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DETERMINE THE SAFE TRANSPORT OF DANGEROUS GOODS ROUTE

Summary. The methods of conflict situations assessment were analyzed, and it was established that the main shortcoming is the disregard of the probability of occurrence of the RTA involving an individual road user. Based on the factor analysis conducted, the non-linear model of the probability of the RTA occurrence in the transport network segments was developed. Also, the model of the probability of the RTA occurrence in transport junctions was improved. It will enable, if using respective optimization algorithms, working out the optimal routes for dangerous goods transportation by the minimum of the RTA occurrence probability.

ОПРЕДЕЛЕНИЕ БЕЗОПАСНОГО МАРШРУТА ПЕРЕВОЗКИ ОПАСНЫХ ГРУЗОВ

Аннотация. Рассмотрены методы оценки конфликтных ситуаций и установлено, что главным недостатком является не учет вероятности возникновения ДТП с отдельным участником дорожного движения. В результате проведенного факторного анализа была разработана нелинейная модель вероятности возникновения ДТП на участках транспортной сети. Также усовершенствована модель вероятности возникновения ДТП в транспортных узлах. Это позволит, при использовании соответствующих оптимизационных алгоритмов, строить оптимальные маршруты перевозки опасных грузов по минимуму вероятности возникновения ДТП.

1. INTRODUCTION

Both the volumes of transportation of dangerous goods, and the number of road traffic accidents (RTA) involving the vehicles carrying such goods grow steadily. But the key issue for the RTA, occurring during transportation of dangerous goods, is the overwhelming consequences there.

Thus, the Law of Ukraine «On Transportation of Dangerous Goods» stipulates that, in the presence of certain factors, the dangerous goods being carried can cause an explosion, fire, damage of technical aids, equipment, structures and other facilities, inflict material damage and harm to the environment, and result in human and animals' loss of life, injury, intoxication.

The routes for carriage of dangerous goods shall be mapped out in order to exclude the passage of the vehicle carrying dangerous goods through commercial or residential areas, environmentally sensitive areas, industrial areas with dangerous facilities, or avoid the use of the roads constituting a considerable physical danger.

That is, a carrier, guided by its personal experience, intuition, and at its own discretion, shall determine the level of danger of the transport infrastructure facilities, laying routes for carriage of dangerous goods through which is undesirable.

The only criterion enabling laying routes for the vehicles carrying dangerous goods is the minimum probability of occurrence of the RTA involving an individual road user.

2. LITERATURE REVIEW

Under the Law of Ukraine „On Road Traffic", the road traffic must be safe, cost-efficient, comfortable, friendly to the environment and human health [1].

The traffic safety assurance is the development of the modern techniques of preventing dangerous situations, in particular, road traffic accidents (RTA).

To evaluate the traffic safety, the statistical monitoring of the RTA is used, with revelation of the general trends regarding an increase and reduction in the overall number of the RTA and the consequences thereof.

The analysis of the overall number of the RTA shows only the trends and does not give consideration to severity of the consequences. To take into account severity of the RTA consequences, the RTA severity rate is given in the papers (Konoplyanko, Laureshyn) [2, 3], which is determined by the ratio between the number of killed and the number of injured in the RTA within a certain period of time.

To assess the area-based accident rate (country, region, city, primary road etc.), the index of the relative accident rate is used, taking into account of the vehicles' mileage [2, 4].

To determine the RTA distribution by other indexes (per the number of residents, per the number of vehicles, per the number of drivers, per mileage of the vehicles, per kilometers of the road), the relative accident rate is also used.

As of today, the main RTA reasons are [5-8]:

1) wrong human performance (a driver's, a passenger's, pedestrians');

2) poor road conditions and the speed of the road conditions of the traffic character;

3) a vehicle's technical fault.

The statistical data of the RTA were used to develop the classification of the types of the road traffic accidents [5, 6, 9]:

1) a collision, when moving motor vehicles hit each other or a railway vehicle;

2) a turnover, when a motor vehicle lost stability and turned over. This type of accidents does not include turnovers, resulting from collisions between motor vehicles or running over immovable objects;

3) running over immovable obstacles, when a motor vehicle run over or hit an immovable object (a bridge pillar, a tree, a fence etc.);

4) a pedestrian accident, when a motor vehicle run over a man, or a man himself stroke a moving motor vehicle due to an injury;

5) a bicyclist accident, when a motor vehicle run over a man riding a bicycle, or a man himself stroke a moving motor vehicle due to an injury;

6) running over an immovable vehicle, when a motor vehicle crashed or hit an immovable motor vehicle;

7) running over animal-drawn transport, when a motor vehicle run over draft, pack, mount animals or carts, driven by these animals;

8) running over animals, when a motor vehicle run over wild or domestic animals;

9) other accidents, that is accidents not belonging to the abovementioned types. Such accidents include tram derailing, the falling of the goods being carried on people, etc.

The existing classification and the statistical analysis techniques induced emergence of the direction of studying assessment of the RTA consequences by the degree of severity. Since there can be the following RTA consequences: material damage; minor and serious injury; severe injury resulting in disability and fatal case, the following RTA consequence severity index was proposed:

$$U = \sum_{i=1}^{n} p_i \cdot n_i , \qquad (1)$$

where: p_i – weighting factors of the RTA severity; n_i – number of the RTA of each type, units.

In different years, groups of researchers investigated the weighting factors of the RTA severity (Table 1) [10]. Variation in the values of weight coefficients is explained by different approaches to determining the period, during which a person is deemed to be dead or badly wounded.

Table 1

RTA severity weighting factors [10]

RTA type	Country, year, author					
	Germany, 1938, Reinhold	Federal Republic of Germany, 1960, Bitzl	German Democratic Republic, 1967, Fisher	USSR, 1968, Divochkin	USA, 1972	Russia, 2003
No casualties	1	1	1	3	1	1
Injury: minor severe severe, causing disability	5 70	30	2 8	8,2 118,2	7	1,4 7 70
Fatal case	130	100	40	140	170	100

The shortcoming of the mentioned techniques of the road traffic safety assessment is that they take into account only quantitative indexes, and the major RTA consequence is the society's loss due to the RTA. Therefore, it was proposed to use the cost of the loss due to a certain RTA type instead of the RTA severity weighting factor.

Both the RTA severity weighting factors and the cost of certain RTA types were investigated in different types and in different countries. The main reason of differences in assessment of the RTA cost is the impossibility to make an unbiased assessment of the monetary value of a human life and health, which may be lost as a result of the RTA.

The accident rate assessment indexes listed above show only the distribution of the RTA number and consequences for different road users. That is why a system for the road traffic safety assessment was proposed, named as the linear graph method [11-13]. The method is based on two key approaches:

1) the linear graph of safety factors;
2) the linear graph of accident rates.

Analyzing the approaches of the linear graph method, one can mention the inadequate consideration of the conflict situations, emerging in traffic. It is the conflict situations that are prerequisites of the RTA.

Regardless of the great number of domestic and foreign developments in the road traffic safety assessment for further determination of the level of accident rate in transport networks, currently there is a problem of assessment of the probability of occurrence of an RTA involving an individual road user in certain road conditions in a certain period of time.

Solving this problem will enable the future use of the RTA occurrence probability as a criterion for working out the safest route when moving from a point of departure to a point of arrival.

3. ASSESSMENT OF THE PROBABILITY OF RTA IN TRANSPORT NETWORK SEGMENTS

The conducted studies made it possible to establish that the RTA occurrence probability is static as compared to such dynamic process as road traffic. In fact, the distribution of the RTA number in time is a non-uniform process and depends on many factors.

The factorial analysis revealed that the probability of a vehicle's involvement in an RTA when passing over a road segment is affected by: road conditions, characteristic of a traffic stream and the period of time, during which the vehicle is in this segment.

It is reasonable to take into account a wide range of road conditions due to the final accident rate, proposed by Babkov [11] both for country roads and urban streets and roads.

It will enable obtaining relevant probability values with equal values of accident rates and different traffic stream characteristics.

The major characteristics of the traffic streams that will be taken into account when finding the probability values are the intensities in forward and backward directions.

The third characteristic that will be taken into account in the mathematical model is the time of the vehicle staying in the road segment under study, which is expressed by this segment length.

Therefore, the probability of a vehicle's involvement in the accident in a transport network segment is a function of certain factors

$$P_{RTA} = f\left(k_a, l, \vec{F}, \overleftarrow{F}, H \right), \tag{2}$$

where: k_a is the final accident rate, calculated using Babkov's method [11]; l – the road segment length, km; $\vec{F}, \overleftarrow{F}$ – respectively, the intensities of the concurrent and countercurrent traffic streams, vehicles/hour; H – the curb-to-curb width, m.

But such probability can be obtained by developing a regression model, where the actual probability under the present conditions must be selected as the response variable.

Statistical data necessary for the study and regression models gathered during 2009-2013 in eastern Ukraine. We investigated some parts of the road Donetsk – Lugansk, Donetsk – Mariupol, Donetsk – Pershotravnevsk, Luhansk – Krasnodon, Kramators'k – Izum, Kharkiv – Vovchansk, Kharkiv – Izum, Kharkiv – Krasnohrad, Kharkiv – Poltava. The total numbers of experiments are 258 experiments. The roads were study sites that were mention in accident, and recorded and calculated the following indicators: the number of the vehicles involved in the RTA in the direction in the road segment under study within the period between the RTA, which occurred with the fixed values of the traffic intensity; respectively, the intensities of the concurrent and countercurrent traffic streams; the curb-to-curb width; the road segment length; the RTA occurrence probability.

The actual probability can be found using the RTA static data from the RTA scene according to the following relationship

$$\vec{P}_{RTA}^{\partial} = \frac{\vec{N}_{RTA}}{\vec{F}_\tau}, \tag{3}$$

where: $\vec{N}_{RTA}$ is the number of the vehicles involved in the RTA in the direction in the road segment under study within the period τ between the RTA, which occurred with the fixed values of the traffic intensity, units; τ – the time with the fixed traffic intensity range within the period between RTA, h.

Topological analysis of road Kharkiv – Vovchansk is shown in Fig. 1-2. Route was divided into 4 sectors due to the presence of different characteristics.
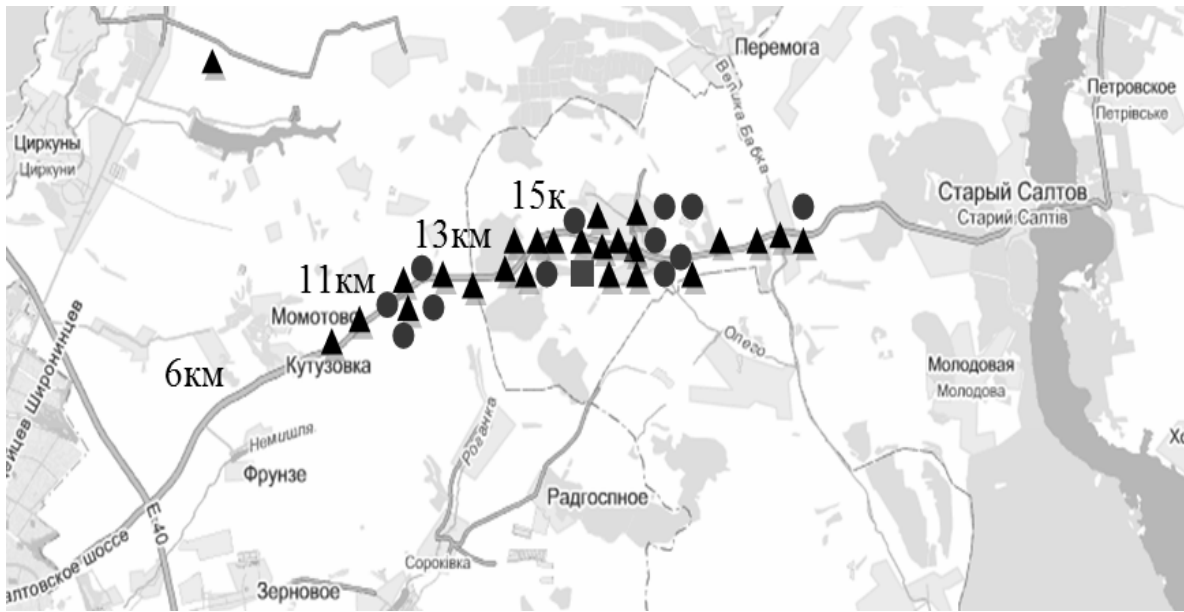
Fig. 1. The highway Kharkiv - Vovchansk with RTA in 2009:
Рис. 1. Схема дороги Харьков – Волчанск с обозначением ДТП за 2009 г.:
● - RTA with victims; ■ - RTA with the dead; ▲ - RTA without victims
● - ДТП с пострадавшими; ■ - ДТП с летальным исходом; ▲ - ДТП без пострадавших

Numbers of RTA are differed significantly for years. The decreasing of RTA without victims is observed in 2010.

Fig. 2. The highway Kharkiv - Vovchansk with RTA in 2010:
Рис. 2. Схема дороги Харьков – Волчанск с обозначением ДТП за 2010 г.:
● - RTA with victims; ■ - RTA with the dead; ▲ - RTA without victims
● - ДТП с пострадавшими; ■ - ДТП с летальным исходом; ▲ - ДТП без пострадавших

The statistical estimates and experimental studies to develop a regression model are shown in Table 2.

Table 2

The value of experimental research

Number of experiment	The traffic intensity in the countercurrent vehicle stream, $\overleftarrow{F}$, vehicle/hour	The traffic intensity in the concurrent vehicle stream, $\overrightarrow{F}$, vehicle/hour	The accident rate, k_a	The road segment length, l, km	The curb-to-curb width, H, m	The RTA occurrence probability, P_{RTA}
1	190	390	5,4	0,11	10	0,0000010213
2	520	490	7,5	0,17	6,4	0,0000081054
3	320	250	3,6	0,84	6,5	0,0000077870
4	460	500	8,2	0,28	10	0,0000114398
5	180	430	7,1	0,45	9	0,0000079429
6	700	540	6,2	0,2	11	0,0000102176
7	840	630	2,8	0,71	7	0,0000303838
8	240	340	4,5	0,55	7	0,0000071794
9	570	480	2,7	0,68	9	0,0000101890
10	370	400	3,5	0,42	7	0,0000071001
11	510	250	2,8	0,62	7	0,0000058421
12	150	310	6,9	0,24	6,5	0,0000033044
13	670	550	3,3	0,58	10	0,0000149551
14	810	960	2,2	0,69	12	0,0000212223
15	210	340	7,1	0,19	7	0,0000036471
16	540	470	5,2	0,32	8	0,0000109521
17	340	290	4,2	0,4	7	0,0000049412
18	480	220	5,6	0,37	8	0,0000048597
19	120	350	4,9	0,53	7,5	0,0000046377
20	770	700	8,5	0,28	10	0,0000253596
…	…	…	…	…	…	…
258	500	730	3,2	0,67	11	0,0000156268

We suggested finding the theoretical probability (2), where the first order linear model was selected as the mathematical model

$$Y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3 + \beta_4 \cdot x_4 + \beta_5 \cdot x_5 + \varepsilon , \tag{4}$$

where: Y – the response variable (3); $\beta_0,...,\beta_5$ – the model parameters; $x_1,...,x_5$ – respectively, variable models $k_a, l, \overrightarrow{F}, \overleftarrow{F}, H$; ε – the error of the specific value Y possible deviation from the regression curve.

The least-squares method, realized in Statistica software solution, is used to find the model parameters. Calculations in Statistica program yielded the following relation

$$P_{RTA} = \text{-}0,000016263 + 0,00000001698 \cdot \overleftarrow{F} + 0,000000027 \cdot \overrightarrow{F} +$$
$$+ \, 0,000001282 \cdot k_a + 0,00001896 \cdot l - 0,0000009323 \cdot H . \tag{5}$$

At that, the obtained pair correlation coefficients are within the limits of -0,16695 to 0,830667 (Table 3).

<div align="right">Table 3</div>

Values of pair correlation factors coefficient

Variables	$X_1(\overset{\leftarrow}{F})$	$X_2(\vec{F})$	$X_3(k_a)$	$X_4(l)$	$X_5(H)$	$Y(\overset{\rightarrow \partial}{P_{RTA}})$
$X_1(\overset{\leftarrow}{F})$	1	0,647816	-0,16695	0,177931	0,454264	0,788088
$X_2(\vec{F})$	0,647816	1	-0,23544	0,294711	0,662693	0,830667
$X_3(k_a)$	-0,16695	-0,23544	1	-0,82462	-0,19475	-0,31085
$X_4(l)$	0,177931	0,294711	-0,82462	1	0,18269	0,482065
$X_5(H)$	0,454264	0,662693	-0,19475	0,18269	1	0,447455
$Y(\overset{\rightarrow \partial}{P_{RTA}})$	0,788088	0,830667	-0,31085	0,482065	0,447455	1

But the correlation coefficient shows only the tightness and direction of the parameter connection. That is why the obtained function (5) must be checked for reliability by one of the criteria. The criterion, using the comparative evaluation between the actual and theoretical values, is the average approximation error, which will be used from this point on.

The obtained value of the approximation error $\varepsilon = 24,27$ % exceeds the universally accepted one by 15% [14]. Therefore, the mathematical model for assessment of the probability of the RTA occurrence in the transport network segments cannot be used to assess the level of the accident rate.

Using the characteristics of source data relationships (1), it was found that the traffic intensity in countercurrent and concurrent vehicle streams, the road segment length and the accident rate have a directly proportional effect, and only curb-to-curb width has the inversely proportional effect. To assess the degrees (coefficients) of the mathematical model, we use the ratio between the values of model (4) free terms and the mean probability value. As a result, we obtained the form of the mathematical model

$$Y = \frac{\left(X_1^a + X_2^b\right)\cdot X_2^c \cdot X_3 \cdot X_4 \cdot 2 \cdot 10^{-d}}{X_5} ,$$ (6)

where: Y – the RTA occurrence probability; X_1 – the traffic intensity in the countercurrent vehicle

stream, vehicle/hour; X_2 – the traffic intensity in the concurrent vehicle stream, vehicle/hour;

X_3 – the road segment length, km; X_4 – the accident rate; X_5 – the curb-to-curb width, m;

a, b, c, d – the model coefficients.

Upon completion of the simulation process and the adequacy check, it was found that for the coefficient values $a = 0,75; b = 0,35; c = 1,25; d = 10$, the theoretical probability of the RTA involving the road user described the real process, and the value of the average approximation value was 5,64%.

4. ASSESSMENT OF THE PROBABILITY OF THE RTA OCCURRENCE
IN TRANSPORTATION JUNCTIONS

Back to the basic concepts of the graph theory, the transport network consists of arcs and vertexes, where the vertexes are the transportation junctions, namely, street and road intersections. And, as is known, the level of the accident rate at the intersections depends on the vehicle's movement direction. That is why the choice of the safest movement direction at the intersection will depend on the minimum level of danger of the formed conflict points.

We found the relationship between the probability of involvement in the RTA in one of the conflict points and intensity of the intersecting directions. But only two vehicle are involved in one conflict point, therefore, the relationship will have the form of

$$P_i = \frac{50 \cdot k_i \cdot M_i \cdot N_i}{k_p \cdot 10^{14}} \cdot K_\Pi, \tag{7}$$

where: K_Π – traffic intensity reduction factor; N_i, M_i – the intensities of the streams crossing in the

conflict point, when the vehicle is passing the intersection, vehicle/day; k_i – rate of relative

accident conflict point; k_p – annual rate of uneven traffic.

The calculated probability value is the daily average. But, to assess the probability of involvement in the RTA with one road user on a certain route, the time, during which the vehicle will be passing the intersection, must be taken into account. For this purpose, let us neglect the time of the vehicle's passing through the conflict point, and consider that the probability of involvement in the RTA is proportional to the traffic intensity. Taking into account this statement, relationship (7) will have the form of

$$P_i = \frac{50 \cdot k_i \cdot M_i \cdot N_i}{k_p \cdot 10^{14}} \cdot \frac{N_{\tau i} + M_{\tau i}}{N_i + M_i}, \tag{8}$$

where: $N_{\tau i}, M_{\tau i}$ – the intensities of the streams crossing in the conflict point, when the vehicle is

passing the intersection for the time with the fixed traffic intensity range within the period between RTA, vehicle/day.

In the experiment, it was determined calculated and experimental the probability of involvement in the RTA with separate road users at different junction directions (tab. 4).

It was discovered, after performing check on the adequacy, that the estimated probability of involvement in the RTA with a separate road users at different junction directions described the real process, and the value of the average approximation value was 12.3%.

Thus, a complex of mathematical relationships was developed, which would make possible their further use as a criterion for working the safest traffic route.

5. MAPPING OUT THE OPTIMAL PATH

From the point of view of the dangerous goods transportation, the optimal path is a vehicle's route passing through the elements of the street-road network, ensuring the maximum traffic safety by the selected criterion. The additional limitation for the route selection is the specified list of streets and roads, where dangerous goods can be carried. To solve the problem of finding the optimal path for carriage of dangerous goods, it is necessary to:

1) find the numerical values of the RTA occurrence probability, for which:
  − evaluate the road conditions;
  − assess characteristics of traffic streams;
2) construct the weighted or graph of the transport network;
3) develop the algorithm for laying the optimal route, considering the limitations related to specific features of the street-road network.

The specific feature of the first item is that the probability of involvement in the RTA between the points of departure and arrival is the function of three time characteristics, namely:

$$P_{ij} = f\left(\tau_\partial, \tau_T, \tau_p\right), \tag{9}$$

where: P_{ij} – the probability of involvement in the RTA when travelling between points i and j; τ_∂ –

the characteristic by times of the day; τ_T – the characteristic by days of the week; τ_p – the

characteristic by months of the year.

Table 4

Calculated and experimental the probability of involvement in the RTA with separate road users at different junction directions

Number of experiment	Rate of relative accident conflict point, k_i	Number of vehicles at the junction of the period τ, $N_{\tau i} + M_{\tau i}$	The intensities of the streams crossing in the conflict point, when the vehicle is passing the intersection, vehicle/day		The probability of involvement in the RTA	
			M_i	N_i	Formula (7)	Experiment
1	0,0001	55860	27350	18740	0,0000003106	0,0000003261
2	0,000968	15680	32000	9600	0,0000005604	0,0000005240
3	0,0001	115320	53300	8940	0,0000004414	0,0000004957
4	0,000102	48750	8360	12000	0,0000001225	0,0000001085
5	0,000968	28900	27350	22050	0,0000017076	0,0000018476
6	0,000968	18380	14040	8226	0,0000004614	0,0000004319
7	0,000048	85400	39510	5868	0,0000001047	0,0000001571
8	0,000968	39340	25560	15480	0,0000018357	0,0000014961
9	0,000102	59870	8874	16965	0,0000001779	0,0000002049
10	0,0001	39840	14040	16560	0,0000001514	0,0000001480
11	0,000207	214800	41000	240	0,0000000530	0,0000000186
12	0,000968	28765	30800	11770	0,0000011856	0,0000010872
13	0,0001	68920	24090	10505	0,0000002521	0,0000002894
14	0,000048	79300	8140	57310	0,0000001357	0,0000001139
15	0,000207	165200	180	14600	0,0000000304	0,0000000529
....	....	....	....	....	....	....
836	0,000048	71300	35000	6650	0,0000000956	0,0000001081

The probability values depending on the time characteristics are found by constructing the matrix (Table 5).

The specificity of the second item consists in the fact, that street and road intersections are the transport network elements. They are vertexes in the oriented graph of the transport network. As a rule, when mapping out the optimal route, the weight of the vertex is neglected, while it is deemed to be a point (Fig. 3a). But it cannot be neglected with regard to assurance of safety when carrying dangerous goods, because the movement direction (straight, leftward, rightward) affects the overall assessment of the probability of involvement in the RTA (Fig. 3b).

Table 5

Matrix of assessment of the probability of involvement in the RTA depending on the time of the day, day of the week and month of the year

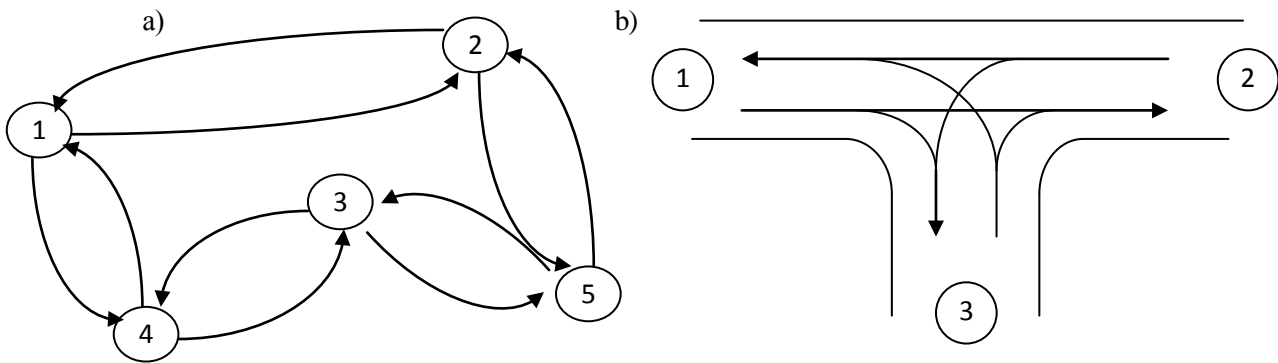| Time of the day , τ_{∂}	Day of the week, τ_T					Month of the year, τ_p
	1	2	3	…….	k	
1	P_{ij}^{111}	P_{ij}^{121}	P_{ij}^{131}	…….	P_{ij}^{1k1}	1
2	P_{ij}^{212}	P_{ij}^{222}	P_{ij}^{232}	…….	P_{ij}^{2k2}	2
3	P_{ij}^{313}	P_{ij}^{323}	P_{ij}^{333}	…….	P_{ij}^{3k3}	3
. . . .	. . . .	. . . .	. . . .	. . .	. . . .	. . . .
m	P_{ij}^{m1n}	P_{ij}^{m2n}	P_{ij}^{m3n}	…….	P_{ij}^{mkn}	n

Fig. 3. The oriented graph fragment (a) and T-junction schematic (b):

Рис. 3. Фрагмент ориентированного графу (а) и схема Т- Образного перекрестка (б):

- the graph vertex (transport junction)
- вершина графа (транспортный узел)
- the number of the approach to the junction;
- номер подхода к перекрестку;
- the arc of the graph (the street-road network segment);
- дуга графа (участок улично-дорожной сети);
– movement direction.
– направление движения

Therefore, each vertex must be presented as a separate oriented graph, with the vertexes – areas of the beginning of the intersection, and the arcs – the vehicle turn-off directions (Fig. 4).

According to relationship (8), the matrix of the probability of involvement in the RTA on the junction depending on the time of the day, day of the week and month of the year will have the following form (Table 6).
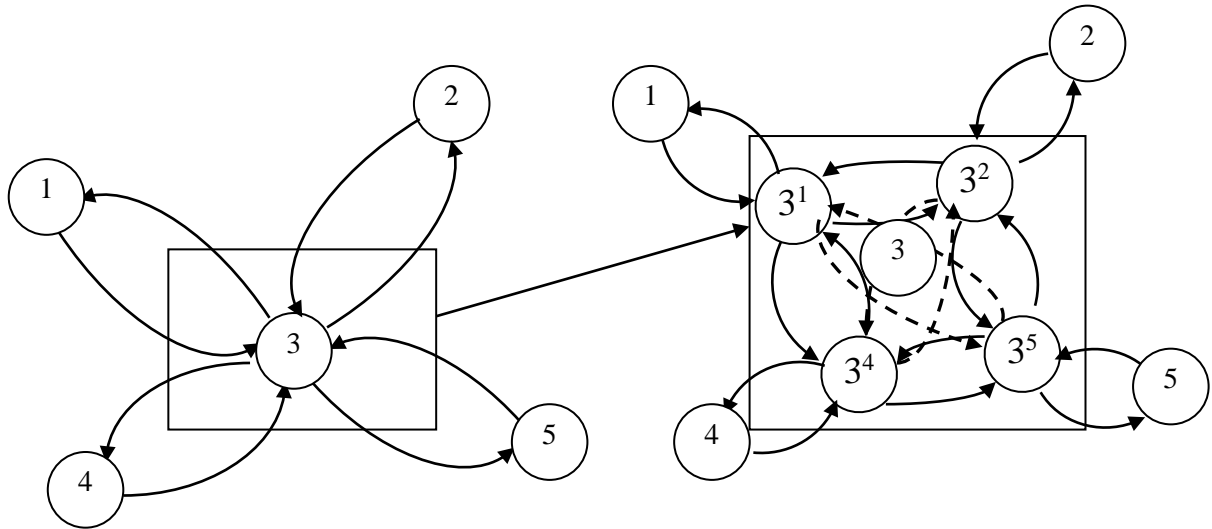
Fig. 4. The oriented graph fragment
Рис. 4. Фрагмент ориентированного графа

Table 6

Matrix of assessment of the probability of involvement in the RTA on the junction depending on the time of the day, day of the week and month of the year

Time of the day, τ_{∂}	Day of week, τ_T					Month of the year, τ_p
	1	2	3	…….	k	
1	P_{ijg}^{111}	P_{ijg}^{121}	P_{ijg}^{131}	…….	P_{ijg}^{1k1}	1
2	P_{ijg}^{212}	P_{ijg}^{222}	P_{ijg}^{232}	…….	P_{ijg}^{2k2}	2
3	P_{ijg}^{313}	P_{ijg}^{323}	P_{ijg}^{333}	…….	P_{ijg}^{3k3}	3
. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
m	P_{ijg}^{m1n}	P_{ijg}^{m2n}	P_{ijg}^{m3n}	…….	P_{ijg}^{mkn}	n

The last phase is the development of the algorithm of the optimal route mapping out. The distinction of the proposed criterion – the probability of involvement in the RTA – is its mathematical features. It is known that all the algorithms of the search for the optimal route use the relationship

$$y_j = \min_{(i,j)\in\text{network}} \left[y_i + x_{ij} \right], \tag{10}$$

where: y – potential point; j – the point of arrival; i – the point of departure; x_{ij} – the optimization criterion (distance, time etc.).

If use the probability as a criterion, the following condition shall be observed

$$\sum_{i=1}^{n} p_i = 1. \tag{11}$$

That is why the following relationship is used to solve similar problems in the theory of probability:

$$1 - (1 - p_1) \cdot (1 - p_2) \cdot (1 - p_3)...............(1 - p_n), \tag{12}$$

where: $(1 - p)$ – the probability of the successful result.

Having assessed the probability of the RTA occurrence in the elements of the street-road network, it is necessary to obtain the optimal route. Fig. 5 show a fragment of circuit topology of the road network, which shows the optimal route in terms of the minimum probability of involvement in the RTA. The probability of involvement in the RTA in the arc of the graph is shown, the probability of involvement in the RTA in the transport junction is shown in Table 7.
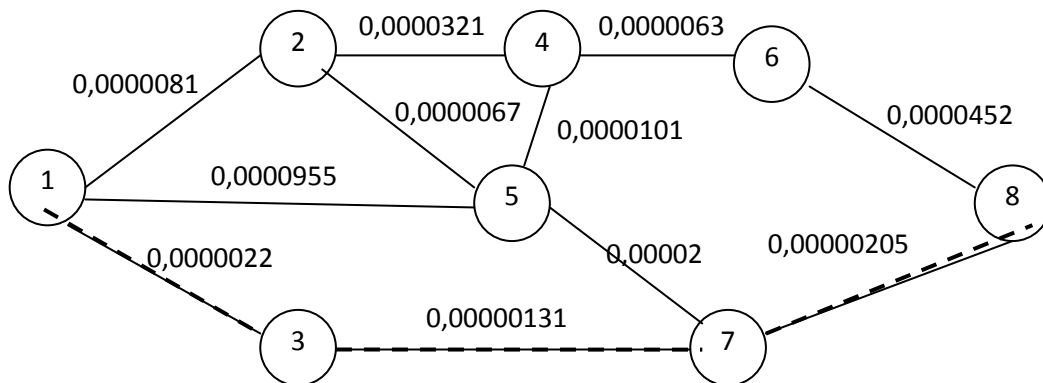

Рис. 5. Circuit topology of the road network fragment:
Рис. 5. Фрагмент топологічної схеми вулично-дорожньої мережі:

— — — — — — · - траса найбезпечнішого маршруту;
- safest track route.

Table 7

Matrix of the probability of involvement in the RTA on the junction

Number of junction	The direction	The probability of involvement in the RTA
1	1-2	0,000006812
	1-5	0,000000321
	1-3	0,000000122
2	2-1	0,000000176
	2-4	0,000000464
	2-5	0,000000104
3	3-1	0,000000324
	3-7	0,000000087
4	4-2	0,000000441
	4-5	0,000005957
	4-6	0,000000108
5	5-1	0,000001847
	5-2	0,000000431
	5-4	0,000001571
	5-7	0,0000004961
6	6-4	0,000000204
	6-8	0,000000148
7	7-3	0,000000182
	7-5	0,000008721
	7-8	0,000000018
8	8-6	0,000000113

	8-7	0,000000495

Calculated the formula (11) for all possible variants have been received safest transportation route 1-3-7-8 (Fig. 5) with a probability of 0.000005787. The goal to build the safest route when moving from point of origin to the destination is recognized.

6. CONCLUSIONS

The analysis of the papers related to assessment of the accident level showed that most of them gave the general estimate of the road traffic safety, disregarding the probability of occurrence of the RTA involving an individual road user.

The developed techniques and algorithms for searching the optimal route, oriented at minimization of the time, distance or cost of the carriage, do not use the probability of occurrence of the RTA involving an individual road user as the weight of the oriented graph arcs.

The relationships of the probabilities of occurrence of the RTA involving an individual road user in the network segments and on the junctions, substantiated in the paper, enabled suggesting an approach in finding the optimal path, using the criterion – the minimum probability of being involved in the RTA, which makes it possible to work out the safest route for carriage of dangerous goods from the point of departure to the destination.

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