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Identification of high accident concentration sections on the Lithuanian roads of national significance

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Abstract

In recent years, safety improvement measures on the roads of Lithuania have been implemented mainly at the pre-determined black spots. Although the road safety situation since 2008 has improved and the number of black spots is decreasing year by year, most of the identified black spots are formed once again. Seeking for accident prevention and not waiting until accidents occur and the black spot is formed, it is necessary to use accident prediction models and to implement safety improvement measures on the potentially dangerous road sections, thus, preventing the formation of new high accident concentration sections. The paper describes how to identify high accident concentration sections on roads using accident prediction models and the critical value of predicted accidents. All high accident concentration sections on Lithuanian roads of national significance were studied during the research. The list of the most hazardous road sections is given in this paper.

Keywords: road safety; homogenous road groups; accident prediction models; high accident concentration section; critical value.

1. Introduction

Road and its infrastructure, being one of the constituent parts of road safety system, are very important when seeking to reduce the risk of road accidents. If, despite preventive measures, the road accident nevertheless occurred the fact were the road users killed or injured and how severe the accident was is mainly dependent on the safety of vehicles and road. Engineering improvements are able to protect road users from injures, as well as to form road users' behaviour in a way to prevent road accidents [1].

In recent years, safety improvement measures on the roads of Lithuania have been implemented mainly on the pre-determined black spots. According the "*Methodology for the Determination of High Accident Concentration Sections on the Roads of National Significance*", a "black spot" in the Lithuanian road network is described as the site where in a four-year period 4 or more injury and fatal accidents have occurred in a 500 m road section [2]. Although the road safety situation since 2008 has improved and the number of black spots is decreasing year by year, most of the identified black spots are formed once again.

Improvement of road traffic safety in European Union (EU) member-states still remains a priority field of transport development. In 2008, the European Parliament and the Council adopted the *Directive 2008/96/EC* on *Road Infrastructure Safety Management* [3] which defines four procedures for the road infrastructure safety management: road safety audit, road safety inspections, road safety impact assessment and network safety ranking, also classification of high accident concentration sections. The above procedures are divided into the already settled in the EU countries two groups of road safety activities – proactive and reactive. The aim of procedures belonging to the proactive group is to detect and eliminate reasons which may cause road accident. Activities of the reactive group are based on information of accidents that have already occurred. One of those procedures obligates to do road network safety ranking and to rank high accident concentration sections. Seeking for accident prevention and not waiting until accidents occur and the black spot is formed, it

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is necessary to use accident prediction models and to implement safety improvement measures on the potentially dangerous road sections, thus, preventing the formation of new high accident concentration sections.

2. Review of Road Network Safety Ranking Procedures

Road network safety management is not a strictly defined procedure of road safety. Network safety ranking (NSR) means a method for identifying, analysing and classifying parts of the existing road network according to their potential for safety development and accident cost savings [3]. This method is used for identifying, investigating and classifying the road network sections in operation for 3–5 last years and on which the largest number of fatal/injury accidents in proportion to the traffic flow or compared to respective conditions have occurred. Network safety ranking is a periodical procedure which should be performed yearly considering at least 3–5 last year data about traffic volume, accidents, road infrastructure changes etc. [4], [5]. This procedure is better developed and more widely used in the countries where safety situation is rather good and there are no black spots or only few [6].

Road network safety ranking procedure can be implemented using several methods:

1. simple methods – accident frequency, accident rate and accident severity;
2. sophisticated methods – combination of accident history and accident prediction models.

The above-mentioned methods belong to reactive road safety activity. Activities of the reactive group are based on information of accidents that have already occurred.

The concept of road network safety and high accident concentration sections ranking is using accident history and the total expected number of accidents to identify locations with local risk factors that are related to the local detailed road layout. Following the principle "prevention is better than cure" the implementation of road infrastructure management procedures – road safety impact assessment and road network safety management – shall be based on the prediction of road accidents.

Over the recent years, several international projects and studies were carried out the aim of which was to give proposals for the implementation of procedures of road safety infrastructure management.

In 2011, the international *BALTRIS* project was started to be implemented the specific objective of which is to develop tools and build capacity/competence for a better safety management of road infrastructure in the Baltic Sea Region. The project focuses on the exchange of experiences, knowledge and joint development of road infrastructure safety management procedures. During the *BALTRIS* project a comprehensive review of investigations carried out in foreign countries in the field of network safety ranking was carried out, the exchange of the best practice was performed and recommendations were given for the implementation of this procedure defined in the *Directive 2008/96/EC* [5], [7].

In the period 2006–2008, the RIPCORD-ISEREST [8] project was developed. The objective of RIPCORD-ISEREST was to develop best practice guidelines based upon the current research results for:

- Road Safety Impact Assessment tools and Accident Prediction Models.
- Road Design and Road Environment.
- Road Safety Audit.
- Road Safety Inspection.
- Black Spot Management and Safety Analysis of Road Networks.

With these tools, RIPCORD-ISEREST [8] intended to give scientific support to practitioners concerned with road design and traffic safety in Europe.

Literature overview [9–12] shows that accident prediction models were developed using four basic methods, i.e. *Multivariate Analysis, Empirical Bayes method, Fuzzy Logic* and *Neural Network*.

Many scientists [9], [11], [13] point out that the empirical Bayes method is well-developed and widely used in the field of road safety. This method is based on the assumption that in a similar environment with the prevailing similar traffic conditions the risk of accidents is similar. Using the empirical Bayes method (Fig. 1) the expected number of accidents is determined by combining two information sources: 1) number of historic accidents on a specific road element, and 2) mathematical accident prediction model describing accident risk of road elements similar in their environment.

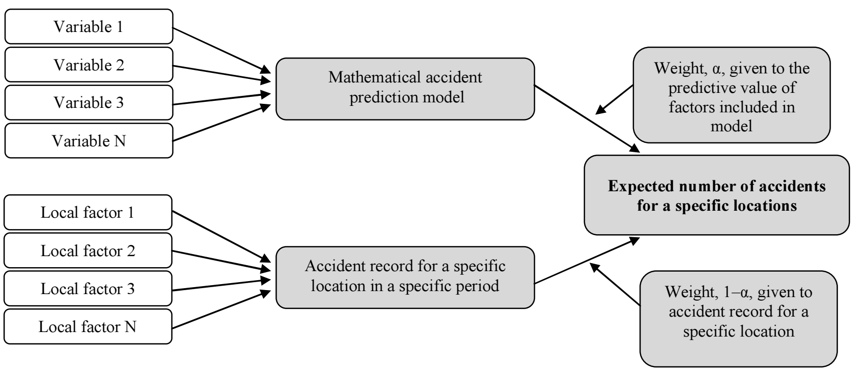

Fig. 1. Example of the use of empirical Bayes method to calculate the predicted number of accidents [8]

For road sections and junctions different mathematical accident prediction models should be used. Accident prediction model for road sections should be based on the number of accidents per the vehicle-travelled distance, whereas, for junctions on the number of accidents per entering vehicles. It should be noted that a mathematical accident prediction model calculates the predicted number of accidents on a road element having certain similar properties. Based on this, road network shall be divided into groups with similar properties depending on the selected independent variables. Accident prediction models are not able to assess all the factors influencing the occurrence of accidents [10]. The main factors having the largest influence shall be distinguished [14].

Prediction of road accidents requires information about historic road accidents, road infrastructure and traffic conditions. Accident modelling is usually based on data of 3–5 year period. This period is recommended because of two reasons: 1) a higher number of accidents gives more reliable modelling results; 2) during this period no general tendencies and changes take place yet [14].

3. Network Safety Ranking in Lithuania

Based on literature overview and recommendations given in the reviewed projects, the specialists of Road Department of Vilnius Gediminas Technical University in partnership with the former State Enterprise Transport and Road Research Institute (now – Public Enterprise Road and Transport Research Institute) and Finnish Technical Research Centre VTT carried out safety ranking of the road network of national significance of Lithuania [7].

Ranking of road network safety and high accident concentration sections can be divided into 5 stages (Table 1).

In step I of the Lithuanian road network safety ranking three stages were implemented: data collection on Lithuanian road network, definition of road groups and junction groups and division of the Lithuanian road network into homogenous road sections and junctions.

Table 1. Typical stages in the ranking of road network safety and high accident concentration sections

Step	Stage	Explication
I	1. Data collection	Collection of data on roads, traffic and accidents
	2. Definition	Definition of road groups and junction groups
	3. Division	Division of road network into homogenous road sections and junctions
II	4. Identification	Road network safety ranking and identification of hazardous road sections
III	5. Analysis	In office analysis of hazardous road sections and junctions and on-site observations of road-user behaviour

The five-year data on Lithuanian road accidents, traffic volume, road parameters and the surrounding environment was collected. Data of the Lithuanian Road Information System LAKIS was systematized into 16 groups: 1) cross-sections of roads, 2) junctions, 3) railway crossings, 4) high accident concentration road sections and black spots, 5) road signs, 6) fatal and injury accidents in 2006–2010 (accidents at junctions are given separately), 7) illuminated road sections, 8) speed measuring equipment, 9) pedestrian paths, 10) protective fences from people and wild animals, 11) road sections with the installed guardrail systems, 12) technical categories of roads, 13) annual average daily traffic on roads; 14) annual average daily traffic at junctions, 15) speed restrictions on road sections, 16) accidents at junctions.

According to empirical Bayes method which is based on the assumption that in a similar environment with the prevailing similar traffic conditions the risk of accidents is similar, Lithuanian road network of national significance was divided into separate groups of roads and junctions. The groups and subgroups of road sections were defined by the following 4 criteria: 1) road type and category; 2) cross-section; 3) speed limit; 4) traffic volume.

The groups and subgroups of junctions were defined by 3 criteria: 1) junction type; 2) road type; 3) traffic volume (i.e. proportion of vehicles entering the junction from the minor road from the total amount of vehicles entering the junction).

The Lithuanian road network of national significance (21 268.4 km) was divided into 13 254 homogenous road sections, the average length of one homogenous section being 2.31 km. Based on the mentioned junction criteria 14 homogenous groups were determined.

Division of Lithuanian road network into homogeneous road sections and junctions were described in details in the research study *Safety Ranking of the Lithuanian Road Network of National Significance and Development of the Accident Prediction Model (stages 1, 2, 3)*. The study was funded by the Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania [15]. The results of this study were published in the scientific journal *The Baltic Journal of Road and Bridge Engineering* [7].

Each group of roads/junctions contains the certain number of road sections/junctions. Comprehensive information gathered about each of them (number of accidents, length, *AADT*, etc.) enables to develop mathematical accident prediction model. Mathematical accident prediction model is a constant for each homogenous group, classified according to the independent variables selected in the first modelling stage, and is equal to the average accident rate of the group.

Mathematical accident prediction models were developed for each homogenous group:

$$Mathematical\_EIPM_{gr_j} = AK_{gr_j} = \lambda = \frac{A_j \times 10^8}{365 \times m \times L_{gr_j} \times AADT_{gr_j}}, \quad (1)$$

where: $Mathematical\_EIPM_{gr_j}$ – mathematical accident prediction model for a homogenous group j; A_j – number of accidents during the study period in the homogenous group j; L_{gr_j} – for the groups of road sections: the total length of sections of the homogenous group j, km; for the groups of junctions: the length depends on the number of roads crossing at the junction and is calculated by multiplying the number of crossing roads by 0.2, km; m – the study period, years; $AADT_{gr_j}$ – for the groups of road sections: AADT during the study period, vpd; for the groups of junctions: AADT of vehicles entering the junction during the study period, vpd. Mathematical accident prediction models for the homogenous groups of roads and junctions based on five-year data is presented in Table 2 and Table 3.

Table 2. Mathematical accident prediction models for the homogenous groups of roads

Road groups	Mathematical accident prediction model			
	All accidents	Accident groups		
		Vehicle	Light	Animal
1. Separated driving directions				
111. Motorway	5.3	4.18	0.71	0.445
112. Motorway	6.4	5.14	0.93	0.350
113. Motorway	5.2	3.51	1.59	0.057
12. Four lanes, median, ≤ 90 km/h	9.8	4.90	4.90	0.000
	11.8	9.65	2.09	0.091
	7.8	5.06	2.69	0.105
13. Four lanes, median, 100 km/h	6.1	3.66	2.41	0.000
14. Four lanes, median, 110 km/h	4.1	2.66	1.23	0.205
2. Main roads, rural				
21. Main road, 9 m	15.7	12.24	3.28	0.219
	12.5	9.65	2.67	0.193
	11.0	8.52	2.46	0.000
22. Main road, 8 m	14.7	10.92	3.66	0.150
	12.2	10.38	1.81	0.000
23. Main road, ≤ 7 m	14.2	10.87	3.29	0.000
	15.8	11.45	4.14	0.244

Continued Table 2

Road groups	Mathematical accident prediction model			
	All accidents	Accident groups		
		Vehicle	Light	Animal
3. Minor roads, rural				
31. Minor roads, 9 m	17.3	11.43	5.72	0.133
	13.1	10.08	2.95	0.102
32. Minor roads, 8 m	20.5	12.99	7.22	0.241
	17.8	13.50	3.98	0.282
	19.8	14.71	5.03	0.097
33. Minor roads, 7 m	28.6	22.07	6.38	0.174
	20.0	14.21	5.60	0.151
	17.2	13.93	3.13	0,165
34. Minor roads, ≤ 6 m	32.4	25.71	6.34	0.326
	20.9	15.93	4.92	0.039
	23.3	15.16	8.16	0.000
35. Gravel roads	59.6	52.58	6.85	0.171
	36.2	31.24	4.99	0.000

	21.9	19.11	2.84	0.000
4. Urban roads				
41. Urban sign, 50 km/h	29.7	17.05	12.56	0.097
	22.7	10.32	12.34	0.000
	23.0	10.19	12.85	0.000
42. Urban sign, 70 km/h	11.6	7.91	3.65	0.000
43. Urban sign, 80 km/h	8.2	6.01	2.14	0.000

Table 3. Mathematical accident prediction models for the homogenous groups of junctions

Junctions group	Proportion of incoming vehicles from others than two main legs, %	Mathematical accident prediction model			
		All accidents	Road accidents groups		
			Vehicle	Light	Animal
T-crossing, main road	0–5.9	9.9	7.3	2.62	0.00
	6.0–15.9	12.5	8.9	3.63	0.00
	≥ 16	15.3	10.3	5.00	0.00
T-crossing, minor road	0–5.9	11.4	8.4	3.05	0.00
	6.0–15.9	12.8	10.4	2.41	0.00
	≥ 16	16.4	11.1	5.28	0.00
X-crossing, main road	0–5.9	11.9	7.9	4.08	0.00
	6.0–15.9	12.8	9.6	3.19	0.00
	≥ 16	17.8	13.9	3.86	0.00
X-crossing, minor road	0–5.9	18.2	16.5	1.65	0.00
	6.0–15.9	16.7	12.7	3.75	0.29
	≥ 16	22.4	16.8	5.54	0.00
Grade-separated crossing		5.2	3.9	1.27	0.00
		4.1	2.8	1.27	0.00

Classification of the road network of national significance of Lithuania into homogenous road sections and development of mathematical accident prediction models make it possible to predict the number of accidents for each homogenous road section by using the algorithm of accident prediction model for the roads of national significance of Lithuania based on the empirical Bayes method:

$$A_{prog_i} = (\alpha \times Mathematical\_EIPM_{gr_j}) + ((1-\alpha) \times A_{istor_i}), \tag{2}$$

where: A_{prog_i} – the predicted number of accidents on the road section *i*; α – weighing coefficient; $Mathematical\_EIPM_{gr_j}$ – mathematical accident prediction model for the homogenous group *j* which includes the road section *i*; A_{istor_i} – the number of historic accidents on the road section *i*. Weighing coefficient α indicates weight given to the mathematical accident prediction model of homogenous group of roads or junctions by combining it with the number of historic accidents. It is calculated by the Eqn. (2):

$$\alpha = \frac{1}{1+\lambda/k}, \tag{3}$$

where: λ – the general expected number of accidents for the whole group of homogenous sections determined with the help of mathematical accident prediction models; *k* – the inverse value of the overdispersion parameter.

Using five-year data and the Eqn. (2) the predicted road accidents were calculated in the road network of national significance.

4. High Accident Concentration Sections on the Lithuanian Roads of National Significance

The mentioned prediction method makes it possible to distinguish in the whole road network the potentially dangerous road sections in respect of road safety where the predicted number of accidents is higher than that on the other road sections similar in their environment. The potentially dangerous road sections can be determined in several ways:

- referred to the critical value – those sections where the values of predicted accidents are higher than the critical value of predicted accidents of a homogenous group;

- referred to predicted accident risk – those sections where the values of predicted accidents risk are higher.
- This paper presents the list of most hazardous road sections according to the predicted accident risk:

$$A_{pred.risk.i} = \frac{A_{pred.i}}{Mileage_i}, \quad (4)$$

where: $A_{pred.risk.i}$ – predicted accident risk of the road section *i*; $A_{pred.i}$ – predicted number of accidents on the road section *i*; $Mileage_i$ – travelled vehicle kilometres on road section *i*. mln.veh.km:

$$Mileage_i = AADT_i \times L_i \times 365 . \quad (5)$$

For each homogenous road section the predicted accident risk was calculated based on the predicted number of accidents using the Eqns (4)−(5). The predicted accident risk factor comprises not only the expected road accidents but also the length of section and traffic volume. Having calculated accident risk it is possible to identify the most hazardous road sections in the whole road network. Table 4 gives the list of the most hazardous road sections in the Lithuanian road network rated according to the maximum predicted accident risk.

The largest number of dangerous sections is represented by the road groups "Urban roads" and "Gravel roads". i.e. the road group of the network of national significance where there is the largest risk to get involved in the road accident. The top of the list of potentially dangerous road sections is taken by the roads of national significance crossing the built-up areas.

Table 4. The list of the most hazardous road sections on Lithuanian road network

No.	Road No.	Road name	Begin, km	End, km	*AADT*, vpd	Predicted accident risk	Predicted No. of accidents	Predicted No. of fatal accidents
1	144	Jonava–Kėdainiai–Šeduva	0	1.25	1542	3.77	2.75	0.44
2	120	Radiškis–Anykščiai–Rokiškis	26.99	29.94	1113	2.06	2.57	0.41
3	144	Jonava–Kėdainiai–Šeduva	1.25	1.745	1542	1.76	0.51	0.08
4	115	Ukmergė–Molėtai	0	0.9	1744	1.69	1.01	0.16
5	186	Kybartai–Vištytis	0.13	0.887	788	1.53	0.35	0.06
6	164	Mažeikiai–Plungė–Tauragė	1.26	1.75	2976	1.44	0.79	0.13
7	5310	Dusetos–Užpaliai–Vyžuonos	16.503	23.056	74	1.43	0.26	0.05
8	148	Raseiniai–Tytuvėnai–Radviliškis	26.38	26.92	1229	1.40	0.35	0.06
9	221	Vievis–Aukštadvaris	0	1.292	339	1.38	0.24	0.04
10	5315	Zarasai–Gražutė–Biržūnai	1.6	8.127	12	1.38	0.04	0.01
11	3408	Radviliškis–Voskoniai–Stačiūnai	14.682	15.986	50	1.35	0.03	0.00
12	3417	Baisogala–Januškoniai–Šeduva	0.94	3.3	138	1.32	0.16	0.03
13	228	Dauparai–Gargždai–Vėžaičiai	6.26	7.669	4113	1.23	2.70	0.25
14	147	Tauragė–Pašventys	0	2.17	3610	1.20	3.55	0.33
15	165	Šilalė–Šilutė	55.59	58.32	3874	1.17	4.68	0.44
16	1122	Pivašiūnai–Butrimonys	0	7.7	90	1.16	0.30	0.06
17	172	Raudondvaris–Giedraičiai–Molėtai	52.325	53.14	660	1.15	0.23	0.04
18	1204	Kavarskas–Taujėnai–Vadokliai–Ramygala	7.09	8.554	189	1.13	0.12	0.02
19	3112	Pumpėnai–Krikliniai–Smilgiai	9.9	11.268	66	1.13	0.03	0.01
20	5103	Kudirkos Naumiestis–Kybartai	15.847	17.525	845	1.12	0.60	0.10
21	5032	Pagilšys–Subartonys	2.25	2.7	80	1.09	0.01	0.00
22	5132	Mockabūdžiai–Pašeimeniai	1.437	2.3	72	1.08	0.02	0.00
23	4717	Vievis–Kazokiškės–Paparčiai–Žasliai	14.32	20.2	62	1.07	0.15	0.03
24	3622	Pakriauniai–Samaniai–Suviekas	1.3	7.814	59	1.05	0.16	0.03
25	123	Biržai–Pandėlys–Rokiškis	62.96	66.75	1309	1.05	1.97	0.32
26	2608	Jusevičiai–Būdvietis–Derviniai	18.528	20.04	163	1.01	0.09	0.01

According to the *Directive 2008/96/EC* [3], Member States shall ensure that the ranking of high accident concentration sections and the network safety ranking are carried out on the basis of reviews, at least every three years, of the operation of the road network. The above list of hazardous road sections could be used by road authorities in improving road traffic safety.

5. Conclusions

1. Road network safety ranking and ranking of high accident concentration sections should be more or less based on the advanced prediction models.
2. The accident prediction algorithm, developed for the road network of Lithuania on a basis of foreign literature with the help of empirical Bayes method, and its implementation showed that the road database of Lithuania is sufficient to properly use this accident prediction method.
3. Based on empirical Bayes method the prediction of road accidents was made for the whole Lithuanian road network of national significance.
4. The list of hazardous road sections of the Lithuanian road network was made according to the predicted accident risk on each homogenous road section. The top of the list of potentially dangerous road sections is taken by the roads crossing the built-up areas. The list of hazardous road sections shall be made every three years.

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