Kornelija RATKEVIČIŪTĖ

MODEL FOR THE SUBSTANTIATION OF ROAD SAFETY IMPROVEMENT MEASURES ON THE ROADS OF LITHUANIA

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
CIVIL ENGINEERING (02T)

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LEIDYKLA
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General characteristic of the dissertation

Topicality of the problem. After Lithuania joined the European Union, due to the expanding economic relations with EU member-states, the flows of transit traffic on the roads of Lithuania and the vehicle ownership have been increasing every year. Based on data of international accident statistics Lithuania is one of those few countries where the number of people killed per one million inhabitants is the highest compared to other EU countries. In 1994–2008 on the roads of Lithuania 10 681 people were killed and 102 850 were injured. Most often the victims are young people, road accidents cause large moral and material losses for the public.

In September 2001 the White Book approved by the European Commission confirmed an ambitious objective to reduce the number of accident victims by 50% by 2010 (from 50 000 to 25 000 per year). This can be implemented by seeking to unify the amount of penalties, to implement additional measures to ensure road traffic safety and to introduce new modern technologies. Having joined the EU Lithuania also undertook this objective: until 2010 to reduce the number of people killed during road accidents by 50%. Unfortunately, statistical data shows that safety situation on the roads of Lithuania is still one of the worst in the European Union. The number of black spots is high, therefore, it is necessary to develop an effective model for the substantiation of road safety improvement measures (further – road safety measures) which would allow to select road safety measures first of all for those road sections where accident indices exceed the limit values.

The results of accident data research showed that the currently used methodology for the substantiation of road safety measures in Lithuania does not allow to accurately select road safety measures for high-accident road sections, to forecast accidents and their preventive measures. Thus, it is necessary to correct it taking into consideration the experience of Lithuania and other foreign countries, to use mathematical statistics and mathematical optimisation models for preventing road accidents. Improvement of this methodology describes the topicality of this dissertation.

Research object covers injury accidents concentration places, black spots, methodology for the substantiation of road safety improvement measures, mathematical statistics and optimisation models for preventing road accidents. Experimental object of the work is 1995–2008 accident data on Lithuanian roads.

Aim and tasks of the work. The aim of the scientific work is to improve methodology for the substantiation of road safety measures in order to eliminate black spots, to construct a draft mathematical model for predicting fatal and injury accidents and to form the optimization problem which enables to model the optimal selection of road safety measures for the main roads of Lithuania.

The following tasks must be solved to achieve the aim of the work:

1. To make the analysis of the currently used Lithuanian methodology for the substantiation of road safety measures.
2. To make the analysis and evaluation of road safety indices after implementation of special measures on the roads of national significance of Lithuania and to determine the effect of methodology used.
3. To study and evaluate similar methodologies for the substantiation of road safety measures used in other foreign countries.
4. Having evaluated the experience of other countries and the shortcomings of methodology currently used in Lithuania, to construct the effective model for the substantiation of road safety measures.
5. To carry out testing of the new software and experimental calculations.
6. To study the use of mathematical methods for predicting fatal and injury accidents.
7. To construct a draft mathematical model for predicting fatal and injury accidents and to form the optimization problem which enables to model the optimal selection of road safety measures for the main roads of Lithuania.

Scientific novelty. Scientific novelty of the work consists of the development of the model for evaluating the effect of road safety measures and its adaptation to the roads of national significance of Lithuania, based on the existing traffic volume and traffic conditions.

For the first time the constructed evaluation model was based on the results of analysis of engineering road safety measures implemented on the high-accident road sections of Lithuania in a period of 12 years, and on the experience of foreign countries. The modern computer program *Evaluation of the Road Safety Measures* was created, its testing was carried out as well as experimental calculations.

For the first time in Lithuania a draft mathematical model is presented for predicting road accidents and modelling the optimal selection of road safety measures on the main roads of Lithuania.

Methodology of research. Statistical methods (descriptive statistics, mathematical models of time series, correlation and regression analysis) were used for the analysis of accident data obtained before implementing road safety measures on high-accident road sections and four years after their implementation. A method of comparative analysis was used for the analysis of methodologies used in Lithuania and other foreign countries for the substantiation of road safety measures. Optimization methods were also used when constructing mathematical models for the selection of preventive measures for the high-accident road sections on the main roads of Lithuania.

Practical value. The constructed model for the evaluation of road safety measures and the developed computer program can be used for the economic evaluation of road safety measures before their implementation on high-accident road sections and on the black spots of Lithuania.

The constructed draft mathematical stochastic model and the optimization problem can be used for accident forecasting, selection of the optimal road safety measures to be implemented on the black spots of the main roads of Lithuania.

Defended propositions

1. Improvement of road safety situation is highly dependent on the implemented engineering road safety measures which must be evaluated in social and economic aspects.
2. For the evaluation of road safety measures to be implemented the modern methodologies must be applied taking into consideration the existing safety, traffic volume and other conditions.
3. For the evaluation of road safety measures to be implemented the special computer programs must be created allowing to use databases of road information systems, to process large amount of data and to perform the rather complicated mathematical calculations.
4. It is necessary to not only implement road safety measures on high-accident sections and black spots of the roads of Lithuania but with the help of mathematical statistical models to also forecast accident concentration locations and to prevent the appearance of high-accident locations.

The scope of the scientific work. The scientific work consists of the introduction, five chapters, conclusions, list of literature, list of publications and addenda. The total scope of the dissertation – 110 pages, 26 pictures, 22 tables and 21 addenda.

1. Lithuanian road network and its safety situation

Chapter 1 gives main data on the road network of national significance of Lithuania, the change in the level of vehicle ownership, the basic accident indices and the basic factors influencing road safety. At the end of the chapter the conclusions are formulated.

Though the number of vehicles and the average annual daily traffic has been increasing every year, the number of people killed on the roads is decreasing (Fig. 1). Due to a continuous improvement of vehicles (air bags, modern safety belts, anti-lock braking systems, reinforced vehicle body, etc.) accident severity becomes more slight.

From 2001 to 2009 the number of people killed on the roads of Lithuania was reduced by 26%. In 2008 the number of people killed during road accidents in Lithuania was one of the least in the recent 40 years. In the year 2008 on the roads of 27 EU member-states 39 thousand people were killed, however, this number has decreased by 15.4 thousand since 2001. Such a rapid decrease in the number of accidents was achieved merely by the united efforts of all the institutions concerned and their joint actions in saving human lives. A perfect result was achieved by a tightened road user control, gradual implementation of the engineering road safety measures for the number of years, active educational activities, therefore, the road users‘ culture and responsibility on the road has notably changed, and the executed scientific works allowed to more effectively work and adopt the best foreign practice.

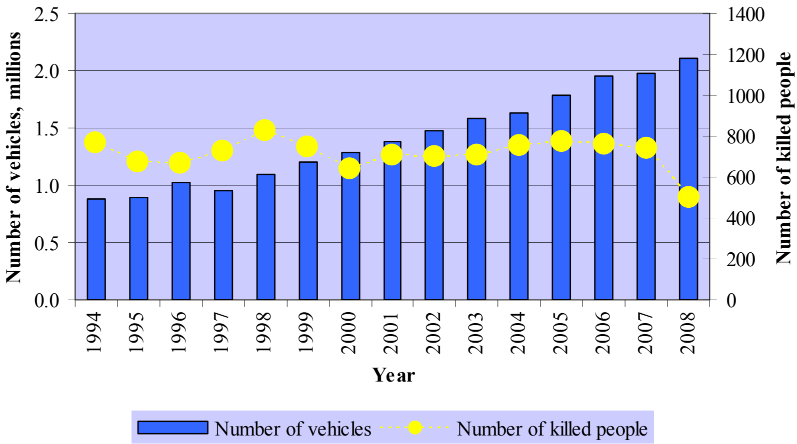

Fig. 1. Number of vehicles and people killed in 1994–2008

In order to select suitable road safety measures it is necessary to identify causes of a road accident and the influencing factors. This is the most important task for the road safety specialists which is attempted to be strategically solved all over the EU in a way of creating common methodologies. The basis of these methodologies – identification of the accident-influencing factors and implementation of appropriate road safety measures on the high-accident road sections.

2. Analysis of methodologies for the substantiation of road safety measures used in Lithuania and foreign countries

Chapter 2 gives a review of research methods used, describes and evaluates methodologies for the substantiation of road safety measures in Finland, Belarus, Poland and other countries, presents a detail analysis of TARVAL methodology currently used in Lithuania for the substantiation of road safety measures.

When comparing methodologies used in Lithuania (TARVAL), Finland (TARVA), Belarus and Poland the following main differences could be distinguished:

- Belarusian and Polish methodologies are more complicated than TARVAL and TARVA;
- Polish methodology enables to predict the reduction of collisions (%) with vehicles, pedestrians and bicyclists;
- Belarusian methodology enables to predict the probability for the reduction of accident number in parts of a unit from the total number of accidents as well as the probability for the reduction of fatal or injury accidents;
- The Lithuanian TARVAL and Finnish TARVA versions make it possible to predict the impact coefficients for the accidents with motor vehicles, pedestrians/cyclists and animals;
- The impact coefficients for animal-involved accidents are used only in TARVAL and TARVA methodologies (but not in Belarusian or Polish methodologies).

Sweden has no methodology for the substantial of road safety measures, similar to that of TARVAL used in Lithuania. However, the Swedish methodology *Traffic Conflict Techniqu*e enables to identify conflict situations between different road users on the road section or junction before the occurrence of road accident. Having this type of data it is possible to select those road safety measures which would prevent from possible accidents.

In Finland methodology for the substantial of road safety measures TARVA is very close to the Lithuanian version TARVAL, however, at present it is much more new and differs from the initial TARVA version. The specialists of the Technical Research Centre of Finland (VTT) have been continuously improving it and adapting to the current traffic situation on the national roads. The newest version of TARVA software also allows to forecast road accidents on the newly constructed or reconstructed road sections, to select road safety measures and to carry out accident prevention.

3. Research and evaluation of accident indices on the roads of Lithuania

This chapter gives the evaluation of the effect of road safety measures implemented on the roads of Lithuania in 1999, 2000, 2001 and 2002. For this purpose fatal and injury accidents were analyzed as well as their causes in a period of 1995–2006. Accident data was compared before implementing the road safety measures and 4 years after their implementation. 48 high-accident road sections were selected for the research where the safety measures were implemented in 1999, 2000, 2001 and 2002.

Economic evaluation was carried out using the cost-benefit analysis. Based on this method benefits, made of savings in accident losses, are compared to the costs made of the implementation costs of road safety measures. Economic evaluation of safety measures was conducted for each black spot. Sensitivity analysis was carried out based on three sensitivity tests (growth of traffic volume, costs of safety measures and change in evaluation period). All 48 cases showed that investments into road safety measures will pay back.

Analysis of the effect of road safety measures implemented on 48 high-accident road sections showed that the expected results of the improvement of safety situation were not achieved on 24 road sections, i. e. 50%; the expected reduction in the accident rate was not achieved on 7 road sections, i. e. 15%; the implemented road safety measures have justified themselves on 24 road sections, i. e. 50%.

In order to make an analysis of only partly justified road safety measures the visual investigations of high-accident road sections were carried out and a detail analysis of safety situation.

4. The use of research data in the models for the substantiation of road safety measures

Lithuania has the comprehensive accident databases and makes an accurate recording of accident locations. The amount and accuracy of other data required for the accident analysis has highly increased: traffic volume and its change, road safety measures, precise locations for their implementation, etc. All this allows us to collect reliable data and based on this data to carry out a detail accident analysis, to correct the list of road safety measures and their impact coefficients, to more accurately forecast accident indices and to execute economic evaluation.

Analysis of accident research data, presented in Chapter 3, showed that the currently used TARVAL software is not sufficiently accurate to evaluate safety measures to be implemented and to forecast accident indices. Therefore, it was necessary to correct it taking into consideration the experience in Lithuania and other countries and the current safety situation on the roads of Lithuania.

Figure 2 gives stages for the improvement of methodology used for the substantiation of road safety measures in Lithuania. For the improvement purposes the results of the analysis of effects of road safety measures implemented in Lithuania in a period of 12 years were taken into consideration, also the foreign experience and methodologies, the road safety measures and their effect on road safety. The list of road safety measures was supplemented with 59 new measures not earlier used.

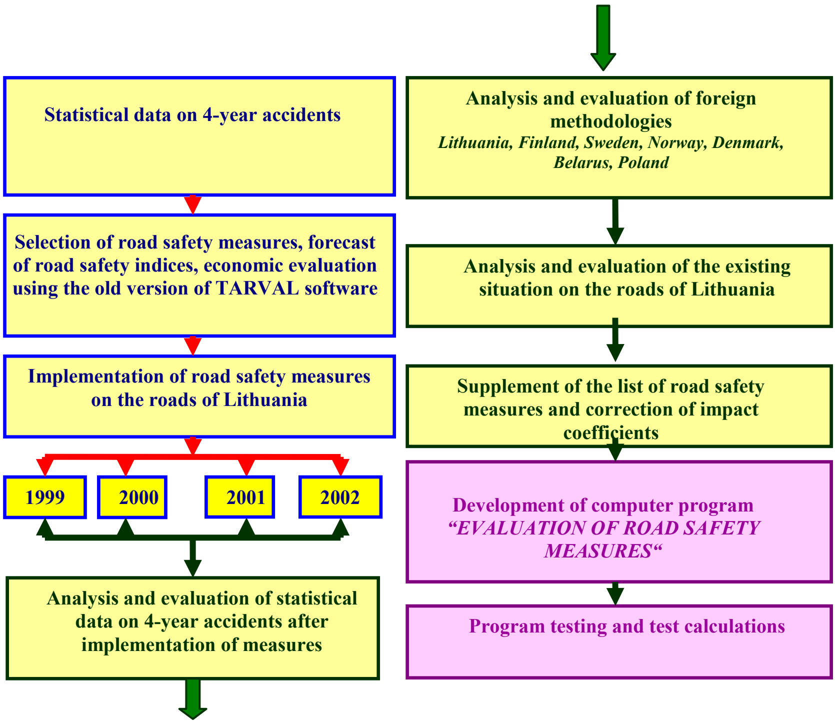

Fig. 2. Stages for the improvement of methodology used for the substantiation of road safety measures in Lithuania

4.1. Improvement of the method for the substantiation of road safety measures under Lithuanian conditions

Computer software for the evaluation of road safety measures consists of two main parts:

- normative tables;
- data and calculations.

Normative tables. Before starting working with the software it is necessary to input the newest initial data into the already made-up normative tables.

Road accident cost. The cost of a road accident is determined according to the unit prices approved by the Director General of the Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania. The latest unit prices were approved by the order No. V-410 of 19 November 2008. In order to make the analysis of measures implemented in the previous years and the effect of those measures the unit prices of that period must be used.

Road safety measures. Data stored in a table of the impact of road safety measures is the main input data of the road safety management system. Impact coefficients are divided into three groups: vehicle-involved accidents, pedestrian-involved accidents and animal-involved accidents. Road safety measures can be standard or individual, not yet included into the system, but there is a possibility to enter new safety measures.

Data and calculations. Having entered data into normative tables the calculations are carried out. Calculations consist of three stages:

- data input;
- forecast calculations of road accidents and accident losses;
- economic calculations.

Data input. Data input is in detail described in the User‘s Manual presented in the dissertation. A very important feature of data input of a new software is that the data input area is joined to the Road Information System of the Lithuanian Road Administration (LAKIS).

Economic calculations. Calculations show if the project is expedient to be implemented from the economic point of view. If several alternatives are studied it is determined which of them is the most acceptable.

Summary table of results. This table gives data on the road section where a certain road safety measure is planned to be implemented, data on the traffic volume and accident rate of this road section, the planned road safety measures, summary data on the forecasted effect of measures after their implementation. Based on economic indices and the forecasted accident rate the software itself makes the evaluation of the project’s attractiveness which can be:

I UNSATISFACTORY:

- if *IRR* < 5.5%, *AR* > 0.8 of the single carriageway roads and *AR* > 0.5 of the dual carriageway roads: **The economic attractiveness of the project**

is unsatisfactory. It is recommended to essentially change the project or to reject it.

- if *IRR* < 5.5%, *AR* ≤ 0.8 of the single carriageway roads and *AR* ≤ 0.5 of the dual carriageway roads: **The project‘s attractiveness is unsatisfactory.**

II SATISFACTORY:

- if 5.5% ≤ *IRR* < 8%, *AR* > 0.8 of the single carriageway roads and *AR* > 0.5 of the dual carriageway roads: **The economic attractiveness of the project is satisfactory. The project must be reconsidered.**
- if 5.5% ≤ *IRR* < 8%, *AR* ≤ 0.8 of the single carriageway roads and AR ≤ 0.5 of the dual carriageway roads: **The project‘s attractiveness is satisfactory.**

III GOOD:

- if 8% ≤ *IRR* < 12%, *AR* > 0.8 of the single carriageway roads and *AR* > 0.5 of the dual carriageway roads: **The economic attractiveness of the project is good. Accident rate is large, thus, the project must be reconsidered.**
- if 8% ≤ *IRR* < 12%, *AR* ≤ 0.8 of the single carriageway roads and *AR* ≤ 0.5 of the dual carriageway roads: **The project‘s attractiveness is good.**

IV VERY GOOD:

- if *IRR* >12%, *AR* > 0.8 of the single carriageway roads and *AR* > 0.5 of the dual carriageway roads: **The economic attractiveness of the project is very good. The accident rate is large, thus, the project must be reconsidered.**
- if *IRR* >12%, *AR* ≤0.8 of the single carriageway roads and *AR* ≤ 0.5 of the dual carriageway roads: **The project‘s attractiveness is very good.**

4.2. A test of the improved model for the substantiation of road safety measures

Experimental calculations were carried out on those road sections where after implementation of road safety measures or their complex the expected decrease in the accident rate was not achieved. Based on the results of experimental calculations the impact coefficients of road safety measures were once again corrected.

5. Accident modelling

The developed computer program *Evaluation of the Road Safety Measures* is used for the evaluation of safety measures to be implemented on black spots. In order to make forecasts of the safety situation on the newly built or reconstructed road sections and to prevent the occurrence of black spots it is necessary to carry out a very comprehensive analysis of historical data on the change of road accidents and traffic volume on the roads of Lithuania, to divide the roads of Lithuania into plenty of homogenous sections and to adapt the methods of mathematical statistics and game theory.

5.1. Forecasts of accident number

In order to forecast the number of road accidents on the main roads of Lithuania a statistical mathematical model of time series was used. Since in the analysis of statistical data of the number of accidents in a time series the clear seasonal variations were observed (Fig. 3 and Fig. 4) a search for regression curve was made which would well reflect the seasonal variations. A random quantity – the number of accidents in a period of 3 months (in a quarter of the year) – is marked by *Y*.

$$\hat{y} = a_0 + at + a_1t_1 + a_2t_2 + a_3t_3, \quad (1)$$

where $\hat{y}$ – forecasted average *Y* value; t – trend variable; t_i – variable taking the value 1 in the quarter i of the year and the value 0 in other quarters (the fourth quarter of the year is corresponded by the values of variables $t_1 = t_2 = t_3 = +$).

Seasonal variations are described by the regression equations (obtained using the *Microsoft Excel* tool *Data Analysis*) (Table 1):

$$\hat{y} = 190{,}19 + 0{,}69t - 76{,}64t_1 - 81{,}63t_2 - 22{,}11t_3, \quad (1997–2006) \quad (2)$$

$$\hat{y} = 187{,}32 + 0{,}60t - 72{,}92t_1 - 74{,}70t_2 - 16{,}49t_3, \quad (1997–2007) \quad (3)$$

$$\hat{y} = 193{,}52 + 0{,}02t - 67{,}78t_1 - 69{,}54t_2 - 14{,}48t_3, \quad (1997–2008) \quad (4)$$

Fig. 3 gives the dependency of the observed (1997–2008) and forecasted (based on 1997–2006 data) *Y* values on time. Accident data studied in a period of 11 years (1997–2007) showed that in the quarters III and IV the number of recorded accidents was significantly larger compared to the quarters I and II. Accident statistics of 2008 breaks even this regularity. The observed dispersion of the random quantity *Y* in the quarters III and IV is also larger compared to the quarters I and II.

The decrease in the number of accidents only in one year, i. e. 2008 is not statistically important to obtain a downward linear trend or a certain non-linear trend. This requires further observations of the accidents on the roads of Lithuania.

Table 1. Reliability and adequacy of forecasting results

Statistical data	**Number of observations (quarters)**	**R**	**R^2**	**Standard deviation**	**p**
1997–2006	40	0.92	0.85	16.59	8.41E-14
1997–2007	44	0.90	0.80	18.19	2.41E-13
1997–2008	48	0.79	0.63	25.31	8.23E-09

where p – probability to make an error after rejecting a hypothesis that the variables t, t_1, t_2, t_3 are insignificant if the values of a random quantity Y is taken into consideration; R^2 – determination coefficient showing in what proportion (percent) the variables t, t_1, t_2, t_3 explain a dispersion of values of the random quantity Y (the more R^2 is close to 1 the more regression curve is suitable to experimental data); R – correlation coefficient, the measure of correlation strength between the variables (the more R is close to 1 or –1 the stronger is correlation between the studied variables).

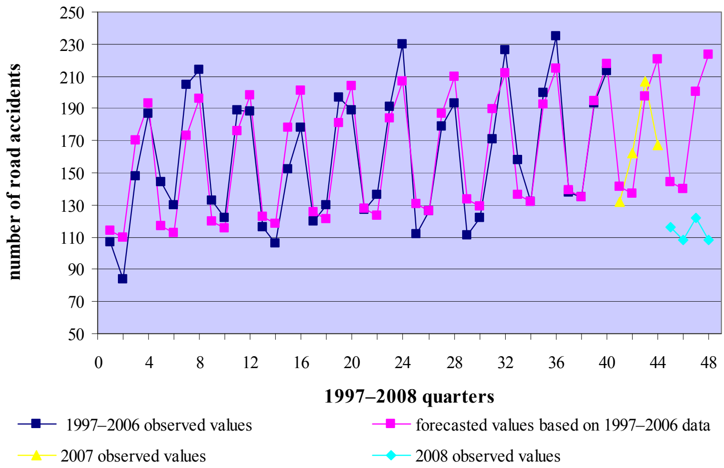

Fig. 3. Y values obtained by the regression equation (1)

Chapter 5 of this dissertation gives a detail analysis of the dependency of the number of accidents on the length of road section and its traffic volume. The chapter also presents a detail statistical analysis of data about the black spots.

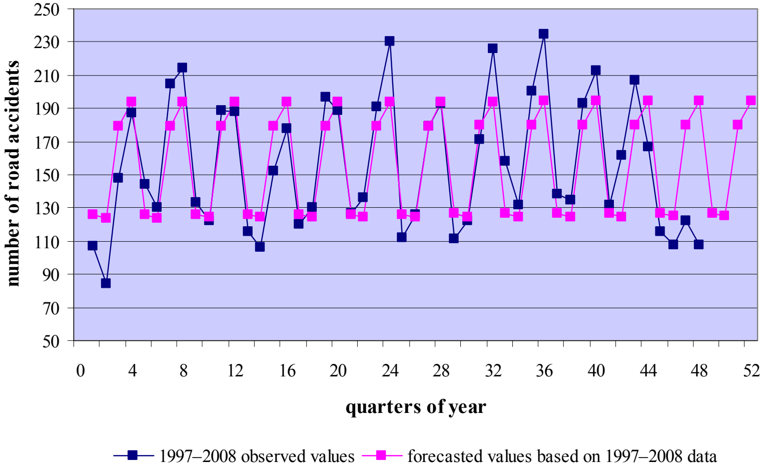

Fig. 4. *Y* values obtained by the regression equation (4)

With the help of a high-volume sample ($n = 7095$) the main numerical characteristics of people killed and injured in one road accident were found. Forecasts were based on the fatal and injury accidents on the main roads of Lithuania in 1997–2008.

When analyzing the number of accidents on the black spots of the main roads in 2004–2007 data was grouped according to the type t of a black spot:

- t_1 – group I – black spots having no junctions;
- t_2 – group II – black spots having at-grade junctions;
- t_3 – group III – black spots having two-level junctions.

The number of black spots of the group I was 26, of the group II – 70, of the group III – 14. Such a grouping enabled to rather reliably forecast the average number of accidents of each group (marked with X_1, X_2, X_3), separately of vehicle-involved accidents and accidents with pedestrians and cyclists (marked with X_{1m}, X_{2m}, X_{3m} and $X_{1dp}, X_{2dp}, X_{3dp}$) and the average number of people killed or injured in a 4-year period (marked with Z_1, Z_2, Z_3 and S_1, S_2, S_3). Regression equations of the statistical models of these parameters are:

$$X_i = aN^bL^c, \quad (5)$$

$$X_{im} = aN^bL^c, \quad (6)$$

$$X_{idp} = aN^bL^c, \quad (7)$$

$$Z_i = aN^bL^{c,} \quad (8)$$

$$S_i = aN^bL^c, \quad (9)$$

where N – average annual daily traffic on the studied road section, veh./day; L – length of the studied road section, km; b – linear regression coefficient depending on traffic volume; c – linear regression coefficient depending on the length of road section; $i = 1, 2, 3$; $a = 1$.

Regression equations obtained in the black spots of all types $(t = 1, 2, 3)$ forecast the averages of the studied random variables with the errors in the interval (1; 2,3), determination coefficients R^2 get the values in the interval (0.69; 0.99), thus, it could be stated that the dependency of random variables on the traffic volume and the length of the black spot gives a fairly good explanation of the dispersion of random variables $X_1, X_2, X_3, X_{1m}, X_{2m}, X_{3m}$ and $X_{1dp}, X_{2dp}, X_{3dp}, Z_1, Z_2, Z_3$ and S_1, S_2, S_3.

This chapter of the dissertation describes also the optimization of the selection of measures which was conducted to reduce the number of black spots on the roads. In the result different mathematical models were constructed. One of them allows the specialists to optimally select road safety measures to maximally reduce the number of people killed under unrestricted amount of funds (10), the other – under restricted financial possibilities (11).

$$\max \sum_{i=1}^{m} d_i \,,$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \le k \,,$$

$$\sum_{j=1}^{n} (\overline{\alpha_m} d_{imj} + \overline{\alpha_{dp}} d_{idpj}) x_{ij} \ge d_i \,, \; i = 1,2,\dots,m \,,$$

$$\sum_{j=1}^{n} x_{ij} \le 1 \,, \; i = 1,2,\dots,m \,,$$

$$0 \le x_{ij} \le 1 \,, \; i = 1,2,\dots,m \,, \; j = 1,2,\dots,n_1 \,,$$

$$x_{ij} = \begin{cases} 0 \\ 1 \end{cases} , \; j = n_1 + 1,\dots,n \,, \; i = 1,\dots,m \,. \qquad (10)$$

$$\max \sum_{j=1}^{m} d_i \,,$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \le C \,,$$

$$\sum_{j=1}^{n} (\overline{\alpha_m} d_{imj} + \overline{\alpha_{dp}} d_{idpj}) x_{ij} \ge d_i \,, \; i = 1,2,\dots,m \,,$$

$$\sum_{j=1}^{n} x_{ij} \le 1 ,\ i = 1,2,...,m$$

$$0 \le x_{ij} \le 1 ,\ i = 1,2,...,m ,\ j = 1,2,...,n_1$$

$$x_{ij} = \begin{cases} 0 \\ 1 \end{cases} ,\ j = n_1 + 1,...,n ,\ i = 1,...,m . \qquad (11)$$

where $\overline{\alpha_m}$, $\overline{\alpha_{dp}}$ – average number of people killed in one vehicle-involved road accident ($\overline{\alpha_m}$) in one road accident with pedestrians and cyclists ($\overline{\alpha_{dp}}$); k – number of preventive measures; d_{imj}, d_{idoj} – average decrease in the number of vehicle-involved accidents (d_{imj},) and in the number of accidents with pedestrians and cyclists (d_{idoj}) after implementation of the measure *j* in the black spot *i*; c_{ij} – cost of implementation of the measure *j* in the black spot *i.* Parameter *C* is the amount of money allocated for the implementation of measures.

General conclusions

1. Having made the analysis of the effect of road safety measures implemented it was determined that from the evaluated 48 high-accident road sections the expected improvement results in safety situation were not achieved on 50% of road sections; the expected reduction in accident rate was not achieved on 15% of road sections; the implemented road safety measures were justified on 50% of road sections.
2. Examination of 1995–2006 results of the substantiation of road safety measures implemented on the roads of national significance of Lithuania, the analysis of accident indices after implementation of special measures and the detail analysis of only partly justified road safety measures showed that methodology for the substantiation of road safety measures, currently used in Lithuania, does not allow to accurately enough select road safety measures for the high-accident road sections.
3. Having made the analysis and evaluation of foreign methodologies for the substantiation of road safety measures and based on the *Microsoft Office Access* program the database was created operating as a separate program or as a sub-program *Evaluation of Road Safety Measures*.
4. The created and tested by test calculations program *Evaluation of Road Safety Measures* gives a possibility to determine the effect of the engineering road safety measures planned to be implemented on a certain high-accident location or black spot, using the suggested forecast coefficients of the impact and elasticity of road safety measures, of traffic volume and the growth in prices of preventive measures and taking into consideration the country's

economic situation the program enables to forecast road accidents and accident losses.

5. In the result of research activities the list of road safety measures was expanded by 59 new measures. The new program *Evaluation of the Road Safety Measures* uses already 131 safety measure. There is a possibility to enter individual road safety measures.

6. With the use of high-volume sample $n = 7095$, data on the fatal and injury accidents on the main roads in 1997–2008, the main numerical characteristics of the number of people killed and injured in one road accident were found. The performed accident modelling allowed us to construct mathematical models for the optimum selection of preventive measures for the main roads.

7. In order to make forecasts of the safety situation on the newly built or reconstructed road sections and to prevent the occurrence of black spots it is necessary to carry out a very comprehensive analysis of historical data on the change of road accidents and traffic volume on the roads of Lithuania, to divide the roads into plenty of homogenous sections and to adapt the methods of mathematical statistics and optimization methods.

List of Published Works on the Topic of the Dissertation

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About the author

Kornelija Ratkevičiūtė was born in Raseiniai, on 13th of July 1980.

First degree in Civil Engineering, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, 2002. Master of Science in Civil Engineering, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, 2004. From 2002 till now is working at Road Research Laboratory of Road Department of Vilnius Gediminas Technical University. In 2005–2009 – PhD student of Vilnius Gediminas Technical University. Kornelija Ratkevičiūtė in 2007 was on internship at Lund University, Sweden. From 2004 participate in action of the club of young road engineers „Kelelis". At present – Assistant in Road Department of Vilnius Gediminas Technical University.

EISMO SAUGUMO GERINIMO PRIEMONIŲ PAGRINDIMO MODELIS LIETUVOS AUTOMOBILIŲ KELIAMS

Mokslo problemos aktualumas. 2001 m. rugsėjo mėnesį Europos Komisijos patvirtintoje Baltojoje knygoje buvo užsibrėžtas tikslas žuvusiųjų eismo įvykiuose skaičių iki 2010 m. sumažinti perpus (nuo 50 000 iki 25 000 per metus). Tai padaryti turi būti siekiama suvienodinant baudų dydžius, įrengiant papildomas priemones saugiam eismui užtikrinti, įdiegiant naujas ir pažangias technologijas. Įstojusi į Europos Sąjungą, Lietuva taip pat prisiėmė šį Europos Sąjungos šalis vienijantį tikslą: iki 2010 m. sumažinti eismo įvykiuose žuvusiųjų skaičių 50 %. Deja, statistiniai duomenys liudija, kad eismo saugumas automobilių keliuose iki šiol Lietuvoje yra vienas blogiausių Europos Sąjungoje. „Juodųjų dėmių“ skaičius Lietuvos automobilių keliuose yra didelis, todėl būtina sukurti efektyvų eismo saugumo gerinimo priemonių pagrindimo modelį, kuris leistų parinkti eismo saugumo gerinimo priemones, pirmiausia tuose kelių ruožuose, kuriuose avaringumo rodikliai viršija ribines reikšmes.

Disertacijoje atliktų avaringumo tyrimų rezultatai parodė, kad iki šiol Lietuvoje taikoma saugaus eismo gerinimo priemonių pagrindimo metodika neleidžia tiksliai parinkti saugaus eismo gerinimo priemonių avaringuose ruožuose, prognozuoti eismo įvykius bei priemones šių įvykių prevencijai. Todėl būtina ją tikslinti, įvertinus Lietuvos ir kitų šalių patirtį, taikyti matematinės statistikos bei optimizavimo matematinius modelius eismo įvykių prevencijai. Eismo saugumo gerinimo priemonių pagrindimo modelio patobulinimas leis efektyviai prognozuoti eismo įvykius automobilių keliuose pagrįsti avaringose vietose diegiamas inžinerines saugaus eismo gerinimo priemones, efektyviai panaudoti mokesčių mokėtojų lėšas, skirtas automobilių keliams.

Darbo tikslas – patobulinti saugaus eismo priemonių pagrindimo metodiką „juodosioms dėmėms“ šalinti, parengti matematinio modelio projektą įskaitiniams eismo įvykiams prognozuoti bei sudaryti optimizavimo uždavinį, modeliuojantį optimalių eismo saugumo gerinimo priemonių pasirinkimą Lietuvos magistraliniuose automobilių keliuose.

Tikslui pasiekti suformuluoti šie ***uždaviniai***:

1. Atlikti šiuo metu Lietuvoje taikomos saugaus eismo gerinimo priemonių pagrindimo metodikos analizę.
2. Atlikti saugaus eismo rodiklių analizę ir vertinimą įdiegus specialias priemones Lietuvos valstybinės reikšmės automobilių keliuose bei įvertinti taikomos metodikos efektyvumą.
3. Išanalizuoti ir įvertinti kitose užsienio šalyse taikomas saugaus eismo gerinimo priemonių pagrindimo metodikas.
4. Įvertinus kitų šalių patirtį bei Lietuvoje taikomos metodikos trūkumus, sudaryti efektyvų saugaus eismo gerinimo priemonių pagrindimo modelį.
5. Atlikti naujai sukurtos programinės įrangos testavimą ir bandomuosius skaičiavimus.
6. Išnagrinėti matematinių metodų taikymo galimybes įskaitiniams eismo įvykiams prognozuoti.
7. Parengti matematinio modelio projektą įskaitiniams eismo įvykiams prognozuoti ir sudaryti optimizavimo uždavinį, modeliuojantį optimalių eismo saugumo gerinimo priemonių pasirinkimą „juodosiose dėmėse“, esančiose Lietuvos magistraliniuose automobilių keliuose.

Mokslinis naujumas. Aprobuota užsienio šalių patirtis leido patobulinti saugaus eismo gerinimo priemonių pagrindimo modelį ir pritaikyti Lietuvos eismo sąlygoms.

Pirmą kartą vertinimo modelis sudarytas remiantis per 12 metų avaringuose Lietuvos automobilių kelių ruožuose įgyvendintų inžinerinių saugaus eismo priemonių analizės rezultatais bei užsienio šalių patirtimi. Sukurta šiuolaikinė kompiuterinė programa „Saugaus eismo priemonių vertinimas“, atliktas jos testavimas ir bandomieji skaičiavimai.

Pirmą kartą Lietuvoje pateikiamas matematinio modelio projektas eismo įvykiams prognozuoti bei modeliuoti optimalių eismo saugumo gerinimo priemonių pasirinkimą Lietuvos magistraliniuose keliuose.

Eismo saugumo gerinimo priemonių pagrindimo modelio patobulinimas leis efektyviai prognozuoti eismo įvykius automobilių keliuose, pagrįsti avaringose vietose diegiamas inžinerines saugaus eismo gerinimo priemones, efektyviai panaudoti mokesčių mokėtojų lėšas, skirtas automobilių keliams.

Tyrimų metodika. Statistiniai metodai (aprašomoji statistika, laiko eilučių matematiniai modeliai, koreliacinė ir regresinė analizė) taikyti analizuojant avaringumo rezultatus. Lyginamosios analizės metodas taikytas atliekant Lietuvos ir užsienio šalyse taikomų eismo saugumo gerinimo priemonių pagrindimo metodikų analizę. Taikyti optimizavimo metodai sudarant matematinius modelius parenkant prevencijos priemones avaringuose Lietuvos magistralinių kelių ruožuose.

Praktinė vertė. Sudarytas eismo saugumo gerinimo priemonių vertinimo modelis ir parengta kompiuterinė programa gali būti taikomi eismo saugumo gerinimo priemonių ekonominiam pagrindimui atlikti prieš įdiegiant eismo saugumo gerinimo priemones avaringuose Lietuvos automobilių kelių ruožuose ir „juodosiose dėmėse“.

Sudarytas matematinio tikimybinio modelio projektas bei optimizavimo uždavinys gali būti naudojamas eismo įvykių prognozei, optimalių eismo saugumo gerinimo priemonių pasirinkimui „juodosiose dėmėse“, esančiose Lietuvos magistraliniuose keliuose.

Ginamieji teiginiai

1. Eismo saugumo gerinimas labai priklauso nuo automobilių keliuose diegiamų inžinerinių eismo saugumo gerinimo priemonių, kurias būtina vertinti socialiniu ir ekonominiu aspektais.
2. Diegiamų saugaus eismo gerinimo priemonių vertinimui reikia taikyti šiuolaikines metodikas, įvertinančias esamas avaringumo, eismo intensyvumo ir kitas sąlygas.
3. Diegiamų saugaus eismo priemonių vertinimui turi būti sukurtos specialios kompiuterinės programos, leidžiančios panaudoti automobilių kelių

informacinių sistemų duomenų bazes, apdoroti didelį kiekį duomenų ir atlikti gana sudėtingus matematinius skaičiavimus.

4. Lietuvos automobilių keliuose būtina diegti saugaus eismo gerinimo priemones ne vien tik avaringuose kelių ruožuose ir „juodosiose dėmėse“, bet pasitelkus matematinius statistinius modelius prognozuoti eismo įvykių koncentracijų vietas ir užkirsti kelią avaringų ruožų susidarymui.

Darbo apimtis. Darbą sudaro įvadas, penki skyriai, išvados, literatūros sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 110 puslapių, 26 iliustracijos, 22 lentelės ir 21 priedas.

Pirmame skyriuje pateikiami pagrindiniai duomenys apie Lietuvos valstybinės reikšmės automobilių kelių tinklą, automobilizacijos lygio kitimą, pagrindinius avaringumo rodiklius, saugų eismą veikiančius pagrindinius veiksnius. Skyriaus pabaigoje formuluojamos išvados.

Antrame skyriuje pateikiama taikomų tyrimo metodų apžvalga. Pateikta Lietuvoje, Suomijoje, Baltarusijoje, Lenkijoje ir kitose užsienio šalyse taikomų eismo saugumo gerinimo priemonių pagrindimo metodikų analizė.

Trečiame skyriuje pateikta atliktų avaringumo tyrimų analizė parodė, kad iki šiol taikoma TARVAL programa nepakankamai tiksliai įvertina diegiamas priemones ir prognozuoja saugaus eismo rodiklius. Todėl buvo būtina ją tikslinti, įvertinus Lietuvos ir kitų šalių patirtį bei dabartinę eismo situaciją Lietuvos automobilių keliuose.

Ketvirtame skyriuje pateikiamas patobulinto eismo saugumo gerinimo priemonių pagrindimo modelio aprašas.

Penktame skyriuje pateiktas matematinių modelių taikymas eismo įvykiams prognozuoti Lietuvos Respublikos magistraliniuose keliuose.

Bendrosios išvados

1. Atlikus Lietuvos automobilių keliuose įdiegtų saugaus eismo gerinimo priemonių efektyvumo analizę, nustatyta, kad iš 48 vertintų avaringų kelių ruožų, lauktų eismo saugumo pagerėjimo rezultatų nepasiekta 50 % kelių ruožų; laukiamo avaringumo koeficiento sumažėjimo nepasiekta – 15 % kelių ruožų; įdiegtos eismo saugumo gerinimo priemonės pasiteisino 50 % tirtų kelių ruožų.

2. Išnagrinėjus saugaus eismo gerinimo priemonių, įdiegtų Lietuvos valstybinės reikšmės automobilių keliuose, pagrindimo rezultatus 1995–2006 m., atlikus avaringumo rodiklių analizę po specialių priemonių įdiegimo bei detaliai išanalizavus tik iš dalies tikusias saugaus eismo gerinimo priemones, nustatyta, kad šiuo metu Lietuvoje taikoma saugaus eismo gerinimo priemonių pagrindimo metodika neleidžia tiksliai parinkti saugaus eismo gerinimo priemonių avaringuose kelių ruožuose.

3. Atlikus kitose užsienio šalyse taikomų saugaus eismo gerinimo priemonių pagrindimo metodikų analizę ir vertinimą, naudojant *Microsoft*

Office Access programą buvo sukurta duomenų bazė, kuri veikia kaip atskira programa „Saugaus eismo priemonių vertinimas“.

4. Sukurta ir bandomaisiais skaičiavimais patikrinta programa „Saugaus eismo priemonių vertinimas“ įvertina avaringame ruože arba „juodojoje dėmėje“ numatomų diegti inžinerinių eismo saugumo gerinimo priemonių efektyvumą, taikant siūlomus saugaus eismo gerinimo priemonių poveikio, elastingumo, eismo intensyvumo bei prevencijos priemonių kainų augimo prognozių koeficientus, atsižvelgiant į ekonominę padėtį šalyje, programa leidžia prognozuoti eismo įvykius bei jų nuostolius.

5. Atlikus tyrimus saugaus eismo gerinimo priemonių sąrašas papildytas 59-iomis naujomis priemonėmis. Naujojoje „Saugaus eismo priemonių vertinimo“ programoje įvesta 131 priemonė. Yra galimybė įvesti naujas eismo saugumo gerinimo priemones, kurių nėra sąraše.

6. Naudojant 1997–2008 metų įskaitinių eismo įvykių duomenis magistraliniuose keliuose (buvo analizuoti 7095 įskaitiniai eismo įvykiai) atliktas eismo įvykių modeliavimas, kuris leido sudaryti optimalaus prevencijos priemonių parinkimo matematinį modelį magistraliniams keliams.

7. Norint prognozuoti avaringumo situaciją naujai tiesiamuose arba rekonstruojamuose automobilių kelių ruožuose ir neleisti juose susidaryti „juodosioms dėmėms“, reikia atlikti išsamią Lietuvos automobilių keliuose įvykusių eismo įvykių ir eismo intensyvumo kitimo istorinių duomenų analizę, suskaidyti Lietuvos automobilių kelius į daugybę homogeninių ruožų, pritaikyti matematinės statistikos bei optimizavimo metodus.

Trumpos žinios apie autorių

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Padėka

Dėkoju savo darbo vadovui profesoriui Donatui Čygui, Kelių katedros vedėjui profesoriui Alfredui Laurinavičiui ir visiems kolegoms už pagalbą rašant daktaro disertaciją. Taip pat norėčiau padėkoti savo artimiesiems už palaikymą, supratimą ir kantrybę.