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## **Historical aspects of construction and operation of train ferry routes**

**Abstract.** *Sustainable development of the transport industry can be provided through the introduction of combined transport systems. And one of the most promising ones is the train ferry transport system which combines railway and marine transport facilities. The article deals with the analysis and systematization of the data on the historical development of train ferry routes and describes the background for the construction of train ferry routes and their advantages over other combined transport types. It also deals with the basic features of the train ferries operating on the main international train ferry routes. The study is concerned with both sea routes and routes across rivers and lakes. The article shows the role of train ferry routes in the improvement of a national economy, and in the provision of the military defense, as it was described by Vinogradov at the example of Saratovskaya Pereprava (route) and by Karakashly and Shklyaruk at the example of the lighter Ishimbay which was loaded from the side. The authors have analyzed the development of the train ferry routes serviced by the ice-breaking train ferries Baikal across Lake Baikal, and the ferries Sakhalin linked mainland Russia and Sakhalin Island. The article deals with the peculiarities of transportation by trains ferries in the USA, Japan, Azerbaijan, Dagestan, Germany, Lithuania, and some other countries, and presents the analysis of the operational features of Ukrainian train ferries which connect Ukraine with*



*Bulgaria, Georgia, and Turkey. Besides, the article describes some peculiarities of the loading and transportation of passenger trains by train ferries. The study deals with structural peculiarities, and processing technology used for modern train ferries operating across the Black Sea, the Caspian Sea and the Baltic Sea. The research is based on the analysis of works by Egorov (the Marine Engineering Bureau, Ukraine). The research emphasizes the importance of train ferry transportation for the sustainable development of national economies including the economy of Ukraine.*

**Keywords:** *train ferry; combined transportation; combined transport; marine transportation; rail ferry route*

## **Introduction.**

The rapid development of economic relations between European countries has required reforms in the transport industry. And one of the most effective solutions in this area is the formation of combined transport systems. The maritime countries are integrated into the international transportation system through their train ferry routes serviced by specially equipped vessels – train ferries – which can transfer rail cars by sea. This type of transportation has a great number of significant advantages over the other types of combined transport, among which are

- the shorter delivery way from consigner to consignee, which can reduce the relative transportation cost;
- no necessity to transship the freight;
- less damage and fewer losses of the freight; and
- faster delivery from consigner to the consignee.

The map of train ferry routes has constantly expanded. Modern train ferries with innovative structures and processing technologies have been put into operation. The higher efficiency of this combined transportation can improve the national economy of any maritime country.

The historical development of the most important train ferry routes were analyzed in studies by Sotnikov (1993, p. 84–92). However, the author focused on the geographic features of these routes. Zemlezin (1970, p. 4–12) and Shmakov (1975, p. 87–94) considered the issue of the technical adjustment of rail cars to transportation by train ferries, and described the dynamics of rail cars during marine transportation. In his work Sukolenov et al. (1989, p. 25-34) studied the processing technology for train ferries.

Tolstov studied the peculiarities of construction and operation of the train ferry route across Lake Baikal. He also analyzed the structure and processing technology of the train ferry *Baikal*. However the author did not describe the other train ferry routes across the lake (Tolstov, 2001).

The development strategy of the railway transport system in the West African Economic and Monetary Union (WAEMU) was studied on the basis of the SWOT/AHP technique by Bouraima (Bouraima, Qiu, Yusupov, & Ndjegwes, 2020). According to the results of the research the authors suggested the strategies for the regional

integration and trade which can balance the national and regional development. However they did not analyze the impact of the already existing train ferry transportation routes on the development strategy of West African countries.

The prospects of development of Silk Road were studied by Gondauri & Moistsrapishvili (2019). The authors described the background for the development of this route and its strategic significance for Georgia, Azerbaijan, Kazakhstan, and other countries. But the study only focused on one train ferry route.

Economic evaluation of train ferry transportation at the example of the Land Ferry system was conducted in the study (Merrill, Paz, Molano, Shrestha, Maheshwari, Haroon, & Hanns de la Fuente-Mella, 2016). The authors substantiated the advantages of this combined transportation over other transport facilities. It should be noted that the historical background for this route was not described in the study.

The studies (Fomin & Lovska, 2020) and (Parkhomenko, Viznyak, Skurikhin, & Eiduks, 2020) described the peculiarities of construction and operation of train ferry routes. However the studies mostly highlighted European routes and did not analyze the historical background of their construction.

The historical aspects and the development concept of train ferry routes across the Baltic Sea in the increasing regional competition were described by Mańkowska (2015). However, the author researched only transportation of passenger trains by ferries in the Baltic Sea.

The operation features of train ferry routes were presented in the study (Tanko & Burke, 2017). The authors researched the most popular international routes. However, they did not consider the background of their construction and development prospects.

The development of Swedish ferry routes was studied (Tanko, Burke, & Cheemakurthy, 2018). In their work the authors made the comparative analysis of the prospects of development and the advantages of ferry routes in Sweden and Australia. However the historical background for their construction was not presented.

The system analysis study into the development of transport-and-technological systems of train ferries was made by (Kazymyrenko, Drozd, Yeholnikov, & Morozova, 2020). In their research the authors analyzed the advantages of train ferry transportation and its development prospects. The prospects and the advantages of combined marine transportation were also described in (Bínová, Březina & Mráček, 2018) at the example of the routes linking European countries and China. However the historical aspects of the development of train ferry transportation were not given.

The analysis of the literature presented above makes it possible to conclude that nowadays it is important to analyze and systematize the data on the historical development of the main train ferry routes, as well as the development of train ferries operating on these routes.

Therefore, the purpose of the article is to describe the main tendencies of development and operation of train ferry transportation. In order to achieve the purpose the following tasks were set:

- to study the background for the development of train ferry transportation;

- to study the peculiarities of the development of train ferry transportation in the world; and
- to study the features of development of train ferry transportation in Ukraine.

### **Research methods.**

The basic method used in the research into the historical aspects of construction and operation of train ferry transportation is the historical approach. The research includes the analysis of periodical and historical literature which covers the issues of construction, development and operational prospects of train ferry transportation.

### **Results and discussion.**

The world first train ferry service was launched in 1851; it operated across the Firth of Forth from Granton and Burntisland (Sotnikov, 1993, p. 84).

In Germany the first train ferry service was put into operation in 1882; the 25-km route linked Stralsund and Altefähr.

In 1905 Italy started a train ferry service across the Strait of Messina. It was an 8-km route with ten ferries in operation. The distance between the ports Villa San Giovanni and Messina was covered in 40 min.

Later on, in 1961, a train ferry route across the Tyrrhenian Sea was launched; it connected mainland Europe and the Island of Sardinia (Sotnikov, 1993, p. 85).

In 1983 Italy built the double-deck ferry *Garibaldi* to link the mainland and the Island of Sardinia. Apart from rail cars it transported wheeled equipment. It also had some passenger rooms. Rail cars and wheeled equipment were rolled on through the stern doors equipped with the ramp. The ferry had two elevators that could simultaneously lift 40-ton rail cars to the upper deck or the hold in 30 seconds. The rail cars were distributed on the hold width with a special platform moving along the transverse axis of the ferry.

The ferry was also equipped with a 25-ton crane for elevating 24 containers to the upper deck. The displacement length of the ferry was 137.8 m, the breadth – 18.9 m, the draft – 5.7 m, and the capacity – 80 rail cars. The ferry speed was 20.3 knots (Sudostroenie, 1983).

In 1909 a train ferry service started between Sassnitz (Germany) and Trelleborg (Sweden). The route was serviced by the ferries *Rügen*, *Rostock*, *Trelleborg* and others (Sotnikov, 1993, p. 85).

The ferry *Rügen* was built in 1972; it could place 37 freight cars. The automobile deck accommodated 12 freight cars or 73 passenger cars. The ferry speed was 20.3 knots (Sotnikov, 1993, p. 85; Serova, 1988). The rail cars were rolled on/off horizontally through the stern ramp. The ferry was equipped with stabilization devices against sea disturbance (Sudostroenie, 1973).

The ferry *Rostock*, built in 1977, could transport 49 freight cars located on its five tracks. The capacity of the motorcar deck was 21 vehicles. The ferry speed was 20.5 knots (Sotnikov, 1993, p. 85; Serova, 1988).

The ferry *Trelleborg* was put into operation in 1982 and it had five tracks for rail cars. The full ferry length was 170.1 m and the breadth – 22.5 m. Its speed was 19 knots. The total length of the tracks amounted to about 700 m. The ferry could accommodate 55 rail cars. It could also transport 800 passengers. The train ferry *Gotland* (Sweden) also had five rail tracks (Serova, 1988).

In 1959 the ferry *Saßnits* was built. Its length was 137.5 m, the breadth along the fender bar – 18.8 m. The four tracks on the deck of the total length 380 m could accommodate 30 freight cars. The ferry speed was 12 knots (Serova, 1988).

The ferry *Sea Wind* (former name *Saga Wind* built in 1972), re-equipped by Blohm & Voss, German shipbuilding and engineering company, was put into operation from Stockholm (Sweden) to Turku (Finland). The ferry transported rail cars located on the main deck, trucks and automobiles on the upper and boat decks; it also carried passengers. The ferry was equipped with devices for rolling on wheeled equipment. Among them were a stern hydraulic ramp and an inter-deck ramp located on the left side, which connected the upper and boat decks, and a stem gangway on the right side for light vehicles. The ferry length was 154 m, the breadth – 21 m, and the draft – 5 m (Sudostroenie, 1990).

In 1920 the shipbuilding company Bell began to build special ships to transport bulky cargo, including rail cars, by sea.

Thus, the ship *Bell Vu* transported 22 cars for an electrified railway and two steel barges from England to Buenos Aires. Each wagon weighed 37 tons. In order to save space, the eight cars were located above the barges on the special wooden platforms at a height of 12 feet thoroughly adjusted for the barges, well in advance before they were loaded on the ship.

One of the ships, *Beldjan*, transported simultaneously 24 rail cars for the underground railway, 20 locomotives, 2 small river tow-boats and engine barges with a length of up to 27 m and mass of 100 tons each. The rail cars were located in two levels (behind the mid-ship superstructure). The height of this construction was the same as the height of the bridge. The upper row of the rail cars was mounted on the special metal frame. Besides, some types of heavy freight cargo were accommodated in the hold; that managed to compensate the elevated center of gravity (Morskoj flot, 1943).

In 1923 in order to transfer the steam ships of the series  $E^{Sch}$  and  $E^{Schg}$  from Sweden and Germany to Russia across the Baltic Sea, a ferry service was launched (Lomonosov, 1923, p. 34–45).

The ferry service between Great Britain and mainland Europe has been in operation since 1924. And the first line across the strait was from Harwich (Great Britain) to Zeebrugge (Belgium). The ferry service with France has been in operation since 1936. In 1967 the second ferry service from Harwich (Great Britain) and Dunkirk (France) was launched. It was closed due to construction of the English Channel Tunnel (Sotnikov, 1993, p. 86).



The ferry service from Hirtshals (Denmark) to Kristiansand (Norway) was launched in 1958 with the ferry *Skagen*. Its length was 80.9 m, the breadth – 13.8 m and the speed – 18 knots. The journey time was 4 hours (Vinogradov, 1960, p. 12–18). The ferry could carry 7 rail cars placed on a 69-m track, 40 automobiles, and 600 passengers.

Later on, Germany built the train-motor-passenger-electric ferry *Teodor Heus*. It was intended for service in ice conditions. The ferry had three tracks for 30 rail cars. The middle deck could accommodate 100 automobiles. The passenger capacity of the ferry was 600 passengers with their luggage. The maximum length of the ferry was 135.9 m, the breadth – 17.7 m, the hull height – 7.35 m, the draft – 4.79 m at the water displacement 6438 tons, the traffic speed – 16.6 knots (Vinogradov, 1960, p. 18–21).

The ferry service between Travemünde (Germany) and Hanko (Finland) was put into operation in 1975. A three-deck ferry intended for transportation of 65 rail cars was in the service. In 1979 the ferry length was extended, thus, its capacity was increased by 30%. And in 1984 the route was supplied with another ferry (Sotnikov, 1993, p. 86).

Ferry transportation was also introduced in America. The loaded freight cars were transported by the tugboats *Dalzell* and *Transfer* (Vinogradov, 1960, p. 21). The tugboats transferred rail cars from station to station along the river Hudson, and also to New Haven. Two ferries loaded with 20 rail cars each were simultaneously towed.

An 18-km route in the Strait of Georgia was serviced by two ferries. They transported both passengers and freight. The journey time was 55 min. One ferry was in operation between Matane and Baie-Comeau (45 km). It transported freight cars. The journey time was 2 hours (Serova, 1988).

In 1964 the longest ferry service in the Pacific Ocean region was introduced between Canada and Alaska (over 2000 km). Double-deck ferries were in service on the route.

The ports Goose Bay and Lewisport in the Atlantic Ocean were linked by a 615 km ferry service. The journey time was 30 hours. The ports Sydney and Port aux Basque were also linked by ferry service. Its length was 164 km. The journey time was 6 hours. The length of the ferry service from Cape Tormentine to Port Borden was 14 km. The ferry transported passengers and freight. The journey time was 2 hours (Serova, 1988).

Japan operated ferry service between the islands Honshu, Hokkaido, Shikoku and Kyushu. The ferry route between Hakodate (Hokkaido) and Aomori (Honshu) was 103.7 km, between Tamano (Honshu) and Takomatsu (Shikoku) was 17 km, between Niigata and Oarai was 34.8 km, and between Simonesi (Honshu) and Moji (Kyushu) was 3.4 km (Vinogradov, 1960, p. 22).

The route from Somory to Hakodate was serviced by a passenger ferry that could accommodate 1200 passengers and 19 rail cars, and a freight/passenger ferry that was intended for 300 passengers and 45 rail cars.

In 1962 the rolling stock units from Baku to the northern coast of the Caspian Sea were transported in accordance with the working project on the re-equipment of the seaborne barge *Ishimbay*. It was a dry-cargo one-deck non-self-propelled double-bottom barge intended for transportation of containers, timber, cotton and grain both in rooms and on the deck (Karakashly, Shklyaruk, 1965).

It had 16 rail tracks on the specially designed platforms for the rolling stock units. They were located on the main deck above the hatch covers across the width and were perpendicular to the centerline plane. The platform length was chosen according to the largest dimension of a rolling stock unit with consideration of rolling-on/off from the left side. The vehicles were rolled on from the head to the stern. The rail tracks of the ferry were joined to the port tracks with pads and screws. The first vehicle was rolled on the stem track with a diesel locomotive and a buffer wagon. There were two variants to fasten a rolling stock unit on the barge deck. The first one supposed the chain binders of a 17-mm chain gauge with a special spring turnbuckle damping dynamic jerks from sea disturbance. The binders were fixed with brackets to the special eye plates welded to the frames of rolling stock units, decks, and hatch covers on the barge.

The second variant provided for application of the rigid buckles made of fabricated wagon buckles intended for 30 tons. Wooden wedges were used as supports hammered between the wheel bogie and the frame.

Due to lack of time the second variant was chosen as less labor-intensive in production.

The deck of the barge *Ishimbay* turned out to be reliable and efficient for transportation.

The shipment across the Caspian Sea was conducted by the ferry *Soviet Azerbaijan* manufactured by the shipyard Krasnoye Sormovo (Figure 1).



**Figure 1.** Train ferry *Soviet Azerbaijan* (Forum rechnyh puteshestvennikov, 2009).

The ports Baku and Krasnovodsk (160 miles) were connected by the ferries *Soviet Azerbaijan* and *Hamid Sultanov* built from 1962 to 1968 (Kuzovkin, 1984). The journey time was 12 hours with 3-hour stops in the destination ports (Ershov, 1978).

All rail cars were located on one deck. The ferry length was 133.8 m, the width along the fender bar – 18.32 m, and the maximum draft – 4.4 m. The ferry could accommodate about 30 rail cars (Rachkov, 1960).

Later on the train ferries *Soviet Dagestan* (see Figure 2 (Nash Baku, n. d.)), *Soviet Tajikistan* (see Figure 3 (Henderson, 2020)) and *Soviet Kalmykia* were built in Yugoslavia by the shipbuilding company Uljanik for servicing the route between Baku and Krasnovodsk. The ferries had a closed rail car deck along the whole length with tracks for rail cars and the hold for the light vehicles. The rolling-on/off was conducted across the head water-proof doors. The lower deck had a ramp for rolling cars into the hold.

The ferry length was 154.4 m, the fender bar width – 18.3 m, the maximum draft – 4.5 m, and the speed – of 17 knots. The ferry could accommodate about 30 wagons (Frik, 1985).

The wagons were fastened on the decks with the chain binders through the deck eye plates and the wagon frame, and by means of the tension mechanical device Speed Lash with a link length of about 2.5 m and the operating tension 80 kN. Similar devices were used for automobiles and trailers. The automobiles were fastened with soft lashing ropes and deck eye plates with braking strength of 12 kN. The stem part of the lower deck was equipped with four end buffers with a SA-3 automatic coupler. The cars were maintained on the brake by the compressed air system connected to them (Kirsanov, 1985). The impact of the sea disturbance was moderated with the active disturbance control system equipped with the side steering wheels. The system decreased the disturbance amplitude from 19° to 4° at the speed 17 knots and sea disturbance of 7 points (Kuzovkin, 1984).

Such ferries operated on the ferry route from Baku to Aktau and were introduced in 1985 (Kargin, 1986).



**Figure 2.** Train ferry *Soviet Dagestan* (Nash Baku, n. d.).





**Figure 3.** Train ferry *Soviet Tajikistan* (Henderson, 2020).

The ferries *Soviet Kazakhstan* and *Soviet Turkmenistan* were built to link Krasnovodsk and Bekdash (Kargin, 1988). The journey time was 9 hours.

With time the number of ferries across the Caspian Sea totaled thirteen (Zorin, 1988). Among them were *Soviet Nakhchivan*, *Soviet Kirgizia*, *Soviet Uzbekistan* and others.

Besides, the ferry *Mercuri-2* operated across the Caspian Sea (see Figure 4 (Korabli vsekh vremen i narodov, 2016, January 26)). But in 2002, due to the loss of stability of the tank cars on its deck, it sank. It carried 16 tank cars with petroleum products, one car with consumer goods, 8 passengers and 42 crew members. The tank wagons fetched away from the fasteners due to the wave impact and slipped to the slope side; thus, it capsized (Kasumova, 2002).

In 2008 the train ferry *Akademik Zarifa Aliyeva* was put into operation (Figure 5 (Korabli vsekh vremen i narodov, 2017)). It was built by the shipbuilding company Uljanik (Croatia). The ferry length was 154.5 m, the breadth – 17.5 m, the capacity – 52 wagons (Korabli vsekh vremen i narodov, 2017).



**Figure 4.** Train ferry *Mercuri-2* (Korabli vsekh vremen i narodov, 2016, January 26).



**Figure 5.** Train ferry *Academic Zarifa Alieva* (Korabli vsekh vremen i narodov, 2017).

The innovative technologies of that time were used to allocate rail cars on the ferry. The ferry was equipped with special devices and elevators (Korabli vsekh vremen i narodov, 2017).

The shipbuilding company Uljanik also built the train ferries *Makhachkala-4* for operation across the Caspian Sea from Makhachkala to Aktau or Turkmenbashi (see Figure 6 (Korabli vsekh vremen i narodov, 2017)). The ferry length was 154.5 m, the breadth – 18.3 m, the draft – 4.67 m, and the capacity – 52 rail cars. The ferry speed was 14 knots (Informacionnoe agentstvo REGNUM, 2005). It could transport up to 52 rail cars (Gadzhiev, 2005).



**Figure 6.** Train ferry *Makhachkala-4* (Korabli vsekh vremen i narodov, 2017).

The Vanino–Kholmsk train ferry service connected mainland Russia and Sakhalin Island. It was launched in 1973. The rail cars were carried by the ferry icebreaker *Sakhalin* (Figure 7 (Starinova & Shcherbakov, 2018)). The ferry length was 127 m, the breadth – 19.8 m, the draft – 6.2 m, and the speed – 18 knots. The ferry had a rail car

(main) deck with four rail tracks for rolling stock vehicles. The cars were located by batch on two middle and two side tracks.



**Figure 7.** Train ferry *Sakhalin* (Starinova & Shcherbakov, 2018).

The loading/unloading operations were conducted across the ramp rested on the stern step of the deck. The rail cars were loaded with locomotives on two tracks simultaneously, and automobiles were rolled on with their own power (Rachkov, Bubnov, Evstifeev, 1972). At present there exist a great number of such ferries.

Port Borden (Prince Edward Island) and Cape Tormentine (New Brunswick) in Canada were connected with an ice-breaking train ferry. The ferry length was 106 m, the breadth – 18.6 m, the draft – 5.8, and the speed – 16.5 knots. The ferry could accommodate 19 freight cars, 60 automobiles, and 900 passengers (Killesso, 1945).

The diesel ferry *Malmohus* connected Copenhagen and Malmo. The ferry length was 94.1 m, the breadth – 16 m, the draft – 4.1 m, and the speed – 17 knots. It was intended for simultaneous transportation of 3100 passengers and freight cars (Killesso, 1945).

Poland also began to develop ferry transportation. Thus, after WWII the train ferry service was launched between Świnoujście and Sweden with only one ferry. In 1953 the ferry service suspended for some period. And in the mid-1960s it was resumed with passenger-automobile ferries.

The ferry route from Świnoujście to Ystad was serviced by the ferries *Nikolaus Copernicus* and *Johannes Hevelius* manufactured in Norway in 1973 and 1975, respectively. The train ferries transported rail cars and trucks. They make several runs per day by necessity (Wojewódka, 1979).

In October 1986 the ferry service between Klaipeda (USSR) and Mukran (GDR) was introduced. The 540-km route was serviced by the train ferries *Klaipeda* and *Mukran* (Figure 8 (Korabli vsekh vremen i narodov, 2016, February 02)). The ferry length was 190 m and the breadth – 28 m. The ferry speed was 16 knots (Morskoj flot, 1987).



They were double-deckers and could transport 103 rail cars. For the first time, the revolutionary loading/unloading technology of that period was used for the route. With its two decks, the ferry joined a 45-m suspension double-deck ramp.



**Figure 8.** Train ferry *Mukran* (Korabli vseh vremen i narodov, 2016, February 02).

The ramp was the front part of a 175-m platform. Each level had five rail tracks similar to those on the decks. Two decks cannot be loaded simultaneously as it could cause loss of stability.

The speed of the locomotive used for loading/unloading operations was 1 m/sec.

An automated anti-tilting system was used for maintaining stability within a range of  $3^0$  during freight operations (Shishin, 1986).

In 1989 the new Ro-Ro/Rail/Passenger ferry *Kaunas* was put into operation (Figure 9 (Informacionnoe agentstvo QIRIM HABER AJANSI, 2017)). The vessel was supervised by the Lloyd's shipping registry. The full length of the ferry was over 190 m and the breadth – 28 m. Two freight decks could simultaneously accommodate 49 universal rail cars and 50 heavyweight trucks TIR (Informacionnoe agentstvo QIRIM HABER AJANSI, 2017).



**Figure 9.** Train ferry *Kaunas* (Informacionnoe agentstvo QIRIM HABER AJANSI, 2017).



In 2006 the ferry service between Ust-Luga and Baltiysk was put into operation. It was serviced by the train ferry *Baltiysk* (Figure 10 (Korabli vsekh vremen i narodov, 2015)). The ferry length was 187.36 m and the breadth – 22 m. The total length of the rail tracks was 1943 m. The capacity of the ferry was 135 rail cars (the length of couplers' axles was 12,020 m) or 92 rail cars (the length of couplers' axles was 16,970 m). Besides, the ferry could carry 76 automobiles on the open upper deck. The ferry speed was 18.5 knots.

The ferry had three freight decks with five rail tracks each. The loading of the middle deck was conducted through the stern doors. Rail cars and wheeled equipment were lifted up and put on the upper and bottom decks with a double-deck elevator with a freight capacity of 94 tons. The upper and lower elevator's platforms had freight areas of the length 28 m with clamping grips for the car wheels and holes to fix lashing ropes.

The cars were transferred on the decks with rotating hands installed in the stem part of the upper and bottom decks. The ferry was also equipped with seven shipboard trailers.



**Figure 10.** Train ferry *Baltiysk* (Korabli vsekh vremen i narodov, 2015).

The rolling-on/off of the freight in ports without dock ramps was conducted with special removable ramps mounted on the stern area with special holes for lashing ropes of hydraulic winches on the middle deck on the left and on the right. A set of removable ramps could be stored in ports or on ferries (Egorov, Kuzmin, & Ilitskij, 2006; Kuzmin & Egorov, 2006).

Later on the ferries *Ambal* (Figure 11 (Sudostroenie.info, 2020) and *Petersburg* (Figure 12 (Novyj Kaliningrad, 2017)) were put into operation on the route.



**Figure 11.** Train ferry *Ambal* (Sudostroenie.info, 2020).



**Figure 12.** Train ferry *Peterburg* (Novyj Kaliningrad, 2017).

The ferry services from Romania to Turkey and from Romania to Georgia, which shortened the distance by 340 km and 1075 km respectively, used the three-deck ferries *Mangalia* and *Eforie* belonging to the state-owned freight railway business of Romania CFR Marfă. These ferries could carry 85 – 100 rail cars located on the deck's rail tracks with a distance of 1435 mm between the running edges of rail heads; the total length was 1680 m.

The ferries had a lift for transferring rail cars from the middle deck to the upper or bottom decks, and a deck crane of five rail tracks for fitting with the on-land rail track infrastructure. To transfer rail cars from one track to another the ferry decks were equipped with one movable platform on each deck. Besides, the ferry had a switching device for shunting operations.

The ferry service was launched across the Black Sea in the middle of the 20<sup>th</sup> century. In 1958 the European and Asian shores of Turkey across the Bosphorus Strait were connected between the ports Sirkeli and Haydar (Egorov, Ilitskij, & Chernikov, 2014).

In March 1955 the ferry service connected Ukrainian and Russian Republics of the former Soviet Union.

Two train ferry complexes between the stations Crimea and Caucasus were built to shorten a journey time of mass freight transportation between the republics. That train ferry service shortened the distance up to 1000 km, and relieved the Rostov railway junction.

Due to a short distance of about four kilometers, the ferry service across the Taman Bay was considered to be rather safe for the rolling stock units, despite the harsh climatic conditions in that region.

As far as Kerch has always been a cross-road of great merchant routes from Europe to Asia, from the Varangians to the Greeks and one of the Great Silk road, the Crimea-Caucasus train ferry service has always been an important link in the transport corridor connecting Ukraine with Russia, Kazakhstan, countries of Caucasus and Central Asia by means of the sea rail ferry routes in the Caspian Sea: from Makhachkala to Aktau and from Makhachkala to Turkmenbashi (Chikanovskij, 2004).

At first the route was serviced by four train diesel electric ferries: *Yuzhny* (Figure 13), *Eastern* (*Chulym* and *Nadym*, respectively (Proekt 723 (zheleznodorozhnye paromy, n. d.)), *Northern* and *Zapoliarny*. These ferries were intended for transportation of 16 freight cars.

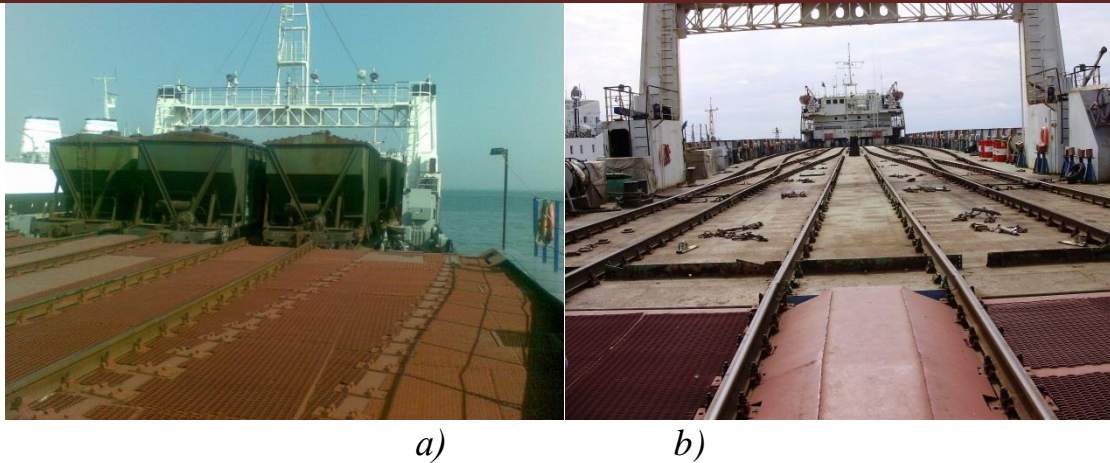


**Figure 13.** Diesel electric train ferry *Yuzhny* (Proekt 723 (zheleznodorozhnye paromy, n. d.)).

After the collapse of the Soviet Union in 1986, the volume of transportation via the route considerably decreased and later on it was closed. It was not until October 2004 that the ferry service was resumed due to the combined efforts of Ukraine and Russia (Egorov, 2007; Sudostroenie i sudoremont, 2004).

And now the ferry service is in operation with the one-deck ferries *Petrovsk* and *Annenkov* (Figure 14) with combined capacity of 25 rail cars.



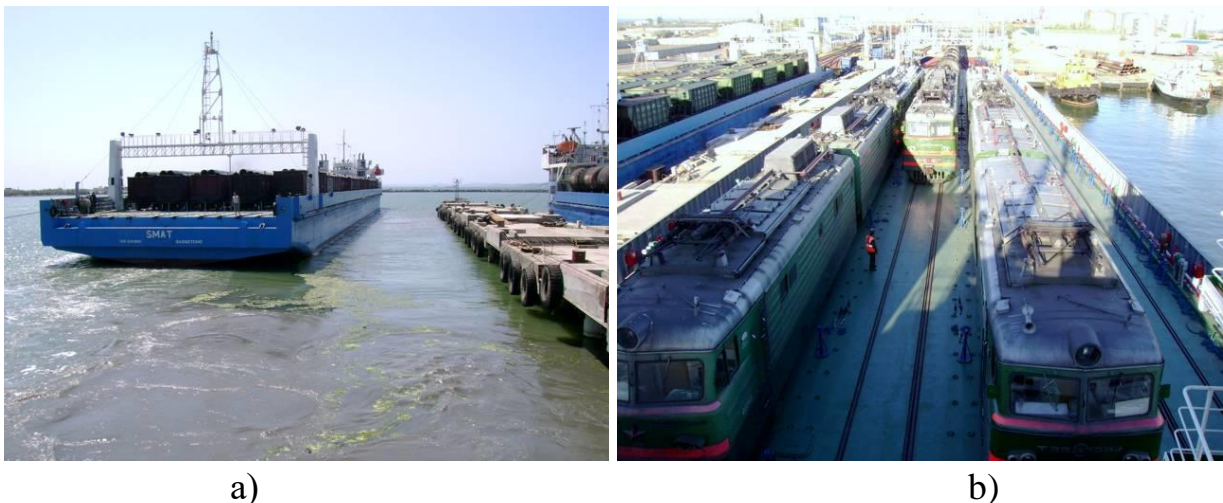


**Figure 14.** Train ferries on the Crimea – Caucasus route  
a) *Annenkov*; b) *Petrovsk* (author's photo).

The ferry decks have four rail tracks for location of rail cars. The ferry length is 110.5 m, the breadth – 16.0 m and the draft – 3.2 m. The speed of the train ferry is 10.0 knots (Nastavlenie po kreplenyu gruzu, 2005).

Due to a constant increase in the freight turnover during the recent years, there has been a need to increase the throughput capacity of ferry transportation. In 2007 the one-deck ferries *SMAT* and *FERUZ* (Figure 15 (Morskoe Inzhenernoe Byuro, Proekt CNF03.01, n.d.)) with the capacity 50 tank cars 1-T with five tracks on the ferry deck were built for the ferry routes Caucasus (Russia) – Samsun (Turkey) and Caucasus (Russia) – Poti (Georgia) (Egorov, Chistjakov, & Avtutov, 2007; Efremov & Egorov, 2007).

The special feature of the train ferry is rail tracks of the narrow and broad gauges on its deck.



**Figure 15.** Train ferry *SMAT*  
a) loaded with open cars (Morskoe Inzhenernoe Byuro, Proekt CNF03.01, n.d.); b) loaded with tractive rolling stock vehicles (Morskoe Inzhenernoe Byuro, Proekt CNF03.01, n.d.).



The ferry length is 150.32 m, the breadth – 22 m, and the draft – 3.8 m. The ferry speed is 10.0 knots (Efremov & Egorov, 2007).

On the basis of the analysis of positive results of the existing train ferry routes and due to the strategic targets, on the 23<sup>rd</sup> April 1975 the Soviet Union and Bulgaria signed a Treaty on organization of ferry service between the ports Illichivsk and Varna to be put into operation in 1978 (Nejding & Korotkij, 1978; Jovchev, 1984).

The port infrastructure for the ferry routes was built by the construction company Chernomorhydrostroy, and the rail infrastructure facilities were built by the construction company Odessatransstroy. One of the major features of the port Illichivsk was its advantageous position on the cross-road of main transport routes between Europe and Asia, North and South, Central and Eastern Europe, industrial regions of Russia and Ukraine, and naval communications via the Mediterranean Sea to the Atlantic and Indian Oceans (Fomin, Lovska, Píštěk, & Kučera, 2019), (Fomin, Lovska, Píštěk, & Kučera, 2020).

The following international transport corridors run via the port Illichivsk:

- TRACECA (the transport Corridor Europe – Caucasus – Asia);
- Crete corridor IX; and
- Baltic – the Black Sea transport corridor.

The ferry route was serviced by four train ferries: *Geroi Shipki* and *Geroi Plevny* from the Soviet Union and *Geroi Odessy* (author's photo) and *Geroi Sevastopolia* from Bulgaria, each could accommodate up to 108 cars 1–T, 0–T and 01–T (Figure 16 (Informacionnoe agentstvo Odessa media, 2017)). These ferries had 13 tracks for rail cars (five tracks on the upper and main decks each, and three tracks on the hold deck) (Vasil'ev, 1976).



**Figure 16.** Rail cars on the upper decks of the ferries

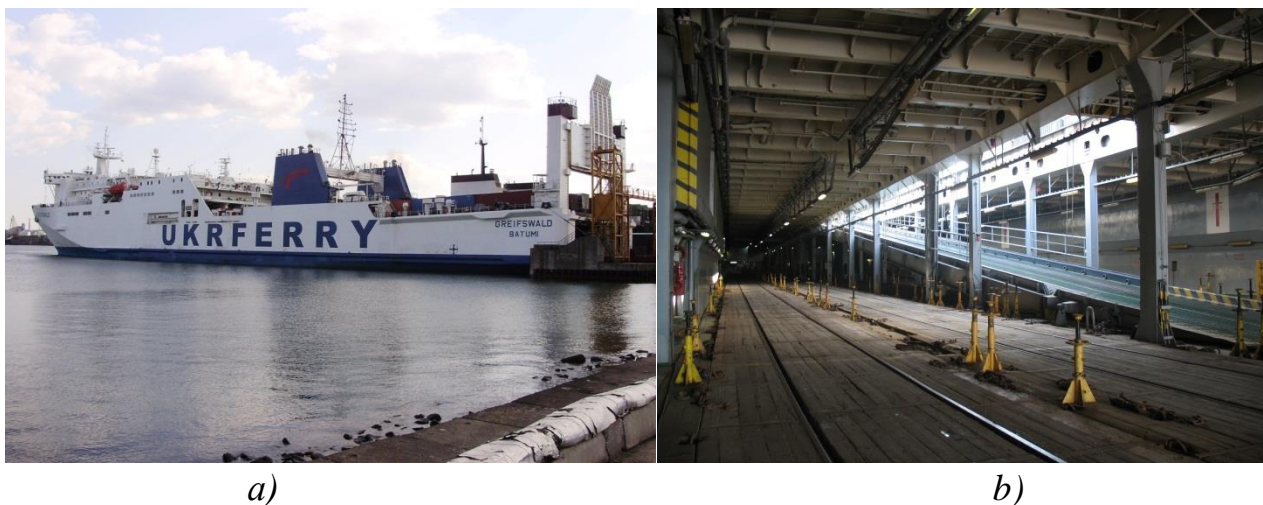
a) *Geroi Shipki* (author's photo); b) *Geroi Odessy* (Informacionnoe agentstvo Odessa media, 2017).

The ferry length is 184.5 m, the breadth – 26.49 m, and the draft – 6.5 m. The speed of the train ferry is 19.5 knots (Nastavlenie po krepleniju generalnyh gruzov pri morskoy perevozke dlja teplohoda “Geroi Plevny”, 1997).

The ferry routes Illichivsk – Poti (opened in 1994) and Illichivsk – Batumi (opened in 1996) are serviced by the Ro-Ro/passenger ferry *Greifswald* (Figure 17) supervised by the Lloyd’s shipping registry.

The ferry was built by VEB Mathias Thesen Werft in Wismar (Germany) in 1988 and it serviced the route Rostok (Germany) – Klaipeda (Lithuania).

The ferry length was 190.8 m, the breadth – 26.0 m, and the draft – 6.0 m. The speed of the train ferry was 16 knots (Cargo securing manual Transocean Line a/s ms “*Greifswald*”, 2001).



**Figure 17.** Train ferry *Greifswald*  
a) side view (author's photo); b) main deck (author's photo).

In 1996 the ferry was re-equipped and a passenger complex was added. The ferry had two freight decks that could accommodate 103 rail cars, but due to the structural features of the loading complexes in Illichivsk and Poti/Batumi, only 50 cars could be placed on the main deck. Besides, it could accommodate 50 heavyweight trailers on the deck, which was an advantage regarding bimodal transport, contrailer transport and other combined transport systems.

It should be noted that potentially the ferry could accommodate 103 rail cars, but as far as they could be accommodated only on the upper deck (due to the structural peculiarities of the loading complexes in Illichivsk and Poti), only 50 cars could virtually be loaded.

Since 2001 the ferry route Illichivsk (Ukraine) – Derince (Turkey) has been in operation with the ferries *Geroi Shipki* and *Geroi Plevny*.

Since 2013 the train ferry route between Ukraine and Georgia has been serviced by the ferry *Vilnius Seaways* (Figure 18), early operated across the Baltic Sea (Informacionnoe agentstvo Odessa media, 2017). Two freight decks could

simultaneously accommodate 50 universal rail cars and 50 heavyweight trucks. The ferry had rooms for 110 and seats for 24 passengers.

The ferry had the certificate of the Guinness World Records on being the biggest world passenger/Ro-Ro/railway ferry (Mihajlova, 2013).



**Figure 18.** Train ferry *Vilnius Seaways* (Informacionnoe agentstvo Odessa media, 2017).

In 2009 the group of companies AnRussTrans built the train ferries *Avangard* for 45 rail cars (Figure 19 (Klimenko, 2012)) and *Slavianin* for 50 rail cars (Figure 20 (Klimenko, 2012)) with accordance to the project of the Marine Engineering Bureau.



**Figure 19.** Train ferry *Avangard* (Klimenko, 2012).

The train ferry *Avangard* was intended for operation on the route Caucasus (Russia) – Varna (Bulgaria) – Samsun (Turkey) – Poti (Georgia). The ferry length was 133.67 m, the breadth – 22 m, and the draft – 4.8 m. The ferry speed was 12 knots.





**Figure 20.** Train ferry *Slavianin* (Klimenko, 2012).

The train ferries were intended for operation on the route Caucasus (Russia) – Varna (Bulgaria) – Samsun (Turkey) – Poti (Georgia).

The length of the train ferry *Avangard* was 133.67 m, the breadth – 22 m, and the draft – 4.8 m. The ferry speed was 12 knots.

The length of the train ferry *Slavyanin* was 149.95, the breadth – 22 m, and the draft – 4.5 m. The ferry speed was 12 knots.

In 2010 the train ferry *Ulfat* was built (Figure 21 (Korabli vsekh vremen i narodov, 2012)). The ferry could transport 45 rail cars and was intended for the Caucasus – Varna – Samsun – Poti route. The ferry length was 133.82 m, the breadth – 22 m, and the draft – 5.0 m. The speed of the train ferry was 12.0 knots (Egorov, Ilnitskij, & Chernikov, 2014).

Train ferries transported not only freight, but also passenger cars, thus they could offer seamless transportation for passengers which were accommodated in passenger rooms. And today this type of transportation is very popular. For example, the train ferries operating across the Baltic Sea can offer this service (Klochenko, 1988).



**Figure 21.** Train ferry *Ulfat* (Korabli vsekh vremen i narodov, 2012).

Formerly, passenger cars were placed on the deck by means of hoisting devices from the tracks of the ferry complex to the ferry's tracks. And now the cars are rolled through the ramp, which has considerably shortened the loading/unloading time.



Besides, train ferries became popular for river transportation. From 1896 to 1935 there was a ferry service across the Volga River near the town Saratov of the Ryazan-Ural Railway (Ivanchenko, & Platonov, 1943, p. 20) with the ferry *Saratovskaya Pereprava* (Figure 22 (Smorodin, 2013)). The ferry was built by the British manufacturing company Sir W. G. Armstrong Mitchel in 1896 (Volkov, 1977). The ferry had a hydraulic elevating mechanism for delivering cars from the ramp to the deck. During navigation seasons the ferry transported 160 cars per day, they were rolled on its deck. In winter seasons it transported 120 cars at shuttle service (28 cars per run).



**Figure 22.** Train ferry *Saratovska Pereprava* (Smorodin, 2013).

Later on the ferry *Pereprava Vtoraya* (Second) built in 1909 was put into service on the route (Figure 23 (Smorodin, 2013)). It was built at the Nizhny Novgorod Machine Factory. At the most advantageous navigation period the route traffic capacity was 200 rail cars. In 1926 the ferry *Stalin* was put into operation on the route.



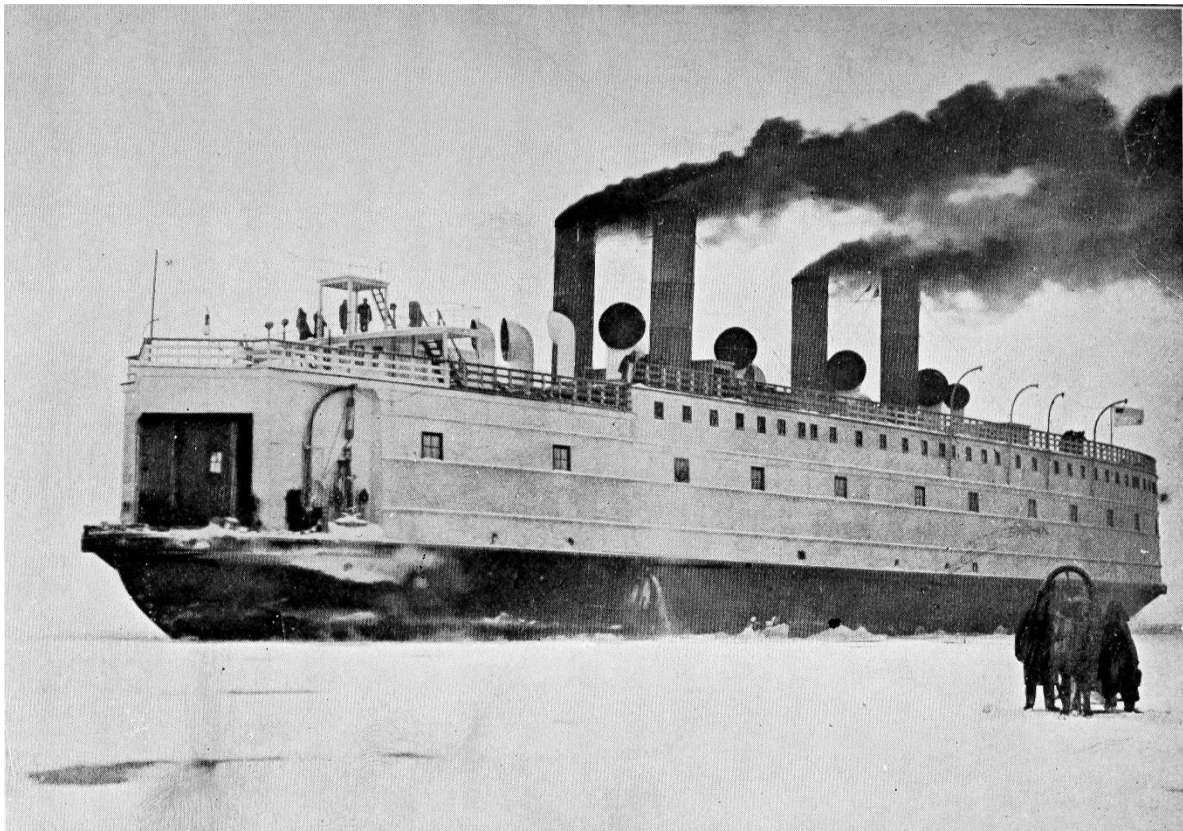
**Figure 23.** Train ferry *Pereprava Vtoraya* (Second) (Smorodin, 2013).

The route was also serviced by the ferry *Saratovsky Ledokol* to break ice and transport passengers and freight (Smorodin, 2013).

From 1903 to 1915 between the harbors Baikal and Tankhoy there was a ferry service across Lake Baikal on the Trans-Siberian route. The icebreaker ferry *Baikal* transported 27 rail cars. Its average speed was 18 km/h in summer and less than 11 km/h in winter. The ferry design was similar to that of the American icebreaker operating on Lake Michigan.

It was built in 1896 and had the biggest water displacement among the existing icebreakers at that time (Killeso, 1945).

The year 1918 saw the last voyage of the icebreaker *Baikal* (Figure 24 (Shoemaker, 1903, p. 99). By its decision the Irkutsk Rada organized the Red Baikal Fleet to fight against the counter-revolutionary movement. It was damaged by field artillery fire, burnt and sank during a battle (Tolstov, 2001).



**Figure 24.** Icebreaker ferry *Baikal* (Shoemaker, 1903, p. 99).

In the period from 1926 to 1936 there was a ferry service between the towns Gorky and Kotelnich. The ferry had a reinforced concrete body intended for breaking ice (Volkov, 1977).

Later, on the Komsomolsk–Pivan section across the Amur River a 7-km ferry service was put into operation with the train ferries *Volga* and *Don* (both built in 1951), and *Amur* and *Komsomolsk* (both built in 1951). They were river ferries with an open deck and a wagon hoist in the head section. The wagons were located in four lines and

lifted with an 80-ton device with a hoist height of up to 5 m. The wagons were transferred on the deck with trailer bogies, ropes and winch generators installed at the end of each track (Volkov, 1977).

In 1939 across the Danube River the cities Ruse and Giurgiu were connected with the ferry service for automobiles and rail cars. This route is now operable though it is not used (Telov, 2006, p. 10).

In 1941 during World War II there was a ferry route across the River Volga. A twin-hulled ferry transported rail cars. The wagons were rolled on simultaneously from two port tracks with a gradual transfer of the ferry along the dockside with two 5-ton wrenches installed in the dock at a distance of 100 m. The train ferry had 18 tracks and each could accommodate three double-axle or two four-axle rail cars, or a steam locomotive with a tender. The cars were rolled on through two suspension linkspans installed on the pier (Kupenskij, 1988).

In 1909 Norway had a train ferry across Lake Tinshe between Tinnuset and Mel. Its length was 28 km. The journey time was 1 hour 20 minutes.

Since 1964 Turkey has operated a train ferry between the ports Tatvan and Van. Its length was 90 km with two train ferries in service.

A train ferry operated between the ports Thunder Bay (Canada) and Superior (US) across Lake Superior. The route length was 285 km. The journey time was 14 hours (Serova, 1988).

There were two train ferry routes across Lake Michigan (US): Ludington – Kewaunee (105 km) and Ludington – Manitowoc (104 km). Each line operated one ferry; the journey time of each was 4 hours.

Since 1971 South American countries Peru and Bolivia have been connected with a ferry service across Lake Titicaca (Serova, 1988).

Since 1983 a ferry service has been in operation across Lake Victoria between Uganda and Tanzania in Africa. Its length was 400 km. In 1985 the line was supplied with two ferries. Their length was 92.13 m and the breadth – 16.5 m each. Each carried 22 freight cars and 5 containers. They could also carry passengers and freight.

Apart from Uganda, ferry transportation across Lake Victoria was carried by Tanzania and Kenya (Serova, 1988).

The research allowed systematizing the historical aspects regarding the construction of the biggest and most important train ferry routes. Unlike the studies by Sotnikov the authors conducted not only systematization and analysis of the geographical allocation of train ferry routes, but also investigation into the technical peculiarities of train ferries which serviced these routes (Sotnikov, 1993, p. 83-90). The authors considered both European train ferry routes and international ones (Fomin & Lovska, 2020) and (Parkhomenko, Viznyak, Skurikhin, & Eiduks, 2020), and defined the background of their construction. This was not covered in earlier publications, such as (Tanko & Burke, 2017), (Merrill, Paz, Molano, Shrestha, Maheshwari, Haroon, & Hanns de la Fuente-Mella, 2016). The authors studied both freight transportation and passenger transportation, which was not presented in the study (Mańkowska, 2015).



Therefore, this research presents the analysis of the historical background and efficient operation of train ferry routes (for transportation of freight and passengers) and proves the unique nature and importance of this type of combined transportation for development of national economies of the maritime countries.

### **Conclusions.**

The research deals with the background for the development of train ferry transportation. It was found that train ferry transportation is advantageous over other types of combined transportation. The first successful train ferry routes encouraged engineers to develop much longer seaways, and at present, there are train ferry routes that connect countries.

The authors studied the peculiarities of the development of train ferry transportation in different countries. Successful transportation across the Baltic Sea (at the example of one of the first train ferry routes between Stralsund and Alterfähr) encouraged the specialists to develop and expand the geography of such routes to other seas: the Caspian Sea, the Black Sea, the Azov Sea, the Japan Sea, the Mediterranean Sea, and some others. Besides, such type of combined transportation was used across lakes and rivers.

The study is concerned with the development of train ferry transportation in Ukraine. It deals with the historical background for the construction of the first train ferry route, and the development of train ferry routes between Ukraine and other countries of the Black Sea. The authors analyzed the technical peculiarities of train ferries and their processing technology.

The research proves the importance of train ferry transportation for the development of national economies (including Ukraine) in the modern world.

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### **Conflicts of interest.**

The authors declare no conflict of interest.

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## **Історичні аспекти створення та функціонування залізнично-поромних перевезень**

**Анотація.** Підвищення ефективності розвитку транспортної галузі викликає впровадження в експлуатації комбінованих систем транспорту. Однією з найбільш перспективних комбінацій в цьому напрямку виступають залізнично-поромні перевезення, які є результатом взаємодії залізничного та водного видів транспорту. У статті проведено аналіз та систематизацію даних щодо історичного розвитку залізнично-поромних маршрутів. Висвітлено

*передумови створення залізнично-поромних перевезень та їх переваги перед іншими видами комбінованого транспорту. Розглянуто основні особливості залізничних поромів, які обслуговують найвідоміші залізнично-поромні маршрути. Дослідження проведені не тільки стосовно морських акваторій, а також відносно річкових та озерних залізнично-поромних переправ. Розглянуто роль залізнично-поромних маршрутів у підвищенні економіки країн, а також їх використання у військово-стратегічних цілях, що відображено в працях Виноградова на прикладі Саратівської переправи, а також Каракашли та Шклярука – відносно ліхтера “Ішимбай” з поперечним завантаженням рухомого складу. Проаналізовано особливості розвитку залізнично-поромних маршрутів з використанням поромів-льодоколів, зокрема “Байкал”, який експлуатувався через озеро “Байкал”, а також типу “Сахалін”, що сполучав материкову частину Росії з островом “Сахалін”. Визначено особливості перевезень вагонів залізничними поромами закордоном, а саме: США, Японія, Азербайджан, Дагестан, Німеччина, Литва та ін. Проаналізовано особливості експлуатації українських залізничних поромів, які сполучають Україну з Болгарією, Грузією та Туреччиною. Висвітлено особливості завантаження та перевезень пасажирських вагонів на залізничних поромах. Визначено конструкційні особливості та технологію обробки сучасних залізничних поромів для Чорного, Каспійського та Балтійського морів. Дослідження проведені на підставі аналізу праць Єгорова Г. В. (Морське інженерне бюро, Україна). Проведені дослідження доводять важливість існування залізнично-поромних перевезень для розвитку економіки багатьох світових держав, у тому числі і України.*

**Ключові слова:** залізничний пором; комбіновані перевезення; комбінований транспорт; морські перевезення; залізнично-водне сполучення

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### **Исторические аспекты создания и функционирования железнодорожно-паромных перевозок**

**Аннотация.** *Повышение эффективности развития транспортной отрасли вызывает внедрение в эксплуатацию комбинированных систем*

транспорта. Одной из наиболее перспективных комбинаций в этом направлении выступают железнодорожно-паромные перевозки, которые являются результатом взаимодействия железнодорожного и водного видов транспорта. В статье проведен анализ и систематизация данных по историческому развитию железнодорожно-паромных маршрутов. Освещены предпосылки создания железнодорожно-паромных перевозок и их преимущества перед другими видами комбинированного транспорта. Рассмотрены основные особенности железнодорожных паромов, обслуживающих самые известные железнодорожно-паромные маршруты. Исследования проведены не только в отношении морских акваторий, а также относительно речных и озерных железнодорожно-паромных переправ. Рассмотрена роль железнодорожно-паромных маршрутов в повышении экономики стран, а также их использование в военно-стратегических целях, что отражено в трудах Виноградова на примере Саратовской переправы, а также Каракашлыи Шклярука – относительно лихтера “Ишимбай” с поперечным погрузкой подвижного состава. Проанализированы особенности развития железнодорожно-паромных маршрутов с использованием паромов-ледоколов, в частности “Байкал”, который эксплуатировался через озеро “Байкал”, а также типа “Сахалин”, соединявший материковую часть России с островом “Сахалин”. Определены особенности перевозок вагонов железнодорожными паромами зарубежом, а именно: США, Япония, Азербайджан, Дагестан, Германия, Литва и др. Проанализированы особенности эксплуатации украинских железнодорожных паромов, которые соединяют Украину с Болгарией, Грузией и Турцией. Освещены особенности погрузки и перевозок пассажирских вагонов на железнодорожных паромах. Определены конструкционные особенности и технология обработки современных железнодорожных паромов для Черного, Каспийского и Балтийского морей. Исследования проведены на основании анализа работ Егорова Г. В. (Морское инженерное бюро, Украина). Проведенные исследования доказывают важность существования железнодорожно-паромных перевозок для развития экономики многих мировых государств, в том числе и Украины.

**Ключевые слова:** железнодорожный паром; комбинированные перевозки; комбинированный транспорт; морские перевозки; железнодорожно-водное сообщение

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