SAFETY CONTROL OF LATVIAN STATE ROAD NETWORK USING STATISTICAL MODELLING METHODS

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ABSTRACT
Latvia has recently seen an increase in volumes of exports and imports of goods, and volumes of cargo transit through the territory of Latvia have also increased. The results of the study of the Latvian Road Carrier Association show that, in 2011, the Latvian trucking companies' freight turnover increased by 20%. At the same time, the number of cars and trucks registered in Latvia is also increasing. The intensity of vehicular traffic on roads of Latvia increases too, especially, the transit traffic on the main roads of Latvia. The aim of this research is to model the incidence of road traffic accidents and populated areas (towns) that occur on the main (national) highways of Latvia and estimate the expected interval of variations in the real damage incurred by the state.
The research envisages the creation of the following models:
1. to determine the possible number of road traffic accidents on the main (public) roads;
2. to calculate the damage (general economic losses $\mathbf{C_{Total}}$) caused for the national economy of Latvia due to road traffic accidents.

The authors believe that the effectiveness of the logistics process should be evaluated not only taking into consideration the volume of goods transported, and the profit derived from it, but should also assess the losses incurred by the state due to increased road traffic accidents and fatalities, destruction of vehicles and road surfaces, and so on. In this research, using statistical modelling, we determine the relationship between parameters describing the state of road infrastructure in Latvia, and intensity on the roads of Latvia, as well as economic losses due to increased intensity of the logistics process and increased numbers of road traffic accidents (resulting value).

Keywords: road accidents, statistical modelling, Monte-Carlo method, management, effectiveness

1. INTRODUCTION

The geographical location of Latvia is extremely favourable for the development of the transport business, since Latvia has ports capable of receiving and serving all classes of ships, as well as an extensive transportation network of railways and highways connecting the ports of Latvia with the CIS countries and the EU (see Figure 1). Roads are an important component of Latvian transport system with the total length of 20,309 km.

Figure 1: The Basic Directions of Road Traffic on Territory of Latvia

Losses on roads have big social and economic value for each country. The information about World road traffic accidents (number of injured and killed in road accidents) is shown in Figures 2 and 3.

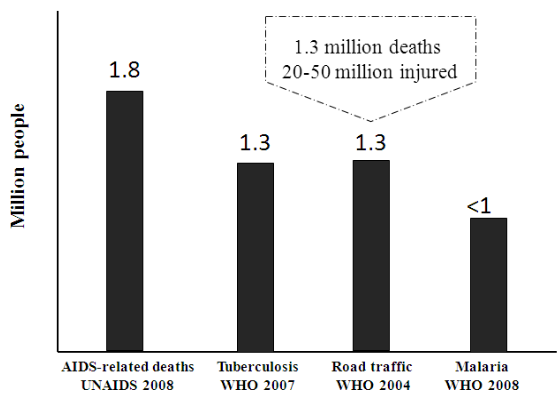

Figure 2: Road Traffic Deaths: the Facts (One-year progress update: Decade of Action for Road Safety 2011-2020)

2004: the Facts		
Rank	**Disease or Injury**	**%**
1	Ischaemic heart disease	12.2
2	Cerebrovascular disease	9.7
3	Lower respiratory infections	7.0
4	Chronic Obstructive Pulmonary Disease	5.1
5	Diarrhoeal diseases	3.6
6	HIV/AIDS	3.5
7	Tuberculosis	2.5
8	Trachea, bronchus, lung cancer	2.3
9	**Road traffic injuries**	**2.2**
10	Prematurity and low-birth weight	2.0

2030: the Prediction		
Rank	**Disease or Injury**	**%**
1	Ischaemic heart disease	14.2
2	Cerebrovascular disease	12.1
3	Lower respiratory infections	8.6
4	Prematurity & low-birth weight	3.8
5	**Road traffic injuries**	**3.6**
6	Trachea, bronchus, lung cancer	3.4
7	Diabetes mellitus	3.3
8	Hypertensive heart disease	2.1
9	Stomach cancer	1.9
10	HIV/AIDS	1.8

Figure 3: Leading causes of death, 2004 and 2030 compared (Global status report on road safety 2009)

The forecast (see Figure 3) for high-income countries, current and projected trends in low-income and middle-income countries foreshadow a big escalation in global road crash mortality between 2000 and 2020. Furthermore, on current trends, by 2020, road crash injury is likely to be the third leading cause of disability-adjusted life years lost. In economic terms, the cost of road crash injuries is estimated at roughly 1% of gross national product (GNP) in low-income countries, 1.5% in middle-income countries and 2%-3% in high-income countries (Global status report on road safety 2009).

The annual material damage due to road traffic accidents on roads, in Latvia, is presented in Table 1.

Table 1: Annual Damage Incurred to Road Traffic Accidents on the main roads in Latvia

Year	Annual Damage, mln. LVL, **C_fact**	Road transport - accidents (road_ac), x_1	People killed in road accidents (road_ac_death), x_2	Number of injured victims, x_3	Model of annual damage, mln. LVL, **C_mod**
1996	79,8	13656	550	4324	86,43
1997	94,4	17328	525	4674	105,19
1998	136,7	25655	627	5414	145,28
1999	152,4	30614	604	5244	151,01
2000	157,9	20454	588	5449	135,23
2001	190,6	36468	517	5852	182,67
2002	207,0	39593	518	6300	203,08
2003	211,3	45555	493	6639	226,48
2004	220,8	48912	516	6416	226,89
2005	210,4	47353	442	5600	199,07
2006	203,7	52102	407	5404	203,62
2007	244,5	61383	419	6088	244,54
2008	208,9	54323	316	5408	209,03
2009	122,6	35058	254	3930	122,51
2010	132,7	38343	218	4023	132,67

2. PROBLEM DESCRIPTION

To build a statistical model it is necessary to investigate:

- traffic intensity on each of the sections of road transport route;
- number of intersections with the other highways;
- number of populated areas, through the territory of which, highways run (the existing empirical data show that biggest concentration of the black spots is evidenced in the populated areas. Moreover, the bigger the populated area, the greater the number of road traffic accidents, i.e., black spots;
- statistics of road traffic accidents on the section of the route of traffic.

The scheme of the i^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point B is presented in Figure 4.

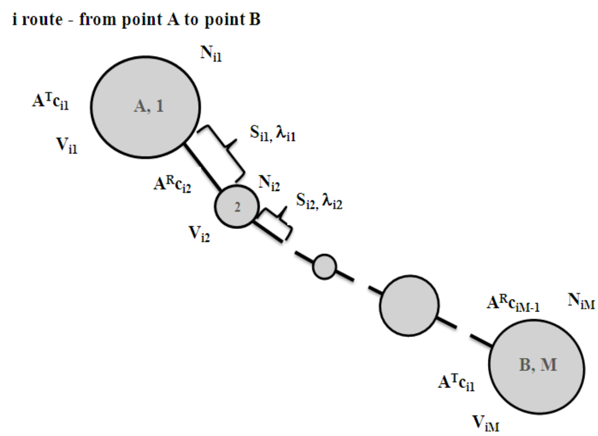

Figure 4: Scheme of the i^{th} Route of Road Traffic between Points of Populated Areas A and B

Parameters of the route scheme (Figure 4):

$A^T c_{ij}$ – incidence of road traffic accidents occurring in the j^{th} populated area (town) i=1,2,…,R; j=1,2,…,M;

N_{ij} – number of population in the j^{th} populated area (town) of the of i^{th} route of traffic i=1,2,…,R; j=1,2,…,M;
V_{ij} – number of transport vehicles in the j^{th} populated area (town), i=1,2,…,R; j=1,2,…,M;
λ_{ij} – intensity of road transport vehicle movement in the j^{th} section of the i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
$A^{R}c_{ij}$ – incidence of road traffic accidents occurring in the j^{th} sector of the of i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;
S_{ij} – length of the j^{th} sector of the of i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1.
R – number of main state routes, R=I, II, …,X.

For statistical modeling of number of accidents as a result of the auto failures occurring in cities, the scheme is used (see Figure 5).

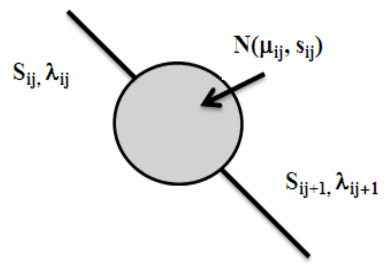

Figure 5: Intensity of Road Traffic Accidents Occurring in Crossed City in the i^{th} Route of Traffic

In Figure 5, $N(\mu_{ij}, \sigma_{ij})$ denotes the normal distribution of the number of road traffic accidents per unit of time (the normal distribution quite well describes the distribution of the number of road traffic accidents, occurring in the populated areas). At sections of roads located outside the populated areas, the number of road traffic accidents occurring per unit of time is described by Poisson distribution with the parameter λ_{ij}, i=1,2,…,R; j=1,2,…,M-1.

The modelling of annual material damage due to road traffic has been performed using the simplified structure of main roads of Latvia (see Figure 6).

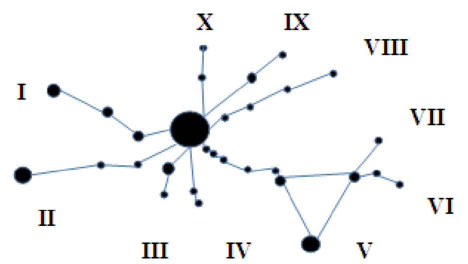

Figure 6: Scheme of Main Road Traffic Routes and Crossed Cities

Using the parameters mentioned above, the total number of road traffic accidents, occurring on the i^{th} route of traffic, can be determined using statistical modelling methods. Thus, it becomes possible to calculate the total expected incidence rate of road traffic accidents on major highways in Latvia.

Having at our disposal the statistical information about material damage, incurred by state, by each type of road traffic accidents occurring on roads, as well as having modelled the incidence rate of road traffic accidents, we may calculate the possible range of variations in the total damage due to road traffic accidents on main roads in Latvia.

In accordance with the evaluation of experts of the Ministry of Economics, the GDP growth could reach 5.5% in 2011 (see Table 2). The more rapid development scenario foresees that growth rates of manufacturing (and respectively also exports) will remain comparatively fast also after 2012, based mainly on both the increased competitiveness of Latvian producers and on the growth of external demand. The slower development scenario assumes that the growth in Europe will be weak and competitiveness in tradable sectors will not improve in the medium-term (see Figure 7).

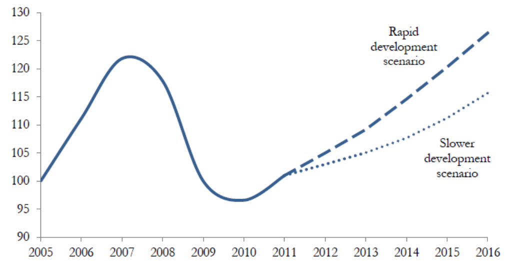

Figure 7: Forecasts of Latvian GDP (Report on the Economic Development of Latvia, December 2011, (Report of Economic Development of Latvia December 2011)

The growth of the economy of Latvia will not exceed 3% in 2012. Yet, considering many uncertainties about possibilities of solving several big debt problems in the euro zone and their potential impact on the real sector of these countries, the Ministry of Economics has prepared also the more pessimistic forecast of 1.5% growth of GDP in 2012 (Economic Development of Latvia, Report 2011).

Table 2: Forecast of Latvian GDP

Forecast of Latvian GDP by Expenditure Items in % over the previous year			
Years	2011	2012	average annually 2013-2016
%	5.5	1.5..3.0	3.0..4.7

Road accidents cost up to 5 % of the gross domestic product – in many countries costs are around 1-3% of GDP. The amounts invested in road safety are likely to be smaller than the costs of accidents, although very few estimates of this are available.

Two scenario are investigated in the paper (Table 3).

Table 3: Two Scenarios Forecast of Latvian GDP Growth and Road Transport Accidents Annual Damage

Year	GDP prediction, thousands LVL		Annual Damage prediction, thousands LVL	
	Slow growth scenario	Rapid growth scenario	Slow growth scenario	Rapid growth scenario
2011	14161028 thousands LVL GDP fact 2011			
2012	14373443,4	14585858,8	215601,7	218787,9
2013	14804646,7	15271394,2	222069,7	229070,9
2014	15248786,1	15989149,7	228731,8	239837,2
2015	15706249,7	16740639,8	235593,7	251109,6
2016	16177437,2	17527449,8	242661,6	262911,7
2017	16662760,3	18351240,0	249941,4	275268,6
2018	17162643,1	19213748,3	257439,6	288206,2
2019	17677522,4	20116794,4	265162,8	301751,9
2020	18207848,1	21062283,8	273117,7	315934,3
2021	18754083,5	22052211,1	281311,3	330783,2
2022	19316706,0	23088665,0	289750,6	346330,0
2023	19896207,2	24173832,3	298443,1	362607,5
2024	20493093,4	25310002,4	307396,4	379650,0
2025	21107886,2	26499572,5	316618,3	397493,6

3. STATISTICAL MODEL

For statistical modelling of annual road transport accidents (road_ac), authors used mathematical model:

$$\sum_{i=1}^{R}\left[\sum_{j=1}^{M}\alpha\left(V_{ij}\right)^{\beta_1}\left(N_{ij}\right)^{\beta_2}+\sum_{j=1}^{M-1}\gamma_{ij}A^{R}_{c_{ij}}S_{ij}\right], \qquad (1)$$

where α, β_1, β_2 – coefficients for model of road accidents in Latvian cities (towns). γ_{ij} – coefficient describing factor risk for the the j^{th} section of the i^{th} route of traffic, i=1,2,…,R; j=1,2,…,M-1;

Using regression tool the model of evaluation of annual damage can be expressed as:

$$C_{\text{mod}}(x_1,x_2,x_3)=-71.9+0{,}002\cdot x_1-0{,}01\cdot x_2+ +0{,}03\cdot x_3\,, \qquad (2)$$

where x_1 – number of road transport accidents;
x_2 – number of people killed in road traffic accidents;
x_3 - number of injured victims.

Regression model (2) has a good approximation of real annual losses of economy (annual damage) of Latvia (see Figure 8).

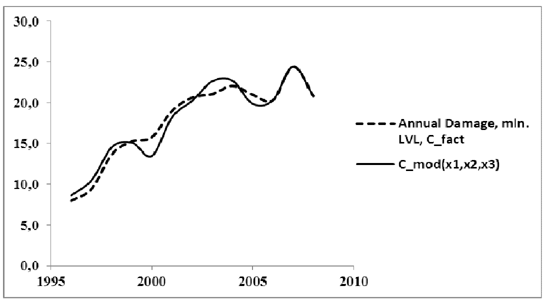

Figure 8: Graphical Illustration of Regression Model of Annual Damage and Real Road Traffic Accidents

The information presented in Figure 8 characterizes intensity of streams of movement of motor transport on modelled sites III, IV main roads A5, A7 and A8. Intensity of movement is shown by numbers, in the form of fraction, for example $\frac{3951}{1976}$. The top number means the general intensity of movement of motor transport on a site of the main road in unit of time (days). The bottom number characterizes intensity of movement of cargo motor transport on the given site of the main road in unit of time (days). Arrows in drawing designate places (black points) with the greatest frequency of occurrence of road accidents (autofailures). Numbers n1/n2/n3 characterizes quantity of road traffic accidents accordingly in 2007/2008/2009 years (see Figure 9).

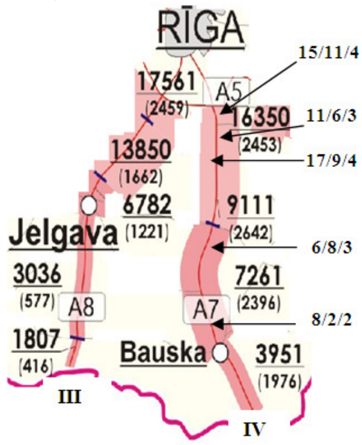

Figure 9: Traffic Intensity on Latvian Roads A5, A7, A8

Authors, using statistical modeling, have estimated the level of annual losses in economy of Latvia in connection with happened road traffic accidents, taking into account the factors influencing an infrastructure of the road system of the country. Using the statistical information characterizing the number of occurring accidents on main roads of Latvia for parameters x_1, x_2, x_3, authors define laws of statistical distribution for parameters x_1, x_2, x_3 and evaluate the confidential intervals for these parameters.

For evaluation of losses of Latvian economy from transport accidents on main Latvian roads such economic parameters are used:

y_1 - an average value of economic losses caused by one traffic road accident LVL.

y_2 - an average value of economic losses caused by one killed in traffic road accident, LVL.

y_3 - an average value of economic losses caused by one injured victims in traffic road accident, LVL.

For modeling the general economic losses of economy of Latvia as a result of transport accidents on the main roads of Latvia $\mathbf{C}_{\mathbf{Total}}$, the formula is used:

$$C_{Total}=\sum_{i=1}^{3}x_i y_i\,, \qquad (3)$$

The number of failures on roads depends on two groups of factors – A - the factors raising number of failures on roads and B – the factors reducing number of failures on roads.

Factors belonging to group A:

- the number of the registered vehicles;
- the technical conditions of vehicles;
- the quality of roads and their infrastructure;
- the intensity of movement of transport streams;
- other factors.

Factors belonging to group B:

- the actions directed on improvement of quality of roads and related infrastructure;
- the investments for the realization of these actions ;
- other factors. In general, overall road safety budgets are allocated in relation to the national annual budget, GDP.

Using the statistical information (see Table 3, Figure 8, 9) and statistical modeling according to formulas (1, 2, 3) paper authors have received statistical distribution of general economic losses of Latvia $\mathbf{C_{Total}}$ for two scenarios – rapid and slow development of Latvian GDP (see Figure 7). The predicted values of each of parameters x_1, x_2, x_3, y_1, y_2, y_3 are presented in Figure 10, 11.

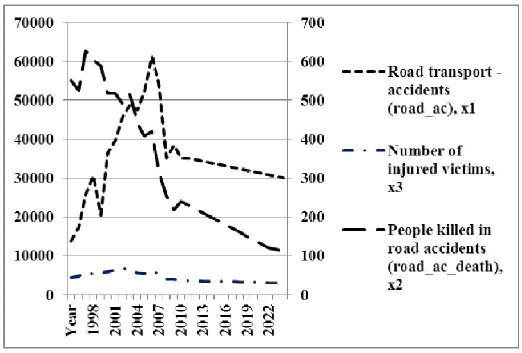

Figure 10: Road Transport Accidents x_1, x_2, x_3 Forecast

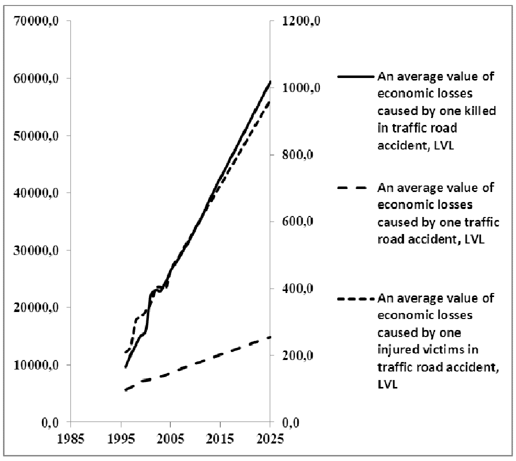

Figure 11: Parameters y_1, y_2, y_3 Forecast

The results of one realization of Monte-Carlo modeling method for parameters x_1, x_2, x_3 are shown in Table 4.

Table 4: The results of modeling for parameters x_1, x_2, x_3

Total, 2025 year		
N_CSNg =	**30623**	x_1
N_bg =	**108**	x_2
N_iev =	**3082**	x_3

Forecast for parameters y_1, y_2, y_3 is shown in Table 5.

Table 5: Forecast for parameters y_1, y_2, y_3

Year	y_1, LVL	y_2, LVL	y_3, LVL
2025	**2555**	**593902**	**9633**

The fragment of modeling of $\mathbf{C_{Total}}$ (number of samples 5000) is shown in Table 6.

Table 6: The table of distribution for $\mathbf{C_{Total}}$

NN	Bin	Frequency	Rel Frequency	Cum Frequency
1	163635638,2	8	0,00160	0,00160
2	165036802,1	1	0,00020	0,00180
3	166437966,0	17	0,00340	0,00520
4	167839129,9	40	0,00800	0,01320
5	169240293,7	94	0,01880	0,03200
6	170641457,6	185	0,03700	0,06900
7	172042621,5	324	0,06480	0,13380
8	173443785,4	439	0,08780	0,22160
9	174844949,3	636	0,12720	0,34880
10	176246113,1	720	0,14400	0,49280
11	177647277,0	675	0,13500	0,62780
12	179048440,9	597	0,11940	0,74720
13	180449604,8	482	0,09640	0,84360
14	181850768,6	356	0,07120	0,91480
15	183251932,5	204	0,04080	0,95560
16	184653096,4	123	0,02460	0,98020
17	186054260,3	61	0,01220	0,99240
18	187455424,2	25	0,00500	0,99740
19	188856588,0	9	0,00180	0,99920
20	190257751,9	4	0,00080	1,00000
21	191658915,8	0	0,00000	1,00000

The graphical illustration of results of modeling for $\mathbf{C_{Total}}$ is shown in Figure 12.

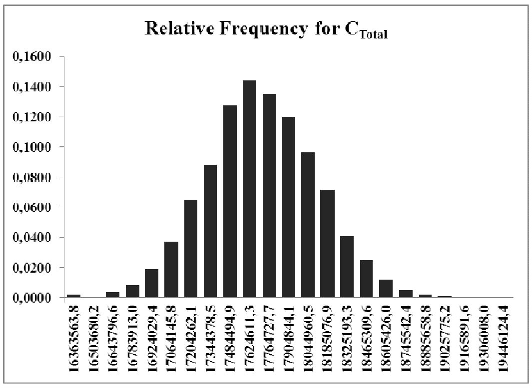

Figure 12: The histogram for $\mathbf{C_{Total}}$

The results of modeling of statistical parameters are shown in Table 7.

Table 7: The results of Modeling: Statistical parameters VaR(5%), VaR(95%), Average and Stdev, LVL

VaR(5%)_C_Total =	170105077
VaR(95%)_C_Total =	182910351
Average(C_Total) =	176413056
StDev(C_Total) =	3934050

Using received information (see Table 7) is possible to define (90%) confidence interval for C_{Total} – (170105077; 182910351). The received results of statistical modeling allow defining expected values of road transport accidents x_1, x_2, x_3 and general economic losses caused by traffic road accidents C_{Total} in Latvia. This information can be base for effective road safety strategy development which make possible to prevent and reduce road traffic crashes and injuries, to optimize decision making process in management of road infrastructure, to implement the recommendations for Latvian government for improving safety on Latvian roads.

CONCLUSION

Road traffic accidents are a growing world social and economic problem. A lot of people killed in traffic accidents are young adults aged between 15 and 44 years (World Report on Road Traffic Injury Prevention). As mentioned above, road traffic injuries cost low-income and middle-income countries between 1% and 3% of their GDP. Road traffic crashes and injuries are preventable. The opportunity of using of statistical modelling for research of road accidents on highways and town's roads of Latvia is presented in this paper.

The application of statistical modelling using Monte Carlo method allows:

- to make analysis of road accidents on highways and in towns and regions of Latvia;
- to predict the possible values of road transport accidents x_1, x_2, x_3 in main roads and populated areas (towns);
- to define economic losses caused by traffic road accidents C_{Total}.
- to analyse the dynamics of changes of road accidents taking into consideration the time factor.

Road traffic accidents prevention must be incorporated into the development and management of road infrastructure.

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