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THEORETICAL PRINCIPLES OF FORECASTING ACCIDENT RATE IN THE CONFLICT SECTIONS OF THE CITIES BY THE METHOD OF POTENTIAL DANGER

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Abstract. The article describes an attempt to apply a catastrophe theory for the process of road transport situation development into a conflict situation, which, in the result turns to the accident, through the interpretation of a potential danger of the conflict. For this purpose the simplest methods (elementary catastrophes) were used, allowing to estimate the values of the basic parameters of road traffic. The suggested method made it possible to take into consideration the interaction of conflict points in joint location, what has considerably increased the adequacy of forecasting.

Keywords. losses in road traffic, accident rate, methods of forecasting, potential danger.

1. Introduction

Road accidents is one of the most severe and tragic losses in road traffic. If other losses, such as economic or ecological, are evenly distributed between all the society members, the accident losses are concentrated on individual road users. Namely these users and their relatives undertake the main weight of accident losses and, if somebody is fated to a disaster, he, as a rule, remains face to face with his problems without an essential help of the society.

In the Republic of Belarus more than 100 000 road accidents take place every year, where nearly 1 700 people are killed and almost 10 000 people injured [1]. Based on data, provided by the Belarusian Bureau for Transport Insurance [2], according to the contracts of domestic insurance 54 955 of insurance events took place in 2005 (in reality the number of accidents is significantly higher: there are accidents recognised as uninsurable events, which are not included into the given statistics; besides, part of the accident-involved road users do not inform the State Automobile Inspection (Road Police) about the accident and prefer "to solve the problem on the spot". Total accident losses, including a social component, is estimated at 200 million dollars each year, and this makes almost 1,5 % of the Gross National Product (in high-income European countries accident losses are estimated at 2÷2,5 % [3]). Besides, with the growth in the amount of vehicles, the accident losses will inevitably increase [4].

There are many interesting questions related to the definition of a road traffic accident itself – why a rather small collision in some countries is officially recognised as an accident, whereas, in the other – only that with a serious injury? What about accident causes? Each year they have been investigated, analysed, conclusions are being made, though the accidents still take place. Especially interesting are the relationships between accident rate and various factors, which could be joined into 5 groups: man, road, vehicle, traffic organisation, natural calamity.

It should be noted that classification of accidents is mainly performed according to their severity, type and category, number of people involved and, what is important, by the form of registration (registered or unregistered). It should be mentioned here that accidents are analysed namely as the registered accidents and, unfortunately, more than 80 % of road accidents are left without any analysis at all. There are cases when the analysis is carried out according to the accident severity, ie property damage, injury, death. However, the definition "killed in road accident" is also a matter of interest. Earlier this definition was used if a person died on the spot; also it was used if a person died in a hospital within 24 h and even within 7 days, 30 days or one year. For the purpose of unification the UN made the decision to recognise a person killed in road accident if he was killed on the spot or died in the hospital within 30 days after the accident. It should be mentioned that the number of such people comes to more than 97 % of the total number of the killed in road accidents. Besides, almost half of the total number of the killed people die on the spot. According to the subsection 1.3 to the Annex 1 of the Order ¹ 104 (18 May 1996) of the Ministry of Inner Affairs of the Republic of Belarus, the number of the killed in road accident includes those people who died from injuries on the spot or within 30 days after the accident moment, if there is a documentary confirmed cause and result relation between the death and the accident.

Even more interesting is the forecasting of accident rate. The endeavours for reducing accident losses are mostly restrained by the lack of reliable methods for the forecasting of accident rate. The current methods are notable for their subjectivity and low accuracy [5]. This could be explained by the fact that accident rate is influenced by a great number of different factors and their combinations. Due to unreliable forecasts the decisions, taken in a practical work of traffic organisation, either take no consideration of accident rate at all or take a subjective consideration, what is not very useful. It is necessary to considerably increase the forecasting accuracy in order to make an objective evaluation of each decision of traffic organisation and to optimise it according to the safety criterion already at the stage of elaboration or planning. This will allow us to substantially reduce accident rate, especially at the conflict objects – crossroads and pedestrian crossings.

2. Occurrence of accidents and their potential danger

Occurrence of a road accident could be interpreted as a sudden transition from a normal process of movement (stable state) to the accident (also stable state) due to the occurrence of a conflict situation (phase of instability: when the driver takes a wrong decision, traffic parameters or traffic direction are changed etc). A general feature of such a road traffic situation is that smooth changes in the values of factors, having the influence on the system of a certain level, can cause sudden changes in the initial parameters and, consequently, the system's transition from one state to another. Investigation of such an approach makes the subject of a scientific trend called catastrophe theory. Namely the given theory explains in a certain way the significance of experimentally observed forms of instability depending on a number of parameters. The word "catastrophe" means a sudden change in a qualitative state of the system. This could be also applied to the road traffic and to the definition of accident or road traffic crash. In organising traffic we solve a number of important tasks, the most important or strategic of which is the task *to move at a sufficiently high speed and to ensure traffic safety.* Besides, in the process of solving the given task a continuous change of tactical tasks is performed – braking and acceleration, uniformly accelerated and accelerated movement, change in a trajectory of movement – ie a qualitative transition from one state to another is predicted and characteristics and conditions of the road traffic are determined. Investigation of such problems is the subject of the catastrophe theory.

Interpretation of parameters of state and management is practically identical in all the models and is developed taking into consideration the following considerations.

Each road traffic situation corresponds to a certain state of the system "Driver-Vehicle-Road-Environment", and the change in this state, depending on the complexity of situation, could be monotonous or sudden. Therefore the situation should be identified by the value of the state parameter X – **potential danger** of one or another conflict, which has a characteristic of a smooth or sudden change. The change in the process of movement is caused by the change in instantaneous speed between the vehicles in a traffic flow. Therefore the catastrophe management parameters could be interpreted as the indicators, characterising instantaneous speed, traffic volume etc. Besides, in order to describe the traffic of the intersection (as a physical system), a general set of potential functions $P_o(x, c)$ was assumed, depending on n variables of state or the parameters of an order $x \in R^n$ and k managing parameters. Further, let us suppose that a state of a physical system is described by the value x, minimising a potential function, at least locally. Then investigation of such a system is restricted to the investigation of equilibrium and local stability of a potential function $P_o(x, c)$:

$$\frac{\partial P_o}{\partial x_i} = 0 \text{ – equilibrium,}$$

$$\frac{\partial^2 P_o}{\partial x_i \partial x_j} > 0 \text{ – local stability,} \qquad (1)$$

and critical values on the branches of stable equilibrium.

In the modelling process the most important is the aim of the system under any conditions to take a position with the minimum value of potential energy at a given combination of management and state parameters (ie minimum potential danger at a zero accident rate). In case of a dangerous road traffic situation, the change in the value P takes place. The rate of this change and the value P, to which a potential energy (danger) strives, is determined by the degree of the complication of situation. In dangerous situations, resulting in a road traffic accidents, or when avoiding them, the value of state parameter changes all of a sudden.

3. The algorithm for investigating inter-phase conflicts

Based on the above considerations, the expected number of accidents on a study object, for example, when investigating the inter-phase conflicts, taking into account the division of object into the conflict elementary zones – conflict points, then into the conflict zones and into the indivisible conflict zones – intersections, is determined by the scheme in Fig 1.

Due to the fact that the inter-phase conflicts usually take place at an angle close to 90^0, in order to access the accident rate of this type on intersections, a convolution of potential danger was carried out using the degree of 0,5, which gives the most reliable description of the process of interaction of transport flows.

Regression equations were made. Statistics was used, characterising a close connection between the factors and a dependent variable – coefficient of multiple correlation. Significance of factors was assessed by the Student criterion. A confidence level of significance γ was assumed to be 0,01–0,1 (the lower the level, the higher are requirements for model reliability). In order to check the hypothesis of the importance of a multiple correlation coefficient and the compatibility of regression equation and experimental data, a statistical Fisher criterion was used. Processing the results of the experiment was performed using the method of the least squares and the computer-based mathematical application packages.

Fig 2 gives the examples of the obtained adequate regression models (experimental data is compatible with the obtained regression equations – estimated by a statistical Fisher criterion is higher than the table values ($F > F_{T\,\min} = 3{,}84$).

In this way it is possible to make a qualitative estimation of the number of accidents, reduced to the property-damage accidents. Besides, the suggested approach allows the forecasting of accident losses, since it is possible to determine and to compare the cost of an individual accident.

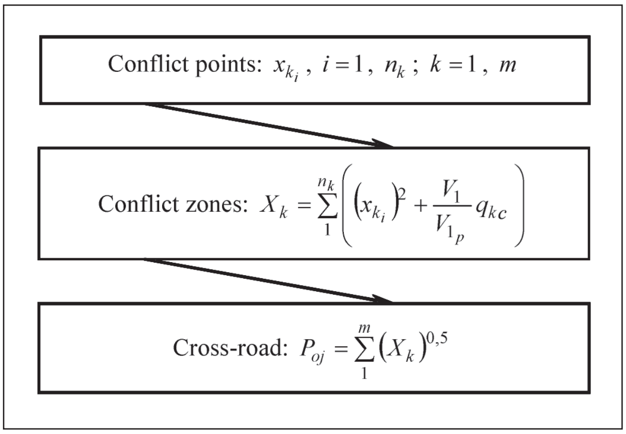

Fig 1. Determination of potential danger

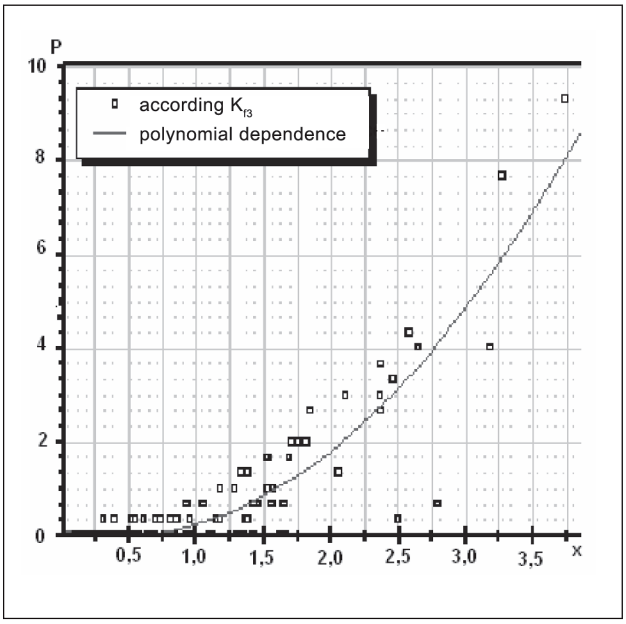

Fig 2. Relationship between the accident rate and the parameter of potential danger of conflict zones

On the ordinate: reduced number of accidents, accidents/year;

on the abscissa: potential danger of conflict zones, conditional units/year

4. Risk of traffic accident

Before taking any decision each road user estimates it from two basic positions – danger and efficiency. On the one hand, he puts on the scales danger and risk, on the other hand – efficiency and benefit. The lower the risk and the higher the benefit, the more frequently he takes the risk.

Each person has its own curve of risk, presented in Fig 3, where the size of risk R is plotted on the abscissa and a probability of taking this risk $P(R)$ – on the ordinate. Curve 1 represents a careful person, curve 2 – a risky person. It is obvious that the curve of risk of the majority of people lies between conditional curves 1 and 2.

Of course, risky people cause many accidents. Strange as it may seem, but the very careful people are also often

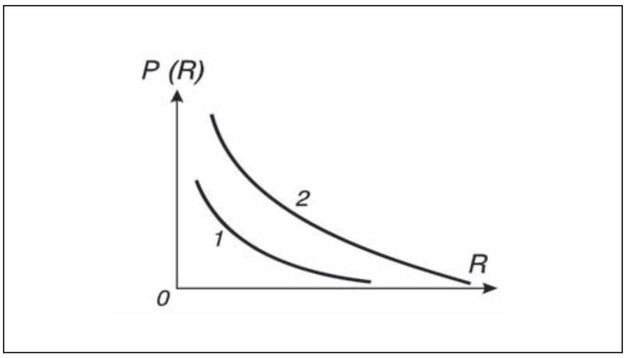

Fig 3. Distribution of the risk to be taken [5]: 1 – careful man; 2 – risky man

involved into road accidents, since their excessively careful behaviour provokes other people to take a risky decision. Though the very careful people do not have a decisive influence on the traffic safety for the reason that there are very few of them – the largest number of accidents is caused by normal people, who make a vast majority, but not those who like the risk or are excessively careful. Normal people, due to a number of reasons (education, adopted experience, ignorance of real possibilities, the herd instinct – „I do what everybody does") do not take a sufficient account of danger and take an increased risk which, as a result, causes an accident. It could be said that this is their trouble rather than their fault.

Based on the above considerations, it is possible to define the main trends for improving a traffic safety situation, ie reduction of the objective danger and the effective influence on the motivation of road users in the way of analysis and forecasting of accident rate and the danger of conflicts. In our opinion, if an objective and available system were developed for the evaluation of capacities with the subsequent recommendations, elimination of "bottlenecks" and correction of the curve of risk, it would find a large number of supporters.

It should be mentioned that when defining the real risks the statistics of insurance events and data on the insurance payments could be used. Since 1999, according to the Order of the President of the Republic of Belarus No 100, the obligatory liability insurance of vehicle owners is carried out. And for five years already the analysis of the results of this type of insurance is made by an authorised institution – the Belarusian Bureau for Transport Insurance which is publicised in analytical collections of the basic indicators of the vehicle owners' liability. This collection includes data, which are stored in the general data base of the Bureau. At present the database contains more than 13,5 mil contracts of domestic insurance, nearly 4 mil contracts of border-crossing insurance and more than 800 000 of the "Green Card" insurance. This is a huge source of information [2].

Data of the average sums of insurance payment by the living place of a person guilty for the accident (the year 2005, domestic insurance) [2]

Name of a residential area – the living place of a person guilty for the accident	Average sum of insurance payment, thous roubles	Name of a residential area – the living place of a person guilty for the accident	Average sum of insurance payment, thous roubles
Minsk	1 110,0	Sluck	1 101,8
Brest	1 237,4	Novopolock	1 072,0
Mogilev	1 075,6	Mozir	1 071,9
Grodno	1 039,4	Soligorsk	1 036,5
Vitebsk	1 002,8	Bobruisk	989,0
Gomel	876,8	Slonim	961,3
Baranovichi	1 389,3	Molodechno	956,5
Zhodino	1 266,5	Pollock	941,9
Zliubin	1 229,8	Orsha	926,9
Pinsk	1 154,8	Rechica	903,7
Kobrin	1 145,3	Borisov	867,8
Lida	1 114,9	Svetlogorsk	864,3
Other	1 084,7		

The term "insurance event" for the purposes of obligatory insurance includes also the unregistered accidents, which are not included into the State reporting. Therefore, based on the number of insurance events, one can roughly judge about the traffic safety level in Belarus. For example, in 2005 only by the contracts of domestic insurance 54 955 of insurance events were recorded. Besides, nearly half of them (25 814) took place in Minsk. The average sum of insurance payment per one insurance event in Minsk came to 1 110 thousand roubles. However, this indicator is slightly less than in nother regional cities (for example, in Brest the average sum of insurance payment makes 1 237,4 thousand roubles) (see Table). Of course, the average sum of payment depends on the type and technical characteristics of the vehicle (the higher the engine cubic capacity, carrying capacity, number of seats, power of the engine, the higher the average sum of insurance). Thus the average insurance payment for private cars of foreign manufacture with the engine cubic capacity up to 1 200 cm^3 made 1 019,9 thousand roubles, with the cubic capacity of more than 3 500 cm^3 – 1 624,3 thousand roubles. In this way it is possible to get a sufficiently reliable information about the damage, caused in the result of accidents. However, it will concern only the victims and taking no account of the loss of market price, the lost benefit and moral damage.

As one of the indicators for assessing the insurance risk, a probability of the insurance event can be suggested, which is characterised by a number of accidents per 100 concluded contracts of insurance (in 2005 this indicator has slightly increased and came to 2,98, in 2004 – 2,67). Based on this indicator, it is also possible to determine the risk to be involved in a road accident: in Minsk this indicator is higher than 5,7 (this is a maximum value), whereas in other residential areas, it varies from 1,5 to 4,6 and, consequently, the risk to be involved in road accident in these cities is considerably lower.

Besides, the analysis of insurance sampling showed that the given indicator is significantly different for the men – 2,82 and for the women – 4,0. Though, based on the statistics of the Ministry of Inner Affairs, women are more rarely involved into the accident (to tell the truth, based on the absolute but not relative indicators).

Based on the data of insurance events, it is also possible to make an analysis of accidents by the time of their occurrence. For example, for many years already the largest number of accidents takes place in October, the lowest – in April; the least dangerous day of the week is Monday (~10 % of insurance events), the most dangerous – Saturday (~20 %).

This information can also be used for the analysis of accident rate in high-accident locations. This is how the insurers analyse the accident rate on separate sections of road network (by separate main streets and other characteristic road sections) by the number of insurance events on these sections.

It should be mentioned that forecasting the pedestrian-involved accidents requires a separate investigation. Pedestrian accidents have been studied by many authors [6, 7, 8]. It was determined that such accidents take 70–75 % of the total number of fatal and injury accidents. Up to 90 % of pedestrian-involved accidents occur with the participation of vehicles moving in a straight (transit) direction. This could be explained by a high speed of traffic flow. It should be noted that, for example, accidents in a *turning transport – pedestrian* conflict make about 10 % and this is explained by a relatively low speed of turning flows (Fig 4).

The studies [10–13] made the investigation of the influence of traffic conditions on the accident rate (including pedestrian-involved accident) with the division of the main causes of accidents on rural roads and in residential areas.

The studies [14–16 etc] give some results on forecasting the accident rate in a *transport – pedestrian* conflict by using a statistical method. It is supposed, for example, that installation of traffic lights at the controlled intersections reduces the number of pedestrian-involved accidents by 40–50 % (data of USA), erection of a functional pedestrian fencing of more than 100 m long reduces the number of accidents by 70 % (data of USSR), erection of an underground pedestrian crossing – by 54 %, construction of footways and pedestrian tracks – by 78 %.

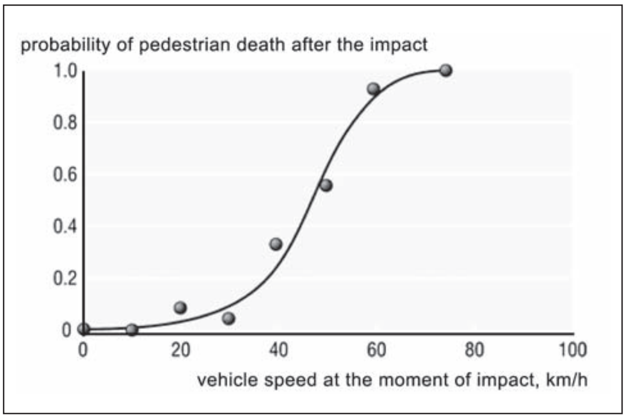

Fig 4. Risk of pedestrian death according to the speed of impact of car. Reproduced with permission [9]

On the ordinate – probability of pedestrian death after the impact; on the abscissa – vehicle speed at the moment of impact, km/h

5. Losses in road traffic

There is always a certain sum of costs and expenditures to characterise the cost of transport services. This cost consists of two basic components – infrastructure costs and transport expenditures:

$$C = Z + E, \tag{2}$$

C – cost of transport services; Z – infrastructure costs; E – transport expenditures.

All of it is estimated in monetary units.

If the investigative cost is close to the minimum, possibly the system is considered to be optimum, without losses. If the cost is not minimum, the **losses** take place*, which mean that the investigation cost exceeds the minimum possible:*

$$\Pi = C + C_{min}\ , \tag{3}$$

Π – losses in the investigation system; C – investigation cost of transport services; C_{min} – minimum possible cost.

The term "minimum possible cost" is rather convential and has a wide interpretation. First, all the non-obligatory expenditures, for example, accidents, are treated as losses, though it is known, that there is no traffic without an accident. Second, the basis for the comparison of, lets say, the speed of traffic, a standard permissible speed is assumed, for example, in residential areas – 60 km/h (or 50 km/h), which until now cannot be achieved everywhere. Third, in order to reach the minimum possible cost it is necessary to collect on a study section or system all the best world-wide achievements in this field and this is, practically, unreal. Therefore today the minimum possible cost is in reality not a standard but a certain landmark to be aimed at. As a result, the term "*losses*" means not only something we lost but also something we missed, did not make use of, did not take etc.

Road transport renders services for all our activities, the whole population of the country take part in it; our roads, streets and environment is a public-wide property etc. Due to this and a number of other reasons the cost of transport services is considered to be the public-wide, state-wide, nation-wide etc. Therefore any loss in road transport, in any of its subsystems and on any section, irrespective of the reason, consequences or victims, becomes the public-wide, state-wide and nation-wide loss. Consequently, any losses in road transport or road traffic, irrespective of the fact are we directly involved in them or not, do we know about them or not, are *our* losses and we all are strongly, or sometimes even vitally, interested in the reduction of such losses.

The "cost of transport services" has several meanings. In one case, when it goes about huge regional or national systems of road transport, the meaning usually covers the total cost, taking into consideration all the components of the extremely complicated and multiple system. This cost could be called the global cost, $C_{гл}$. In other cases, for example, when studying alternatives for the control of a restricted section of the road network, the term "cost" comprises only traffic expenditures, the other components could be simply excluded, since they take no part in the assessing alternatives and decision-making. Such cost could be called the cost of expenditures, C_e. In third case we can only speak about the infrastructure costs, for example, should we design the traffic-lights ourselves or buy them abroad. This cost could be called the cost of infrastructure costs, C_z. However, in most cases the engineer deals with intermediate alternatives, where the term "cost" comprises merely the comparative components; most frequently, the traffic expenditures and certain costs of a limited change under traffic conditions. This cost could be called a comparative, C_{cn}, or simply C.

Since losses, according to their definition, is a derivative from cost, they could be classified analogically – global, caused by traffic expenditures, and infrastructure costs. This article studies the losses in road traffic, which mean a socio-economic cost of non-obligatory, unforced expenditures in the process of traffic.

Losses due to expenditures, like expenditures themselves, could be divided into 4 types – economic, ecological, accident-related and social. All these types are closely related and sometimes it is difficult to make a clear separation between them. Therefore the above division as well as the given terms should be treated as conditional. Nevertheless, more than twenty-year experience of the use of this classification showed that it is understandable and easy to be used, especially for the analysis of the structure of losses on an individual section.

Economic losses in road traffic are related to non-obligatory delays (reduced speed if compared to the permissible one), stoppages and useless run of vehicles, delays for passengers and pedestrians, over-consumption of fuel, tear and wear or damage of vehicle because of a poor quality of traffic conditions etc. They also include the loss of benefit for the road users and losses in the related industries due to unfulfilled obligations because of, eg time delay or breakdown on the road etc. Economic losses are characterised by their almost even distribution between all the society members and are concealed when merged with really unavoidable expenditures, as a result, we get used to them and do not notice them. This is not right, as, according to their extent, the economic losses are significantly higher than the accident and ecological losses taken together and have a large influence on the level of our welfare.

Ecological losses – those exceeding the minimum possible emissions of hazardous materials into the atmosphere, water and soil pollution, noise impact, vibrations and electromagnetic radiation. The main causes for the increased level of ecological losses are: excessive loading on separate road sections, increased level of manoeuvring of high-volume flows, including breaking, stoppages and accelerations; forced reduction of speed and travelling on uneconomic regimes; useless run in any of its expressions; unsatisfactory technical condition of vehicles etc. Even such "useful", as it may seem, measures as the reduction of permissible speed in residential areas or the obligatory use of headlights in a day-time, result in a higher fuel consumption and the increased ecological (not talking about the economic) losses and eliminates the expected "benefit".

In ecological losses it is necessary to separate the produced and the consumed damage. It is one case when a high-volume urban motorway runs through uninhabited, for example, industrial zone, and quite another case when the same motorway crosses a densely populated residential area and comes in the closest proximity to the residential houses, hospitals, children establishments etc. Evidently, the produced damage being the same, the consumed damage in the second case will be incomparably higher. This separation, though insufficient, but is, nevertheless, taken into consideration when estimating ecological losses. For example, the cost of damage due to the same amount of emissions into the atmosphere in the city is almost one and a half times higher than outside the city, and when determining the concrete damage, caused by the ecological impact, the number of pedestrians and local residents, affected by this impact, is taken into consideration.

Ecological losses have an insidious characteristic that their effect is delayed in time for a rather long period. As a result, the today‘s generation reaps the harvest of the ecological activities of previous generations, while the harvest of our activities will be reaped by our descendants. The danger is that the results can become unpredictably terrible, for example, disappearance of ozone layer or genetic changes in the human himself. What concerns a monetary equivalent, the ecological losses, in today‘s estimation, fall significantly behind the economic losses and considerably exceed the accident losses. It should be reminded that in future the importance of ecological losses will highly increase.

Accident losses are all the losses caused by the accidents of any type and of any severity, also legal and other expenditures, related to the accidents. In accident losses, unlike the economic and ecological ones, damage is caused for the individual road users – for them this type of losses is thousand times more important than other types of losses. At the same time, the society's attitude towards accident losses is easily defined by the results, the accident rate, ie by the actions the society takes to reduce these and other losses, but not by its declarations on this matter.

Social losses are all losses related to the breach of human rights and liberty, inobservance of laws and moral degeneration of a personality. They could be caused by self-will, dishonesty or incompetence of the authorities, disobedience of the set norms by the road users, as well as absurd and non-realisable certain items of these norms; compulsion or incitement not to satisfy the standards; uncontrol or impunity of individual persons etc. For a long time social losses have not been treated as a fact and by no means as losses. It seems it will take a certain time to understand the importance of these losses and not only for the road traffic, where they take a prevailing position, but also for other areas of our life.

All types of losses are socio-economic and include two components – material and moral or economic and social. Economic component makes that part of losses, which has a clear monetary equivalent, for example, the cost of vehicle or goods damage during the accident or reimbursement of the sick-lists due to ecological impact on the human.

Social component has no clear monetary equivalent and characterises that part of losses which is reflected on a full value of life of an individual person or the whole society. Social losses are related to the death of person or the loss of his health, including the mental one (ie "heartache"); environmental conditions, state of the society, education of children etc. Economic evaluation of these losses is carried out through the system of insurance relations, public priorities, compensation of moral damage etc. And though this evaluation is only approximate, not very strict, nevertheless it exists and gives an opportunity to compare different types of losses.

A comparison of losses could be carried out by the "given" losses, including both components – economic and social:

$$\Pi = \Pi_e + \Pi_c, \quad (4)$$

Π – given losses of a given type, roubles/year; Π_e – economic component of the losses of a given type, roubles/year; Π_c – social component of the losses of a given type, roubles/year.

6. Conclusions

Based on investigation results and using the gained experience, the following trends could be pointed out to reduce the accident rate:

1. The performed investigations allowed us to determine the statistically significant relationships between the level of accident rate and a complex parameter – potential danger. The suggested method gives a possibility for estimating the level of accident rate in the stage of elaboration and acceptance of design solutions as well as in assessing the existing alternatives of road traffic organisation. The most statistically-significant relationships between the accident rate and the parameter of potential danger were obtained for the conflict zones and intersections.

2. In our opinion, all the accident information (together with other components of the cost of transport services) should be accumulated in a centre, created especially for this purpose, from which it will be distributed to the users. Everybody knows that it is not possible to manage a certain process without having a detail information about it, and the costs of getting this information is ten, hundred or even thousand times lower than the losses caused by the non-optimum management.

Therefore the situation with the so-called unregistered accidents, in which 80 % of information about the accident rate has not been collected and analysed, seems not only absurd but also criminal. Especially in the country where the level of accident rate (according to the killed people) is several times higher than in the developed countries.

3. It is necessary to create a methodology for forecasting accident rate by a potential danger in the transport–pedestrian conflict, which would also consider the degree of accident severity.

4. The use of the developed method together with the presented data will give a possibility to increase the adequacy of forecasting results and the low expenditure of labour and will help reduce the accident rate as well as the accident severity in road traffic.

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