# Efficiency of "Green" Logistics Technologies in Multimodal Transportation of Dangerous Goods

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# Prospects for the Use "Green" Logistics as a Safety Factor in Multimodal Transportation of Dangerous Goods

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**Abstract.** The improvement of the technology for performing international and domestic transportation of dangerous goods through the use of container and piggyback trains is considered. It has been established, that these technologies have significant advantages in terms of reducing the negative impact on the environment in comparison with the delivery of dangerous goods only by certain modes of transport. A brief feature of the main environmental characteristics of the routes of multimodal trains is given and assessed the negative impact of each type of transport separately and as part of a multimodal system on the environment. The ways of further development of "green" logistics as a safety factor in the transportation of dangerous goods in containers and contrailers are proposed.

## INTRODUCTION

The emergence of "green" logistics, as a concept for ecologically rationally designing and operation of logistics systems, refers to the methodology of sustainable economic development. According to experts, transport accounts for about 8% of all carbon pollution of atmospheric air on the planet, therefore, the introduction of "green" technologies in logistics activities will make it possible to take certain steps to preserve the climate on the planet. In this regard, research and development of technologies for multimodal transportation of dangerous goods are relevant [2].

Automobile transport, except affecting the atmospheric air, carries out contaminates soil, water resources, acoustic pollution of the environment and has a high probability of significant negative consequences as a result of road accidents during the transport of dangerous goods. Therefore, a strategic direction for the development of "green" logistics in the transport of dangerous goods is the refusal or reduction of the share of transport in favor of more environmentally rail transport.

## RELEVANCE

According to experts, transport accounts for 8% of all carbon dioxide emissions on the planet, storage facilities - another 3% [1]. In this regard, the widespread introduction of "green" technologies in logistics activities will make a significant contribution to the preservation of the climate on the planet, suitable for safe human life. Synonymous with the term "green" logistics experts call ecological logistics.

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The development of combined and multimodal transport provides for the creation of a unified system for the functioning of the transport system, in particular rail and road, which makes it possible to carry out transport services on a scheme "door-to-door" and "just-in-time". As a result, on the railways of many countries run piggyback, container trains and route container groups, as well as trains of combined transport.

The purpose of the article is a brief analysis of the state of container and piggyback transportation of dangerous goods, consideration of the advantages and disadvantages of operating various types of transport and their impact on environmental safety. The task "green" logistics to reduce the negative impact of transport on the environment is the integration of various modes of transport, the implementation of their interaction with minimal involvement of automobile transportation. Thus, it will be the task of organizing multimodal or intermodal transportation and the formation of promising multimodal transport chains.

## MAIN PART

If the main function of traditional logistics is the optimal management and coordination of all types of logistics flows in order to meet the needs of customers with minimal costs, then "green" logistics pays great attention to external costs associated with climate change, air, water and soil pollution, noise influence in in order to achieve a sustainable balance between economic performance, the environment and the requirements of society regarding safety standards. Container and piggyback transportation in comparison with traditional delivery methods is currently the most widespread technology, contributing to the development of "green" logistics.

Analyzing the above advantages of modes of transport, it can be noted, that none of them is universal. Each mode of transport is cost-effective and environmentally friendly only with certain characteristics of the dispatch. For rail and water transport are cost-effective bulk shipments over long distances. Automobile transportation is beneficial to use for the transportation of small consignments of cargo over relatively short distances, but its environmental performance raises certain questions.

Effective measures that will allow the development and strengthening of container and piggyback transportation of goods include:

- improvement of legislative acts on multimodal transport and combined transport, will become a prerequisite for the creation of a modern regulatory framework for the transport of dangerous goods, harmonized with the EU regulatory framework;
- further development of the network of logistics centers in terms of replenishment and renewal of specialized rolling stock for dangerous goods;
- differentiation of freight and passenger traffic in order to reduce transport risks;
- introduction of special environmental tariffs and financial and economic support from the state.

## METHOD

In the work systematizes the main regulatory instruments in the field of decarbonization of transport and logistics [4]. They are aimed at reducing greenhouse gas emissions into the atmosphere, increasing the practical significance of the concept of "green" logistics and allowing to form an organizational mechanism for implementing the principles of sustainable development in logistics activities. The role of railway, air and water transport in air pollution is insignificant. According to the State Statistics Service of Ukraine, emissions of pollutants into the air from road transport in 2018 amounted to 1,358.4 thousand tons, railway transport - 27.6 thousand tons, that is, the relative excess of emissions from automobile transport is 49 times [3]. Taking into account the level of cargo turnover in the research year (road transport - 42569.5 mln tkm, railway transport - 186344.1 mln tkm), without a large error, we can consider the specific average level of emissions of pollutants in the country into the atmosphere from road transport - 31.910 g/tkm, from railway transport - 0.148 g/tkm. Long-term studies of leading scientists in the world, the results of which were published by the Intergovernmental Commission on Climate Change in its report in 2018 (Figure 1), showed that in the period from 1970 to 2010, emissions of such modes of transport as road transport, international aviation, domestic aviation, international and coastal shipping are showing a steady upward trend [4].

Operators of multimodal transportation and operators of container and piggyback terminals are faced with the task of meeting the requirements for ensuring transport safety and environmental protection in terms of the implementation of an environmental management system in accordance with the international standard ISO 14001

(DSTU ISO 14001) “Environmental management systems. Requirements and guidance for use” [7]. This standard contains information and a system of measures for a specific plurality environmental aspect.

Railway transport enterprises are objects that have a negative impact on people in the form of physically dangerous and harmful factors. In addition, the activity of transport under the influence of hazardous and harmful chemical factors of dangerous goods leads to environmental pollution and increase cost on its restoration. Taking into account requirements, an environmental criterion for assessing transport risk is proposed in general form, calculated as the value of financial damage from the negative impact of the vehicle and its cargo on the environment [7]

$$B = P \cdot \left(B_a + B_w + B_l + B_{sa} + B_{fn} + B_{fl}\right), \tag{1}$$

where, $P$ – probability of an adverse event occurring during the transportation of dangerous goods; $B_a$ – damage from air pollution, million UAH; $B_w$ – damage from water pollution, million UAH; $B_l$ – damage from pollution and land degradation, million UAH; $B_{sa}$ – damage from the spread of harmful substances in the surrounding area, million UAH; $B_{fn}$ – damage to fauna, million UAH; $B_{fl}$ – damage to flora, million UAH.

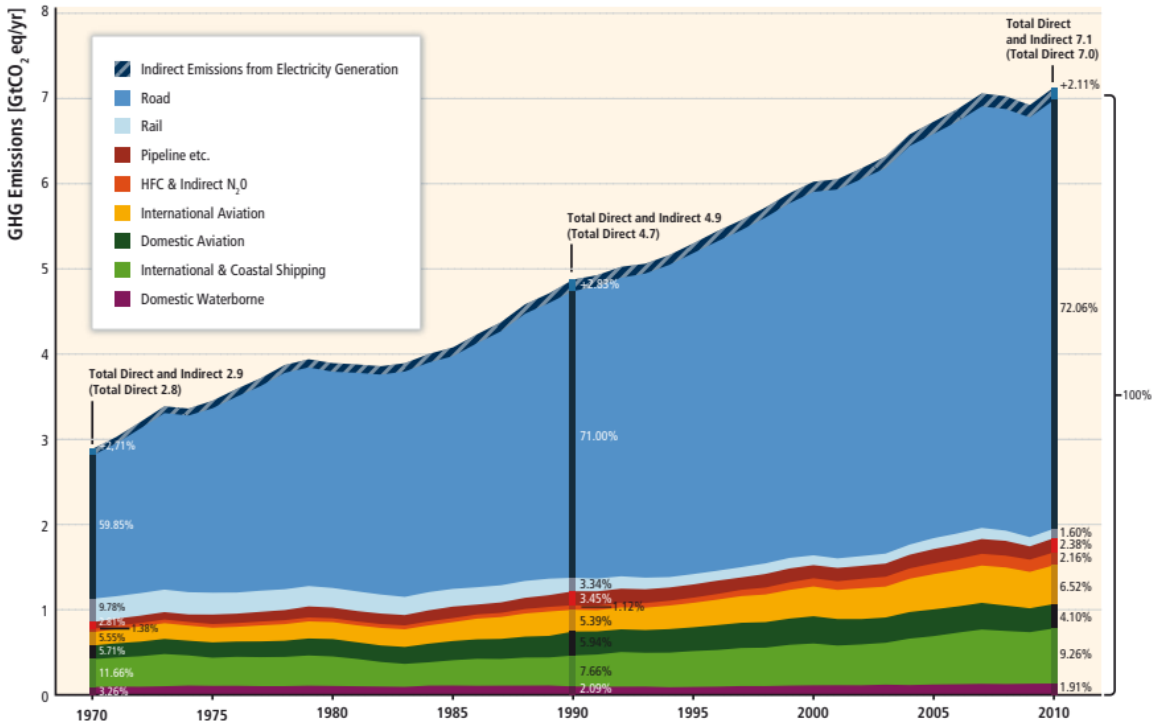



**FIGURE 1**. Trends in the increase of harmful emissions by mode of transport [4]

One of the ways to develop and improve the technology for performing international transportation of dangerous goods is the use of piggyback trains. Piggyback transportation is a type of combined transport in which road trains (tractors with semi-trailers, cars with trailers), semi-trailers, swap bodies are used as cargo units.

A diagram of the organization of conventional (unimodal) and multimodal transportation of goods is shown in Figure 2. In case of unimodal transportation, it is considered that the entire route distance Lpr is realized by one mode of transport. In case of multimodal transportation, the route distance consists of the initial sections with the participation of road transport La1, the main transportation L3(M) by rail transport (water transport) and the final sections of delivery by road transport La2. At the terminals, the interaction of modes of transport is implemented, a cargo unit (container) is reloaded and shunting work is performed with a duration of Tterm (further it is assumed that it will be 1 hour at each terminal on the train route).

The flexibility and adaptability of the dangerous goods delivery system is realized due to the rapid movement of reliable information using electronic data interchange (EDI). The main principles of EDI are the exclusion of multiple data entry, acceleration and increase in the accuracy of logistic information by automating data entry, the use of modern intelligent systems and cognitive technologies processing information flows. Practical solutions in the field of improving the quality of logistics services are manifested in ensuring the acceleration of order execution and shortening delivery times, the use of cross-docking concepts, a just-in-time system, a quick response system (QR), the use of bar codes and RFID tags, strategies for determining the exact location based on GPS [6].

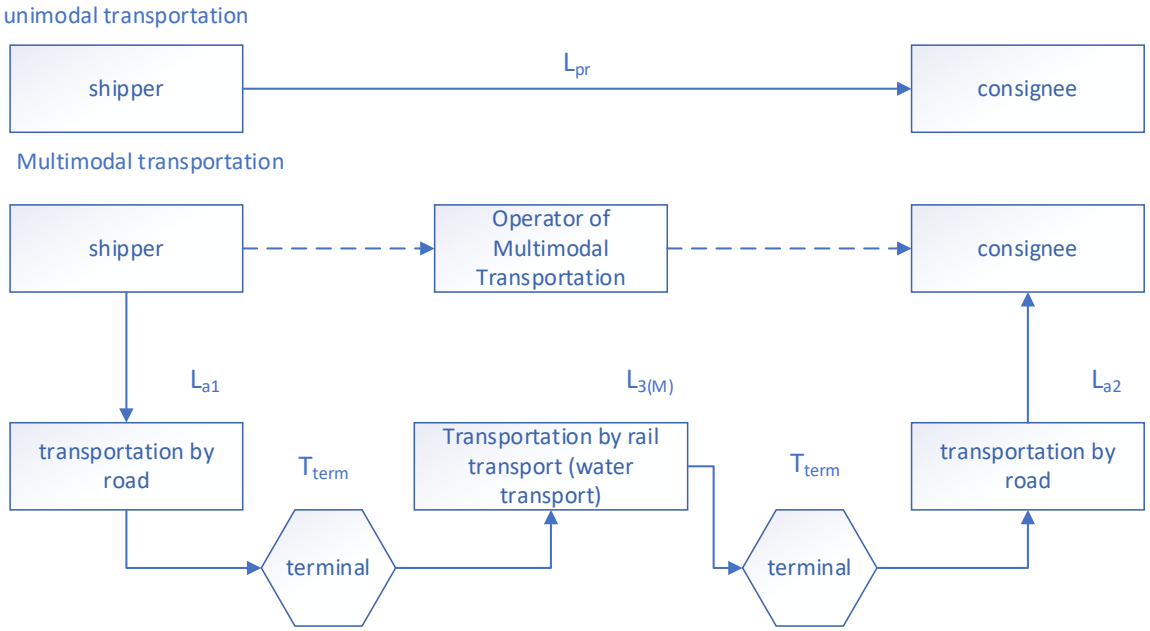



**FIGURE 2**. General scheme of organization of unimodal and multimodal transportation of dangerous goods

Research results. In the framework of multimodal "green" logistics, analysis of existing and prospective logistics channels for the movement of dangerous goods was carried out in order to identify their influence on the environment. In part of improving the level of preservation of dangerous goods due to innovative packaging, the following areas of activity should be envisaged: the use of environmentally acceptable packaging materials, the creation of a system for the return of packaging materials, disposal of packaging and goods, unsuitable for their intended use.

If we consider the activities of each type of transport separately, then each of them has a negative impact on the environment. Exception is railway transport, due to a significant share of electric traction, constantly reducing harmful emissions.

Share of road transport is 72% of all emissions. Therefore, it is obvious that with a combination of various types of transport in a piggyback scheme of cargo delivery, the harm from the effects of pollutants contained in the exhaust gases and substances of a technically sound tractor truck will be minimize. In particular, emission indicators CO2 for rail transport are low compared to road and water transport: according to the estimates, transporting 1000 tons of dangerous goods by rail requires three times less energy than transporting them by road transport. The approximate level of specific emissions of exhaust gases are given in table 1 [5].

Taking into account the data in the table 1, an assessment of energy costs and harmful emissions into the environment was made during the transportation of containers by various modes of transport:

• average specific electricity consumption by an electric locomotive 0,6040 ... 0,6552 kW·h / TEU·km;

• average unit consumption of electricity for railway electric traction, taking into account losses in the power supply system 0,6647 ... 0,7208 kW·h / TEU·km;

• average specific emissions of harmful substances on railway electric traction CO = 0,0033 ... 0,0038 g / TEU·km, NOx = 0,8170 ... 0,8174 g / TEU·km, SOx = 0,8696 ... 0,8763 g / TEU·km (with mixed mode of power generation by power plants fuel oil / coal);

**TABLE 1.** Specific emissions of exhaust gases [5]

| Type of transport | Specific emissions of exhaust gases, kg / h | | | | | | |
|---|---|---|---|---|---|---|---|
| | carbon monoxide (CO) | nitric oxide ($NO_x$) | Hydrocarbon (CH) | soot (C) | sulfur oxide ($SO_x$) | plumbum (Pb) | benzo(a)pyrene |
| internal combustion engine truck | 1,104 | 0,0120 | 0,1776 | - | 0,00168 | 0,00045 | $0{,}26\ 10^{-6}$ |
| diesel truck | 0,171 | 0,0486 | 0,0180 | 0,0042 | 0,0045 | - | $0{,}38\ 10^{-6}$ |
| shunting locomotive | 6,410 | 12,400 | 3,540 | 0,380 | 1,870 | - | $0{,}80\ 10^{-6}$ |
| ocean vessel | 4,812 | 15,390 | 3,849 | 0,962 | 0,962 | - | $0{,}80\ 10^{-6}$ |

• average specific emissions of harmful substances when performing shunting work CO = 320,50 g / TEU·h, NOx = 620,1 g / TEU·h, SOx = 93,50 g / TEU·h (diesel locomotive ChME-3 in mode engine Ne = 75% of the full power, the composition of the shunting train is accepted for 10 cars);

• average specific emissions of harmful substances during the transportation of containers by sea (for example, a container ship of the type Emma Maersk with a 14-cylinder diesel engine with a capacity of 80800 kW) CO = 8,1955 ... 13,3927 g / TEU·km, NOx = 2,5625... 4,1875 g / TEU·km, SOx = 1,8750 ... 3,0562 g / TEU·km (specific fuel consumption is expertly accepted as 205 g / kW·h.);

• average specific emissions of harmful substances from a truck CO = 13,194 g / TEU·km, NOx = 3,750 g / TEU·km,
SOx = 3,200 g / TEU·km (6-cylinder diesel engine, average speed 60 km / h, full container load).

Thus, it has been proven that railway transport is the most environmentally friendly in terms of CO, NOx, SOx emissions into the atmosphere. In figure 3 shows a comparison of the specific polluting effect on the environment when transporting a 20-foot container (TEU) with dangerous goods by various modes of transport.

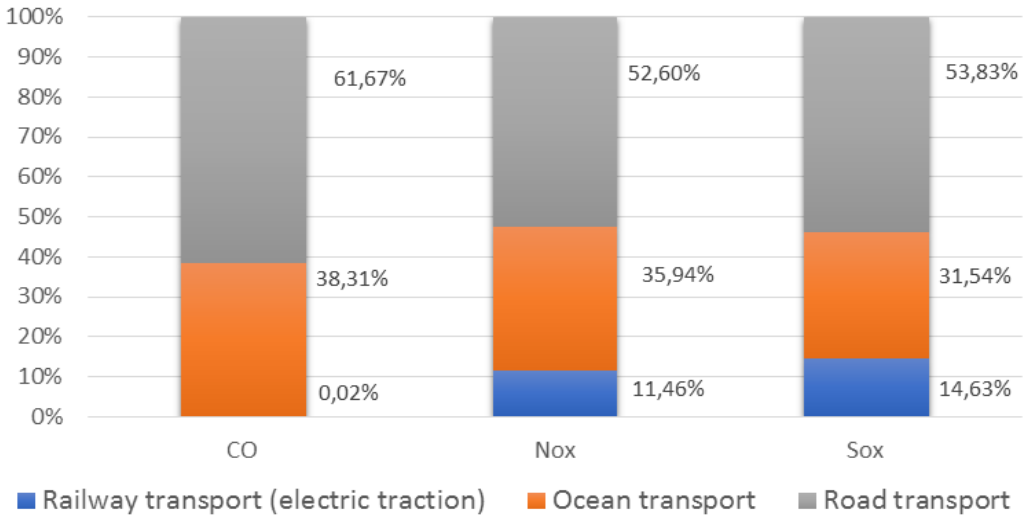
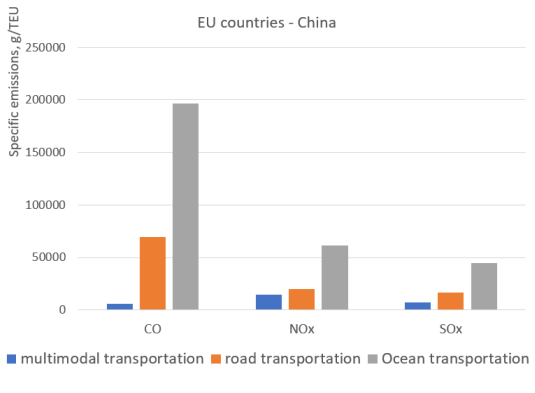



**FIGURE 3**. Comparison of the specific polluting effect on the environment when transporting a 20-foot container (TEU) with dangerous goods by various modes of transport

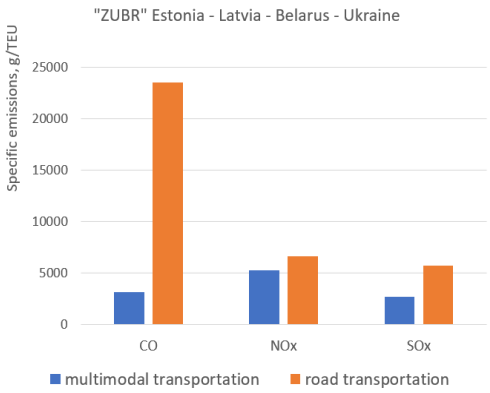
In order to compare the quantitative assessment of harmful emissions into the environment during the transportation of containers with dangerous goods by various methods and modes of transport along the routes of delivery by some container trains and similar unimodal routes, based on the scheme (Figure 3), a table 2 has been constructed. The table takes into account that the distance to follow the route by different modes of transport depends on the topology of the corresponding communication routes.

**TABLE 2.** Estimation of the amount of harmful emissions into the environment during the transportation of containers with dangerous goods by various methods and modes of transport, g / TEU

| **Multimodal route, distance and estimated duration of the route** | **Emissions on a multimodal route: by train (Additional emissions for initial / final and shunting operations)** | **Total emissions of the multimodal route** | **Unimodal emissions from transport (road, water)** |
|---|---|---|---|
| "Viking", combined transport train, Lithuania - Belarus - Ukraine - Bulgaria - Moldova / Romania / Georgia - Azerbaijan, $L_3$ = 1766 km, $t_{pr}$=59 h. | CO 5,83<br>$NO_x$ 1 442,82<br>$SO_x$ 1 535,71<br>(CO 2 865,28<br>$NO_x$ 2 930,40<br>$SO_x$ 758,00) | CO 2 871,11<br>$NO_x$ 4 373,22<br>$SO_x$ 2 293,71 | $L_{pr}$ = 1486 км<br>CO 19 606,28<br>$NO_x$ 5 572,5<br>$SO_x$ 4 755,2 |
| "ZUBR", container transportation, Estonia - Latvia - Belarus – Ukraine<br>L3 = 2162 km, tpr =84 h. | CO 7,13<br>NOx 1 766,35<br>SOx 1 880,08<br>(CO 3 185,78<br>NOx 3 550,50<br>SOx 851,50) | CO 3 192,91<br>NOx 5 316,85<br>SOx 2 731,58 | Lpr =1782 км<br>CO 23 511,71<br>NOx 6 682,50<br>SOx 5 702,40 |
| EU countries - China, container transportation, Altinkol – Mostiska<br>L3 = 6333 km, tpr = 360 h.<br>(15 days) | CO 20,8989<br>NOx 5 174,061<br>SOx 5 507,1768<br>(CO 6 070,28<br>NOx 9 131,40<br>SOx 1 693,00) | CO 6 091,18<br>NOx 14 305,46<br>SOx 7 200,17 | Lpr =5244 км<br>CO 69 189,34<br>NOx 19 665,00<br>SOx 16 780,80<br>(Ocean transport<br>CO 196 692,00<br>NOx 61 500,00<br>SOx 45 000) |




a)




b)

**FIGURE 4**. Comparison of the specific environmental impact of the transport of a 20-foot container (TEU) with dangerous goods

In figure 4 shows a comparison of the assessment of harmful emissions into the environment during the transportation of containers with dangerous goods along the considered routes. The analysis showed that the most environmentally friendly is the multimodal container transportation technology, but in terms of NOx emissions during transportation over relatively short distances (up to 500 km), transportation by road can be conventionally considered more environmentally friendly (under normal weather conditions). If we take into account the impact of

the deterioration of natural conditions (snowfall, ice, low temperatures, heavy rains), then even at such short distances, vehicles are inferior to railway ones in terms of environmental indicators.

Except to these factors of air pollution, it is also necessary to take into account the harmful effects of the operation of trucks on the state of the roads, the level of noise pollution of the environment, the criteria for the safety of people when using various technologies for the transport of dangerous goods. Taking into account the expected minimization of the movement of road transport when performing piggyback transportation, the likelihood of injury to a person by the remnants of dangerous goods during a road accident, also decreases.

## APPLICATION PROSPECTS

The above factors of the possibility of using piggyback transportation of dangerous goods is a multi-criteria task, therefore, in the future, it must be formalized in order to scientifically substantiate the rational time for preparing a piggyback train for a trip and the probability of failure-free reception or passage of trains by the transport system, protection from physical hazards and harmful factors, increasing safety level, technical capability and processing capacity places of locations piggyback terminals.

## CONCLUSIONS

The introduction of "green" logistics technologies in general when using container and piggyback transportation of dangerous goods makes it possible to highlight the following promising areas of activity:

• investing in the development and construction of new logistics and multimodal centers, which improve the efficiency of logistics operations and indicators of transportation of dangerous goods;

• introduction of specialized technologies in warehouses for the purpose of rational organization of warehouse logistics. As a result, there will be a reduction in storage areas and energy consumption, an increase in safety indicators when performing cargo operations with dangerous goods;

• development of the transport system, incl. transport interchanges, construction of new roads, optimization of routes for transporting dangerous goods in order to reduce emissions of harmful gases;

• reducing the share of unimodal road transport, replacing them with multimodal ones with the participation of rail, sea and river modes of transport, makes it possible to increase environmental friendliness when transporting big numbers of dangerous goods - this reduces the number of flights during transportation and reduces the harmful impact on the environment;

• informing consumers about the environmental direction of the carrier's and multimodal operator's activities by labeling the packaging with special signs, increasing the importance of the environmental impact on the quality of life of consumers and the market stability of the carrier during the implementation of activities;

• development and stimulation of waste processing, reduction of tariffs for the disposal residues of container and packaging, development of container transport, providing for the minimization of packaging.

The prospect of "green" logistics today should be linked to the requirements of ISO 14001 (DSTU ISO 14001) “Environmental management systems. Requirements and guidance for use” [7]. It is recognized worldwide as a tool for creating an effective environmental management system. With the correct implementation of the provisions standard ISO 14001 for the entire structure of the organization of multimodal transportation, it is possible to achieve two goals at once: creating conditions for reducing the harmful impact on the environment, subject to the maximum preservation of financial resources.

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