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RISK ASSESSMENT DURING THE TRANSPORTATION OF DANGEROUS GOODS CONSIDERING THE FUNCTIONAL STATE OF THE DRIVER

Summary. Increase in motorization and densification of populations in cities have led to the use of more resources both for the construction of different objects and for the service and operation of automotive vehicles. As a result, volumes of freight transportation, which are related to the construction and servicing of these objects, increase. New scientifically applied tasks that are related to the safety of freight transportation have emerged. Special attention is being paid to those that are related to dangerous tasks. It is obvious that traffic safety and the quality of the transportation process significantly depend on the behaviors and actions of the driver. The driver, as it is known, is the main chain of the "driver – automobile – road – environment" (DARE) system. With improvements in the technical and operational parameters of vehicles and road characteristics, the study of the functional state (FS) of the driver and the reliability of his skills become more important every time. The specific importance of this becomes clear when drivers operate vehicles that transport dangerous goods.

Therefore, research on the interaction of chains of the DARE system (using improved existing and developed methods by the authors) is carried out in this paper, taking into account the indicators of drivers' FS in different situations (stress index, which consists in evaluation of the heart and brain operations). The results obtained provide an opportunity to predict their behavior in different road situations and, as a consequence, to determine possible risks during the transportation of dangerous goods. The authors improved the methodology of determining the levels of possible risks of accidents and assessment of their consequences, taking into account the peculiarities of transportation routes, traffic conditions, and psychophysiological indicators of the driver`s body during the transportation of dangerous goods within settlements and on the roads between them.

1. INTRODUCTION

An increase in motorization and consolidation of populations in large cities have occurred worldwide. This leads to the use of more resources for the construction of different kinds of objects as well as for the service and operation of automotive transport. In this respect, transportation of goods has increased. Therefore, accordingly, new problems have emerged related to the safety of transportation of goods; in particular, special attention is being paid to transportation of dangerous goods.

During transportation, factors such as driver behavior, the automobile used, road conditions, and the environment interact with each other, which forms the DARE system. If the technical and technological parameters of vehicles and roads are known and they can be predicted, then, variable parameters of the environment are the least-investigated elements of this system. During transportation of dangerous goods, the cost of the driver's mistake is extremely high as accidents that occur due to these vehicles can have severe consequences. Consideration of the conditions and regimes of movement and the change of the FS of the driver determine the relevance of such studies.

2. ANALYSIS OF RESEARCH PAPERS

The question of risk assessment and management related to the transportation of dangerous goods is one of the modern relevant topics of scientific research even at the European level [1]. Dangerous goods transportation relates to risky activities because the consequences of emergency situations occurrence are unpredictable. It is especially relevant for those settlements that have the most adverse conditions for transportation of dangerous goods.

The common definition of "risk" includes a measure of the frequency and severity of the damage due to the danger. In the context of transportation of dangerous goods, the danger is that goods have toxic, explosive, and inflammable properties that can impact the environment adversely [2]. Other authors [3] assume that the risk that exists during transportation of dangerous goods is a particular threat that needs special strategies and tools for its reduction.

The main aims of this research were to precisely determine the risks in automotive transport, determine the parameters for this type of system, and develop permanent sets of delivery routes based on risk optimization, and the cost of risk assessment and uncertainty.

Risks related to ecological pollution were investigated in this article [1]. On the basis of the results obtained, practical recommendations were developed for cities for prohibition of private transport movement on sections of city streets and reduction of the average age of vehicles to an acceptable European level.

E. Erkut and V. Verter reviewed an approach [4-5] and proposed a method to assess the probability of the occurrence of a possible incident. In general, road accidents are the main reason for the unpredictable emissions of hazardous substances during transportation. The authors consider that in the context of transportation of dangerous goods, the risk includes the probability of occurrence of unintended consequences from a possible event of leakage, explosion, or ignition of hazardous substances. Authors considered the probability of incident which can permanent for road segments. This kind of probability can be assessed only in the presence of historical data.

Transportation of dangerous goods is an important part of freight transportation, although it occupies a small share by volume. The consequences that can arise due to non-compliance with transportation rules, human mistakes, or force majeure events and circumstances can have unpredictable harmful effects [6]. Precise knowledge of operational risks in practice creates opportunities for risk management of the entire transportation chain. Investigation and assessment of risks during transportation of dangerous goods are the main factors that should be considered for risk minimization (management) taking into account the human factor in automotive transport [7].

3. REVIEW OF PREVIOUSLY OBTAINED RESULTS

Researchers in the USA [8] pay special attention to risk assessment during transportation of dangerous goods (it can influence insurance cost) and previous routing. In an article [9], the problem of fuel transportation in Sweden and methods for improvement of the safety of these operations are reviewed. Proposals both for transportation account system and monitoring of vehicles, loaded with dangerous goods are given. A somewhat different principle of special monitoring of motor transport for vehicles of the Italian Oil Company is developed by researchers in their study [10]. Other researchers [11] reviewed methods of road network (RN) construction and global routing for transportation of dangerous goods.

To increase the level of traffic safety, it is necessary to consider and improve not only the construction parameters of vehicles, standards of road management, etc., but also to forecast driving conditions [12]. Analysis of previous work points to the fact that the basis for reliable driver activity is the driver's functional state. In research [13], authors note that during driver operations, a lot of external and internal factors have an impact. All of them have a negative influence on indicators of driver operation, which can lead to a decrease in accident-free movement duration.

A. Conca, C. Ridella, and E. Sapori [14] evaluated accident statistics in Italy in relation to transport of dangerous goods (including fuel) and, after a range of tests, proposed the calculation method of transportation routing taking into account traffic intensity and density, vehicle speed on the road sections, etc.

Taking into account the sections of separate roads, the conducted research [15] indicated that geometric features of the road that define its category have a significant impact on drivers' productivity and therefore on the reliability of their operations. Accordingly, it provides an opportunity to forecast the FS of the driver in different road conditions and also to adjust vehicle routes.

During movement in dense traffic flow, the driver's capability to engage in high level of safe driving manifests [16]. The road volume–capacity ratio has a direct influence on movement comfort, which is linked to the FS of the driver. Especially, it is linked to transportation of dangerous goods, where the cost of a driver's mistake is extremely high.

Based on theoretical coefficients that characterize traffic conditions, V. Silianov proposed and recommended 4 levels of service [17]:

- Level of service A. It is described by free movement in the flow; the volume–capacity ratio is $Z \leq 0,2$.
- Level of service B. The average speed of traffic flow movement is reduced, overtaking maneuvers occur, and vehicles in the flow divide into groups. Z = 0,2-0,45.
- Level of service C. Further reduction of speed of movement occurs. Traffic flow divides into separate large groups. Z = 0,45-0,7.
- Level of service D. Traffic motion is extremely complicated and vehicles move in a column at low speeds, Z = 0,7-1,0.

Canadian scientists studied risks linked to transportation of dangerous goods through settlements [18]. Analysis of the change in transportation costs depends on the measure of the vehicle route`s deviation. However, for the present study, they could not set the balance between acceptable risk and optimal transportation costs as it directly depends on route length.

M. Dziubiński [19] proposed three different methods for assessment and further analysis of risk, which are given in fig. 1. Among them, there are qualitative, quantitative, and semi-quantitative methods of risk assessment. The difference between them is in the different numbers and nature of input data and the method of calculation and interpretation of results.

This author proposed a method for the determination of causes of failures, mistakes, and possible consequences. It includes the calculation of individual and social risks [20].

The Tomassoni methodology feature considers combination of qualitative and quantitative methods of assessment (fig. 2). Semi-quantitative methods are used for the determination of possible accidents [21].

As can be seen from figs. 1 and 2, the authors use one of the most promising methods of probability. Depending on the information available, these methods are divided as follows: statistical, when the probability can be determined by statistical data, and theoretical-probabilistic, when statistics are almost absent.

The results of previous works are showing that the largest number of recommendations for the provision of traffic safety is developed with the use of qualitative methods. However, quantitative methods of risk assessment can be considered as the only acceptable methods for comparison of various kinds of dangers [22].

Transport process simulation in the city of Lisbon is also related to the interrelation of risks of occurrence of accidents and the calculation of fuel transportation costs across city gas stations [23]. It should be noted that in this work, the methods of graph theory were used for making an optimal decision. A similar task was reviewed by Iranian scientists in their paper [24].

Despite the large number of studies on the nature of risks and their occurrence in different fields, there is no strict definition of risks during transportation of dangerous goods in the literature at present [21].

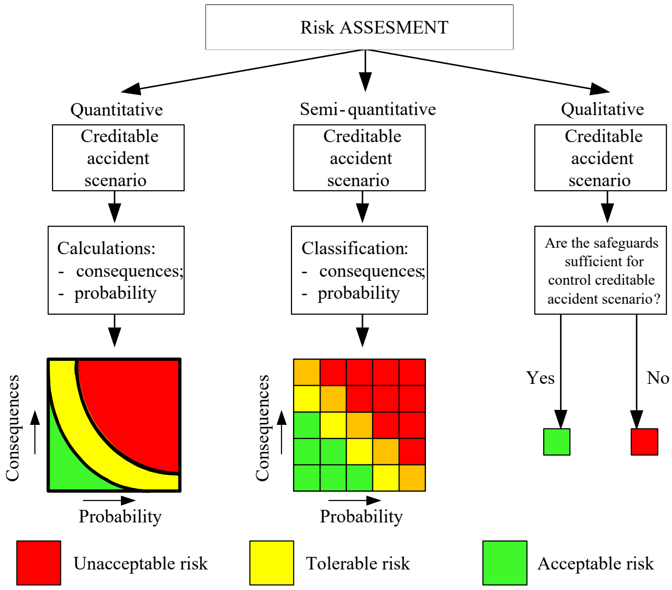

Fig. 1. Risk assessment methods by M. Dziubiński [19]

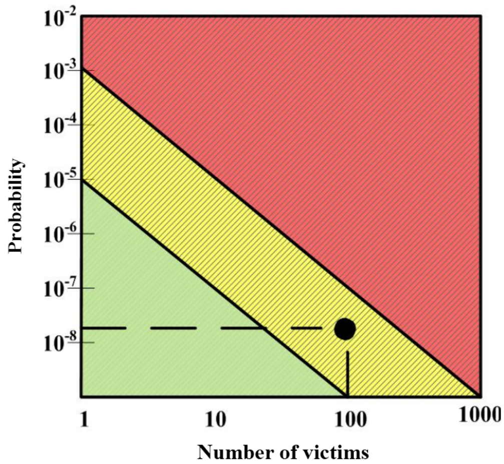

Fig. 2. Determination of risk level using the method of A. Tomassoni

4. REGULARITIES OF CHANGES IN THE DRIVER`S FUNCTIONAL STATE IN DIFFERENT TRAFFIC CONDITIONS

As traffic conditions have the biggest impact on the FS of the drivers, we carried out extensive research during transportation of dangerous goods (in our case, oxygen in balloons) by different routes, using special vehicles for this type of cargo.

Vehicle routes were characterized by the following conditions:

a) during movement in settlements:
- No fewer than 3 consumers were allowed to be present;
- the general length of the route was 65-85 km depending on the characteristics of the orders;
- the driver`s working hours were 6-8 h depending on the amount of work and the road conditions;
- working hours of goods delivery were from 8:00 to 18:00;

- movement on the main streets and local streets with different lanes (1-3 in one direction); and
- areas of human presence (mostly on main streets) composed by 10-30% from the length of the route;

b) during movement outside settlements:
- the general length of the route was 170-300 km depending on the number of consumers and their location;
- the route was characterized by changes in road conditions; the following typical road segments were marked out:
  - the first type: road segments with one or two lanes in one direction that were on flat-bottom land with radii of horizontal curves more than 1000 m and sections of ascending with slopes (*i*) up to 30‰ (called light road conditions);
  - the second type: road segments that moved from flat-bottom land to mountains (or vice versa), where radii of horizontal curves (*R*) were within 600 – 1000 m and sections with longitudinal slopes were within 35-50‰ with a length of 300-1000 m (called complicated road conditions);
  - the third type: road segments on which the limited visibility was typical, topographic elevation was more than 500 m above sea level, radii of horizontal curves less than 600 m and longitudinal slopes more than 50‰ with a length of 500-1500 m (called dangerous road conditions);
- presence of people on sections and vehicle crowding: zones of public transport stops and other points where pedestrians and passengers can be found, located at a distance of 15-50 m from the roadway. The total proportion of such sections was 3-5% in the total length of the route.

Investigation of traffic intensity was carried out by the videotape method and density – by photofixation of RN sections by which the route runs. FS of drivers was recorded using the device Polar H7 and the mobile application CardioMoodLite. The results were saved and processed in the program software CardioMood. The stress index (SI) of regulatory systems was chosen as the main indicator that reflects the current FS of the driver quantitatively (normally, it is 100-150 c. u.; during an increase in psycho-emotional load on a person, this increases).

Because, during dangerous goods transportation, unauthorized persons are not allowed in a vehicle cabin, all the recording was performed automatically. Before the start of the operation, the driver attached the device on himself for the recording of electrocardiogram indicators and connected it to a smartphone. The coordinates of the vehicle in space and time were received by a satellite receiver in a video recorder. After the records were processed, the data received were transformed into systematized views for further analysis.

Based on the results obtained during the research, first, the complexity of the drivers` SI distribution in different road conditions was determined.

A sample of 200 observations during the transportation of oxygen in balloons by specialized vehicles was subjected to analysis. The empirical and theoretical distributions of SI in different traffic conditions within the settlement were obtained (Fig. 3).

Analysis of the given data shows that the level of divergence between experimental and theoretical data is not critical, which is confirmed by frequency and cumulative distributions. It additionally confirms the form of a histogram and theoretical curve (Fig. 4), as the probability of agreement of the experimental data distribution with the theoretical normal is $p=0,73$. According to this, we can confirm that the distribution of drivers` SI is normal.

Similarly, the sample of SI values in the RN level of service „B" was analyzed. The obtained results are shown in figs. 5-6.

Values of drivers` SI during movement in RN sections with higher volume–capacity ratios are bigger, but the majority of these are within permissible limits (200-250 c. u.).

The results of the experimental data distribution obtained can also be described by the normal distribution, as evidenced by the probability of agreement, $p=0,73$.

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 168,55556	16	16	8,00000	8,0000	15,52429	15,5243	7,76215	7,7621	0,47571
173,11111	17	33	8,50000	16,5000	18,49647	34,0208	9,24824	17,0104	-1,49647
177,66667	26	59	13,00000	29,5000	28,65780	62,6786	14,32890	31,3393	-2,65780
182,22222	43	102	21,50000	51,0000	35,82493	98,5035	17,91247	49,2517	7,17507
186,77778	29	131	14,50000	65,5000	36,13473	134,6382	18,06736	67,3191	-7,13473
191,33333	32	163	16,00000	81,5000	29,40773	164,0460	14,70386	82,0230	2,59227
195,88889	21	184	10,50000	92,0000	19,31024	183,3562	9,65512	91,6781	1,68976
200,44444	10	194	5,00000	97,0000	10,23029	193,5865	5,11514	96,7932	-0,23029
< Infinity	6	200	3,00000	100,0000	6,41352	200,0000	3,20676	100,0000	-0,41352

Fig. 3. Numerical values of empirical and theoretical distributions of drivers` SI in the RN level of service „A”

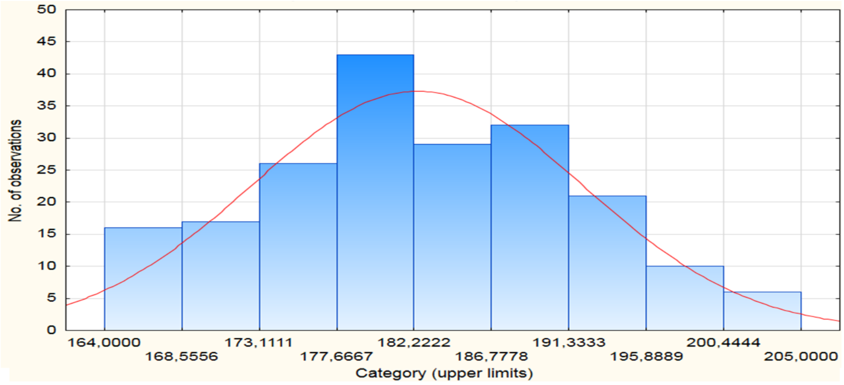

Fig. 4. Distribution of drivers` SI when driving the vehicle with dangerous goods within settlements in the RN level of service „A”

Upper Boundary	**Observed Frequency**	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 209,44444	15	15	7,50000	7,5000	15,78706	15,7871	7,89353	7,8935	-0,78706
217,88889	16	31	8,00000	15,5000	16,26868	32,0557	8,13434	16,0279	-0,26868
226,33333	28	59	14,00000	29,5000	24,51692	56,5727	12,25846	28,2863	3,48308
234,77778	32	91	16,00000	45,5000	31,07795	87,6506	15,53897	43,8253	0,92205
243,22222	39	130	19,50000	65,0000	33,13724	120,7879	16,56862	60,3939	5,86276
251,66667	29	159	14,50000	79,5000	29,72071	150,5086	14,86035	75,2543	-0,72071
260,11111	21	180	10,50000	90,0000	22,42222	172,9308	11,21111	86,4654	-1,42222
268,55556	11	191	5,50000	95,5000	14,22884	187,1596	7,11442	93,5798	-3,22884
< Infinity	9	200	4,50000	100,0000	12,84038	200,0000	6,42019	100,0000	-3,84038

Fig. 5. Numerical values of empirical and theoretical distributions of drivers` SI in the RN level of service „B”

Distributions of SI values in RN levels of service „C” and „D” were investigated (figs. 7-8).

These levels of service have a significant impact on drivers` SI, which is confirmed by SI values, which frequently exceed 300 c. u. This indicates the state of expressed nervous and emotional stress during driving. In terms of the distribution, then, there are no critical differences between the values of empirical and theoretical quantities ($p=0,63$).

Similar to the reported results, an analysis of the characteristics of SI distribution of drivers who transport dangerous goods by road on routes with segments of different complexities was carried out. In Figs. 9–10, the characteristics of SI distribution in dangerous road conditions are presented.

The obtained distribution can be described as normal ($p = 0,70$).

Previous research results showed that the FS of drivers who travel by road in complicated road conditions is not always satisfactory because drivers are in a state of pronounced stress. In such conditions, all the obtained values of SI can have high scatter rates but show a normal distribution. The characteristics of this distribution are shown in Figs. 11-12.

The hypothesis about the description of the SI indicator as having a normal distribution can be accepted despite the slightly lower value of the probability of agreement $p = 0,62$.

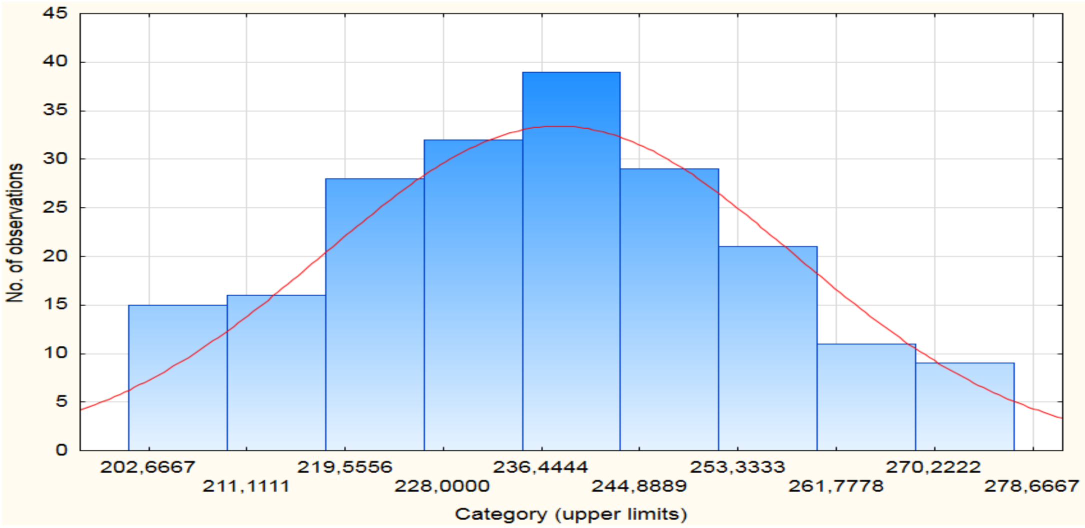

Fig. 6. Distribution of drivers` SI while driving the vehicle with dangerous goods within settlements in the RN level of service „B"

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 273,11111	31	31	15,50000	15,5000	23,92571	23,9257	11,96286	11,9629	7,07429
279,22222	19	50	9,50000	25,0000	21,45621	45,3819	10,72811	22,6910	-2,45621
285,33333	29	79	14,50000	39,5000	29,41787	74,7998	14,70894	37,3999	-0,41787
291,44444	33	112	16,50000	56,0000	33,68182	108,4816	16,84091	54,2408	-0,68182
297,55556	36	148	18,00000	74,0000	32,20394	140,6856	16,10197	70,3428	3,79606
303,66667	20	168	10,00000	84,0000	25,71287	166,3984	12,85644	83,1992	-5,71287
309,77778	16	184	8,00000	92,0000	17,14413	183,5426	8,57206	91,7713	-1,14413
315,88889	10	194	5,00000	97,0000	9,54541	193,0880	4,77270	96,5440	0,45459
< Infinity	6	200	3,00000	100,0000	6,91203	200,0000	3,45601	100,0000	-0,91203

Fig. 7. Numerical values of empirical and theoretical distributions of drivers` SI in the RN level of service „C" and „D"

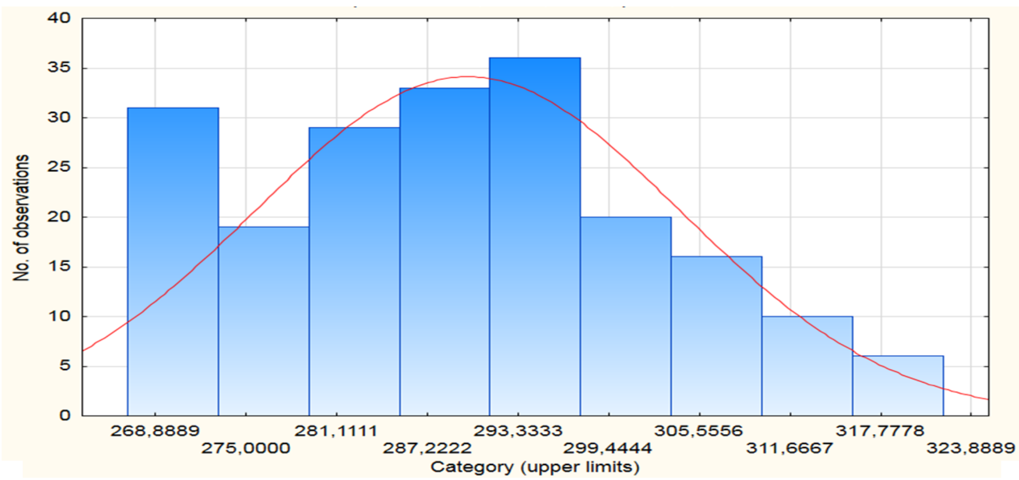

Fig. 8. Distribution of drivers` SI while driving the vehicle with dangerous goods within settlements in the RN level of service „C" and „D"

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 221,11111	2	2	1,00000	1,0000	3,49893	3,4989	1,74946	1,7495	-1,49893
248,22222	11	13	5,50000	6,5000	8,04136	11,5403	4,02068	5,7701	2,95864
275,33333	19	32	9,50000	16,0000	18,28213	29,8224	9,14106	14,9112	0,71787
302,44444	28	60	14,00000	30,0000	31,45396	61,2764	15,72698	30,6382	-3,45396
329,55556	46	106	23,00000	53,0000	40,95617	102,2325	20,47808	51,1163	5,04383
356,66667	41	147	20,50000	73,5000	40,36275	142,5953	20,18137	71,2976	0,63725
383,77778	32	179	16,00000	89,5000	30,10637	172,7017	15,05318	86,3508	1,89363
410,88889	12	191	6,00000	95,5000	16,99526	189,6969	8,49763	94,8485	-4,99526
< Infinity	9	200	4,50000	100,0000	10,30308	200,0000	5,15154	100,0000	-1,30308

Fig. 9. Numerical values of empirical and theoretical distributions of drivers` SI in dangerous road conditions

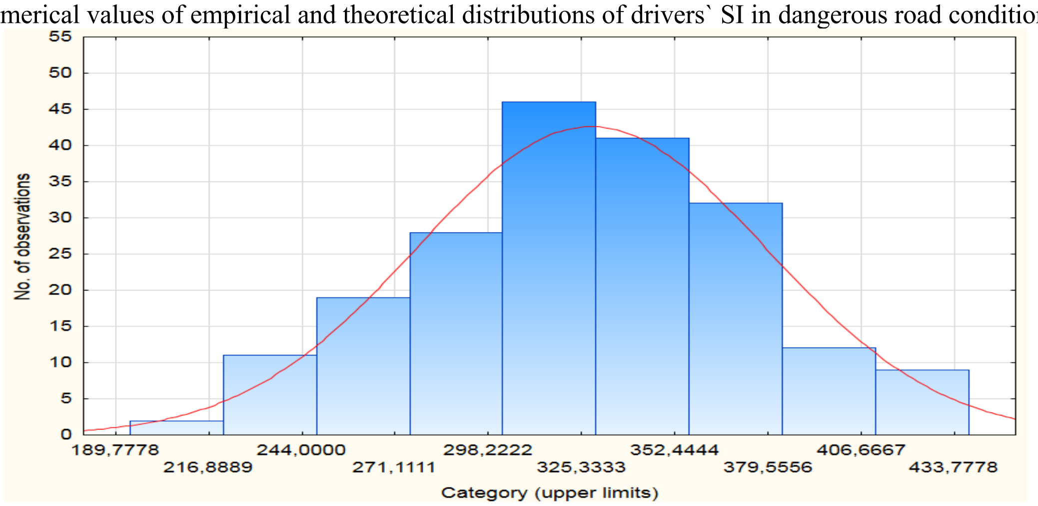

Fig. 10. Distribution of drivers` SI while driving the vehicle with dangerous goods outside settlements in dangerous road conditions

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 126,66667	19	19	9,50000	9,5000	15,52325	15,5233	7,76163	7,7616	3,47675
163,33333	19	38	9,50000	19,0000	25,03001	40,5533	12,51500	20,2766	-6,03001
200,00000	41	79	20,50000	39,5000	40,30368	80,8569	20,15184	40,4285	0,69632
236,66667	49	128	24,50000	64,0000	46,30172	127,1587	23,15086	63,5793	2,69828
273,33333	39	167	19,50000	83,5000	37,95240	165,1111	18,97620	82,5555	1,04760
310,00000	20	187	10,00000	93,5000	22,19429	187,3054	11,09715	93,6527	-2,19429
346,66667	10	197	5,00000	98,5000	9,25815	196,5635	4,62908	98,2818	0,74185
383,33333	2	199	1,00000	99,5000	2,75401	199,3175	1,37700	99,6588	-0,75401
< Infinity	1	200	0,50000	100,0000	0,68248	200,0000	0,34124	100,0000	0,31752

Fig. 11. Numerical values of empirical and theoretical distributions of drivers` SI in complicated road conditions

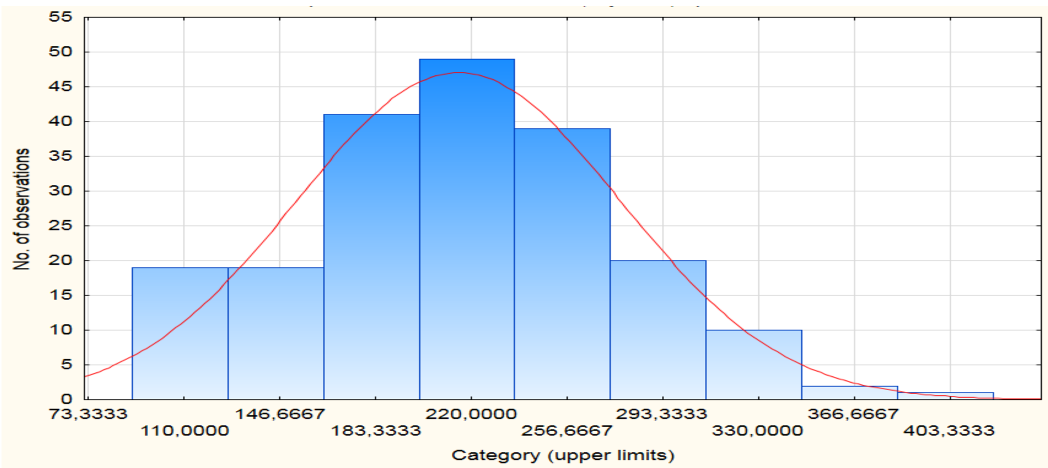

Fig. 12. Distribution of drivers` SI while driving the vehicle with dangerous goods outside settlements in complicated road conditions

Based on the obtained distributions that describe the distributions of real data, the probability of obtaining such a value of the SI indicator (*P(SI)*) can be determined, which corresponds to the state of nervous and emotional overstress. Taking into account the fact that the values of drivers` SI are described by a normal distribution, this probability can be determined by z-standardization using the following formula:

$$z = \frac{x - \mu}{\sigma} \quad (1)$$

where x is the value according to which the appropriate probability is calculated; μ is the average value; and σ is the average deviation.

Based on the obtained value z, from the z-table, the area under the curve is chosen, which corresponds to the probability of obtaining the required value.

The probability of obtaining an SI value that indicates that the FS of the driver is unsatisfactory will take the following form:

$$P(SI) = 1 - z = 1 - (\frac{x - \mu}{\sigma}) \quad (2)$$

Calculations of probability by this equation were carried out for different RN volume–capacity ratios and road conditions. The results for levels of service „C" and „D" are given in fig. 13. SI > 300 c. u. is accepted as the extreme value of SI, which corresponds to the state of overstress, and this state is unsatisfactory.

The shaded area under the curve of the distribution corresponds to the probability of obtaining an SI value > 300, confirming that the driver is in a state of nervous and emotional overstress while transporting dangerous goods. From calculations for levels of service „A" and „B", the reliability of drivers' operation is found to be high: $P(SI)=10^{-7}$ and 10^{-2}, respectively. For levels of service „C" and „D", the probability of obtaining SI > 300 is *P(SI)=0,24*.

Similar investigations were carried out with values obtained during the research while driving on roads outside settlements. The results are given in the form of standardized distributions, which are shown in fig. 14.

Calculations show that while driving in difficult road conditions, the probability safe operations in a satisfactory FS is *P(SI)=0,87* for drivers, and for dangerous road conditions, it is only *P(SI)=0,33*. The results obtained were used to determine risk levels and to assess the danger of these kinds of transportation in different conditions.

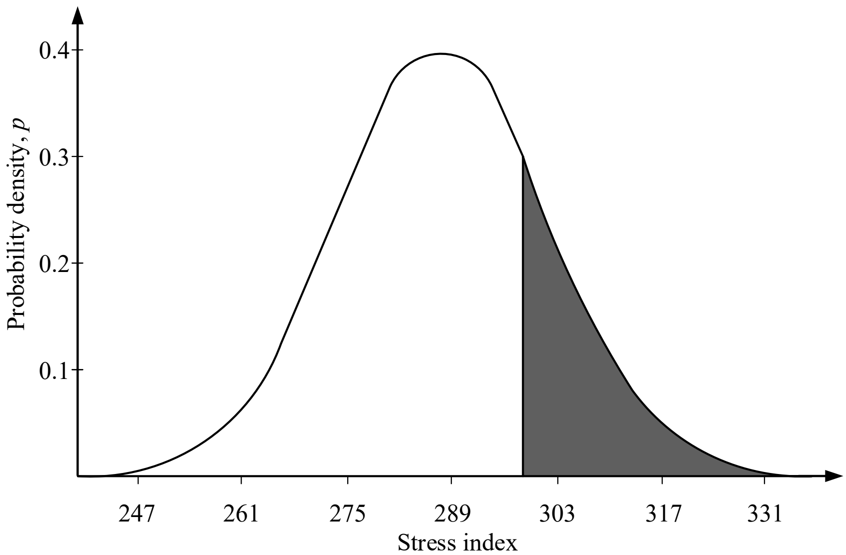

Fig. 13. Standardized distributions of drivers` SI while transporting dangerous goods within settlements for levels of service „C" and „D"

5. METHODOLOGY FOR RISK LEVEL ASSESSMENT DURING TRANSPORTATION OF DANGEROUS GOODS CONSIDERING THE FUNCTIONAL STATE OF THE DRIVER

While carrying out research on the route within settlements, the sections with a dense population and housing areas, and vehicle crowding were determined. The total length of such sections was 8,8 km, with a total length of the route of 80 km. In such sections, the density of people (drivers, pedestrians, visitors to street shops) was 8-10 persons per 100 m^2. During the transportation of dangerous goods within settlements, the probability of the vehicle traveling on such a section was *P(l)=8,8/80=0,11.*

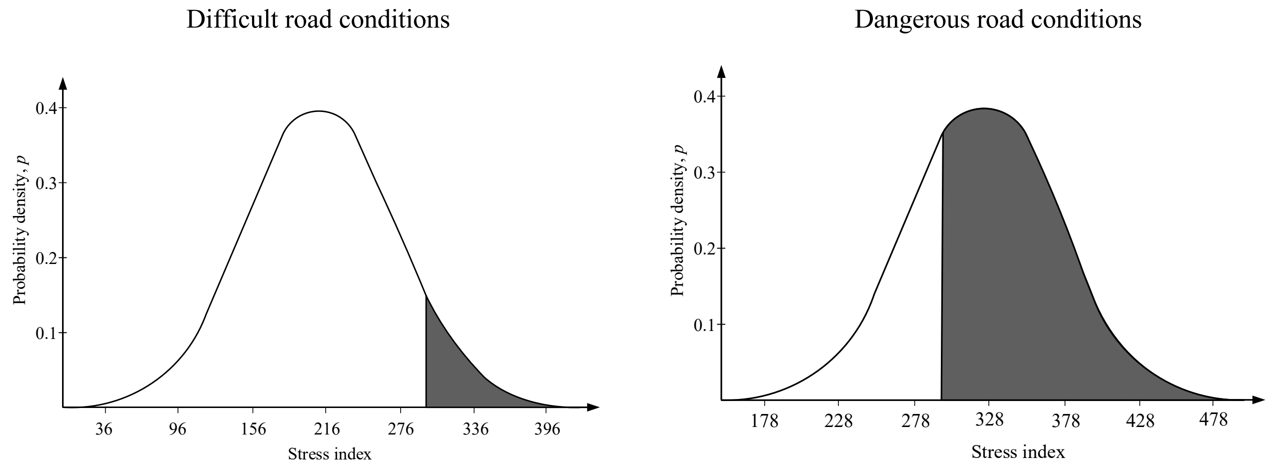

Fig. 14. Standardized distributions of drivers` SI while transporting dangerous goods in different road conditions

If the transportation route is outside settlements by road, then, sections with crowding of vehicles and people are much less common. However, in such conditions, the road is frequently in small settlements, where there are service facilities or construction areas at a small distance from the roadway. The density of people in such sections is much less than in cities and is 0,5-1,0 persons per 100 m^2 (taking into account drivers of other vehicles). The length of these sections on the investigated route (280 km) is 3–8 km. In this case, the probability of occurrence in this section during transportation of dangerous goods is *0,019.*

Based on the obtained results, the probability that the driver`s SI will not meet the regulatory values required on this route can be determined. In such conditions, the risk of occurrence of adverse consequences as a result of an accident is the highest. This probability is calculated by an alternative formula of Bayes` theorem as follows:

$$P(A/B) = \frac{P(B/A)\cdot P(A)}{P(B/A)\cdot P(A) + P(B/\neg A)\cdot P(\neg A)}, \tag{3}$$

where *P (A)* is the probability of occurrence in a section with the presence of people; *P (A/B)* is the conditional probability of occurrence on the section with the presence of people at a certain moment in time at an SI value that is higher than admissible; *P (B/A)* is the probability of obtaining an SI value that is higher than admissible on the section with crowds of people; *P (¬A)* is the conditional probability of occurrence on the section without the presence of people; *P (B/¬A)* is the conditional probability of obtaining an SI value higher than admissible on the section without the presence of people. In this formula: *P(B/A)=P(SI); P(A)=P(l);* and *P(¬A), P(B/¬A)* – from figs. 13 and 14.

Taking into account formulas (2) and (3), the probability that the driver`s SI will be higher than normative, conditional probability, takes the following form:

$$P(A/B) = \frac{(1-(\frac{x-\mu}{\sigma}))\cdot P(A)}{(1-(\frac{x-\mu}{\sigma}))\cdot P(A) + P(B/\neg A)\cdot P(\neg A)}. \tag{4}$$

For calculation, one typical section within the settlement was chosen with levels of service „C" and „D" and in movement on roads outside settlements – segments that are considered difficult and dangerous in terms of road conditions. Based on formula (4), the probabilities of occurrence of SI > 300 were determined during movement as follows:

- in cities with dense vehicle and pedestrian movements:

$$P(A/B) = \frac{0,11 \cdot 0,24}{0,11 \cdot 0,24 + 0,89 \cdot 0,76} = 0,038;$$

- on roads with difficult conditions:

$$P(A/B) = \frac{0,019 \cdot 0,13}{0,019 \cdot 0,13 + 0,98 \cdot 0,87} = 0,003;$$

- on roads with dangerous conditions:

$$P(A/B) = \frac{0,019 \cdot 0,67}{0,019 \cdot 0,67 + 0,98 \cdot 0,33} = 0,038.$$

The obtained results can be considered to be conclusive for the risk assessment.

To conclude on the acceptance or infeasibility of a certain type of risk, it is also necessary to know the extent of injury as a result of a possible accident. The determination of the severity of injuries is based on the number of people who may be within the radius of damage. Also, the probability of occurrence of an SI indicator that indicates that a driver‘s FS is unsatisfactory on a given route is considered.

The number of people who can be affected after the explosion of a dangerous substance is calculated by the following formula:

$$n_{dam} = \left(\frac{\pi R_{dam}^{2}}{100} \right) \cdot q_p \quad (5)$$

where R_{dam} is the radius of the damage zone; q_p is the number of people who within a radius of 100 m^2 of the potential accident area.

Taking into account the conducted research, during which transportation of oxygen balloons on RN and roads outside settlements was carried out, it is clear that the consequences of an accident can be severe. This can be attributed to the radius of lethal damage of 18 – 20 m after the explosion of oxygen balloons. According to this, the number of injured people in areas with crowding of people (from formula 5) can be 100-110 persons within the settlement and– 10-15 persons outside the settlement.

To determine the risk level for a specific case, it is necessary to determine the position of a point in the plane as indicated in fig. 2. The abscissa of the point is determined by formula 5 (in this case, 100 and 15 persons). Position on the y-axis is determined as the probability of the appearance of a vehicle (*P(A/B)*) on the section with crowding of people, and the driver has unsatisfactory FS at this moment. This value increases with the conditional probability of occurrence of accidents (for calculations of the probability of accidents, different sources suggest $25 \cdot 10^{-7}$ accidents per year by 1 millions of automobile kilometers). Taking into account the previous results, we can find the positions of points in the plane that correspond to specific road conditions (by analogy with fig. 2). By their position, we can determine the level of risk acceptance (Table 1). Therefore, based on the obtained results, we can state that the risks for different conditions need to be reduced. These results assess risks during the transportation of a specific type of freight (oxygen in balloons) for specific features of dangerous segments; therefore, for other variants of transportation (only the second class of danger), the value of potential risks can be different, considering their explosiveness.

Research focuses on the process of transporting dangerous goods that belong to the second class. This limits the use of the proposed methodology for other cargo types in connection with the technical and ergonomic characteristics of vehicles. The regularities of FS changes of drivers under various road conditions are established for specific vehicles, and consequently, for one dangerous freight class. The impact of changing the magnitude of road conditions on the driver's FS while transporting other goods classed as dangerous is high due to differences in vehicle characteristics. This should be researched further, and transport of other types of dangerous goods should be covered.

6. CONCLUSIONS

Analysis of literary sources of the features of transportation of dangerous goods confirmed that despite the presence of a large number of norms and rules in this field, and also scientific research, the question of the role of the human factor (driver) in this process remains unclear. In research relating to the psychophysiology of the driver, the question of the change of their FS is covered insufficiently. Methods of investigation of the complexity of road conditions and drivers` FS are well known and widely used as the main features that define the nature of their work and have a direct impact on traffic safety. Experimental research on the changes of the driver`s FS, which was assessed by the values of SI, was conducted in this article. Complicated and dangerous road conditions (longitudinal slopes are more than 30‰, radii of horizontal curves are less than 1000 m, and the volume–capacity ratio is more than 0,5) cause the deterioration of indicators of the driver`s FS by 1,5 – 2,0 times. This is confirmed by the values of the SI of more than 200 c. u.

Table 1

Risks during the transportation of oxygen balloons considering the human factors and road conditions

		Movement within the settlement		
		Level of service		
		«A»	«B»	«C/D»
Length of dangerous sections (from the general), %	10%	acceptable	acceptable	allowable
	20%	acceptable	acceptable	unacceptable
	30%	acceptable	allowable	unacceptable
	40%	acceptable	allowable	unacceptable
	50%	acceptable	allowable	unacceptable
		Movement outside the settlement		
		Complexity of road conditions		
		Light	Complicated	Dangerous
Length of dangerous sections (from the general), %	3%	acceptable	acceptable	allowable
	5%	acceptable	acceptable	allowable
	10%	acceptable	acceptable	allowable
	15%	acceptable	acceptable	allowable
	20%	acceptable	acceptable	allowable

A new scientific approach to the risk assessment during transportation of dangerous goods considers both the impact of peculiarities of the road conditions on the driver`s FS and the possibility of accidents on roads and street sections. According to this, the method was developed for such road conditions when the probability of obtaining an SI was greater than permissible, and it (probability) includes an additional factor that increases risks in the technological process of transportation of dangerous goods. Besides, the features of the route of transportation and explosiveness of freight are included in the risk assessment.

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