Analysis of road safety assessment methods

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Abstract. This article analyzes advantages and disadvantages of the methods approved at the legislative level and methods developed by various researchers. To identify advantages and disadvantages of each method, experiment were carried out. During the experiments, safety of 796 km section of the federal road R255 was assessed. Based on the analysis, all the methods were divided into three large groups: statistical methods, probabilistic methods, and methods based on the analysis of car movement on the road section under consideration. All the accident analysis methods applied in Russia and approved at the legislative level assess road safety when the accident has already occurred, i.e. post-factum. In this regard, it is relevant to identify patterns between the characteristics of the road section, vehicle movement parameters and road accident probability. Using these patterns, road safety can be improved.

Introduction

Every year, thousands of people die or get injured in road accidents. Accidents are one of the most significant research problems, as they are connected with health and lives of young and middle-aged people. Therefore, they prevent the population from demographic reproduction.

A comprehensive analysis of all types of accidents should be followed by identification of factors and causes of road accidents. Accidents should be analyzed from the systemic point of view, and factors determining or accompanying the accident should be classified according to the complex properties of the "Driver - Automobile - Road - Environment" ("DARE") system.

Main body

At present, road safety is assessed in compliance with the road safety guidelines developed by the Road Research Laboratory of MARI and approved by the Ministry of Automobile Roads of Russia on January 29, 1986. According to the guidelines, in order to obtain comparable data for analysis of road conditions, it is necessary to use the following parameters:

Relative accident coefficient (accident coefficient)
The relative accident coefficient (accident coefficient) can be used for initial processing of statistical data on road section accident rates. When analyzing the relative traffic hazard, in order to obtain a reliable estimate, it is necessary to collect data on accidents for at least 3-5 years (traffic intensity and number of accidents on the road section under study). In the United States and some European countries, similar accident rates are also used [1] to determine the number of road users involved in traffic accidents per 1 million participants. In Russia, the number of traffic accidents per 1 million cars is calculated without regard to the number of participants.

In addition to relative accident rates, absolute accident rates are used. Absolute indicators allow for assessment of the danger of a road section using the total number of accidents for a given period. In this case, those areas where the number of accidents for the period under study exceeds a certain number are considered dangerous. Different countries have different road section danger criteria. Actual values are compared by these criteria. In the UK, a road section is considered dangerous if one or more accidents involving injured people occurred on the road section of 0.16 km (0.1 miles) for three years [2]. In Bulgaria, the location of accident concentration is a section where two or more accidents occurred for one year, and one or more accidents occurred for every 100 m of its length. The place length is 100/200 m, and the section length is 200 m. In Belgium, road sections of up to 1 km in length are considered dangerous if at least ten accidents were registered during the year [3].

In Russia, an accident section (a place of concentration of road accidents) is a road or a street section of more than 1000 meters in length outside settlements or 200 meters in length in a settlement, or the intersection of roads and streets where three or more traffic accidents of one type or five or more accidents, regardless of the type, caused human deaths and injuries.

Safety coefficient

To assess the accident risk at calculated speed rates, safety coefficients are used. These coefficients are calculated on the basis of the automobile theory and do not take into account psychological perception of road conditions by drivers. Probability of the accident on the section under study depends on speed rates and safety coefficients.

Accident coefficient

The method of accident coefficients is used to identify how each element of the road plan and profile contributes to the increased probability of an accident in comparison with the reference section. Since each partial accident coefficient characterizes relative probability of accidents on the section under consideration due to deteriorated road conditions for one reason independent of other influencing factors, their combined effect can be estimated in accordance with the probability theory statement about event probability under the influence of several independent factors by the product of the partial coefficients - a generalized (final) accident coefficient.

The list of partial accident coefficients in the road safety guidelines is not exhaustive. Partial coefficients were suggested by Varlashkin. They take into account the steepness of mountain slopes affecting driving patterns; Sadyrhodzhaev suggested coefficient for alleys of roadside plantings on roadsides and irrigation canals, Nechaev – for road surface evenness, Shevyakov - for highways, Blizniceniko - for foothill road conditions [4].

To identify the most dangerous sections, implement public control and take urgent measures to improve these sections, Tyulkin created a software product to automate collection and processing of statistical information about road accidents "Multi-level information and analysis system of traffic safety management" (RSM MIAS)". The developed system whose mathematical model is presented by formula (1) allows the researcher to obtain data on the factors that have the greatest impact on the RS on a particular road section and their quantitative expression in order to calculate the numerical safety value of the road section having the maximum equal to the optimality criterion:

$$P = k_1 \times x_1 + k_2 \times x_2 + k_3 \times x_3 + \cdots + k_n \times x_n \rightarrow \max \qquad (1)$$

where k_n is the coefficient of the road factor; x_n is the degree of compliance with the standards for the road section calculated by formula (2);

$$x_n = \frac{c \cdot s}{100}\% \qquad (2)$$

where *s* is the point estimate of the presence of elements of the road environment (10 points - all elements are present, 5 points - partial presence, etc.); *c* is the constant showing the ratio of the influence of factors in the system *s* - score-based assessment of the presence of certain elements of the road environment (10 points - all elements are present, 5 points - partial presence, etc.); c is the constant showing the ratio of the influence of factors in the DARE system.

Thus, the numerical value of the road section safety is a sum of the calculated coefficients of homogeneous factors of road environment k_n, obtained by pairwise comparisons [5].

In India, to determine the road safety level, a simple additive-weighted method (SAW) is used. It is also an accident method which takes into account factors affecting road safety. In addition, this method takes into account the weight of each factor. To calculate the scores corresponding to specific criteria, the average weight of the criterion and the individual score of each parameter are determined by equation (3).

$$P_i = W_i \times R_i \qquad (3)$$

The total weighted value for a specific alternative is determined by equation (4).

$$LOS_i = \frac{\sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} W_i} \qquad (4)$$

n = the number of parameters that determine overall road safety; P_i = individual assessment of each parameter; W_i = weight associated with the i-th parameter; R_i = score value for the i-th parameter.

The weight of each parameter (priority determination) is calculated according to the theory of Thomas Saaty [15].

Method of conflict situations
The method of conflict situations assumes that accidents are preceded by repeatedly occurring dangerous situations. To prevent these situations, one or both participants have to change the mode of car movement. It is believed that the conflict is a situation occurring on the road in which cars are so close to each other that if their further movement remains unchanged, collision will be inevitable. The danger of an accident can be eliminated by maneuvering or braking. Therefore, the actual number of accidents is significantly less than the number of conflict situations, but there is a fairly stable correlation between these characteristics. There are three types of conflict situations (light, medium, and critical).

Ryabchinsky developed a model for predicting accidents using the method of conflict zones for potential danger on urban accident sections. Based on the research, a system of new methods for predicting accidents according to the conflict zone method was developed. It includes three methods for predicting accidents at regulated intersections in "transport – transport" (collisions with rear and passing impacts), "pivoting transport – pedestrian", "transit transport – pedestrian" conflicts and two methods for predicting accidents on road bumps in "Transport – Transport" conflicts (collisions with rear and passing impacts) and "transit transport – pedestrian" conflicts. These methods account for different factors which are characterized by 110 parameters affecting the accident coefficient and high prediction accuracy (by more than five times as compared with the known method) [6].

Sarbin and Eryomin suggest using a method for modeling conflict situations at unregulated intersections instead of traditional road safety assessment approaches. The method is based on computer experiments with virtual intersections in order to study causes and severity of conflict situations arising in various road conditions [16].

Canadian and Chinese researchers suggest using two-dimensional threshold exceedance models to assess accidents involving several sections at the overhead road entry. Based on the results of the model assessment, the researchers found that the two-dimensional model of extreme values with a logistic distribution function is the best, and its performance is further assessed by comparing it with one-dimensional models in terms of accuracy and efficiency [7].

In addition to the recommended methods, there are a number of methods developed by Russian and foreign scientists.

One of the oldest methods is the score-based method. Road quality assessment systems based on the sum of scores were used for identifying priority reconstruction sections in the UK, USA and France. In the USSR, Sidenko and Rybalchenko suggested using a qualimetric method for assessing the road quality. The method accounted for three groups of factors affecting road safety — technical (geometrical parameters of the road, traffic conditions), ergonomic (aesthetic qualities of the road, psychophysiological features of road perception by drivers) and economic (cost of road construction and maintenance) [4].

The method for assessing danger of road sections by noise acceleration is based on the same idea.

Unequally evaluating the degree of road section danger, the drivers move at different speed rates. Accordingly, acceleration rates are different in different places. The theory of traffic flows suggests describing the degree of heterogeneity of movement and intensity of speed change on different road sections using the mean square value of accelerations (first, deceleration when entering the section, then acceleration when leaving it - "acceleration noise" (m/s^2) calculated by formula (5) [3]:

$$J = \frac{(\sum_1^n (a_i - a_{cp})^2)^{1/2}}{n} \tag{5}$$

where a_i is acceleration on each section; a_{cp} is the average value of accelerations on the whole section; n is the number of sections.

For simplicity, instead of summing up car rates, modal values of the speed distribution curve on each section are used.

Using the method based on the theory of reliability or the theory of risk, probability of failure-free operation (reliability) of the "DARE" system, or accident probability (risk) can be determined. The concept "accident risk" (r_v) at speed v is a qualitative engineering characteristic of the danger of a geometric element of the road which is determined by formula (6):

$$r_v = \frac{n_v}{N_v} \tag{6}$$

where n_v is the number of accidents at speed v due to the imperfect geometrical element of the road; N_v is the total number of cars having moved along the section at speed v [8,3].

Researchers suggest using the method of multivariate correlation analysis to determine the probable number of accidents on various road sections. To do this, according to the data on road conditions in the places of concentration of accidents, the system of equations covered all the influencing factors was developed (formula (7)):

$$n_j = a_{1j} + a_{2j} \times R_j + a_{3j} \times j_{\text{пр}} + \cdots \tag{7}$$

where a_j is the target coefficients of various affecting factors; n_j is the number of accidents; $R_j, j_{\text{пр}}$ is characteristics of road conditions and traffic patterns on the accident section [9].

Using the accumulated data and identifying influencing factors, the results of the correlation analysis can provide indicative forecasts of the number of accidents for roads located in similar terrain and climate conditions at similar traffic intensity rates.

Ideas of identification of dangerous roads sections according to accident statistics using the methods of the theory of probability have been expressed in several countries. Researchers assumed that on the road with the same traffic safety, accidents are rare events obeying probability theory laws. The accident statistics showed that the number of road sections of equal length with a different number of accidents corresponds to the binomial or Poisson distribution. According to the schedule of distribution of accident sections for several years and focusing on dangerous sections (narrow bridges, sharp turns at the end of a long descent), one can find the smallest distance between the places of two accidents [4].

To determine the state of accidents, the "before and after" method is used. It involves comparison of the accident status of a given section based on the accident statistics before and after the event to improve traffic safety. Specific accident rates reflect the percentage of one absolute accident rate from the other. They characterize the structure of accidents and help compare different sections [3].

The Canadian researchers suggest using formula (8) to determine road safety before and after measures aimed at improving road safety have been implemented:

$$\ln(\lambda_{i,t}) = \ln(section\ length_i) + \alpha + \beta_1 \times \ln(AADT_{i,t}) + \beta_2 \times t \tag{8}$$

where λ_{it} is the expected number of accidents on road section i in year t; $AADT_{i,t}$ is traffic intensity on road section i in year t, where AADT is the average annual daily traffic (the number of vehicles per day), a is the intersection complexity coefficient, β_1 is the coefficient for $AADT_{i,t}$, β_2 is the coefficient for the time pattern [10].

Based on the Smid's formula, Chubakov suggests determining the impact of social, economic and administrative factors on traffic accident rates. He says that the specific number of deaths caused by

road accidents per vehicle (D / N) should be a power function of the level of automobilization (N/P) calculated by formula (9):

$$D/N = \alpha(N/P)^{-2/3} \tag{9}$$

The existence of a relationship between the numbers of road traffic accidents, population and vehicles can be justified by rank correlation analysis and simple physiological considerations.

Salmin suggests using a heuristic method for assessing the DARE system using formula (10):

$$Y = a_o + \sum a_i \cdot x_i^j \tag{10}$$

where Y is the accident severity coefficient; a_o is the coefficient considering the influence of factors which were ignored when calculating values of j i x ; a_i are weight coefficients of the DARE system elements; x_i^j are the DARE system elements [11].

Yeryomin developed a method for assessing the impact of road conditions on accidents on federal roads for planning road safety measures. The method involves determining the degree of danger of a road section based on the section length and parameters (lane width, roadside width, road surface flatness, visibility distance) [12].

Korchagin assessed risks for each violation of road traffic rules. To assess the risks, 16 most typical types of traffic violations were selected. Eight experts, including representatives of various segments of the population, took part in the experiment. The generalized risk assessment for each type of traffic violations is carried out by aggregating expert assessments according to formula (11):

$$r_k = \frac{1}{m}\sum_{j=1}^{m} r_{kj} \tag{11}$$

where m is the number of experts; r_{kj} is the type of a risk for the k-th violation of the traffic rules carried out by the j-th expert [13].

In Europe, to analyze road safety, the index of road safety efficiency is used. The value of the road safety efficiency index depends on the selected indicators, weight distribution and data aggregation, as well as on the degree of correlation between the indicators and the final results. The road safety efficiency index derived from a wider set of indicators ensures accurate identification of trouble-free and emergency road sections.

For each country, the summary index from zero to one can be obtained. Higher values indicate better relative efficiency. For countries with an optimal complex index which is less than one, accident sections can be identified using weight coefficients. The road safety performance index is determined by formula (12):

$$RSPI_j = \frac{max}{w_{ij}}\sum_{i=1}^{n}(\overline{r_{ij}w_{ij}}) \tag{12}$$

where r_{ij} = modified value of indicator i for country j; w_{ij} = weight of indicator i for country j.

For calculations, minimum and limit values are calculated for each indicator [14].

Experiment
To determine disadvantages and advantages of each method, we assessed road safety of the 796 km section of the R255 road using all the methods used in practice (determination of the absolute indicator, determination of the accident coefficient and accident rate, the method of conflict situations

and the "noise acceleration" method). It is impossible to assess road safety by determining the safety coefficient for a given section, since the safety coefficient is calculated only for sections with low traffic intensity. The other methods will not be used due to their peculiarities. The characteristics of the section are presented in Table 1, and its configuration is shown in Figure 1. The results of the experiment are summarized in Table 2.

Table 1. Technical characteristics of the 796 km section of the federal road R255.

Parameter	Value
Average daily traffic, cars per day	24627
Average speed, km/h	93
Maximum allowable speed, km/h	90
Number of lanes	4
Relative width of the road surface, m.	25
Curb width, m	3
Longitudinal slope, %	2
Visibility, m	More than 500 m
Presence of intersections	At the same level
Presence of buildings	present

Fig. 1. Configuration of the 796 km section of the federal road R255.

Table 2. Results of road safety assessment for the 796 km section of the federal road R255.

Road safety assessment methods	Results
Accident coefficient caluclation	0,44
Absolute accident coefficient calculation	Accident section (4 accidents per year)
Accident coefficient	Safe section
Methods of conflict situations	Mild danger
The method for assessing the danger of road sections by "noise acceleration"	Light danger

The analysis of road safety assessment using various methods showed that these methods have different relative and absolute values.

Discussion
All the methods can be divided into 3 groups:
- Statistical methods (determination of absolute accident indicators; determination of relative accident indicators (accident rates); the "before and after" method);

- Probabilistic methods (based on the theory of system reliability, risk theory, mathematical statistics);
- Methods based on the analysis of vehicle movement on the road section under consideration (the accident rate method, the multivariate correlation analysis method, the safety coefficient method, the acceleration noise method, the score-based method, the method of conflict points).

Statistical methods were the first methods used for determining accident indicators. The methods for assessing the road safety level are based on accounting and processing of statistical data and have a number of disadvantages: the need to have reliable statistical data for at least 3-5 years; statistical data on accidents can be considered comparable only if there were no works which could influence road conditions and traffic safety during the entire period under study; possible distortion of true causes of accidents due to incompetent persons making up accident reports; for the period under study (3-5 years), the traffic flow (its intensity and composition) can change; these methods cannot be used for a comparative analysis of accidents in different regions due to the different number of vehicles, length of roads and other features of regions or road sections.

The probabilistic methods are based on the analysis of statistical data on accidents due to which one can identify how each element of the road plan and profile increases the probability of accidents compared to the reference section. The disadvantages of these methods are as follows: the need for a large amount of statistical data on accidents on road sections with a wide range of changes in influencing factors to identify various partial accident rates that depend on these factors; the effect of possible combinations of adjacent elements of the plan, longitudinal and transverse profiles on the accident rate is ignored; it is impossible to accurately predict accidents on a mountain road using the correlation dependence obtained from statistical data for flat roads; the risk of accidents is determined only for cars that move at a constant speed rate, without taking into account their acceleration rates.

The methods based on the analysis of car movement on the section under consideration are used to analyze relatively small local sections. The disadvantages of these methods are as follows: only the number of theoretically possible contacts is taken into account, regardless of the actual flows and their subdivisions according to the type of maneuvers; when analyzing the car movement, only one parameter of the movement is taken into account; the need to adjust data to the traffic intensity rate.

The main disadvantage of the methods used in practice is mandatory availability of statistical data on accidents. These methods cannot be used for assessing or modeling new roads.

Conclusion
The methods used in Russia for assessing traffic safety are similar to those used in other countries, but there is a significant difference. In some countries, in order to determine the accuracy of the road section accident rate, attention is paid to the weight of each parameter of the road network.

The accident analysis methods applied in Russia involve post-factum assessment of road safety, when the tragedy (accident) has already occurred. This approach does not allow for assessment of the suggested accident reduction measures at the development and implementation stages. The same is true for the design and reconstruction of existing roads. The method is unacceptable when implementing ambitious plans of the Russian Government aimed at reducing road accident rates.

The analysis of various methods showed that only the methods based on the analysis of vehicle movement on the section under consideration take into account road accidents based on complex properties of the "DARE" systems. Only the influence of one parameter ("Road") is taken into account. The relationship of the "Road" - "Environment" elements is established when calculating the accident rate using the partial coefficient "Visibility". The relationship of the "Road" - "Car" elements is established when calculating the safety coefficient and determining the "acceleration noise".

The above-mentioned disadvantages of the methods for assessing traffic safety require development of new methods that allow for more detailed consideration of the interrelationship of the DARE system elements, namely, the methods which take into account the cumulative effect of such elements as the automobile, the road and the environment.

It is necessary to identify relations between the characteristics of the road section and vehicle movement parameters and probability of road accidents in order to improve road safety.

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