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A Comparative Analysis of Identification of Hazardous Locations in Regional Rural Road Network

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ABSTRACT

The first step of the road safety management cycle is the identification of hazardous road locations. Traditionally, the identification criterion was recorded accident frequency or rate; however, it has tended to omit the significant influence of natural fluctuation known as regression to the mean. Using the expected number of accidents and empirical Bayes adjustment is the recommended solution; see e.g. Hauer (1997). This number is calculated with the use of an accident prediction model, taking into account several explanatory factors and controlling for potential confounding variables at the same time.
An accident prediction model for the regional rural road network was developed for the purpose of this study. The whole 2nd class road network in one of the Czech regions (South Moravia) was used. This network is used as a traffic connection between towns and larger territorial units in the region. The resulting expected accident frequency was further adjusted by the empirical Bayes estimate (Hauer et al., 2002).
The empirical Bayes estimate was used as a criterion for the ranking of hazardous road locations producing the list using top 5% as a threshold. At the same time, the ranking was performed using the Czech traditional criterion of recorded accident frequency, resulting in another list. This way three pairs of lists were developed for three time periods (2007 - 2009, 2008 - 2010 and 2009 - 2011).
The paper discusses the results of this comparison of hazardous road location lists. In the end, conclusions about the differences are made. Recommendations are provided with regards to using the hazardous road locations identification based on recorded or expected accident frequency.

Keywords: hazardous road locations, accident prediction model, empirical Bayes, regional roads, rural roads.

INTRODUCTION

Traffic is an inevitable part of everyday life of humans all over the world; however, its negative outcomes include traffic accidents. Road safety is thus a major social issue, calling for specific interventions, framed within a road safety management system (European Road Safety Observatory, 2009).
The first step of the road safety management cycle is the identification of hazardous road locations. An identification criterion is needed to detect a hazardous road location. According to a survey of identifying criteria of hazardous road locations in a number of European countries (Elvik, 2008), most of them rely on recorded number of accidents. However, this criterion has tended to omit the significant influence of natural fluctuation known as regression to the mean (as summarized e.g. in Hauer, 1997). Therefore, it is, compared to state-of-the-art techniques for identifying hazardous road locations, likely to involve substantial inaccuracies (Elvik, 2008).
To this end, state-of-the-art techniques based on the empirical Bayes (EB) adjustment have been promoted by a number of authors (Hauer, 1997; Persaud et al., 1999; Hauer et al., 2002; Elvik, 2010; AASHTO, 2010). Their calculation uses expected number of accidents derived from an accident prediction model with EB adjustment taking into account several explanatory factors and controlling for potential confounding variables at the same time.

For that reason, road safety prediction models were developed. Three time period, years 2007 - 2009, 2008 - 2010 and 2009 - 2011 were investigated. For each of these periods, a separate prediction model was developed.
Temporal continuity in the identification of black spots was compared with the prediction model and the currently used approach, based on traditional definition.
The objective of the study was a part of Czech regional rural road network. The whole 2nd class road network in one of the Czech regions (South Moravia) was used. This network is used as a traffic connection between towns and larger territorial units in the region.
The study was undertaken in the following steps:

1. The data collection and development of accident prediction models, calculation of expected accident frequency and EB estimate.
2. Identification of hazardous road locations based on the EB estimates.
3. Identification of hazardous road locations based on traditional criterion.
4. Comparison of the hazardous road location lists.

These steps are described in the following text. The aim of this study is to compare these two methods based on the percentage of the agreement in the identified locations in different time periods. Theoretically, the ideal method of identifying hazardous road locations should identify true hazardous locations which should be the same in time (provided there are no changes in the infrastructure). The prediction models and the EB approach work with the influence of exposure and regression to the mean, therefore, the results should be more consistent.

DATA COLLECTION AND ACCIDENT PREDICTION MODELS

An accident prediction model for the regional rural road network was developed in a previous study (Šenk et al., 2012; Striegler et al., 2012). The original model was prepared for the period of 2009 - 2011 for all accidents in Czech Traffic Police records regardless of their severity. For the purpose of this study it had to be modified; the data from the period of 2007 - 2011 were used. In addition, there was an accident reporting threshold change in 2009: the value of property damage only aaccidents increased from the value of CZK 50 000 (2000 €) to CZK 100 000 (4000 €). In order to avoid the resulting incompatibility in time series of numbers of property damage only accidents, only the accidents with personal consequences were therefore used. New forms of prediction models were developed.

Segmentation

The segmentation was done in a way similar to Cafiso et al.'s (2010) paper. The road sections, excluding intersections, were divided into segments which were homogenous with the respect to the several following variables:

- annual average daily traffic (AADT)
- presence of speed limit reduction
- road category
- number of lanes
- presence of paved shoulder

A change of any of these variables marked the end of the segment and the beginning of another one. There were 839 segments with the length ranging from 51 to 6456 m. Therefore, segments longer than 500 m were divided into 250 m parts. Finally, the length of the segments is between 50 and 500 m. Most of the segments (2925) are 250 m long, 196 segments are shorter and 643 segments are longer. These segments were assigned with specific values of a response variable (accident frequency) and various explanatory variables. The length of 250 m was chosen due to the similarity to the traditional criterion, where the sliding window of the length of 250 m is used.

Variables

In this part, variables used for statistical modelling are briefly described. Table 1 summarizes variables used in analysis.

Table 1 Overview of variables and their descriptive statistics

Type of variable	*Name of variable*	*Data type and unit*	*Descriptive statistics (min/max/mean/SD or frequencies)*
Dependent	Accident data 2007 - 2009	Count	0.00/10.00/0.22/0.58
	Accident data 2008 - 2010	Count	0.00/9.00/0.21/0.57
	Accident data 2009 - 2011	Count	0.00/9.00/0.21/0.57
Continuous	AADT 2007 - 2009	Continuous [vehicles per day]	90.09/18313.02/2434.78/2207.85
	AADT 2008 - 2010	Continuous [vehicles per day]	90.09/18313.02/2434.78/2207.85
	AADT 2009 - 2011	Continuous [vehicles per day]	91.91/18682.98/2483.97/2225.45
	Percentage of heavy vehicles	Continuous [-]	0.06/0.50/0.18/0.06
	Length	Continuous [m]	51.00/499.88/264.29/64.03
	Density of junctions with minor rural roads	Continuous [-]	0.00/16.90/1.16/2.40
	Density of road facilities	Continuous [-]	0.00/52.00/2.58/5.76
	Logarithm of curvature change rate	Continuous [-]	-100/9.21/3.39/13.39
Categorical	Presence of forest around roads nearby	Binary Yes = 0, No = 1	0 : 2977, 1 : 787
	Presence of paved shoulder	Binary Yes = 0, No = 1	0 : 431, 1 : 3333
	Reduction of speed limit	Yes = 0, No = 1	0: 42, 1 : 3722

Accident data were provided by the Police of the Czech Republic. This data contain the information on the accident localization recorded by GPS from 2007, so it was possible to use only three time periods: 2007 - 2009, 2008 - 2010, 2009 - 2011.
Exposure variables were represented by annual average daily traffic and the percentage of heavy vehicles. These data were provided by the Czech Road and Motorway Directorate, based on the results of national road traffic census in 2010. These data were adjusted by a growth factor for different periods.

The road characteristics, context and environment variables were obtained from the database of the Czech Road and Motorway Directorate or from our own databases. The used variables included the presence of a paved shoulder, curvature change rate (for a straight section where curvature change rate is zero, the value -100 was used for the logarithm), reduced speed limit, density of junctions and road facilities and the presence of forest around roads nearby were used.

Model form

The statistical models were developed according to recommendations provided by e.g. Hauer, (2004) or Reurings et al. (2005). The accident frequency in each of the periods was a dependent variable. The model form was negative binomial with a log-linear link function.
The general form of the models is as follows:

$$\widehat{N} = \beta_0 \cdot AADT_i^{\beta_1} \cdot \exp(\textstyle\sum_{i=2}^{n} \beta_i x_i) \quad (1)$$

where:

$\widehat{N}$	expected number of accidents
$AADT$	annual average daily traffic
β_i	model parameter
x_i	explanatory variable

Parameters of all model forms are listed in Table 2.

Table 2 Models for injury accidents on rural 2nd class roads in South Moravia in different time periods

Variable	*Variable level*	*Coeff. 2007 – 2009*	*Coeff. 2008 – 2010*	*Coeff. 2009 – 2011*
Intercept		-9.556	-10.230	-9.615
Logarithm of annual average daily traffic		1.041	1.181	1.077
Annual average daily traffic		$8.770 \cdot 10^{-5}$	$-1.125 \cdot 10^{-4}$	$-7.057 \cdot 10^{-5}$
Percentage of heavy vehicles		-1.912	-	-
Logarithm of curvature change rate		0.008	0.014	0.006
Length		0.003	0.003	0.002
Presence of forest around roads nearby	Yes	0	0	0
	No	-0.490	-0.516	-0.486
Presence of paved shoulder	Yes	0	0	0
	No	0.233	0.221	0.351
Reduction of speed limit	Yes	-	0	0
	No	-	-0.645	-0.543
Density of road facilities		-0.013	-0.020	-0.017
Density of junctions		-0.030	-	-

Table 2 shows the following several implications:

- Traffic volume has big influence on accidents.
- The influence of the length of segments is as expected: on longer segments one can expect higher number of accidents.
- Curvature change rate and the presence of forest around roads nearby influence sight distances and speed choice.

- In forests, there can be higher risk because of worse adhesion due to wet road surface or leaves.
- Presence of paved shoulder is also a significant variable in all cases and it is easily explainable, since it offers space for error corrections.
- The influence of the percentage of heavy vehicles is significant only in the first period. It can be due to relatively low traffic volume on the 2nd class roads. According to the results, the higher percentage of heavy vehicles, the lower risk of accident. Heavy vehicles are usually slower; cars have to adapt their speed to them because there is often little chance to overtake on the 2nd class roads.
- Density of junctions and road facilities has low influence on safety and, moreover, the density of junctions is significant only in the first period.
- Reduction of speed limit unexpectedly increases the risk. It is therefore possible, that negative influence of presence of speed limits masks other variables, which were not incorporated into the model. Speed limits can be merely a result of dangerousness of given location and not its cause.

IDENTIFICATION OF HAZARDOUS ROAD LOCATIONS BASED ON THE EMPIRICAL BAYES ESTIMATE

The EB approach is used to refine estimates of the multivariate accident prediction models. This approach is recommended as a state-of-the-art approach to estimate expected number of accidents (Hauer, 1997; Persaud et al., 1999; Hauer et al., 2002; Elvik, 2010; AASHTO, 2010). It increases the precision of estimation and corrects the regression to mean bias.
The procedure combines the accident record of every entity and the accident frequency expected by the prediction model. The basic functional form is as follows:

$$EB = w \cdot \widehat{N} + (1 - w) \cdot N \quad (2)$$

where:

EB	EB estimate for a segment
w	weight
$\widehat{N}$	expected number of accidents from prediction model for similar sites
N	recorded number of accidents on this segment

The weight indicates the significance of the accident data and the model. It helps to say how different can be safety of a specific site from the average specified with the prediction model.

The weight is calculated as follows:

$$w = \frac{k}{k + \hat{N}_i} \tag{3}$$

where:

k negative binomial parameter of the prediction model calculated as a linear function of segment length

$\hat{N}_i$ expected number of accidents predicted by a model

The negative binomial parameter of the prediction model is 1.081 for the period of 2007 – 2009, 1.229 for the period of 2008 – 2010 and 1.203 for the period of 2009 – 2011.
In order to quantify the quality of models standard deviations for each model were calculated according to Hauer et al. (2002) and shown in Table 3, as well as coefficients of variation, i.e. ratio of standard deviation to mean.

Table 3 Average values of descriptive statistics of EB estimates

Time period	*Mean*	*Std. deviation*	*Coefficient of variation*
2007 - 2009	0.220	0.105	0.477
2008 - 2010	0.207	0.093	0.449
2009 - 2011	0.205	0.093	0.454

IDENTIFICATION OF HAZARDOUS ROAD LOCATIONS BASED ON TRADITIONAL CRITERION

The methodology, which is currently employed for the identification of hazardous road locations in the Czech Republic, is based on a calculation of recorded accident frequency at a given section. According to this methodology of Andres et al. (2001), hazardous locations are defined by sliding window with the length of 250 m, which meets at least one of the following criteria:

- at least three accidents with personal consequences within one year,
- at least three accidents with personal consequences of the same type within three years,
- at least five accidents of the same type within one year,

while used limits (three and five) have been determined empirically by experts in the field of road safety.

Personal consequences are defined as injury or death of one or more people involved in an accident. There are three levels of personal consequences: slight injury, severe injury or fatal injury.
Type of accident is defined by the main cause of an accident and can be one of the following types: not caused by driver; speeding; faulty overtaking; denying the right of way; faulty driving style; technical fault of vehicle.

The definition above shows that there are serious shortcomings when it comes to the identification of hazardous road locations. One can imagine the following examples:

- A road segment, where one accident with slight injury happened in each of three consequent years, will be identified as hazardous.
- A road segment, where two slight injuries, two serious injuries and two deaths occurred within three consequent years, will not be identified as hazardous.

Due to the methodological changes in 2009, which were described above, it made sense to use only the accidents with personal consequences for the comparison with the prediction models. Therefore, only first two criteria of the definition were used for the identification of hazardous road locations.

Table 4 shows that these results were compared to results in a situation when all accidents would have been used. It is obvious that after the methodological change in Police records the omission of the third criterion does not cause any significant change.

Table 4 Number of identified hazardous road locations using traditional approach

Time period	*All criteria (all available data)*	*First two criteria (accidents with personal consequences)*
2007 – 2009	55	42
2008 – 2010	50	42
2009 – 2011	42	41

42 identified segments will be used in further comparisons and referred to as the “worst” segments. They will be compared with 42 highest values according to descending values of EB estimates.

COMPARISON OF HAZARDOUS ROAD LOCATION LISTS

Regarding effective investments in road safety measures, it is necessary to know which locations are truly hazardous. However using traditional hazardous locations criteria, one cannot distinguish whether hazardous road location is true or not. It is practically impossible to decide without a detailed on-site inspection, ideally also with comparison to similar location without accidents (Elvik, 2006).

In a hypothetical case when only true hazardous road locations are identified, they do not vary with time. In order to minimize such variations, all potential risk factors should be ideally controlled for by including them in a prediction model. However, this goal is not practically feasible – the data covering all risk factors are unlikely to be available, therefore, the variation explained is never complete. The prediction models in this study included the influence of traffic and infrastructure. The expected accident frequency and EB approach were used to control for the regression to the mean. These results should contain less variability than the results obtained by the traditional approach, which is based on a frequency of recorded accidents.

In order to compare two methods of calculation standard deviations and coefficients of variation were computed for first 42 worst segments as well as using recorded accident frequency. Results given in Table 5 show approximately half variability of EB estimate in comparison to accident frequency.

Table 5 Average values of descriptive statistics for 42 worst segments

Time period		*Mean*	*Std. deviation*	*Coefficient of variation*
2007 -2009	EB estimate	1.161	0.507	0.437
	Recorded accidents	2.500	1.943	0.777
2008 - 2010	EB estimate	1.088	0.383	0.352
	Recorded accidents	2.452	1.789	0.730
2009 - 2011	EB estimate	1.002	0.312	0.311
	Recorded accidents	2.333	1.808	0.775

The comparison of the number of locations identified in all three periods or just in two of them or only in one period, as illustrated in Table 6 and Table 7 for the prediction models and in Table 8 for the traditional approach.

Table 6 Number of identically identified locations by prediction models adjusted by the EB approach – 42 worst segments

		Number of locations in agreement			
Time period	2007 - 2009	2008 - 2010	2009 - 2011	All	Sum
2007 - 2009	11	8	2	21	42
2008 - 2010	8	3	10	21	42
2009 - 2011	2	10	9	21	42
All	21	21	21		
Sum	42	42	42		

Table 7 Number of identically identified locations by prediction models adjusted by the EB approach – upper 5 % of values

		Number of locations in agreement			
Time period	2007 - 2009	2008 - 2010	2009 - 2011	All	Sum
2007 - 2009	38	21	3	126	188
2008 - 2010	21	13	28	126	188
2009 - 2011	3	28	31	126	188
All	126	126	126		
Sum	188	188	188		

In the time periods of 2007 – 2009 (period 1), 2008 – 2010 (period 2) and 2009 – 2011 (period 3), 64 different hazardous locations were identified for 42 worst segments. Some of them were identified only in one period, some in two periods and the rest in all of them. 42 worst locations were chosen for a better comparison with the traditional approach. If the upper 5 % of values are used, 260 different locations are identified in the first 188 values. In all time periods 21, resp. 126 locations were identified identically. Converted to percentages, it is 33 % agreement for 42 worst values and 49 % for the upper 5 % of values.

Table 8 Number of identically identified locations by the traditional approach

	Number of locations in agreement				
Time period	2007 - 2009	2008 - 2010	2009 - 2011	All	Sum
2007 - 2009	16	10	1	15	42
2008 - 2010	10	5	12	15	42
2009 - 2011	1	12	13	15	41
All	15	15	15		
Sum	42	42	41		

Using the traditional approach, 72 locations were identified as hazardous in all three time periods. 42 locations were identified in 2007 – 2009, 42 in 2008 – 2010 and 41 in 2009 – 2011.
In all time periods, 15 locations were identified identically, 10 in the first two periods, 12 in the second two periods, and one in periods 1 and 3. In 2007 – 2009, 16 locations were identified which were not identified in later periods. In 2008 – 2010, there were 5 locations and in 2009 – 2011 there were 13 locations which were not identified in any other period.
Overall, 34 out of 72 (47 %) hazardous locations were identified in only one time period and 15 (21 %) were identified in all three time periods.
Another way of the results comparison is the portion of the number of locations identified identically in all three periods and the number of identified location in the period. This approach to results can be useful especially for road authorities and maintenance.
If countermeasures were implemented at all identified 42 locations, it would be with the reliability of 50 % (worst 42 values) or 67% (upper 5 % of values) for the prediction models adjusted with the EB approach and 36% for the traditional approach.
All of these results correspond with the previous statement that the EB approach identifies temporarily stable locations; while locations identified using the traditional approach vary significantly more in time. This property can be seen in Figure 1 and Figure 2. There are some identified locations close to interchanges with motorways. This may be caused by the high traffic volumes induced by people living near Brno and daily commuting to work. In Figure 1, the major group of the identified locations by the EB approach lies north of the city of Brno. The traffic situation in this area is unsatisfactory: there are high traffic volumes and poor quality of roads of the national importance, a four-lane divided expressway is in preparation. Therefore nowadays many drivers choose the lower class roads for longer journeys.

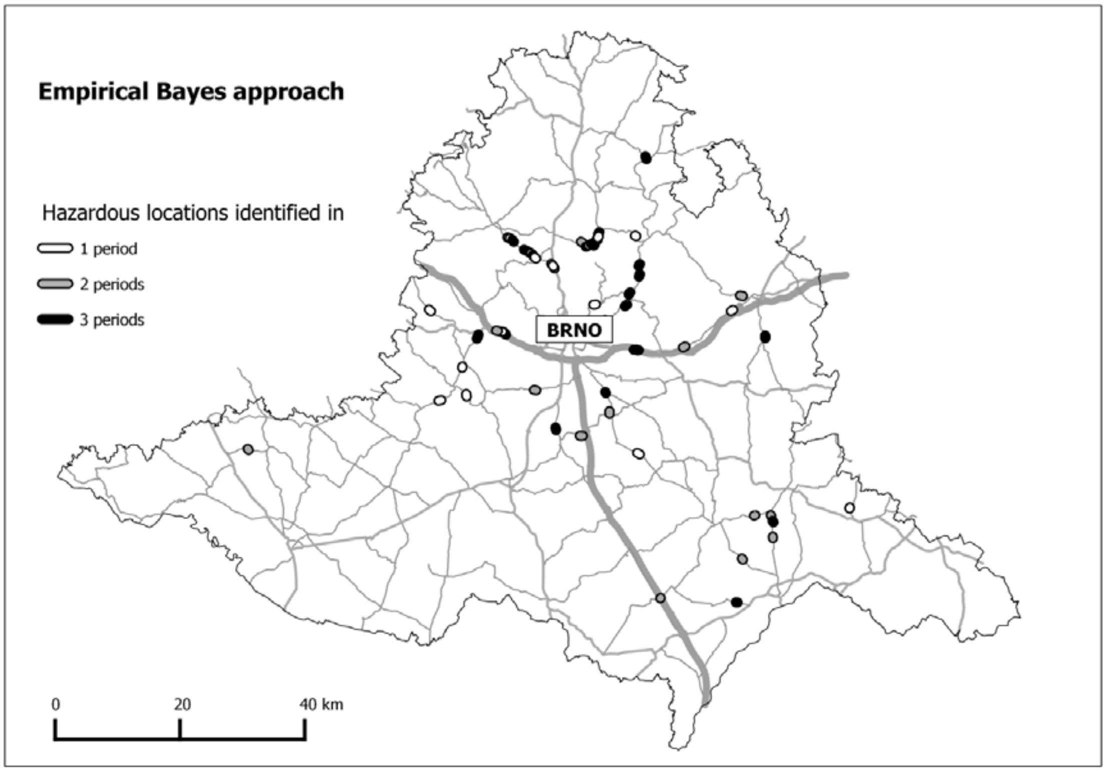

Figure 1 Hazardous locations identified by the EB approach

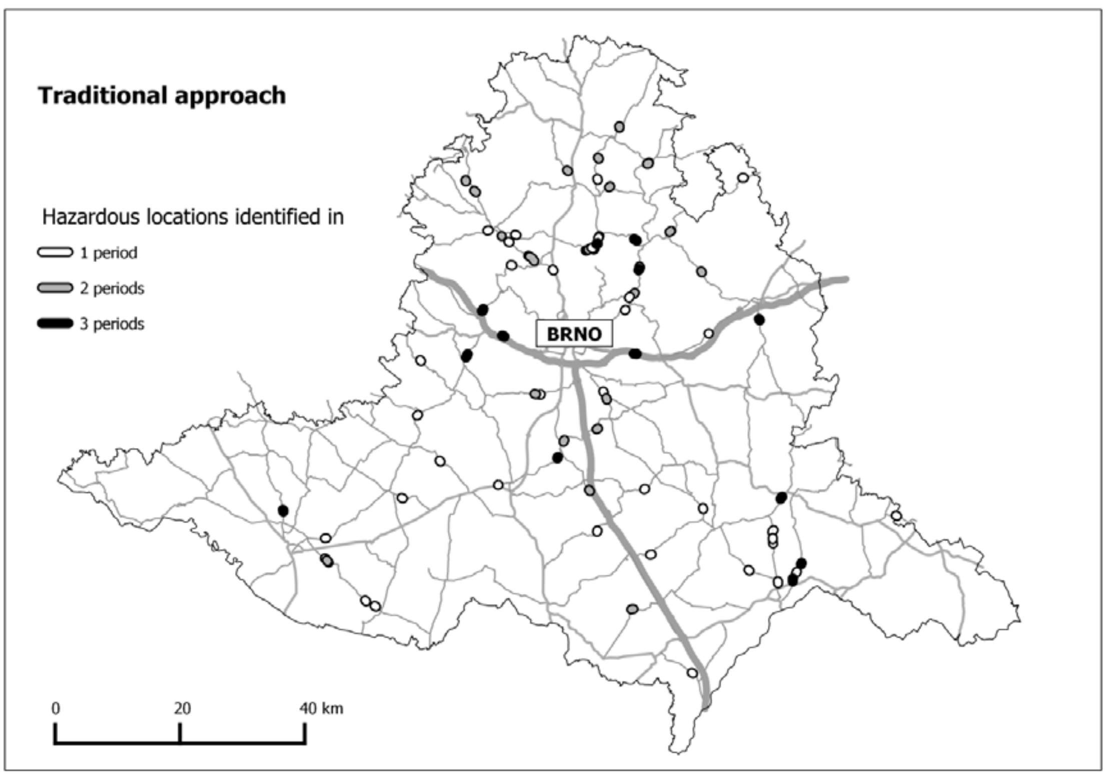

Figure 2 Hazardous road locations identified by traditional approach

DISCUSSION AND CONCLUSIONS

The study compared two methods of the identification of hazardous road locations: the traditional approach based on traditional definition and the prediction models refined by the EB adjustment. The method used for the comparison is based on the percentage of agreement in identified locations. The results showed that the predictions models followed up by the EB approach offer the results which are more stable in time compared to the traditional approach. The difference is quite significant. From the perspective of the road administrator, the statistical methods are almost twice as reliable.

On the other hand, using neither of identification methods established worldwide ensures that identified hazardous road locations are true until an on-site inspection is conducted. However, it is possible to use more time periods and investigate them separately. The segments identified in more periods have a higher chance of being true hazardous road locations. This approach was used in the study and seems to be promising.

The study shows that the use of the accident prediction models is a step forward in road safety management. There were a lot of data used for this study and the difference in the consistency of identified hazardous road locations is significant. As can be seen in Figure 1 and in Figure 2, spatial dispersion of the hazardous road locations is much larger for the use of the traditional approach. The results of the prediction model are more consistent and can be used not only for countermeasures in these locations, but also for the planning of new roads and for the investment priority ranking.

Three partially overlapping time periods were used in this study. The year 2009 is used in all three periods. Alternative solution would be comparing three independent periods. Theoretically, if there had been a higher number of accidents in 2009, it could have influenced the results. However, the trend in the data was similar to the national trend in the number of accidents and the number was slowly decreasing year by year, so probably did not bias the results. In case three different three-year periods were used, other difficulties could have occurred. In addition, there could be significant changes in the safety of vehicles and other properties which cannot be included in the prediction model. Some of the parameters included in the model could also alter the identification of locations, e.g. the complete reconstruction of some hazardous road locations identified in the earlier period.

The idea of the same locations identified consistently in more periods seems to be a more reliable way of identifying true hazardous road locations. The validity of the identification can be checked by an on-site investigation, where the identified sites are compared to similar locations, which are not hazardous road locations. The percentage of true hazardous road locations between the locations, which were identified in all three periods, should be significantly higher than in the case of locations which were identified only in one period.

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