USE OF MODELLING FOR ASSESSMENT OF LATVIAN ROAD SAFETY AND LOGISTICS COSTS MINIMIZATION

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ABSTRACT

In this article attention is paid to the assessment of the number of accidents on main roads of Latvia, as well as the analysis and evaluation of the cargo insurance premium and modelling of logistics service costs $P^*_{delivery,}$ taking into account the most essential risks of the logistics process.

The principal objectives of this research work are:

- to consider an option of modelling for the assessment of Latvian road safety and number of accidents on roads;
- to model the value of the cargo insurance premium P and logistics service costs $P^*_{delivery}$.

Keywords:
Logistics systems, nonparametric modelling, road safety, insurance modelling, cost optimization.

1. THEORETICAL APPROACH TO THE PROBLEM AND SYSTEM DESCRIPTION

Organisation of processes in the sphere of logistics requires optimization of time parameters and costs with regard to cargo transportation. At the same time, a problem arises to establish an agreed amount of price $P_{delivery}$ for the delivery of cargo from the point of dispatch to the point of destination, the insurance premium P for cargo and as result value $P^*_{delivery}$ – logistic service cost. In a general case, the value of $P_{delivery}$ can be presented as a function of a range of variables (factors characterizing the particular cargo and its terms of delivery), namely:

$$P_{deliv} = \Phi\ (KF,\ V,\ W,\ KT,\ FR\ ,\ KR\ ,\ T,\ F_{t_1},\ F_{t_2}\ ,\ M,\ Y). \qquad (1)$$

Corresponding feasible sets for model parameters are defined below:

$$KF \in A_{KF},\ V \in A_V,\ W \in A_W,\ KT \in A_{KT},\ FR \in A_{FR},\ KR \in A_{KR},\ T \in A_T,\ F_{t_1}, F_{t_1} \in A_{F_t}, M \in A_M,\ Y \in A_Y. \qquad (2)$$

Feasible sets A_{KF}, A_V, …, A_Y for model parameters depend on the characteristics of the logistics process.

The parameters of the model are follows: KF – type of cargo transported (table 1); V - total volume of cargo carried in containers; W - transportable cargo weight; KT – type of cargo transportation (table 2); FR - types of financial risks (table 3); KR – the type of roads (table 4); T - time of delivery from the consignor to the consignee; F_{t1} - price of 1L of diesel fuel used by transportation vehicles at the moment of signing the contract; F_{t2} - price of 1L of diesel fuel used by transportation vehicles when transporting cargo; M - route which is used for transporting cargo. Y - other factors characterising the particular cargo to be transported and its terms of delivery.

Table 1: Types of Cargo Transported

i	KFi
1	General Goods
2	Dangerous Goods (hazard risk of cargo, according to the IMO (International Maritime Organization classification)
3	Perishable goods (mostly, consumable goods)
4	Non-standard and heavy cargo
5	Consolidated cargo
6	Transportation of bulk and liquid cargoes
7	Car transportation
8	Live transportation
9	Other types of cargo

The type of equipment used for transportation of cargoes is (V_1 = 20` or $V_2$ = 40` containers). The dimensions of a 20` container are: L = 6m, w = 2.25 m, h = 2.33m. The dimensions of a 40` container are: L = 12m, w = 2.25 m, h = 2.33m; (W_1 – 3 ton container, container loading rate 2,400 kg; W_2 – 5 ton container, container loading rate 4,000 kg; W_3 - 20' container, container loading rate of up to 21,800 kg of packaged unit cargo; W_4 - 40' container, container loading rate of up to 30,000 kg (30 t).

Table 2: Types of Cargo Transportation

i	KTi
1	Railroad transportation
2	Sea transportation
3	River transportation
4	Road transportation
5	Air transportation

Types of financial risks (FR) are shown in table 3.

Table 3: Types of Financial Risks

i	FRi
1. Market Risk	Absolute risk, Relative risk, Directional risk (Linear risk exposure), Non Directional risk, Basis risk, Volatility risk.
2. Liquidity Risk	Asset Liquidity risk, Funding Liquidity risk.
3. Credit Risk	Exposure, Recovery rate, Credit event, Sovereign risk, Settlement risk.
4. Operational Risk	Model risk, People risk, Legal risk.

Types of roads (KR_i) to transport goods are shown in table 4.

Table 4: Types of Roads

	Lenght of roads on 1 January 2012, km			
Classification of roads, incl.	Paved roads	Single and gravel roads	No cover	Total
State roads	8,455,688	11,660,644		11,660,644
Main roads	1,650,522			1,650,522
Regional roads	4,188,236	1,127,487		5,315,723
Local roads	2,616,93	10,533,157		13,150,09
Local goverment roads and streets, uncl.	5,643,787	33,039,365		38,683,15
Roads	1,055,61	29.593		30,648,61
Streets	4,588,177	3,446,365		8,034,542
Forest roads		6.216	3.926	10.142
Private roads	500	3		3.5
Total roads and streets	14,599,48	53,916,009	3.926	72,441,48

The scheme of the M_i^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point D is presented in figure 1.

Figure 1: Scheme of the M_i^{th} Route of Road Traffic between Points A and D

2. METHODOLOGY OF INVESTIGATION

This paper investigates the possibility of minimizing the function $P^*_{delivery}$ depending on the additional parameters introduced into the model by the authors, namely:

- road conditions, as indicated by the number of traffic accidents on the roads of Latvia;
- modelling of logistic service cost;
- assessment of financial stability of TLS;
- investigation of weak points in TLS;
- amount of the insurance premium.

Methods of investigation are: multistatistical methods of modelling; scanstatistics methods; Monte-Karlo nonparametric statistical methods; financial and actuarial mathematical methods.

The main blocks of modelling of transport logistic process are presented in figure 2.

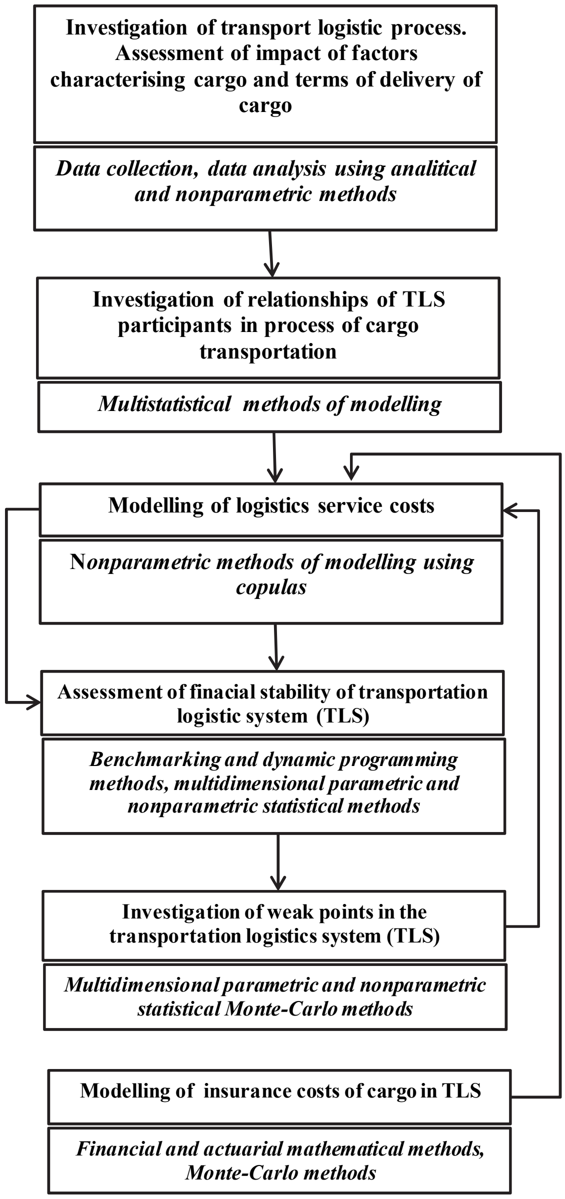

Figure 2: Main Blocks of Modelling of Transport Logistic Process

The scheme of modelling the financial parameters of TLS is presented in figure 3.

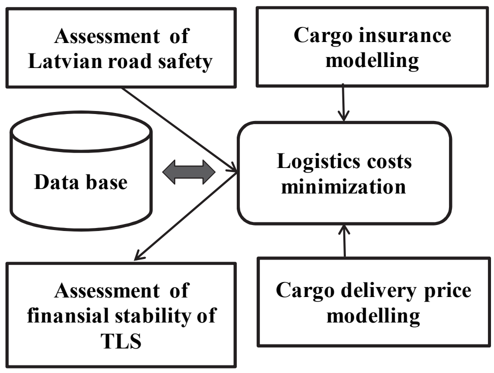

Figure 3: Scheme of Modelling of the Financial Parameters of TLS

3. MODELLING OF LOGISTICS SERVICE COSTS

One of the essential components of the logistic service is cargo insurance. The formula for calculating $P^*_{delivery}$ – logistic service cost can be written as:

$$P^*_{delivery} = P_{delivery} + \;\; P, \qquad (3)$$

where the value of P - the insurance premium for cargo.

Therefore, it is important to build an economic and mathematical model for calculating the premium P (4) at different parameters of the transportation process.

$$P = F\,(S, DP, H, T, KT, TF, KR, FR, M, F_{t1}, F_{t2}, Y), \qquad (4)$$

where - DP – declared value of the goods carried;
- S – amount of insurance sum for cargo carried, calculated by formula (5):

$$S = k \cdot DP, \qquad 0 < k \le 1, \qquad (5)$$

where k – correction coefficient of sum for cargo insurance;
- T - time of delivery from the consignor to the consignee;
- F_{t1} - price of 1L of diesel fuel used by transportation vehicles at the moment of signing the contract;
- F_{t2} - price of 1L of diesel fuel used by transportation vehicles when transporting cargo;
- H_i - hazard risk of cargo, according to the IMO (International Maritime Organization) classification;
- M_i - route which is used for transporting cargo. The scheme of the M_i^{th} route of traffic with the relevant road traffic parameters of every section of the route from point A to point D is presented in Figure 1.

For the calculation of the insurance premium P, the empirical data and methods of statistical Monte Carlo simulation are used.

The scheme of financial modelling of insurance process is presented in figure 4.

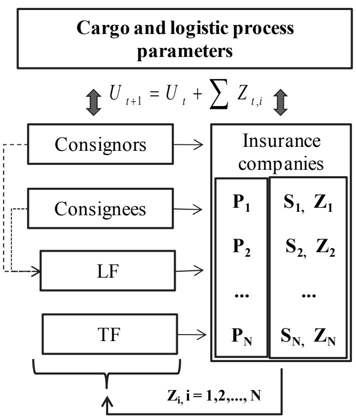

Figure 4: Scheme of Financial Modelling of Insurance Process

In figure 4 are presented parameters: Z_i – insurance indemnity; N – number of insurance objects. For the insurance process, the possibility of performance of insurance obligations is most significant, irrespective of the intensity of the stream of insured events $\{t_j, Z_j\}$ and size of insurance reserve U_{t+1} in time moment t+1.

$$U_{t+1} - \sum_{i=1}^{N} Z_{t,i} > 0. \qquad (6)$$

The insurance process should be financially stable during all the functioning time of the insurance system.

We understand the stability of the insurance process as performance of an inequality (6) during all time T ($0 < t \le T$) of functioning of the insurance process with probability 1-α. To solve the inequality (6), the premium P is calculated based on the parameters of the insurance process (4). Based on the above, the formula for calculating value P (the insurance premium for cargo) can be presented as:

$$P = P_0 + DP(r_T + r_{KT} + r_{TF} + r_{KR} + r_M + r_{FR}), \qquad (7)$$

where P_0 - risk-free component of the premium, which also includes the burden of insurance;
- r_T – risk of exceeding the time of delivery of the goods envisaged in the contract;
- r_{KT} – risk due to the type of cargo transportation;
- r_{TF} – risk due to the type of cargo transported;
- r_{KR} – risk due to the state of the quality of roads along which the goods are transported (estimated by the number of traffic accidents);
- r_M – risk due to the route by which the goods are transported;
- r_{FR} – financial risks.

4. STATISTICAL MODEL OF ACCIDENT NUMBER ON LATVIAN ROADS

For statistical modelling of annual road transport accidents N_a, authors used mathematical model:

$$N_a = \sum_{i=1}^{R}\left[\sum_{j=1}^{M} \alpha (V_{ij})^{\beta_1}(N_{ij})^{\beta_2} + \sum_{j=1}^{M-1} \gamma_{ij} A^R_{c_{ij}} S_{ij}\right], \qquad (8)$$

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;
- $A^T c_{ij}$ – 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.

Using regression tool the model of evaluation of annual damage C_{mod} can be expressed as:

$$C_{\text{mod}}(x_1, x_2, x_3) = -71.9 + 0{,}002 \cdot x_1 - 0{,}01 \cdot x_2 + \\ + 0{,}03 \cdot x_3 \,, \qquad (9)$$

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 (9) has a good approximation of real annual losses of economy (annual damage) of Latvia (figure 5).

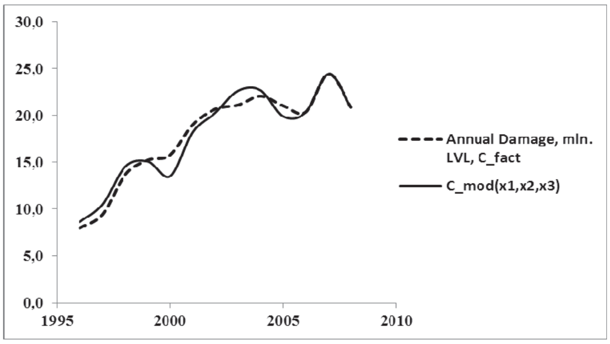

Figure 5: Graphical Illustration of Regression Model of Annual Damage and Real Road Traffic Accidents

5. ASSESSMENT OF SAFETY OF LATVIAN ROADS USING SCAN STATISTICS METHOD

The researchers seek to use scan statistics to monitor future road traffic accident data with the purpose to minimize the number of accident events and reduce the insurance premium paid for cargo. Let us have N events, distributed in the time interval (0, T). Denote S_w maximal number of the events, which is in the time interval with length w (window of fixed length w of time). The maximum cluster S_w is called the scan statistics, from the viewpoint that one scans the time period (0, T) with a window of size w and observes a large number of points. W_k is the shortest period of time containing a fixed number of k events. The interval W_{r+1} is called the minimum r^{th} order gap, or r-scan statistics. The distributions of the statistics S_w and W_k are related. If the shortest window that contains k points is longer than w, then there is no window of length w that contains k or more points:

$$P(W_k > w) = P(S_w < k). \qquad (10)$$

Analysing the statistics of accident events on roads of Latvia, it is seldom possible to get exact analytical solution for distribution of accident events on roads. In this case there exists only one possibility, which is to use computer modelling. In the paper we consider the possibility of using Monte-Carlo method in scan statistics for calculating p-value and testing null hypothesis H_0 (no clusters). Let S[x, x + w) = $S_{x,w}$ denote the number of events in [x, x + w). The scan statistics S_w is defined as shown in (11):

$$S_w = \sup_{0 \le x \le 1-w} S[x, x+w) \,. \qquad (11)$$

This is often suggested as statistics (with an appropriate window length w) for testing the presence of clustering. Indeed, it arises from the generalized likelihood ratio test of uniformity (H_0) against the alternatives (H_1), using density function f(x):

$$\begin{aligned} f(x) &= 1/\{1 + (\mu - 1)\cdot w\}, \quad 0 \le x < T, \\ &= \mu/\{1 + (\mu - 1)\cdot w\}, \quad T \le x < T + w, \\ &= 1/\{1 + (\mu - 1)\cdot w\}, \quad T + w \le x < 1 \,, \end{aligned} \qquad (12)$$

where $\mu > 1$ and T are unknown, but w is known.

In our case, the computer programs model the constant background rate of events and the scenarios of grouped data. The authors compute the scan statistics S_w for continuous data, where it has been assumed that N = n events occur on the time line (0, T). The authors generate uniform samples from this time interval and construct an empirical distribution of Pr ($S_w > k$), where k is the maximum number of events in a subinterval of width w (scanning window). We are interested in finding the value of "k" which shows a small p-value, typically 0.05 or smaller. The modelled p-value can be used for testing the null hypothesis that samples are uniformly distributed against the clustering alternative.

Figure 6: Illustration of Road Accident (Black Spots) in a Small Fragment of One Region of Latvia

In practice, it is essential to investigate the situation, when the number of events in the time interval is not viewed as fixed number N, that has already occurred, but rather as random variable with known probability distribution. We will consider a more popular discrete distribution for Poisson process – Poisson distribution function with an average of λ events per unit time. The illustration of road accident black spots in the fragment of one region of Latvia is shown in figure 6. Having studied the quality of main roads of Latvia, taking into consideration the number of road accident black spots (figure 6), we came to conclusion that, due to this factor, risks r_{KR} may change in the interval (0.01%, 0.04%). The researchers seek to use scan statistics to monitor future road traffic accident data with the purpose to minimize the number of accident events and reduce the insurance premium paid for cargo.

6. PRACTICAL USE OF STATISTICAL MODELLING

Let us consider the example of calculating $P^*_{delivery}$ using the values of model parameters, obtained by simulation (1, 4, 7). Transportation of goods includes the following steps (figure 1):
- transportation of goods by motor transport on US roads from point A to the port of loading the cargo on the ship – to point B (New York port);
- transportation of goods by sea from point B (Port New York) to point C (Riga port (Latvia);
- transportation of goods by motor transport on the roads of Latvia and Russia from point C (Riga port (Latvia) to point D – destination of the consignee in Russia (Moscow).

Types of the main risks and the results of modelling of $P^*_{delivery}$ are shown in table 5.

Table 5: Types of Risks

Cargo delivery route USA (New York) - Latvia (Riga) - Russia (Moscow)	
Cargo delivery main parameters	20' container (max weight 21800 kg)
DP	USD 250 000
P_delivery by sea	USD 4 000
P_delivery by road	USD 2 840
P_0	USD 1 200
r_T	0.009%
r_{KT}	0.006%
r_{TF}	0.07%
r_{KR}^{USA} =	0.006%
r_{KR}^{Latvia} =	0.04%
r_{KR}^{Russia} =	0.05%
r_M	0.02%
r_{FR}	0.01%
$P^*_{delivery}$ =	USD 8 568

Substituting these values into the equation of the model (3, 5, 7), we obtain the value of the $P^*_{delivery}$, taking into account the risk factors (see table 5). As a result, the actual amount of the financial payment made from the account of the logistics firm and other logistics process participants for the technological operation and cargo insurance in the time of realization of logistics process can be calculated, which creates the basis for the assessment of TLS stability in the "risk zones" of TLS participants. By financial stability, we understand the ability of all TLS participants to perform all the financial obligations undertaken with the view of ensuring complete continuous technological process in the terms agreed.

CONCLUSION

In this article attention is paid to the assessment of the safety of main roads of Latvia, as well as the analysis and estimation of the cargo insurance premium and modelling of logistics service costs $P^*_{delivery.}$

The methods used in the study (method of scan statistics, simulation method for assessing the safety of roads and risks of the logistics process, method for modelling the financial risks) allow us in a more complete and accurate way assess the borders of the changes of the logistic service cost.

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 investigate the safety of Latvian roads;
- to detect road accident black spots on Latvian roads;
- to analyse the dynamics of changes of road accidents taking into consideration the time factor)
- to define economic losses caused by traffic road accidents $C_{Total.}$.
-to model the value of the cargo insurance premium P and logistics service costs $P^*_{delivery}$.
- to set alternative strategies of insurance system performance;
- to manage functioning of insurance system.

Road traffic accidents prevention must be incorporated into the development and management of road infrastructure. The theoretical and practical results obtained as a result of this research can be applied for evaluation of premium values for different scenarios of insurance process in conditions of uncertainty.

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