Comprehensive Methodology for Choosing a Rational Route for Road Transport When Transporting Dangerous Goods

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Abstract. The General trend in the development of the technosphere implies a constant increase in the volume of transport of dangerous goods by road. The combination of "dangerous cargo and vehicle" is potentially dangerous because it can pose additional risks to road users, as well as to the environment (nature and population). For this reason, it is necessary to conduct appropriate risk analyses for the transport of dangerous goods by road, which makes it possible to assess such risks.

1. Introduction

Natural and man-made emergencies pose a threat to the life and health of the population, economy and ecology of the regions. The problem is justified by the growing threats of man-made and terrorist nature, and especially for those territories that are characterized by a high concentration of production facilities that receive, use, process, store and transport dangerous substances [1].

Transportation of dangerous goods (hereinafter referred to as OG) by road is a complex and dangerous technological process regulated by law. The need to determine the route of dangerous cargo transportation is reflected in a number of planning documents, including the territory security passport, as well as the passport and Declaration of safety of potentially dangerous and critical objects [2,3]. At the same time, the current legislation defines the requirements for the carrier, the cargo owner, the container manufacturers, the rolling stock, and even the traffic control authorities, but there are no methodological approaches to choosing a safe route for the transportation of LPG.

2. Relevance of the topic and the current state of the problem

The problem of choosing a safe route is important, since the damage from the consequences of a road accident (hereinafter referred to as an accident) with a car carrying exhaust GAS, due to its features and physical and chemical properties, is multiplied, presenting a real danger to the population and the environment.

It should be noted that the essence and mechanism of an accident depends on many factors related to the process of driving a vehicle under the influence of the environment, and least of all with the
nature of the cargo being transported. This paradigm allows us to identify approaches to the analysis of accidents involving road transport involved in the transport of dangerous goods with the General approaches to the analysis of road accidents. Thus, it is reasonable to assume that the probability of an accident with a transport carrying dangerous goods is identical to the risk of a man-made emergency.

3. Problem statement
The task is to develop a scientific and methodological apparatus for substantiating the rational route of a motor vehicle in the transport of dangerous goods, taking into account the physical and geometric properties of the road, traffic flow mode and dynamically changing factors that contribute to the occurrence of man-made emergencies.

4. Theoretical part
The essence of this task is to build or choose a route for the transportation of dangerous goods, where the risk of man-made emergencies is minimal. Setting the problem in this form is identical to the fact that you need to choose a route where the probability of an accident is minimal. Accordingly, to solve this problem, an objective function is introduced, which is an expression for estimating the probability of an accident on the route of the vehicle. Moreover, this probability depends on the characteristics of the route, its physical and statistical properties. Ultimately, the optimization problem is solved, in which the risk of an emergency on the route of dangerous goods transportation is minimized by choosing a rational route.

5. Results of experimental studies
A model for assessing the probability of emergencies of a man-made nature on a section of the automobile transport route during the carriage of dangerous goods.

To build a model for assessing the probability of emergencies of a man-made nature on a section of the route of automobile transport during the carriage of dangerous goods, it is necessary to have a large set of historical (retrospective) data on previously occurring emergencies.

However, there are certain difficulties with such statistical studies. Firstly, although every road accident involving dangerous goods is (or potentially could be) a very dangerous event, such events do not occur often enough to have representative statistics. Thus, in 2005-2007, the Ministry of internal Affairs of Russia received information on 219 road accidents involving vehicles carrying dangerous goods [4,5]. Secondly, the state statistical reporting on traffic accidents includes information only on traffic accidents where people died or were injured [6,7].

This means that if, by coincidence, the only consequence of an accident was damage to infrastructure or damage to the environment, it is difficult to obtain information about it.

Thus, in order to solve the problem of reducing the risk of accidents involving dangerous goods using methods that require the processing of statistical data, it is necessary to make certain assumptions that allow the use of more complete statistics. As such an assumption, it is proposed to take into account statistics for all accidents, and not only for accidents with dangerous goods. The correctness of this assumption is based on the fact that the special danger of an accident with a hazardous cargo, in comparison with ordinary accidents, lies in the specifics of the development of the situation after a road accident, while the conditions that contribute to its occurrence coincide with those for ordinary accidents [8,9].

In more detail, the proof that the risk of an accident coincides with the risk of an emergency with dangerous goods is as follows (figure 1).

According to statistics, the majority of accidents (85%) occur outside settlements, and most of them are caused by rollovers, which in most cases leads to loss of cargo. At the same time, the rest of the considered accidents – collisions – due to the high speed of movement outside the settlement, also lead to the loss of cargo.
According to statistics, there are approximately the same number of rollovers and collisions within localities. Moreover, in the first case, the loss of cargo is also almost guaranteed, in the second case, the risk of loss is also great.

In the end, we get that almost any accident with a dangerous cargo has an extremely high risk of loss of cargo and, as a result, a high risk of developing an emergency with a dangerous cargo.

**Figure 1.** Scheme of the development of an accident with a dangerous cargo in an emergency.

*Choice and justification of the distribution law of the number of accidents in sections of the route.*

The number of accidents in a particular area is twofold. On the one hand, this quantity is a random variable. Indeed, even if we consider the same section on different days, but with fixed factors (weather, road, etc.), it is impossible to say with certainty that the number of accidents on these days will be the same.

On the other hand, this random variable has characteristics (for example, the average value, spread, etc.) that can be derived as deterministic (non-random) functions of the values of factors.

Thus, the number of accidents can be modeled as a random variable which distribution law can be predicted based on the properties of the road section. The law of distribution of a random variable [10] is a function that corresponds to each value that a quantity can take – the probability that it will actually take this value.

The assumption of one or another form of the distribution law of a random variable is called the data distribution hypothesis. Different types of random variables can be modeled by different types of distributions. This choice depends on the properties of the random variable – whether it is continuous or discrete, whether its values are limited (for example, strictly positive numbers or negative numbers), whether the set of possible values of the random variable is finite.

A strict logical description of a random variable that describes the number of accidents on a particular section may look as follows. This is a discrete random variable that takes integer non-negative values that are unbounded (potentially) from above. In addition, road accidents are independent of each other and are relatively rare events. The same random variables can be modeled by the Poisson distribution law.

The Poisson distribution is completely determined by a single positive parameter, which is usually denoted as $\lambda$ [11]. Both the mean (average) and variance (a measure of the spread of values) are equal to $\lambda$. This means that it is required to find the functional dependence of $\lambda$ on the values of various factors. In this case, for each given section, having data on its characteristics, it is possible
to predict the average value of an accident in the area, which will be considered a measure of the danger of this section.

The general view of the Poisson distribution is shown below:

$$p(y|x_1, x_2, ..., x_n) = e^{-\lambda} \frac{\lambda^y}{y!},$$

$$\lambda = f(x_1, x_2, ..., x_n)$$  \hspace{1cm} (1)

Examples of probability functions for various parameters $\lambda$ are shown in Figure 2. From the analysis of the presented graphs, we can conclude that when the parameter $\lambda$ increases, the graph shifts to the right, which corresponds to an increase in the probability of more accidents.

![Poisson distribution graphs](image)

Figure 2. Poisson distribution.

In addition, the Poisson distribution has another remarkable property. If two independent random variables are distributed according to the Poisson law with parameters $\lambda_1$ and $\lambda_2$, then their sum will be a random variable distributed also according to the law of Poisson distribution, the parameter of which is equal to the sum $\lambda = \lambda_1 + \lambda_2$ [12]. This property implies that to assess the danger of a route consisting of multiple sections, it is sufficient to add all the $\lambda_i$ for individual sections. The same should be done when comparing the dangers of different routes.

However, the question of the specific form of the functional dependence of $\lambda$ on the values of factors on a given section of the road network remains open.

The construction of a regression model for estimating the expected number of accidents on a section of the route of a motor vehicle during the transport of dangerous goods. The classical and at the same time one of the most universal and effective methods for estimating unknown parameters of distributions is the maximum likelihood method [12]. This method became widespread in the 20s of the XX century due to the work of the English statistician R. Fisher. The essence of this method as applied to the problem of forecasting accidents is as follows.

Let historical data be given on sections of the road network, namely their properties $x_i$ and the number of $y_i$ accidents that occurred on them over a certain period of time. Based on these data, it is necessary to predict the expected number of accidents in these and other (even those for which there
are no data on the number of accidents in them) sections. Tasks of this type are called regression restoration problems [13].

A random variable (the number of accidents) is modeled, distributed according to Poisson's law with the parameter \( \lambda_i = f(x_{i1}, x_{i2}, ..., x_{in}|\theta_1, \theta_2, ..., \theta_n) \), where \( x_{ij} \) are the values of factors on the \( i \)-th section of traffic, \( \theta \) are the parameters of the functional dependence to be found. We assume that this dependence is linear, i.e., \( \lambda = \theta_1 x_{1} + \theta_2 x_{2} + ... + \theta_n x_{n} \). With fixed distribution parameters, it is possible to calculate the probability of a certain number of accidents in the area \( p(y_i|\theta) \), i.e., to obtain a probability function (specific distribution law) of a random variable.

**Likelihood** for one section is the probability of a real number of accidents. In addition, since the number of accidents in different sections are independent random variables (i.e., their combined probability is equal to the product of their probabilities), we can calculate the likelihood of the entire set of historical data by formula (2):

\[
L = \prod_{i=1}^{l} p(y_i|x_{i1}, x_{i2}, ..., x_{in}, \theta_1, \theta_2, ..., \theta_n)
\]  

(2)

Thus, if the parameters of the \( \theta \) model are not selected correctly, i.e., they give a poor estimate of the distribution parameter (the expected number of accidents) \( \lambda_i \), the likelihood of the data will be low. On the contrary, if \( \lambda_i \) is well predicted by the properties of the road network section, the likelihood will be high. This means that to get accurate estimates of the expected number of accidents in the area, it is necessary to solve the optimization problem (to maximize the likelihood of the parameters \( \theta \)). The problem of maximizing the logarithm of likelihood (9) is solved, since this allows us to move from the product of probabilities to the sum of the logarithms of probabilities:

\[
\log L = \sum_{i=1}^{l} \log p(y_i|x_{i1}, x_{i2}, ..., x_{in}, \theta_1, \theta_2, ..., \theta_n) \rightarrow \max \theta
\]  

(3)

Problem (3) can be solved by the gradient descent method, or by one of the variants of the least squares method – the least squares method with iterative recalculation of weights [14].

6. Conclusion

It is proved that the risk of an emergency of a technogenic nature can be estimated as the probability of a road accident with a vehicle carrying a dangerous cargo. To assess the probability of an accident with dangerous goods, it is proposed to take into account statistics for all accidents, and not only for accidents with dangerous goods. This assumption is justified by the fact that the conditions that contribute to the occurrence of an accident depend on many factors related to the process of driving the vehicle, and are least related to the nature of the cargo being transported.

Taking into account the specifics of the random variable "number of accidents", the Poisson distribution law was chosen, which allows approximating data on accidents. The maximum likelihood method is used for approximation. Metrics (criteria) for evaluating the quality of the resulting model were defined. Thus, the constructed mathematical model for estimating the probability of man-made emergencies on the route section is a generalization of the model for estimating the probability of road accidents.

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