference. ICS RAS, October 3 - 5, 2016* (Vol. 2, pp. 85 – 88).

Solovyov, E. M. (2015). On a difficult route: transportation of non-standard cargoes. *Logistics & System, 45*, 36 - 48.

Union of haulers of bulky, heavy and dangerous goods (SAKTOG). http://caktg.com/ The date of appeal 04.05.2021.