

# Determination of safety criteria when choosing the type of transport for transportation of cargo

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**Abstract.** The article analyzes the volumes of transported goods, freight traffic, during transportation by railway transport. The dynamics of transport accidents on railway transport were studied, the distribution of the number of transport accidents per 1 million tons of transported cargo and cargo turnover by various types of transport was determined. The concept of the criterion of transport accidents was introduced, and the correlation between the volume of transported goods and freight traffic and the number of accidents, incidents, and catastrophes was investigated. The components of the criterion of transport accidents and approaches to the calculation are substantiated.

## 1 Introduction

According to the transport strategy of Ukraine for the period until 2030, it is stated that the transport industry as a whole satisfies only the basic needs of the population and the economy in terms of transportation in terms of volume, but not in terms of quality. It is necessary to increase the efficiency and competitiveness of the transport industry [1].

Improving the quality of transport services is a top priority for the transport industry. The problems of transportation safety, environmental friendliness of transportation, non-compliance of transportation, transported goods with European standards, violation of cargo delivery schedules, high cost of transportation, etc. are very acute at the moment. For railway transport of Ukraine, the issue of ensuring traffic safety and transportation safety is one of the important problems. In order to increase the level of attractiveness for carriers and attract new sales markets for transport services, it is advisable to define and analyze the safety criteria that influence the choice of a carrier by consumers.

## 2 Main part

### 2.1 Analysis of research and publications

A large number of works by domestic scientists are devoted to safety problems in railway transport. The work [2] of scientists Samsonkin V.M. and Moiseyenko V.I. dedicated to the development of theoretical approaches to control, ensuring and managing the safety of train traffic in railway transport. In works under the guidance of Chernetska-Biletska N.B. from V.Dal East Ukrainian National University [3] and O.V. Rozsokha [4] from the Ukrainian State University of Railway Transport

proposed a project of a unified system of traffic safety management on railway transport in international traffic, a comprehensive approach to assessing the level of train traffic safety on railway transport was proposed. In the works of scientists from Lviv and Kyiv [5-6], the approaches that are used in assessing the safety of wheels coming off the rail and specifying the coefficient of safety against wheels of railway rolling stock have been investigated.

In the works of scientists from the Pryazovsky State Technical University, together with scientists from other institutions [7-10], issues of modernization and development of new traction rolling stock are considered, taking into account traffic safety.

All these works are dedicated to solving the problems of traffic safety management in railway transport, taking into account the requirements for new traction rolling stock and do not consider the safety of transportation as a criterion when choosing a type of transport for transporting goods.

### 2.2 Setting tasks

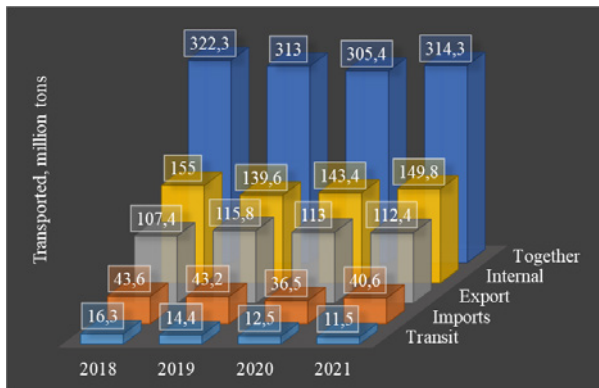
The purpose of this article is to justify approaches to the development of safety criteria when choosing a mode of transport and a carrier for freight transportation. To do this, it is necessary to analyze statistical data on the volume of freight transportation, freight traffic using the example of railway transport. Investigate the state of accidents in railway transport and develop certain criteria for compliance with the state of safety depending on the volume of transportation.

### 2.3 Teaching the main material

We will analyze cargo transportation by railway transport of Ukraine. According to data [11], the volumes of transported

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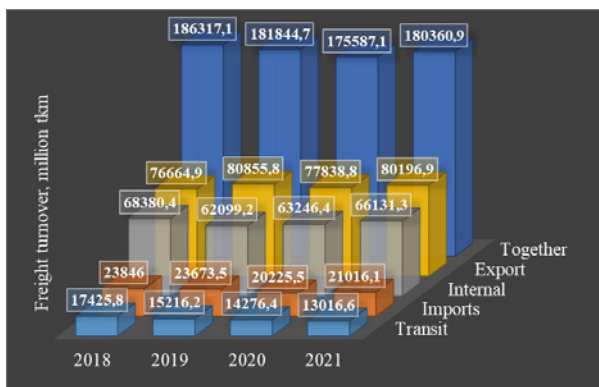
goods, million tons, for the period from 2018 to 2021 were analyzed. In Fig. 1. the dynamics of cargo transportation by years and types of transportation are given.



**Fig. 1.** Volumes of transported goods by railway transport for the period 2018-2021 by types of transportation

It is possible to observe a reduction in the volume of transportation from 2018 from 322.3 million tons to 314.3 million tons in 2021, that is, a gradual downward trend is observed. Annually, on average, the volume of rail transit transportation is 13.675 million tons (4% of all transported cargo), import transportation is 40.975 million tons (13%), export transportation - 112.15 million tons (36%), and the volume of domestic cargo transportation annually reaches - 146.95 million tons. (47%). Thus, it can be assumed that more than 53% of transportation is the transportation of goods in international traffic.

In Fig. 2. freight turnover for the period 2018-2021 by rail transport is given. On average, during the year, the cargo turnover in the export of products is 78889.1 million tkm, in domestic transportation - 64964.325 million tkm, in the import of products - 22190.275 million tkm, in transit transportation - 14983.75 million tkm.



**Fig. 2.** Freight traffic for the period 2018-2021 in railway transport

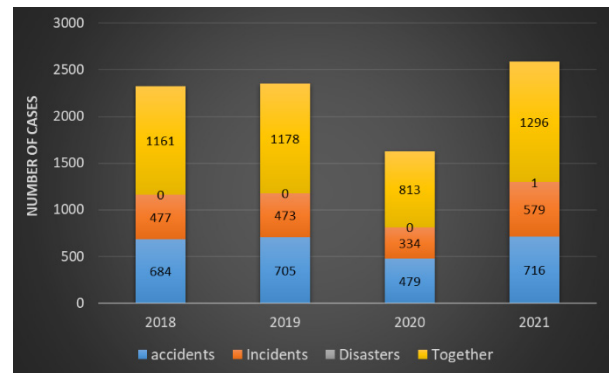
The percentage of all transported goods by railway transport in Ukraine in 2021 is 50.59%, by road transport – 36.05%, by pipeline transport – 12.49%, by water – 0.85% and by air – 0.02% [12].

The main consumers of transport services for the transportation of goods by rail transport are: the mining industry - 42%, the processing industry - 22%, the agricultural sector - 20% and others - 16% (according to 2019 data) [13].

Control over the safety of transportation is carried out both at the state level and at the level of the management of Ukrzaliznytsia, management of regional branches and management of linear railway transport enterprises. The Ministry of Infrastructure is the main body in the system of central bodies of executive power, which ensures the formation and implementation of state policy in the spheres of railway and other types of transport on issues of safety on railway transport [14]. The State Transport Safety Service of Ukraine (Ukrtransbezpeka) is the central body of the executive power, whose activities are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Infrastructure and which implements state policy on land transport safety [15].

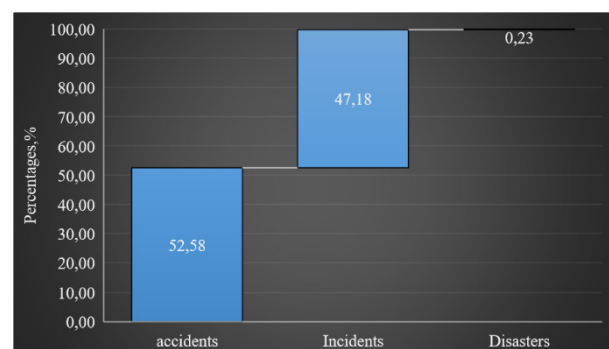
At the state level, measures have been implemented to improve traffic safety, but the current state of transportation safety is quite critical.

According to the statistical data of the State Transport Safety Service of Ukraine [16-18], an analysis of transport accidents (incidents, accidents, catastrophes) in railway transport for the period 2018-2021 was performed (see Fig. 3).



**Fig. 3.** Dynamics of transport events on railway transport for the period 2018-2021

For 4 years (2018-2021), there is a tendency to increase the number of accidents in railway transport. In 2021, the number of transport incidents amounted to 1,296 cases, which is 135 cases (11.6%) more than in 2018. There is also an increase in the number of incidents in 2021 - 579 cases, which is more than in 2018 by 102 cases (21.4%) and the number of accidents by 4.7% in 2021 - 716 cases, in 2018 - 684 cases. During this period, there was one disaster on railway transport in 2021.



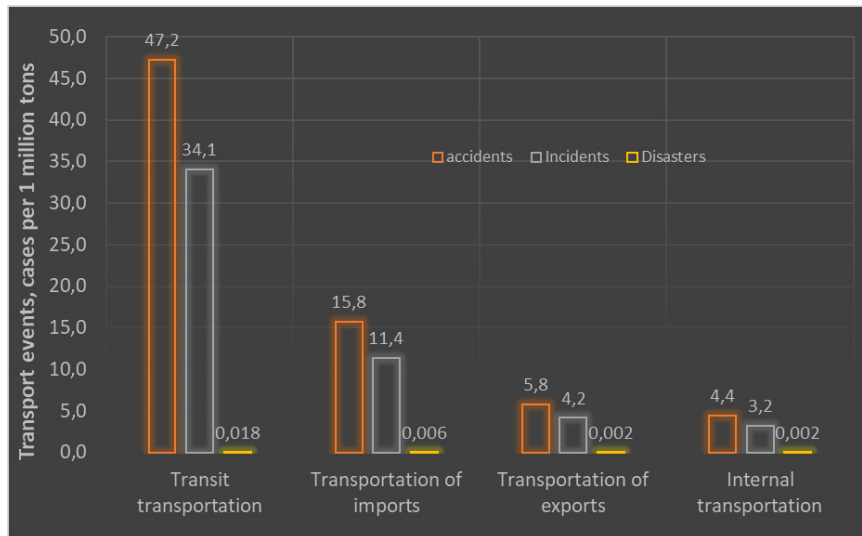
**Fig. 4.** Percentage of component transport events on railway transport on average for the period 2018-2021.

Research has established that an average of 1,112 transport incidents occur annually on railway transport, of which 646 are accidents (which is 58.09% of all transport incidents, see Fig. 4), 465.75 are incidents (41.88 %) and 0.25 – disasters (0.02%).

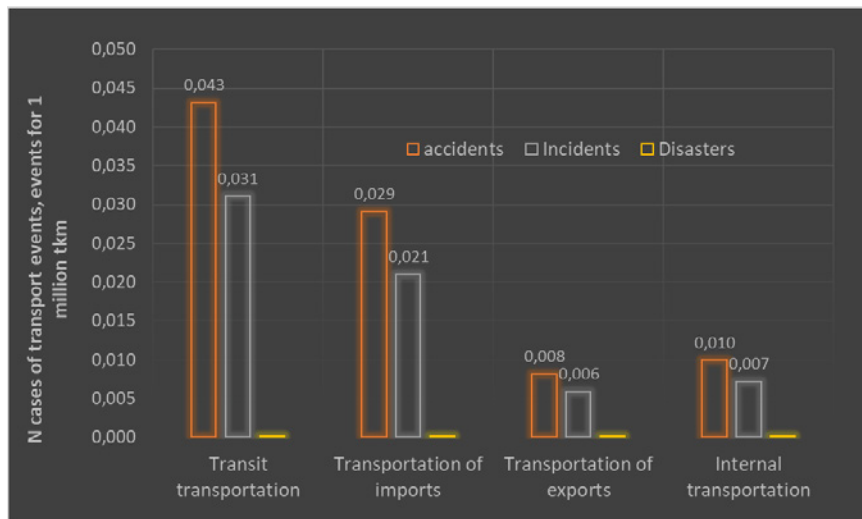
According to the current Regulation on the safety management system of railway transport (Order of the

Ministry of Infrastructure No. 842 dated 24.12.2020), the indicators for assessing the state of train traffic safety are the number of traffic accidents per 1 million vehicles. tkm [19].

Let's determine the number of transport accidents per 1 million transported tons of cargo in various types of transportation (see Fig. 5) and per 1 million tkm of freight traffic (see Fig. 6).



**Fig. 5.** Distribution of the number of transport incidents per 1 million tons of transported cargo by various types of transportation for the period 2018-2021.



**Fig. 6.**

Accidents were distributed as follows: 47.2 cases per 1 million tons of transported transit cargo, 15.8 cases per 1 million tons of transported imports, 5.8 cases per 1 million tons of transported exports, and 4.4 cases per 1 million tons. tons of domestic cargo transportation. The number of incidents per 1 million tons of cargo: 34.1 cases for transit transportation, 11.4 cases for import transportation, 4.2 cases for export transportation, and 3.2 cases for domestic transportation. The rate of accidents in all types of transportation is very low, from 0.018 cases per 1 million tons of transported cargo.

The number of accidents per 1 million tkm: in transit transportation is 0.043 cases, in import transportation - 0.029 cases, in export transportation - 0.08 cases, and in

domestic transportation 0.01 cases. The number of incidents per 1 million tkm: transit transportation is 0.031 cases, import transportation - 0.021 cases, export transportation - 0.06 cases, and internal transportation 0.007 cases. The average number of accidents per 1 million tkm of transported cargo is  $0.87 \cdot 10^{-6}$  cases.

Thus, it should be noted that the state of transportation safety is an important criterion for choosing a mode of transport. In order to make an informed decision taking into account factors of transportation safety, it is necessary to investigate the state of the transportation safety system. The system considers the volume of transported goods  $Q_i$ , million tons, cargo turnover  $P_i$ , million tkm and the number of transport events  $N_j$ , vol.

are shown in Table 1. To assess the closeness of the relationship between these parameters, we will construct a correlation field and an empirical regression line.

**Table 1.** The volume of transported goods, freight turnover and the number of transport accidents on railway transport for the period 2018-2021

The name of the indicator	The studied period, years				Average parameter values	Mean-square deviation
	2018	2019	2020	2021		
Number of accidents, $N_a$ , number of cases	684	705	479	716	646	194,20
Number of incidents, $N_i$ , number of cases.	477	473	334	579	465,75	174,25
Number of disasters, $N_k$ , number of cases.	0	0	0	1	0,25	0,87
Volume of transported goods, $Q_i$ , mln.t.	322	313	305	314	313,75	11,99
Cargo circulation, $P_i$ , $10^3$ mln. tkm	186	182	176	180	181,27	7,66

The scatter field and regression lines are shown in Fig. 7-8.

Thus, the correlation between the volume of transported goods and the number of accidents can be described by the equation:

$$N_a = 1174,8 \cdot Q_i - 1,8523 \cdot Q_i^2 - 185337 \quad (1)$$

At the correlation coefficient  $R^2 = 0,9996$ .

The correlation between the volumes of transported goods and the number of incidents can be described by the equation:

$$N_i = 1093,9 \cdot Q_i - 1,7285 \cdot Q_i^2 - 172522 \quad (2)$$

At the correlation coefficient  $R^2 = 0,855$ .

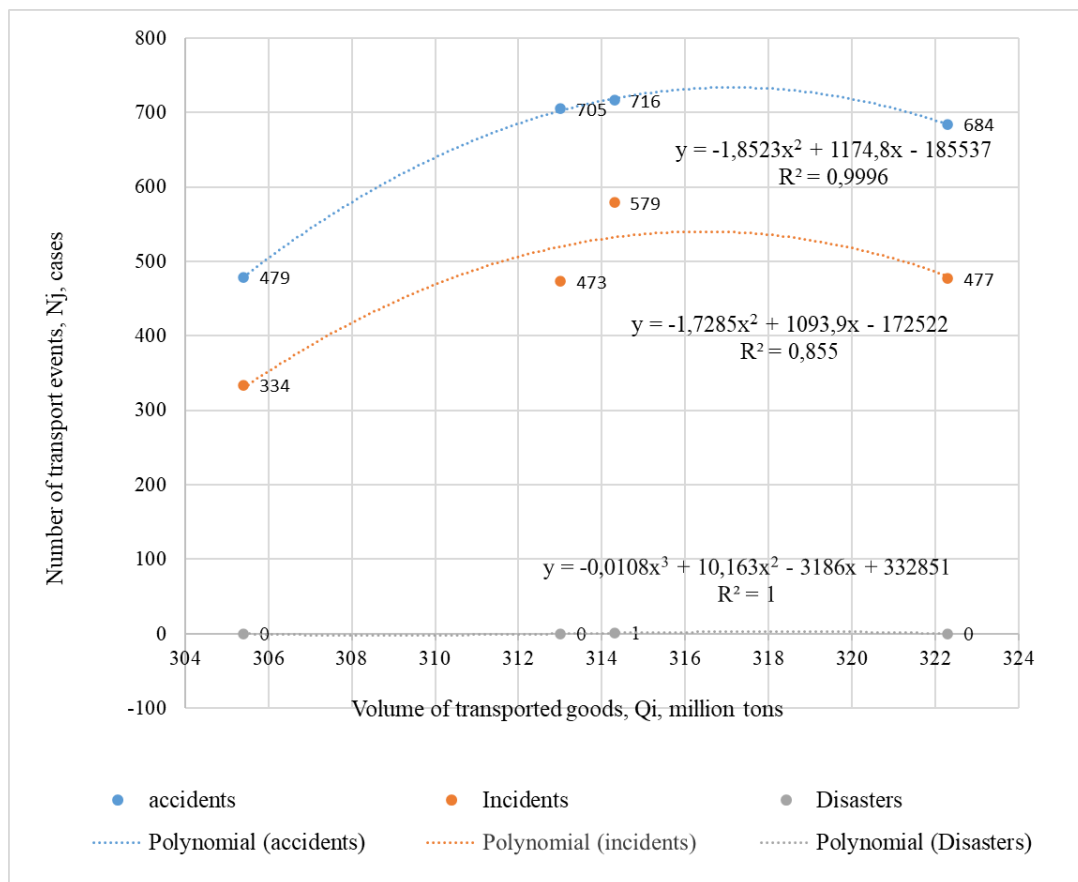
The correlation between the volume of transported goods and the number of accidents can be described by the equation:

$$N_k = 10,163 \cdot Q_i^2 - 0,0108 \cdot Q_i^3 - 3186 \cdot Q_i + 332851 \quad (3)$$

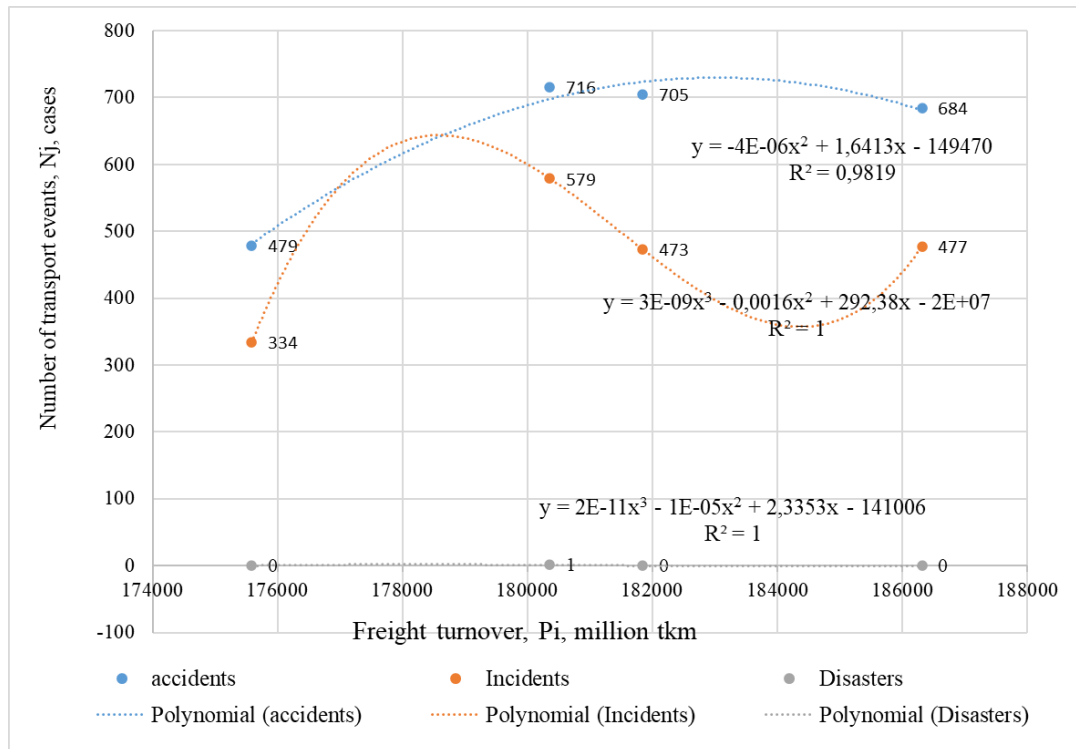
At the correlation coefficient  $R^2 = 1$ .

Correlation between freight traffic and the number of traffic accidents and regression lines are shown in Fig. 8.

From the obtained data, it can be concluded that there is a weak degree of connection between the parameters of the volumes of transported goods, freight traffic and the number of transport accidents on railway transport. This may be due to insufficient number series statistics.



**Fig. 7.** Scatter field and regression lines of indicators  $Q_i$  and  $N_j$ .



**Fig. 8.** Scatter field and regression lines of indicators Pi and Nj.

It is advisable to conduct such an analysis in order to determine the level of safety of transportation when solving multi-criteria tasks of choosing a carrier by a consumer of transport services.

Let's introduce the concept of "Criteria of transport accidents" –  $K_{т.п.}$  for a separate type of transport, which will assess a certain degree of transport safety. Criterion of transport accidents,  $K_{т.п.}$  transportation may have several components:

$$K_{т.п.} \in (k_{3,т.п.}, k_{мат.зб.}, k_{фин.зб.}, k_{ек.}, k_{ин.}), \quad (4)$$

where  $k_{3,т.п.}$  – is a criterion that characterizes the level of social safety of railway transportation (the number of people killed and injured as a result of a transport accident);

$k_{мат.зб.}$  – a criterion that characterizes the level of material safety of railway transportation (number of damaged means of transport and cargo units, objects of railway infrastructure, containers, packaging, etc.);

$k_{фин.зб.}$  – a criterion that characterizes the level of financial security of railway transportation (related to the financial obligations of the consignor and consignee, for example, compliance with the traffic schedule, regularity of deliveries, speed of cargo delivery, preservation of the merchandise appearance of cargo, etc.);

$k_{ек.}$  - criterion characterizing the level of environmental and man-made safety of cargo transportation;

$k_{ин.}$  – a criterion that characterizes other negative consequences of the occurrence of transport accidents, for example, the reputational consequences of the shipper due to non-compliance with the delivery schedule, etc.

Thus, the value of the criterion of transport accidents for a certain period T can be estimated by the formula:

$$K_{т.п.} = \sum_{i=1}^T (k_1, k_2, \dots, k_n) \quad (5)$$

and

$$K_{т.п.} = \sum_{m=1}^T (N_{т.п.} \cdot B_{т.п.}), \quad (6)$$

where  $N_{т.п.}$  – the number of traffic accidents for a certain period,

$B_{т.п.}$  – expenses related to the occurrence of a traffic accident, hryvnias.

The specific value of the criterion of transport accidents,  $K_{т.п.}$  UAH/t or UAH/tkm can be determined by the formula:

$$k_{т.п.} = \frac{\sum_{m=1}^T (N_{т.п.} \cdot B_{т.п.})}{\sum_{m=1}^T Q_i} \text{ or } k_{т.п.} = \frac{\sum_{m=1}^T (N_{т.п.} \cdot B_{т.п.})}{\sum_{m=1}^T P_i} \quad (7)$$

### 3 Conclusions

The use of the criterion of transport accidents will be appropriate when solving the task of finding the optimal option for cargo transportation when analyzing various types of transport for consumers of transport services (shippers). This criterion makes it possible for the shipper to quickly assess the possible risks and costs of cargo transportation from the point of view of transportation safety.

In the future, in the model of the optimal choice of the type of transport for cargo transportation, it is advisable to use the expert method and determine the weight of the criterion of transport accidents among other criteria and choose the optimal strategy taking into account all the limitations of the objective function.



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