DEVELOPMENT OF A MECHANISM FOR THE ECONOMIC EFFICIENCY EVALUATING OF MEASURES TO ENHANCE ROAD TRAFFIC SAFETY

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Abstract. The implementation of preventive measures to reduce traffic accidents has long-term social, environmental and economic consequences. Thus, the assessment of the economic effectiveness of measures to improve road safety is of great importance. Since it makes possible to determine the long-term economic effect of the implementation of a separate measure or a complex of measures to reduce traffic accidents. *The purpose* of the research is to improve the method of evaluating the effectiveness of measures to ensure traffic safety by developing more detailed indicators of modern modes of passive anti-accident traffic protection, which are not reflected in existing regulatory documents. *Methodology.* Study of modern regulations and methods in the field of traffic safety. Materials and methods of the study include consideration of modern methods of evaluating measures to prevent road accidents, methods of economic evaluation and forecasting, methods of theoretical generalization and analysis of scientific literature. *The results.* A method of calculating losses from traffic accidents has been developed, in which it is proposed to take into account the influence of passive anti-accident traffic safety measures when calculating the risk of traffic accidents. This method of calculating losses from road traffic accidents takes into account the composition and conditions of traffic and allows minimizing losses from road traffic accidents by means of changes in the use of modern modes of passive anti-accident traffic protection. *Practical implications.* A comparative analysis of the effectiveness of measures

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(complexes) to ensure traffic safety was conducted using the example of a specific area of the concentration of traffic accidents. The first calculation used modern technical modes of traffic organization, the second – capital investments. According to the results of the assessment using real data, from the two proposed sets of measures for a quick effect, the first strategy can be implemented. The second strategy has a longer-term perspective effect, but requires an increase in initial investments. The results of testing the developed method for assessing the economic efficiency of measures to reduce the level of accidents have proven its efficiency. *Value/originality.* Effective use of the methodology enables the expert to make the right engineering decisions in conditions of insufficient financing of measures and the need to obtain relatively quick results.

1. Introduction

Road traffic management measures at any level of activity (state, departmental, engineering) require certain, often significant funds. Therefore, the appointment of such measures should provide for their thorough technical and economic justification [1–3]. The indicator of damages from traffic accidents is included in economic calculations when making decisions about the feasibility of implementing road safety measures [4]. Reflecting the priority of road safety as a political goal of the state, the assessment of losses in road traffic accidents is aimed at the implementation of measures to increase road safety [5].

Technical modes of traffic management have an impact on traffic and pedestrian flows. At the same time, the flow parameters change. These changes can be used as a basis for indicators used to evaluate the effectiveness of the use of both individual technical modes and their combination. In general, taking into account the tasks of traffic management, performance indicators should reflect the capacity of the transport process and traffic safety. At the same time, the search for a single indicator – universal, which can be measured in real traffic conditions, and which has a monetary value, is associated with certain difficulties [6–7]. For different users of management systems, various indicators can be brought to the fore: the number and severity of traffic accidents, road capacity, traffic delays, the number of vehicle stops, the length of queues at intersections, travel time, the degree of environmental pollution, the level noise from the movement

of vehicles. In addition to the first indicator, all the latter refer, as a rule, to city roads and streets.

To calculate the economic efficiency of the introduction of modes of passive anti-accident protection of road traffic, it is more correct to take into account all indicators of their monetary value [8-10], which should include the cost of the modes itself, as well as the costs of its installation and operational maintenance [11]. Currently, there are a number of different methods that allow you to calculate the effectiveness of the implementation of road safety measures. However, when studying them, it was found that these methods mainly take into account measures involving capital investments. With the existing financing of the road industry, most of these measures remain unimplemented. Therefore, it is pro-posed to improve the method of evaluating the effectiveness of measures to ensure traffic safety by developing more detailed indicators for modern modes of passive anti-accident protection of road traffic, which are not reflected in existing regulatory documents. The basis was a study [12–13], which includes the appointment and evaluation of the effectiveness of measures aimed at improving road traffic safety in places of traffic accidents concentration. The assessment of the measures impact to improve road safety at the places of traffic accidents con-centration is performed on the basis of the accidents level comparison before the implementation of the relevant road works with the accidents level after their implementation.

2. Solving the problem of the economic efficiency evaluating of measures to enhance road traffic safety

The predicted reduction in the level of accidents after the implementation of the planned measures is established by calculation using the results of previously performed field observations of the change in the traffic accidents number as a result of road works aimed at improving traffic conditions.

As an initial indicator characterizing the expected change in the state of accidents as a result of taking measures, it is proposed to use the average probability of a decrease in the number of traffic accidents on a given section of the road expressed in units of shares. Table 1 shows the proposed values of the specified indicator for various measures to improve traffic safety on highways.

Types of measures that were missing from the basic table were added based on practical experience, the probability of reducing the number of traffic accidents was equated to related, but more expensive measures.

Table 1

Measures to increase road safety

№	New measures to increase traffic safety on elements and characteristic sections of roads are proposed	Probability of reducing the number of traffic accidents in the shares of the unit	
		The total number of traffic accidents	Traffic accidents with victims
1.	Installation of flexible signal poles	0,14	0,16
2.	Installation of new road signs (signs on a yellow background)	0,44	0,55
3.	Arrangement of noise bands on the distribution strip	0,12	0,30
4.	Installation of means of forced reduction of speed	0,21	0,16
5.	Installation of the "Driver! Slow down"	0,20	0,15
6.	Installation of red and white markings at the pedestrian crossing	0,26	0,35
7.	Installation of road marking inserts	0,23	0,20
8.	Installation of anti-glare screens	0,60	0,50
9.	Installation of an elevated ground pedestrian crossing	0,21	0,16

Measures to reduce accident rates in the areas of concentration of traffic accidents can be divided into two categories from the point of view of the final results:

1) those that contribute to the prevention of certain types of traffic accidents (individual measures);

2) those aimed at preventing all traffic accidents (sets or complex of measures).

The average probability of a decrease in the number of road accidents in year *t* as a result of the implementation of measures is determined by the formula:

$$Pm = \frac{\sum_{m=1}^{M} (\frac{1}{1-Pm} - 1)}{1 + \sum_{m=1}^{M} (\frac{1}{1-Pm})}, \quad (1)$$

there M – the number of measures to improve traffic safety, which in year t have an impact on the reduction of accidents $(t_m^{c\eta} \text{ " } t)$.

The expected reduction in the number of traffic accidents in year t as a result of the implementation of several measures is determined by the formula:

$$\Delta n_1 = P_M \cdot n_1, \quad (2)$$

there n_1 – the predicted number of traffic accidents in year t in the absence of measures to improve traffic safety.

The overall expected reduction in the number of road traffic accidents in the area under consideration with the concentration of road traffic accidents as a result of the implementation of a set of measures to improve traffic safety is determined taking into account its service life:

$$\Delta n_1 = \sum_{t-0}^{t_{\max}^c} \Delta n_t , \quad (3)$$

there $t_{\max}^c$ – the longest service life of the event included in this complex, years.

The service life of the m-th measure is established in accordance with the current regulatory and methodological documents, taking into account the regional characteristics of road operation. The expected decrease in the number of traffic accidents as a result of measures to improve traffic safety on the road network, which has the i-th number of accident concentration areas:

$$A = \sum_{i=1}^{I} \Delta n_i , \quad (4)$$

there Δn_1 – decrease in the number of traffic accidents in the i-th area of the concentration of traffic accidents, taking into account the zones of its influence.

The reduction in the number of traffic accidents as a result of the implementation of measures to improve traffic safety is accompanied by

a simultaneous decrease in the number of dead and injured. The expected decrease in the number of dead and injured per place of traffic accidents concentration in comparison with the initial level before road works is allowed to be determined in proportion to the reduction of the total accidents volume.

Indicators of the economic effectiveness of measures to improve traffic safety characterize the national economic feasibility of spending on the specified measures. According to the study [9; 10], the following methods currently exist to assess the cost-effectiveness of road safety measures (Figure 1).

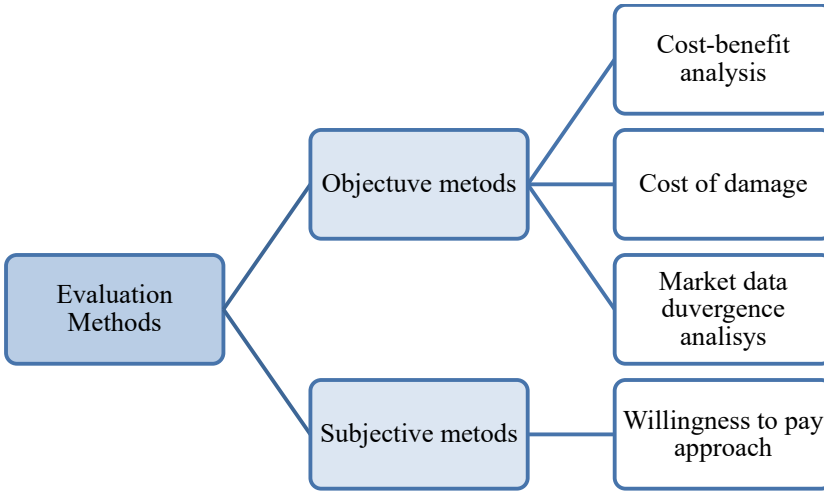

Figure 1. Evaluation methods to assess the cost-effectiveness of road safety measures

In our case, we will use the «Cost-benefit analysis» approach. Efficiency is determined by comparing the effect of reducing the number of traffic accidents and the costs of measures to reduce accidents. The evaluation of the result and costs when determining the performance indicators is carried out for the entire service life of the measures. When comparing two or more options for the implementation of measures sets, the effectiveness assessment is made for the same calculation period. When determining

the settlement period, we should focus on the most durable option. The beginning of the calculation period is determined by the moment of time, starting from which the choice of the option affects future costs and results. The end of the calculation period is the moment from which costs and results for all compared options are practically unclear or insignificant.

Different prices types can be used for the cost assessment of the effect of reducing the traffic accidents number and the costs of measures to reduce accidents:

– on a temporary basis – basic and estimated prices;

– in the field of price formation – national and world prices;

– by type of currency – in national currency, in foreign currencies.

Base prices are prices that have developed in the country's economy or at the world level at a certain point in time. The base price is considered unchanged throughout the settlement period.

Estimated prices are prices that reflect projected changes in current prices at each step of the calculation. The calculation of the cost of road works is carried out in accordance with the regulatory documents in the road industry at the field of pricing. All results and costs received (carried out) at different points in time are brought to the beginning of the calculation period by multiplying them by a factor determined by the discount rate.

The discount rate (E) is the rate of net income per year and per unit of costs. It can be established by the state as a specific socio-economic standard, mandatory for the evaluation of projects from the standpoint of society as a whole. In the absence of an officially established discount rate, it is recommended to use $E = 0.12$.

The system of indicators of the effectiveness of measures to increase road traffic safety includes:

– integral effect (hereinafter – E_{int}) – sum of effects for the entire period of comparison;

– profitability index (hereinafter – ID) – the ratio of the sum of effects to the total amount of one-time costs;

– the payback period (hereinafter – t_{ok}) – is the minimum time interval from the beginning of the calculation period beyond which the integral effect becomes and remains non-negative;

– integral costs – the sum of costs for the entire settlement period;

– internal rate of return (*INR*) – represents the one that is unchanged during the calculation period of the discount, in which the sum of effects is equal to the sum of simultaneous costs.

Decisions about the measures effectiveness to improve traffic safety should be made taking into account all the above efficiency indicators, the main of which is the integral effect (E_{int}). If the integral effect is positive, then the implementation of measures is effective. With a negative value of E_{int}, this option is ineffective and should not be implemented at any values of other efficiency indicators. If the results are the same for all alternative options, then the calculations can be simplified by limiting ourselves to the determination of only the value of integral costs for each of the options.

The profitability index, the internal rate of return and the payback period are used in the evaluation of options as auxiliary indicators. If any option has $E_{int} > 0$, then it must have $ID > 1$. The assessment of the profitability index plays an important role when one of the main criteria for choosing options is the expected value of the effect obtained per unit of costs for the entire calculation period. If the size of the effect obtained per unit of costs annually is important, then *INR* will play a decisive role. At the same time, it should be taken into account that the option is considered effective if the INR is greater than the given external discount rate. In the case when the period after which the invested funds will have a return is important, the option with the shortest payback period will be considered the best.

To calculate the effectiveness of measures to increase traffic safety, the following calculation formulas are used:

Integral effect (E_{int}):

$$E_{\text{int}} = \sum_{t}^{T} \frac{(R_t - Z_t)}{(1+T)^t} - \sum_{t}^{T} \frac{K_t}{(1+T)^t}, \quad (5)$$

there *Rt* – the effect of reducing the number of traffic accidents i n the year *t*;

Zt – current expenses in the year *t*;

Kt – one-time expenses per year *t*;

E – discount rate;

T – the moment of the end of the settlement period.

Profitability index (*ID*):

$$ID = \sum_{t}^{T} \frac{(R_t - Z_t)}{(1+E)^t} \div \sum_{t}^{T} \frac{K_t}{(1+E)^t}. \quad (6)$$

Payback period (t_{ok})

$$E_{\text{int}} = 0 \rightarrow for \rightarrow 0 < t <= T,$$

at the same time for everyone t_{ok} the condition must be met $E_{\text{int}^3} 0$.

Integral costs:

$$Z_{\text{int}} = \sum_{t-0}^{T} \frac{Z_t}{(1+E)^t} - \sum_{t-0}^{T} \frac{K_t}{(1+E)^t}. \quad (7)$$

The effect of taking measures to improve traffic safety consists, first of all, in reducing losses from traffic accidents, which are divided into three groups:

– losses associated with loss of health and death of people involved in traffic accidents;

– losses related to property damage (recovery of vehicles, damage to roads and road structures, cost of damaged goods);

– public losses, which include expenses related to the violation of normal traffic conditions in the area of the traffic incident, and expenses of the National Police and courts.

If, as a result of a measure to improve road safety, a significant increase in the speed of cars in the traffic flow is expected, then if it is possible to objectively evaluate this change (the quantitative assessment of the speed of movement is established by a calculation method or on the basis of these experimental studies), it should be taken into account the effect of increasing the speed of movement.

The measures effect to improve traffic safety can be determined by direct calculation using the formula:

$$Rt = Alt'Cl + A2t'C2, \quad (8)$$

there *Alt, A2t* – the expected decrease in the number of dead and injured in traffic accidents in t years;

C1, C2, – average cost of losses from one road traffic accident with fatal outcome and injury.

According to the results of the developed method of economic efficiency evaluating of measures to enhance road traffic safety the following sequence of its implementation can be suggested (Figure 2).

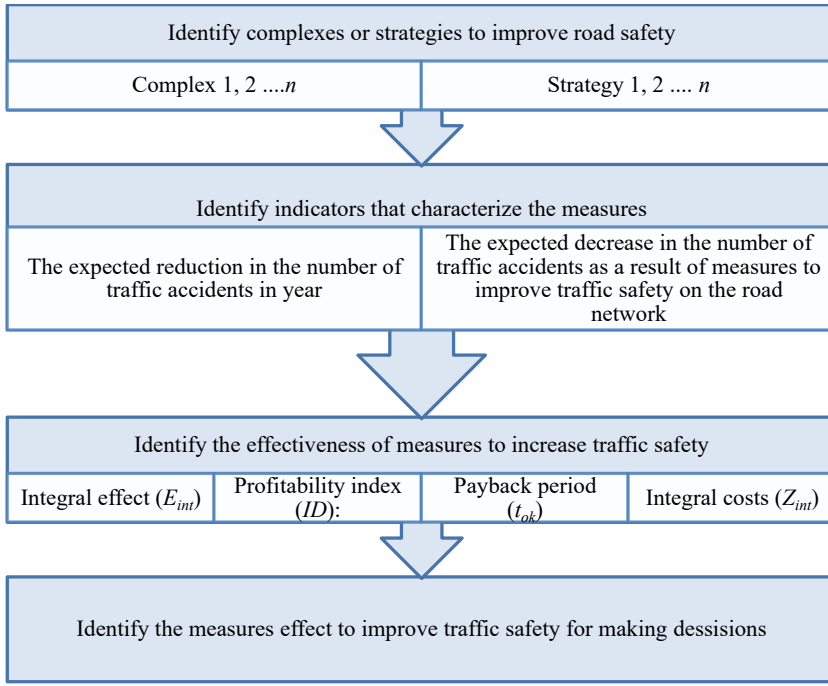

Figure 2. Economic efficiency evaluating of measures to enhance road traffic safety

According to this sequence (Figure 2), we will analyze road safety measures for a specific object (place of concentration of road traffic accidents).

3. Results of research

As a result of the diagnostics of the place of concentration of traffic accidents on the example of km 7 of the national road of state importance N-21 Starobilsk – Luhansk – Krasniy Luch – Makiivka – Donetsk, the following elements and characteristics of the road that do not meet the regulatory requirements were established:

– insufficiently equipped pedestrian crossing (more than 50% wear and tear of markings, no road signs);

– the distribution strip is expressed only in the form of markings.

Selection of basic measures to increase road safety. The accident analysis in this area showed that almost all traffic accidents (8) occurred in the dark hours of the day, 2 traffic accidents occurred at 15:00 and 17:00, but respectively in November and December (twilight). Due to these factors, we can make a preliminary conclusion that, among other things, the cause of the accidents was insufficient visibility of objects on the road and fatigue (or falling asleep) of drivers.

Based on the analysis of the results of diagnostics at the given place of traffic accidents, the following measures can be taken:

The first complex (option):

– application of red and white horizontal road markings at the pedestrian crossing;

– installation of the insert of marking road VRD – 3;

– installation of signs 5.35.1, 5.35.2 on a yellow background;

– installation of the "Driver! Reduce speed" on a yellow background;

– installation of a means of forced speed reduction "reclining policeman" on both sides of the pedestrian crossing in the direction of traffic of cars;

– along with marking 1.3, arrangement of noise strips on the axis of the road according to a previously developed scheme.

The second complex (option):

– installation of an overhead pedestrian crossing;

– arrangement of a dividing lane with a width of 5-6 m with the transfer of the carriageway at the expense of the shoulder and reserve.

In accordance with the current regulatory and methodological documents, the cost of the measures and their service life are established (Table 2, Figure 3). The longest service life of the considered measures is taken for the calculation period.

To assess the economic effectiveness of measures to improve traffic safety, the following is required:

– predict the number of traffic accidents with victims, which will occur if measures to improve road safety are not implemented in this section, based on the years of the calculation period;

– coefficients characterizing the impact of these basic measures to increase road safety on the reduction of the number of traffic accidents;

– according to formula (1) (in the case of two or more measures to increase road safety), for each planned set of measures by years of the calculation period, establish the average probability of a decrease in the number of traffic accidents in the area of concentration of traffic accidents as a result of their full implementation;

– according to formula (2), for each year of the calculation period, the expected decrease in the number of traffic accidents as a result of the implementation of the selected sets of measures is established.

Table 2

Main activities of the complexes

Complex	Main activities of the complex	Probability of reducing traffic accidents (P_m), Table 1	Service life, t_M^c years	Cost of events, monetary units
1	1) application of red and white horizontal road markings at the pedestrian crossing;	0,26	3	4200
	2) installation of the insert of marking road VRD – 3	0,23	5	2100
	3) installation of signs 5.35.1, 5.35.2 on a yellow background	0,44	1	1600
	4) installation of the "Driver! Reduce speed" on a yellow background	0,20	3	3000
	5) installation of a means of forced speed reduction "reclining policeman" on both sides of the pedestrian crossing in the direction of traffic of cars	0,21	5	9000
	6) along with marking 1.3, arrangement of noise strips on the axis of the road according to a previously developed scheme	0,12	5	1050
2	1) installation of an overhead pedestrian crossing	0,24	5	3370000
	2) arrangement of a dividing lane with a width of 5-6 m with the transfer of the carriageway at the expense of the shoulder and reserve	0,12	5	2750000

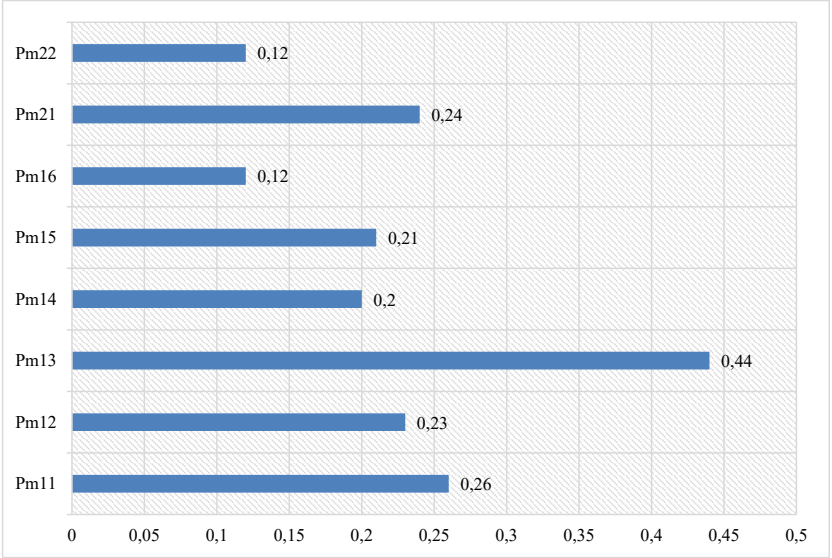

Figure 3. Probability of reducing traffic accidents (P_m) according to main activities of the complex

In this stable place of concentration of traffic accidents, there are reasons to believe that the level of vehicle accidents will continue to be of the same nature. Let's assume that the severity of traffic accidents that will occur if measures to increase road safety are not implemented will also have a stable character and on average, 0.5 – dead and 0.8 – injured for every 1 traffic accident. These values are used when calculating the effect, which is expressed in the reduction of losses from the death and injury of people, according to formula (8).

The results of the calculation for establishing the predicted parameters required for calculating economic efficiency are listed in Table 3 and shown in Figure 4, 5.

Thus, the expected number of traffic accidents with victims in the absence of measures to improve them was 10. The average probability of reducing the number of traffic accidents as a result of the implementation of measures under strategy 1 – 0.23 %, and under strategy 2 – 0.13 %. The expected number of traffic accidents averted as a result of implementing measures under strategy 1 was 0.46 %, strategy 2 – 0.26 %.

Table 3

Calculations for establishing predicted parameters required for calculating economic efficiency

Forecast indicators	Value of forecasted indicators by years of the calculation period					Total
	1	2	3	4	5	
1. Expected number of road accidents with victims in the absence of measures to improve road safety	2	2	2	2	2	10
2.1. Average probability of reducing the number of road accidents as a result of implementing measures under strategy 1, %	0,23	0,23	0,23	0,23	0,23	0,23
2.2. Average probability of reducing the number of road accidents as a result of implementing measures under strategy 2, %	0,13	0,13	0,13	0,13	0,13	0,13
3.1. Expected number of traffic accidents avoided as a result of implementing measures under strategy 1, %	0,46	0,46	0,46	0,46	0,46	0,46
3.2. Expected number of traffic accidents avoided as a result of implementing measures under strategy 2, %	0,26	0,26	0,26	0,26	0,26	0,26

The calculation of economic efficiency indicators is carried out according to formulas (5) – (8). The summarized results of the calculation of economic efficiency indicators of measures are presented in Table 4 of the applications of two strategies.

For the considered case, it was not possible to establish how much the average speed of the traffic flow on km 7 of the H-21 highway will change as a result of the implementation of the measures included in complex 1, therefore, in this example, as an estimate of the effect in year *t*, we accept the cost of diverted as a result of the implementation of the complexes measures of losses from death and injury to people equal to R_t. The monetary value of current costs was not taken into account due to its insignificance compared to the cost of the first and second sets of proposed measures.

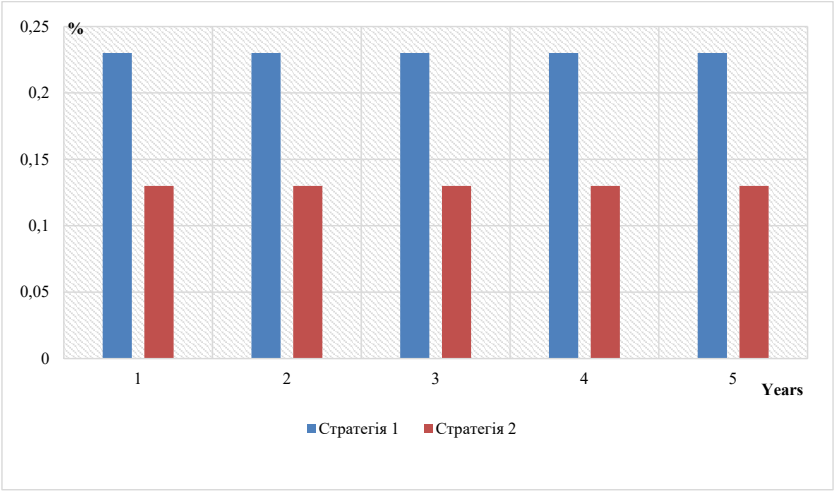

Figure 4. Average probability of reducing the number of road accidents as a result of implementing measures

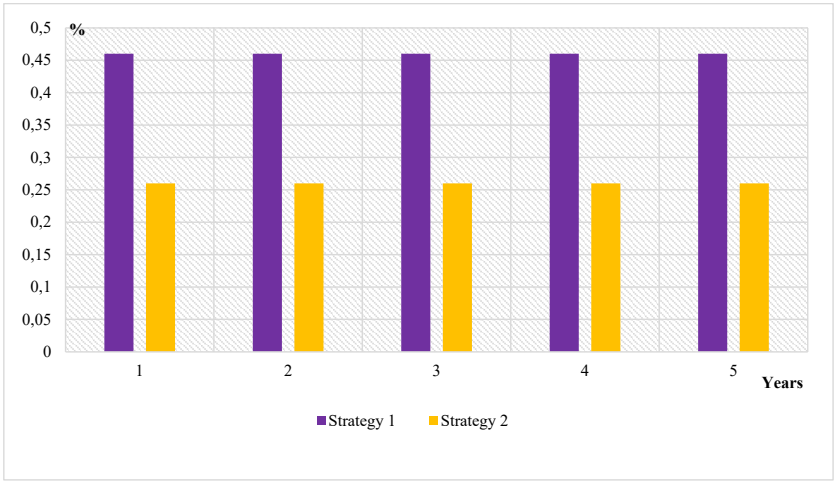

Figure 5. Expected number of traffic accidents avoided as a result of implementing measures

Table 4

Calculations of economic efficiency indicators of measures

Years	Complex of measures, estimated in monetary units			
	1		2	
	Rt	***Rt/(l+E)t***	***Rt***	***Rt/(l+E)t***
1	59400*	53035	59400	53035
2	59400	26517	59400	26517
3	59400	17678	59400	17678
4	59400	13258	59400	13258
5	59400	10607	59400	10607
Total		121098		121098
E_{ium}		7547		-1247959
ID		2,8		0,019
t_{ok}, *month*		7		214

The assessment determined that the payback period of the proposed measures is 7 months for strategy one with a profitability index of 2.8. However, it was determined that strategy two requires more initial investment, since it is estimated that a similar economic effect of road accident reduction measures would require 214 months for the payback period. This figure could be reduced by increasing the initial investment, since strategy two has a more global impact on the road safety system.

In any case, the practical implementation of the developed mechanism for the economic efficiency evaluating of measures to enhance road traffic safety based on real data.

4. Conclusions

The problem of the increase in the number of road accidents is recognized by scientists around the world [1; 4; 6–10]. The consequences of road accidents harm the economic resources of the region. Understanding the economic consequences of road accidents is important, so the development of a mechanism for evaluating measures to reduce road accidents is necessary. Since the economic evaluation of road safety measures allows you to organize work to improve safety in accordance with economic criteria as effectively as possible [10]. Socio-economic assessments (or evaluations) of road safety measures are crucial for determining the long-term economic

effect of implementing a single measure or complex of measures to reduce road accidents.

Thus, in this study, a mechanism for assessing economic efficiency was developed, which allows assessing the effect of measures to improve road safety. The developed method within the approach is based on use the «Cost-benefit analysis». At the same time, when assessing the measure to reduce accidents, the probability component was taken into account.

The method of determining the effectiveness was tested on real data on the location of the concentration of road accidents. Two strategies (complexes of measures) were adopted to increase road safety. This testing allowed us to establish that the payback period of the proposed measures is 7 months for the first strategy and 214 months for the second strategy. This discrepancy is due to the fact that the first strategy has a quick but short-term impact on road safety, and the second strategy requires more significant initial investments than specified for the calculation. Since the second strategy has a more global and long-term impact on the road safety system.

Further research will be aimed at developing a set of strategies and programs to improve traffic safety at the regional and global levels.

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