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EMPIRICAL APPROACHES OF ROAD INFRASTRUCTURE SAFETY MANAGEMENT

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Abstract: The focused effort of European Union in a form of safety improvement as one of the essential quality attributes of a transport system was reflected in several legal norms governing the conditions for each element of this system. Road infrastructure is no exception, where rules and principles of safety shall be applied in the process of its preparation, implementation and within the operation as well. The Directive 2008/96/EC on road infrastructure safety management has defined the basic framework for performance of individual procedures, which was transposed into national legislation and gained detailed outlines through adoption of the Act on road infrastructure safety management and related decrees.

1 Introduction

Based on the provisions of the legislation, following procedures are considered as elements of road infrastructure safety management:

- road safety impact assessment (hereinafter Impact Assessment),
- road safety audit (hereinafter Safety Audit),
- safety management and inspection on road in operation [1], [2].

Impact assessment means a comparative analysis of the impact of a new road or a planned substantial modification to the existing network on the safety performance of the road network. The impact assessment shall be carried out within the investment plan, i.e. before the development of detailed project documents [1], [2].

Safety audit' means an independent, systematic and technical safety check relating to the design characteristics of a road infrastructure project or a planned substantial modification to the existing road having effect on the traffic flow. Procedures related to the performance of safety audit shall be carried out from the phase of road planning to the phase of its operation [2].

Safety management and inspection of road in operation is a procedure comprising of regular verification of characteristics and deficiencies, which due to the safety reasons require maintenance work (hereinafter Safety Inspection) and classifications of sections with high accident rate, or classifications of network safety [3].

Each element of the road infrastructure safety management represents an independent procedure, being understood that the knowledge and principles identified through the safety inspection shall be applied within the performance of the safety audit and impact assessment. This fact presents the safety inspection as a fundamental issue as the quality of its outputs affects the quality of other safety management procedures. Therefore, this issue needs to be given more attention and this article is considering what could contribute to improvement of the status quo [3], [4].

2 Approaches to implementation of safety inspection

The content and form of implementation of safety inspection depend on the choice of approach applied for assessing the safety level of existing roads. Basic attribute, which affects the decision about the choice of approach, is the difference between perceived and observed level of safety. Preventive approach to the performance of safety inspection is aimed at the periodic detection of deficiencies (perceived level of safety), which are present on the entire considered network without a detailed analysis of accidents occurred in the past. This type of safety inspection is mandatory, conducted at least once every three years on all sections of road corridors that are part of the TEN-T network. Active approach to the implementation of the safety inspection lies in the identification of shortcomings (observed level of safety) resulting from the analysis of the accident rate and from the outcomes of the inspection at black spots, which are based on the classification of sections with high accident rate [4], [5].

The classification of high accident rate sections is presently carried out by the Slovak Road Administration on motorways, expressways and on the I. and II. class roads as well. Procedures for the management and

inspection of road safety do not apply to road tunnels. It is necessary to distinguish between the safety inspection and maintenance, or repairs on roads. Maintenance and repairs mean regular process of checking of equipment and elements of roads and their subsequent repair as specified in technical regulations. The maintenance and repairs of roads may be performed by persons, who do not qualify for the performance of safety inspections referred to in the regulations [4], [5].

Active approach to the performance of the safety inspection starts with a systematic collection of data enabling the identification of problem areas. These problem areas include sections with high accident rate (hereinafter black spots), which are characteristic with high concentration of accidents compared with other sections [5].

In Slovakia, the evaluation of the safety of the road network is presently carried out by the Slovak Road Administration, which annually processes and publishes a list of black spots on motorways, expressways and on the I. and II. class roads. The identification is based on the assumption that accidents are homogeneously distributed all over the road network. They are using one parameter Poisson probability distribution characterized only by the mean value calculated as the arithmetic average of the number of accidents in previous year per standard length (e.g. 1 km) of the road [4].

Based on the presently used method, the defined frequency distribution will return the value of a cumulative probability of exceeding a certain discrete number of traffic accidents, a so-called critical number of accidents at a particular level of significance. If the value of the distribution function of a Poisson distribution beyond the critical level of the number of road accidents exceeds the level of significance, the methodology evaluates the section as a black spot. For their classification they are also using the recorded number of accidents and their consequences in a form of the sum of products of the number of fatalities, heavy and light injuries and corresponding values of economic losses from damage to life and health and the overall material damage estimated by the police [5], [6].

After the process of selection of high risk road sections measures are implemented, depending on the funds available and their cost. A specific type of measure is based on recommendations of experts from the scope of road managers or other entities (e.g. Police) that are aware of the conditions at risky road sections [5].

The efficiency of measures is not examined in a way to be able to estimate benefits in a form of savings in socioeconomic costs (e.g. reduction of the number of road accidents, emissions, noise, etc.), but to solve the problem. Whereas the funds available for this purpose are low, typically it is concerning low cost measures (e.g. modification / renewal of road markings). This approach cannot be considered as systematic for two main reasons. The current method for determining risk sections indicates that the list is also including the sites, where the high number of accidents (or a smaller number of accidents with a higher severity) was recorded only as a result of seasonal variation. In other words, the scope of actions includes also road sections, where the number of accidents in the past and likely in the future as well will not be that high. The second reason is that there is an absence of a procedure allowing the prioritisation of sections and measures with the greatest expected benefits in terms of social costs savings. It is because of the lack of resources why there is a need for optimisation, which would allow to implement a set of measures with highest benefits. Based on the latest knowledge in this field, the mathematical modelling is being preferred, which eliminates the shortcomings of the current procedures [5], [6].

3 Definition of black spots

First of all, for the purpose of formulation of the problem it is necessary to determine criteria specifying an appropriate definition of a black spot. Research institutions are dealing with the determination of these criteria for more than 25 years. One of present analyses (Madsen, 2005) suggests following criteria for a relevant definition of a black spot:

1. Checking of random variations in the number of road accidents.
2. Considering as many known factors affecting the road safety as possible.
3. Identification of sites with extremely high share of fatalities and severe injuries.
4. Identification of sites with local risk factors related to construction layout and traffic control significantly contributing to accident rate.

The first criterion implies that the identification of black spots should be based on the expected number of traffic accidents, as opposed to actually recorded. In practice, however, it appears to be much more difficult to use the expected number of accidents, since it cannot be recorded but only estimated. Nevertheless, at present there are methods that make it possible to provide a qualified estimate (empirical Bayesian method).

The second (or the fourth) criterion also assumes the utilisation of Bayesian method for the identification of black spots, which is supported by a multi-dimensional model of accident rate forecast. The development of a model can consider several factors to explain systematic variations in accident rates (volume of traffic, characteristics of the construction arrangement and elements of traffic control). Of course, it is unrealistic to expect the model to produce exactly accurate estimates, since it does not include all the factors (local risks) because of their specific nature. The third criterion on assessing the severity of the accident clearly states that

the decision-makers are trying to eliminate accidents with serious consequences.

The systematic use of empirical Bayesian method for estimating the safety of an infrastructure currently represents the pinnacle of the state-of-the-art theoretical knowledge focused on the management of black spots and on the management of road network safety. Following important elements arise from the latest knowledge:

- Black spots should be defined on the basis of expected and not recorded number of road accidents.
- Black spots should be identified by a clearly defined core set of sites,
- It discourages the use of continuous validation approach, which artificially increases the variation in the number of road accidents.
- In order to estimate the expected number of accidents, multi-dimensional models for the forecasting of the accident rate should be developed.
- The best estimate of the expected number of traffic accidents for each site is derived by combining the recorded number of traffic accidents with the model estimates for this site. Empirical Bayesian method should be applied within this procedure.
- Interpretation of alternative critical values for the expected number of accidents, which further specifies the site as a black spot should be investigated in terms of sensitivity and special characteristics, whereas an optimal criterion should be selected.
- Traditionally used criterion for black spots, which is the trend in the accident rate, has not been confirmed. Analysis of accidents at black spots is best conceived in terms of making hypotheses about the factors contributing to accidents.
- The black spots analysis should consider the possibility that the result of a random option may be an apparent behaviour pattern. Binomial tests should be applied to determine the probability that a certain number of a particular type of accident is merely a result of a chance.
- The black spots analysis should use the blind test, i.e. count with the comparison of such sites with safe sections. The aim of the analysis is to identify risk factors for the occurrence of accidents and the person performing this analysis should not be familiar whether it is concerning a black spot or not.
- Evaluation of the effects of black spots treatment should be based on empirical Bayes scheme before and after the implementation.

Current definition of a black spot is insufficient in the theoretical point of view because it is based on the recorded number of road accidents (history of adverse events on short sections of road infrastructure). However, it is considered as effective to identify those sites, where there is expected (estimated) an abnormally high number of accidents and not the sites with a presence of high number of accidents each year due to extreme statistical fluctuations. Therefore the definition of a black spot should read as follows: Black spot is a location with expected higher number of accidents than at similar sites as a result of local risk factors. Black spots are identified from a known sample set of sites representing the monitored road network in the Slovak Republic.

The condition of similarity of sites is assessed in terms of interpretative values of models for the forecast of the accident rate. Two sites can be regarded as similar in case that they have, for example, the same traffic volumes, speed limits, same number of driving lanes, etc. Within the identification of black spots, the comparison with other similar sites ensures that the interpretative factors included in models for forecasting may be regulated. Regulation of these factors is important because it is not the purpose to identify a black spot only because of higher traffic volumes. It is logical that the risk of an accident grows with the increasing traffic.

The above mentioned theoretical definition of a black spot shows that the method that can reliably identify these locations is only the one that allows to determine the impact of the three main factors on the expected number of accidents. The empirical Bayesian method meets these requirements, but it is possible that other procedures provide adequate outputs as well. On the other hand, the empirical Bayesian method allows to relativize the effect of stochastic fluctuations, general and local factors.

Empirical Bayesian approach was developed by Ezra Hauer and it can be used for estimation of objective estimates of a long-term expected number of traffic accidents for the individual elements of the road system, such as specific intersections or road sections. This method allows elimination of systematic errors that are attributable to random fluctuations in the recorded number of road accidents (errors due to a phenomenon, when each variance returns back to normal). There are several variants of empirical Bayesian approach and the most sophisticated of them estimates the number of accidents through the combination of knowledge extracted from two sources:

1. The multidimensional model for the forecast of accident rate, which describes the normal level of safety and the effects of variables that are affecting it. The most common form of the forecasting model is the negative binomial regression model.
2. Recorded number of accidents for a specific site during the same period as used within the setting of the model for forecasts of accident rate.

4 Conclusions

Current trends in research in this area are drawn towards the prediction of expected effects of the implementation of actions by means of mathematical - statistical methods and on the basis of relevant data. The estimate of effects of a particular measure can be quantified if we know the costs related to its

implementation as well as the benefits in the form of a reduction in social costs, which represent a monetary effect of the accident rate at given site / road section, where that measure is being implemented.

The reduction of social costs of traffic accidents can be quantified if we can estimate the change in the number of traffic accidents, which is the result of the measure. The latest procedures used to predict the expected number of accidents are working with the term Accident Modification Factor - AMF, which is used to calculate the expected number of accidents following the implementation of the measure on that particular site / road section. It is virtually a coefficient multiplied by the expected number of accidents at the considered site without the implementation of the planned measure. AMF estimate values higher than 1.0 represent an increase in accident rate (negative development) and values lower than 1.0 indicate vice versa the decrease in the accident rate (positive development). For example, for the value of AMF estimated at 0.8 we can talk about the reduction of the number of traffic accidents by 20%.

The methods, by which it is possible to derive the values of AMF can be generally classified into two groups according to the way of the data collection. Experimental studies using comparison between sites that are selected for the implementation of the measure and sites, where the measure is not to be implemented. Both groups are created before the implementation of the measure. In the case of observational studies, the data collection is carried out retrospectively through the recording of changes to road infrastructure, where relevant measures were implemented. For both types of studies, the method of measure efficiency is usually preferred to the cross sectional method. The modification factor of the accident rate is then estimated from the change in frequency of occurrence of traffic accidents before and after the measure implementation. Within this estimate, it is necessary to consider the effects of general changes in traffic accidents, which are not directly related to the measure.

The group of sites without implemented measure can be identified retrospectively and used for the consideration of changes in the level of safety due to factors other than the measure itself. In this regard, there are several types of observational effectiveness studies, which differ from each other by the usage of a control group for consideration of confounding factors. Naïve effectiveness method includes a simple comparison of the frequency of traffic accidents before and after the implementation of the measure without considering the changes that are unrelated to this measure. This deficiency is the reason why the method is not considered credible. There are two methods - comparing group's method and full Bayesian method - for the derivation of the modifying factor of the accident rate from the measure effectiveness study. The method of comparing groups is a simpler way compared to the empirical Bayesian that is, on the other hand, more complex and thorough. The so-called full Bayesian method can be also considered, which an extension of the empirical Bayesian method is.

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