Energy-efficient means of transporting oil products to Ukraine during martial law

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Abstract. Carrying out transportation of oil products, there is a danger of having a negative impact on the environment - a leak of liquid can create an environmental problem for a certain area. Transportation of oil-containing cargoes to Ukraine, during martial law, is carried out by multimodal transport, namely, road, sea and rail modes of transport.As of June 2023, there are 14 border railway stations connecting Ukraine with five countries: Poland, Slovakia, Hungary, Romania and Moldova. International railway transshipment stations were studied, which allow oil products to be transshipped into tankers for further customs clearance and transportation to warehouses, civilian or military recipients. The distance of the transportation path is not always decisive in the matter of energy saving. Environmental friendliness and energy consumption during the transportation of petroleum products are also affected by the topography of the road, the landscape of the area where the roads pass, and the traffic on the roads with other vehicles.

1 State of the issue

Comprehensive solutions to the tasks of transport planning, improving safety and reducing the negative impact of transport on the environment should be concentrated, first of all, in relation to large cities, resort zones and territories adjacent to international transport corridors in order to further spread the application of the most successful solutions in each of the regions [1].

Special environmental requirements are imposed on international transit corridors and international transshipment stations for the transportation of dangerous goods - the existing lack of information about the goods being transported is compensated by careful control of their movement. The transit policy of the country is being developed, taking into account the natural environment of the transportation area, which includes the use of reserves of the national transport system, the preparation and implementation of transport projects that belong to the complex with the actions of state and regional authorities regarding the improvement of the legislative and legal framework, tariff policy, innovative activities, investment climate will create favorable conditions for attracting transit passenger and cargo flows to the transport communications of our country. That is, environmental protection measures should be carried out simultaneously with technical, technological, organizational, legal and other measures regarding the formation and development of international transport systems in Ukraine.Основним завданням у процесі формування мультимодальної системи перевезення є комплексний розвиток усіх її підсистем та елементів [1].

From the point of view of the system approach, it is advisable to consider the multimodal cargo delivery system as a component subsystem of the country's transport and logistics system, which includes:
– a multimodal transport network (a network of various types of transport providing multimodal transportation);
– multimodal (international) transport corridors;
– objects of multimodal transport infrastructure (multimodal transport hubs).

A special place in the multimodal system is occupied by the objects of transport infrastructure, which ensure the performance of auxiliary technological operations (cargo operations, short-term storage, processing, etc.) in the process of transportation and must meet the following basic conditions:
– being at the intersection of several transport routes of various types of transport (road, rail, water, air, pipeline);
– the development of various types of transport in the territory of the formation of a multimodal transport hub;
– availability of powerful warehouse and terminal complexes for processing various types of cargo and cargo units, including containers;
– availability of customs infrastructure capable of providing customs support for cargo flows;
– availability of financial infrastructure (branches of banks, insurance companies) for providing insurance and financial services;
– the presence of a developed information infrastructure to provide information support and control of technological processes of cargo processing, etc. [1].

Multimodal nodes as constituent elements of a specific multimodal transport system differ significantly

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in terms of their importance, the level of concentration of freight flows, and the area of influence.

Oil products are one of the most demanded products in Ukraine today. The transportation process has many restrictions and requirements.

Carrying out the transportation of oil refining products, there is a danger of having a negative impact on the environment - a liquid leak can create an environmental problem for a certain area.

Transportation of oil-containing cargoes to Ukraine, during martial law, is carried out by multimodal transport, namely, road, sea and rail modes of transport.

Despite the naval blockade of Ukrainian ports, there is still the possibility of transporting oil products by tankers.

According to information from the navigation portals Vesselfinder and Marinetraffic, tankers with oil products are delivered from the port of Marmara Yereglisi to the Danube ports of Reni, Izmail and the seaport of Chornomorsk.

According to Ukrainian customs, 5.8 million tons of oil cargoes were imported into the country in the first ten months of 2022. Supplies from Marmara Ereglisi account for more than 12% of average monthly supplies, making this port the largest source of seaborne fuel for Ukraine. But there are great risks of cargo loss during a massive attack by missiles and drones on those tankers that have left neutral waters and are heading to unloading ports in Ukraine.

The railway is the most efficient option for the supply of fuel, from the point of view of energy consumption and environmental safety, but in Ukraine, the tracks are 1520 mm wide, in the EU countries - 1435 mm, so at the border wagons with fuel need to be moved from one pair of wheels to another, or overloaded of petroleum products into tank cars with pairs of wheels for a gauge of 1520 mm, which takes some time.

However, there is another problem - trains with oil and oil-containing cargoes are at customs clearance stations much longer than road transport, due to the larger volume of cargo.

In situations where speed and flexibility of decision-making are extremely important, combined transportation is used to speed up the delivery procedure.

The main regions and countries of export of oil and oil products are Central/Eastern Europe, Western Europe, North America, Central Asia, Central America, Austria, Canada, Finland, Ireland, Latvia, Portugal, Virgin Islands (Britain).

The provision of multimodality services is a modern trend in international transport logistics, actualizing further research into the methods of using multimodal transportation and the search for ways to develop transport and logistics systems of multimodal infrastructure.

Unfavorable trends associated with the use of the transport complex (TC) contribute to the search and development of new methods of minimizing the negative effects of transport on the environment and human health [2].

In addition, environmental issues are the most important in the complex of issues of the creation and functioning of TC: on the one hand, increasing the capacity of cargo transport increases anthropogenic pressure on the environment; on the other hand, the danger of some transported goods makes it necessary to take special measures to prevent their unauthorized distribution in the environment [2].

The main causes of an environmental incident can be:

– natural disasters that lead to depressurization of cargo containers (including dangerous cargo);
– violation of cargo transportation technology;
– terrorist acts aimed at seizing dangerous goods and using them for criminal purposes [3].

Decisions in the field of development of the transport system and regulation of transport activities should be evaluated both from the point of view of economic efficiency and from the point of view of road safety, minimizing the impact of transport on the environment, and the specified criteria are equivalent [3].

2 International transfer stations

Oil products are delivered to the border station with Ukraine in tank cars, then reloaded on the territory of the European Union into tank trucks, the customs clearance procedure is carried out and the cargo is transported to warehouses, civilian or military consignees.

As of June 2023, there are 14 border railway crossings connecting Ukraine with five countries: Poland, Slovakia, Hungary, Romania and Moldova.

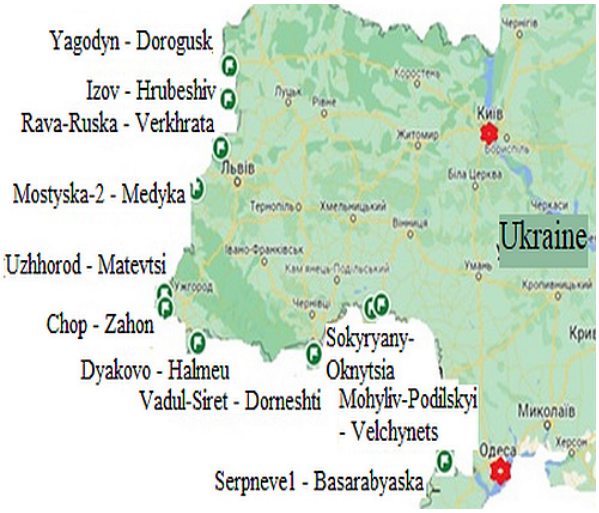

Fig. 1. Border transfer stations

We consider the international transfer stations indicated above to be the points of loading of petroleum products into road transport, and the final destination to be the cities of millions, namely Kyiv, Dnipro, Odesa, Kharkiv.

The largest number of transitions between Ukraine and Poland: there are 6 transfer stations, of which 4 are working. Car transfers are carried out at the Yagodyn - Dorogusk, Izov - Hrubeshiv, Mostyska-2 - Medyka and Rava-Ruska - Verkhrata crossings. In general, the volume of oil cargo transportation here increased by more than a third last year.

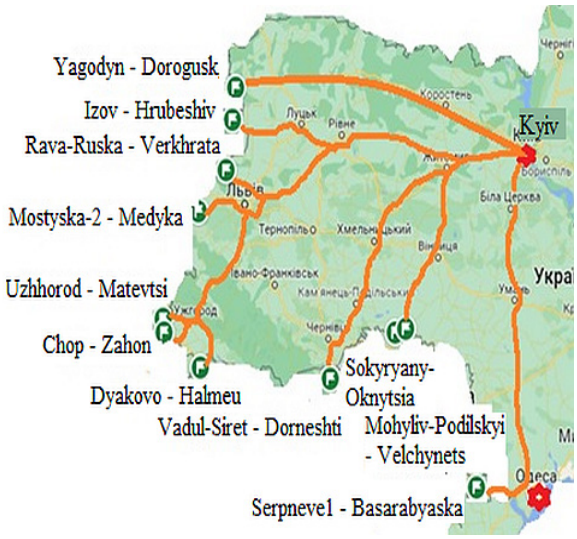

Fig. 2. Schemes of oil product transportation routes in the Kyiv city.

Table 1. Routes of transportation of petroleum products in the Kyiv city.

State of border crossing	Transportation route	Distance
Poland	Yagodin - Kyiv	511 km
	Verkhrata – Lviv – Zhytomyr – Kyiv	570 km
	Medyka - Rivne - Zhytomyr - Kyiv	580 km
	Hrubeshiv – Lutsk – Rivne – Zhytomyr – Kyiv	530 km
Slovakia	Matevtsi - Lviv - Rivne - Zhytomyr - Kyiv	820 km
Hungary	Zahon - Lviv - Rivne - Zhytomyr - Kyiv	816 km
Romania	Halmeu – Mukachevo – Lviv – Rivne – Zhytomyr – Kyiv	809 km
	Dorneshti - Khmelnytskyi - Zhytomyr - Kyiv	570 km
Moldova	Oknytsia - Vinnytsia - Zhytomyr - Kyiv	400 km
	Basarabyaska - Odesa - Uman - Kyiv	660 km

It should be noted that the Kovel-Khelm transition has great potential, in particular, on the 1435 mm track and provides the shortest transit to the ports of Lithuania, Latvia and Estonia from the central, northern and eastern parts of Ukraine along the general line Kyiv – Kovel – Yagodyn – Dorogusk – Lublin – Bialystok – Elk – Močkava – Šeštokai – Kaunas – Klaipeda. Further branches are possible even to a number of large and small ports in Latvia and Estonia.

The Ukrainian and Slovak railways are connected by two border crossings, namely Uzhhorod - Matevtsi (track 1520 mm) and Chop - Chierna nad Tisou (with tracks 1435/1520 mm), but this station has no road connection with the territory of Ukraine.

The Austrian company Rail Cargo Group has launched an intermodal connection between Kyiv, Lviv, Budapest and Vienna through the Chop – Zahon junction, the Ukrainian and Hungarian railways. Also in demand is the junction Batyovo – Epereshke, but this station, too, does not have an automobile connection with the territory of Ukraine.

Fig. 3. Schemes of oil product transportation routes in the Dnipro city.

Table 2. Oil product transportation routes in the Dnipro city.

State of border crossing	Transportation route	Distance
Poland	Yagodin - Kyiv - Reshetylivka - Dnipro	1020 km
	Verkhrata – Lviv – Ternopil – Khmelnytskyi – Vinnytsia – Kropivnytskyi – Oleksandria – Dnipro	990 km
	Medyka - Lviv - Ternopil - Khmelnytskyi - Vinnytsia - Kropivnytskyi - Oleksandria - Dnipro	1030 km
	Hrubeshiv – Ternopil – Khmelnytskyi – Vinnitsa – Kropivnytskyi – Oleksandria – Dnipro	1030 km
Slovakia	Matevtsi – Mukachevo – Ternopil – Khmelnytskyi – Vinnytsia – Kropivnytskyi – Oleksandria – Dnipro	1200 km
Hungary	Zahon – Mukachevo – Ternopil – Khmelnytskyi – Vinnytsia – Kropivnytskyi – Oleksandria – Dnipro	1180 km
Romania	Halmeu – Mukachevo – Ternopil – Khmelnytskyi – Vinnytsia – Kropivnytskyi – Oleksandria – Dnipro	1200 km
	Dorneshti - Chernivtsi - Khmelnytskyi - Vinnytsia - Kropivnytskyi - Oleksandria - Dnipro	930 km
Moldova	Oknytsia – Vinnytsia – Kropivnytskyi – Oleksandria – Dnipro	650 km
	Basarabyaska - Odesa - Mykolaiv - Kryvyi Rih - Dnipro	680 km

There are several railway crossings between Ukraine and Moldova: Berezyne – Basarabyaska, Serpneve-1 - Basarabyaska, due to their close location, they can be combined into one point, and Sokyryani – Oknytsia, Mohyliv-Podilskyi – Velchynets, also, due to their close location, they can be combined into one point in the further review of routes.

Between Ukraine and Romania, cargo delivery takes place at two junctions: Dyakovo – Halmeu and Vadul-Siret – Dorneshti.

Fig. 4. Schemes of oil product transportation routes in the Kharkiv city.

Table 3. Transportation routes of oil products in the Kharkiv city

State of border crossing	Transportation route	Distance
Poland	Yagodin - Kyiv - Kharkiv	1015 km
	Hrubeshiv – Lutsk – Rivne – Zhytomyr – Kyiv – Kharkiv	990 km
	Verkhrata – Lviv – Rivne – Zhytomyr – Kyiv – Kharkiv	1070 km
	Medyka - Lviv - Rivne - Zhytomyr - Kyiv - Kharkiv	1120 km
Slovakia	Matevtsi - Lviv - Rivne - Zhytomyr - Kyiv - Kharkiv	1310 km
Hungary	Zahon - Lviv - Rivne - Zhytomyr - Kyiv - Kharkiv	1320 km
Romania	Halmeu – Mukachevo – Lviv – Rivne – Zhytomyr – Kyiv – Kharkiv	1330 km
	Dorneshti - Khmelnytskyi - Zhytomyr - Kyiv - Kharkiv	1070 km
Moldova	Oknytsia – Uman – Kropivnytskyi – Kremenchuk – Poltava – Kharkiv	805 km
	Basarabyaska - Odesa - Mykolaiv - Kryvyi Rih - Dnipro - Kharkiv	910 km

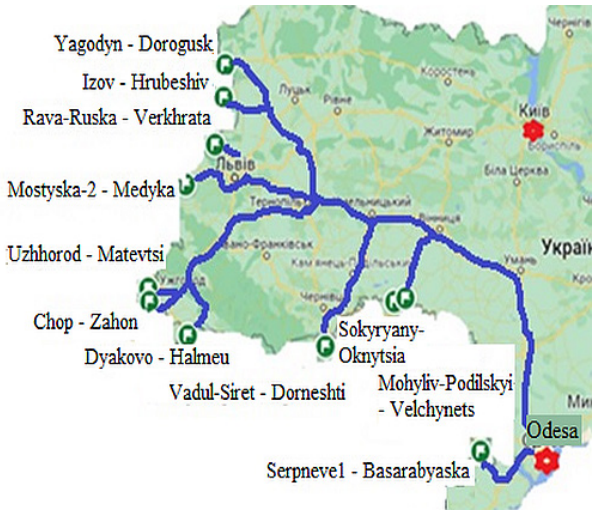

Fig. 5. Schemes of oil product transportation routes in Odesa city.

Table 4. Oil product transportation routes in Odesa city.

State of border crossing	Transportation route	Distance
Poland	Yagodin – Brody – Ternopil – Khmelnytskyi – Vinnytsia – Uman – Odesa	940 km
	Hrubeshiv – Brody – Ternopil – Khmelnytskyi – Vinnytsia – Uman – Odesa	890 km
	Verkhrata – Lviv – Ternopil – Khmelnytskyi – Vinnytsia – Uman – Odesa	850 km
	Medyka - Lviv - Ternopil - Khmelnytskyi - Vinnytsia - Uman - Odesa	880 km
Slovakia	Matevtsi - Mukachevo - Ternopil - Khmelnytskyi - Vinnytsia - Uman - Odesa	1060 km
Hungary	Zahon – Mukachevo – Ternopil – Khmelnytskyi – Vinnytsia – Uman – Odesa	1025 km
Romania	Halmeu – Mukachevo – Ternopil – Khmelnytskyi – Vinnytsia – Uman – Odesa	1015 km
	Dorneshti - Chernivtsi - Khmelnytskyi - Vinnytsia - Uman - Odesa	780 km
Moldova	Oknytsia – Vinnytsia – Uman – Odesa	580 km
	Basarabyaska - Sarata - Odesa	200 km

3 Factors of energy-efficient use of trucks when transporting petroleum products

The process of transportation of dangerous substances by road transport is strictly controlled and regulated at the legislative level by the "Law of Ukraine on the Transportation of Dangerous Goods", "Traffic Rules of Ukraine", "Agreement on the International Road Transportation of Dangerous Goods (DOPNV)".

The route of transportation of petroleum products should bypass densely populated places, nature reserves and recreation areas.

The shortest transportation path is not always the most energy efficient.

During the transportation of petroleum products, energy consumption is affected by many factors:
– technical condition of the car;
– road surface – asphalt, soil;
– topography of the area;
– quality of diesel fuel;
– engine power;
– driving style.

The last factor is of significant importance, since it is uniform movement that gives fuel savings. In city conditions, especially in traffic jams, it is quite difficult to move at a constant speed.

Reducing energy consumption also depends on engine speed, resistance and wheel friction. If certain driving conditions are observed, fuel consumption can be reduced by a third. The main algorithm of the lowest fuel consumption is provided for diesel engines under conditions where the optimal number of revolutions should not exceed 1500-2000 per minute. This is relevant for turbodiesel power units.

Depending on the make and model of the truck in the highest gear, the average most economical speed varies in the range of 75-90 km/h when driving on the highway.

Road and weather conditions are also factors that directly affect the amount of fuel consumed by a vehicle. The first include both the condition of the road surface and the density of traffic in urban or mixed modes of transportation. Overcoming mud or snow requires additional engine effort, automatically increasing fuel consumption.

The influence of weather conditions is especially noticeable at a time when high or low temperatures are established outside, which require turning on the climate control units. The heater and air conditioner put an additional load on the on-board network, taking part of the power.

A comparison of data from different sources shows that regular use of the air conditioner increases fuel consumption by approximately 15%.

The weight of the cargo being transported, the technical condition and the quality of the fuel have a serious effect on the economy of the engine.

Studying the issue of energy-efficient use is possible thanks to traffic simulation.

Many mathematical models have been created for the simulation of traffic flows, which allow to study various parameters of the movement of traffic flows, approaches to their management. In works [5, 6], for example, sufficiently thorough lists and descriptions of the main methods and ideas in the field of mathematical modeling of transport flows are given, the issues of modeling the loading of transport networks and the dynamics of transport flows are discussed.

There are several classifications of mathematical models of traffic flows. According to one of them [5], it is customary to divide models into three classes: analogue models, models of following the leader and probabilistic models, each of which implements one of two approaches - deterministic or stochastic.

The basis of deterministic models is the functional dependence between individual indicators.

In stochastic models, the transport flow is considered as a probabilistic process using the appropriate mathematical apparatus.

In probabilistic models, the transport flow is considered at the micro level as a result of the interaction (it has a stochastic nature) of individual vehicles on the elements of the transport network. Some models use the principles of cellular automata. And although models based on cellular automata are inferior in accuracy to time-continuous models, they are still able to reproduce a large number of traffic situations. Due to the simplicity of the models, they are numerically the most efficient and can be used to simulate large road networks in real time.

Modeling the movement of a car is the most effective and fastest means of studying characteristics and parameters in different driving conditions and with different changes in structural parameters. The main problem is, however, ensuring sufficient accuracy and adequacy to real movement processes, which necessitates experimental studies to assess the accuracy of the mathematical model and the results of calculations.

Taking into account that in the absolute majority of cases when moving at a constant speed, the car engine operates at partial load modes, the use of the external speed characteristic of the engine for the above-mentioned studies, generally accepted in the theory of the car, is unacceptable, as it will not ensure the reproduction of real processes and the necessary accuracy [6].

The second basic feature of the vehicle motion modeling structure is a fairly accurate fixation - calculation of the necessary power consumption (according to the traction moment at the determined most favorable gear in the transmission for a given speed of movement in various driving conditions, including on roads with deformed surfaces (dirt).

4 Conclusions

Forecasting and research of the process of energy-efficient transportation of oil products requires a comprehensive consideration of this issue, which includes:
– studying the ways of transportation;
– studying the road landscape;
– modeling of road conditions;
– study of the type and characteristics of cars;
– simulation of the movement of a car with specific petroleum products.

Based on the results of research, it is possible to establish fuel consumption depending on the transportation routes. After all, fuel consumption is a direct characteristic of CO_2 emissions and the energy efficiency of using a particular type of road transport.

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