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Transport and Telecommunication, 2011, Volume 12, No 2, 4–11
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

APPLICATION OF THE FUZZY DECISION TREES FOR THE TASKS OF ALTERNATIVE CHOICES

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The article deals with solving the alternative choice problem on the base of fuzzy decision trees or fuzzy positional games, which peculiarity lies in using fuzzy quality estimation of decisions consequence and nature states. The proposed approach and numerical algorithm can be used for a large number of transport services problems. Among them, there are the investment decisions in the transport sector, the choice of types of trucks, cars, buses etc, the choice of variants for transportation organization, financial services problems and others. Corresponding example of practical calculations in the specialized program Fuzicalc for fuzzy numbers has been given and described.

Keywords: alternative choice problem, fuzzy decision trees, fuzzy positional games, Fuzicalc program

1. Introduction

The problem of decision-making is one of the most common in business, production and service activities of transport enterprises. In particular, such corresponding tasks arise in making a variety of investment and financial decisions when choosing a park (types of vehicles) and various equipment, choice of variants for transport services and traffic, for variants of interaction between producers and consumers of transportation and logistics services, and so on. These decisions are made in competitive alternatives and market conditions. In fact, there is a considerable number of different options, alternatives, possibilities and situations. At the same time, the decisions must take into account the various factors, trends, developments, which are of fairly vague, fuzzy character [1, 2]. The above reasons require the application of appropriate mathematical tools, models and algorithms for recording and processing the uncertainties, in particular on the basis of the fuzzy sets theory.

2. Traditional Approach to the Use of Decision Trees

Decision trees are one of the most frequently used methods of selecting the best variants of actions on the set of available possibilities. Many tasks of alternative analysis and selection of decisions require to solve situations and environmental states in which one set of policies and states generates a different state of this or similar type. If there are two (or more) consecutive sets of solutions, and subsequent decisions ,based on the results of the previous and / or two (or more) sets of states of the environment (i.e., there is a whole chain of decisions emanating from one to another, which corresponds to the events, occurring with some probability), then such situations can be represented by formal models in the form of positional or multi-stage games. The graphical representations of these games are called decision trees.

For building a decision tree, the decision-maker must determine (in accordance with his views) a sequence of decisions and environmental states, with estimated probabilities and gains (losses) for any combination of alternatives and environmental states. Thus, we could argue that the concept of expected value is an integral part of the method of decision trees. Traditionally, the use of decision trees in the tasks of alternative choice use point estimates for probabilities of states of nature, gains or losses. Thus, we consider the estimated expected values, and they themselves explicitly in the problem solving process are not represented. In addition, for the traditional variants of using the decision trees it is not possible to use qualitative estimates of the parameters of the problem.

3. Solution to the Multi-Criteria Choice Problem, Using Fuzzy Decision Trees

Reflection of the concept of expected value can be achieved if we move from the point estimates to the estimates in the form of fuzzy numbers. In this case, the fundamental changes in the process of decision tree passing is not required. All calculations will be realized on the basis of so-called "fuzzy calculations", and the final results will be presented in the form of fuzzy numbers. Modeling the level of uncertainty in this case can be realized by extending the base set of relevant assessments and choice of type of membership function.

When in the final evaluation uses the fuzzy numbers along with the numerical results the distribution of its validity as the corresponding membership function will be obtained. And the type of this function (the degree of fuzziness) will characterize the degree of fuzziness of the solution. All this will give more information for the decision-makers.

3.1. Main Features of Fuzzy Decision Trees

If the fuzzy decision trees contain only quantitative evaluation of alternatives and states of nature in the form of the fuzzy numbers, then (if we want to find the best solution) we must use the traditional calculation methods, grounded in the basis of so-called soft calculations. The results will be represent as a set of fuzzy numbers with corresponding membership functions:

$$M = \{\mu_f(z) : f = \overline{1,F}\}, \tag{1}$$

where $\mu_f(z)$ – is the membership function of fuzzy number that represents the integral evaluation of a tree branch with the *f* – number.

In case of quantitative estimations, the integral conclusions, which are presented by fuzzy numbers (1), are located in natural order on the real numerical axis. Therefore, if under conditions of the problem we are interested in maximizing the effect, then score the best solution should be placed on the right side of the real axis. However, if we solve the inverse problem, such as to minimize the risk, the assessment of the best solution should be in the left side of the real axis.

Obtained (for each branch of fuzzy decision tree) integral estimates will be in the form of fuzzy numbers with certain membership functions (Fig. 1), where *f, h, h+1* – are the numbers of branches of a decision tree.

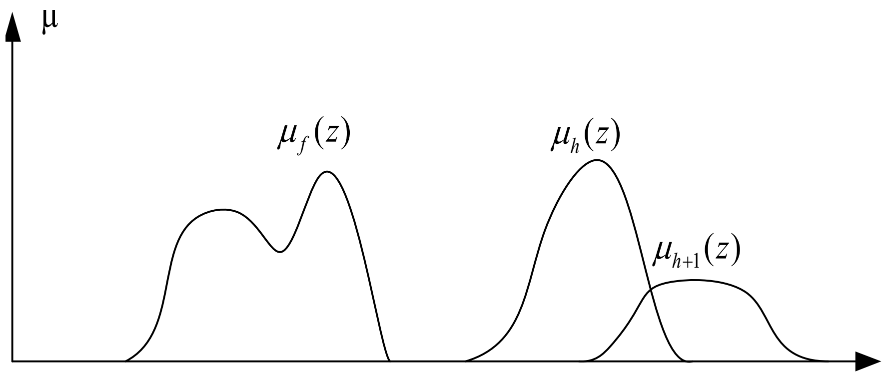


Figure 1. Membership functions for the branches of a decision tree

It is obvious, that, in general, the membership functions for the estimation of the relevant branches of the tree can be arbitrary. Therefore, choosing the best alternatives should be performed on the coordinate of center of gravity:

$$CG_f = \frac{\sum_i \mu_f(z_i) z_i}{\sum_i \mu_f(z_i)} \tag{2}$$

According to this estimate (2) as the best alternative would be considered an alternative with the relevant branch of the tree with the number *h +1*.

However, this solution cannot be regarded as a quite reasonable one.

The fact, the membership function can be interpreted as estimates of the distribution function of the truth of the decision. It is easy to see (Fig. 1) that the estimate of the true for solution on a tree branch with index *h* will be higher than at on branch with index *h+1*.

For solving this situation, we can use the multiplicative estimate $R_f = CG_f \mu_f (CG_f)$, multiplication of the coordinates of the gravity center and the truth-value at this point. It is possible that for the situation, shown in Fig. 1, $R_h > R_{h+1}$, and then the solution corresponding to the branch with index *h*, can be seen as more preferable.

We can also use the reliability of the decision [3], which takes into account the degree of vagueness of fuzzy estimates.

In decisions making practice there may be the situations, when some or all of the states of nature and evaluation of alternatives may have only qualitative views. Since fuzzy numbers – there are, in essence, the fuzzy sets, whose elements are defined on the set of real numbers, the processing of fuzzy decision tree in the presence of quantitative and qualitative assessments can be based on operations on fuzzy sets without using arithmetic operations. In case the decision tree contains both quantitative and qualitative assessments, they all must be reduced to a single universal set *U = [0,1]*.

3.2. Example of Problem Formulation for the Decision Tree with Fuzzy Estimates

Some examples (fragments) of the fuzzy estimates for the decision tree, presented on Fig. 2, are show on Fig. 3.

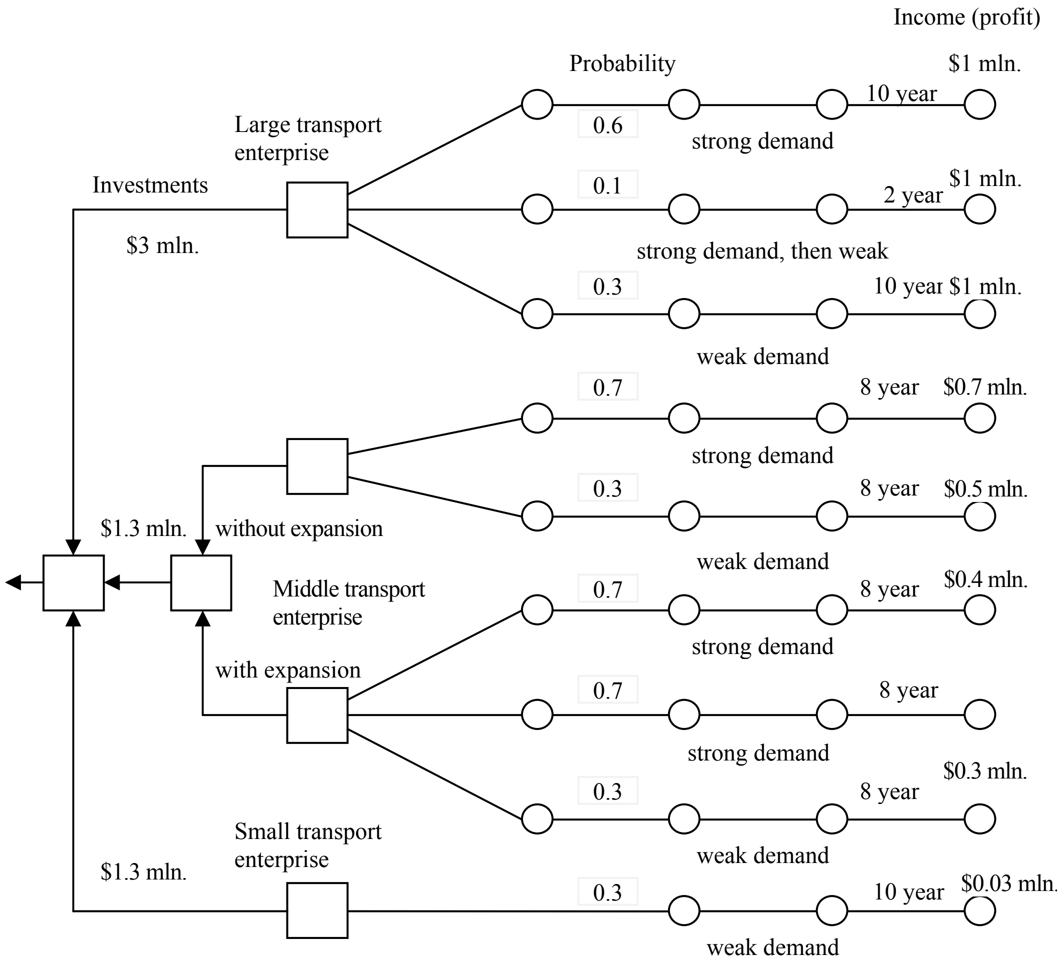
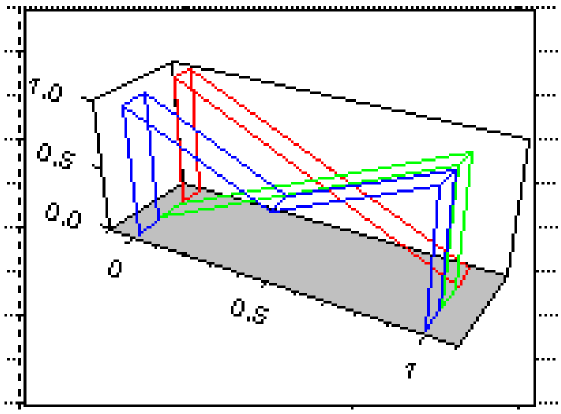


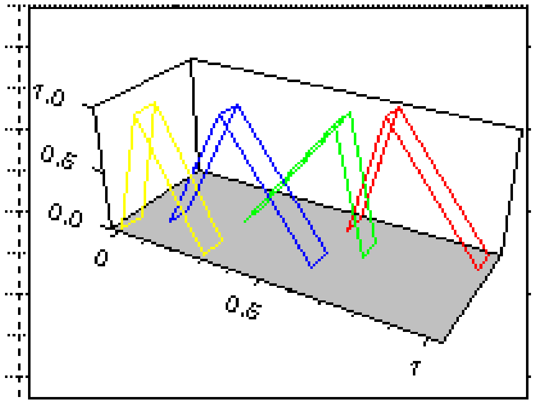
Figure 2. Decision tree for calculations (example, numerical values are approximate)

The problem for solving is to make investment decision for transport enterprise in the situation of the uncertainly of the market conditions and states of nature (the value of the expected demand, the size of the enterprise in which investments are assumed etc).

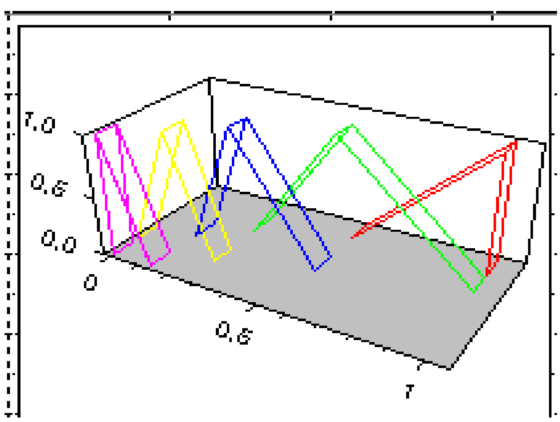
In this example, using triangular membership functions, can be explained only by considerations of simplicity of calculations.



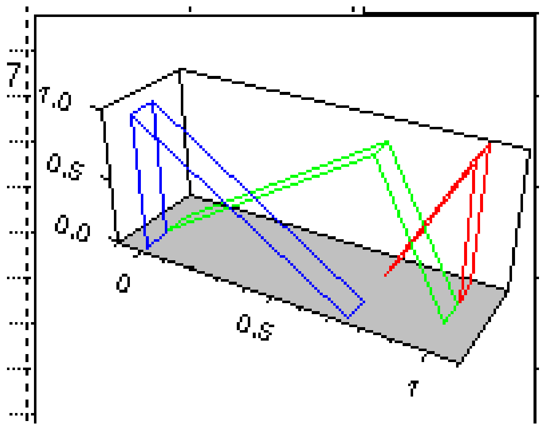
Demand: weak (0.293), strong (0.707), Strong then weak (0.5)



Probability: 0.7 (0.76), 0.6 (0.54), 0.3 (0.33), 0,1 (0.13)



Expected revenue US$, mln.: 1 (0.87), 0.7 (0.61), 0.5 (0.33), 0.4 (0.14), 0.3 (0.42)



The timing of the project's realization: 10 years (0.93), 8 years (0.61), 2 years (0.22)

Figure 3. Fragments of the fuzzy estimates for the decision tree

3.3. General Approaches to Problem Solution for the Described Example

To solve this variant of the problem, we propose to use the following approach. Let us assume that the decision tree consists of a set of nature states $S = \{s_i : i = \overline{1, I}\}$ and a variety of assessment alternatives $Q = \{q_j : j = \overline{1, J}\}$. For each nature state there are many linguistic assessments $L(s_i) = \{l_k(s_i) : k = \overline{1, K}\}$ and the corresponding fuzzy sets defined by membership functions $\mu_{k,i}(z), k \in [1, K], i \in [1, I]$, where $z \in U = [0,1]$ is a formal variable.

The sets of alternative assessment are also the fuzzy sets $L(q_j) = \{l_p(q_j) : p = \overline{1, P}\}$ and $\mu_{p,j}(y), p \in [1, P], j \in [1, J]$, where $y \in U = [1,0]$ is a formal variable.

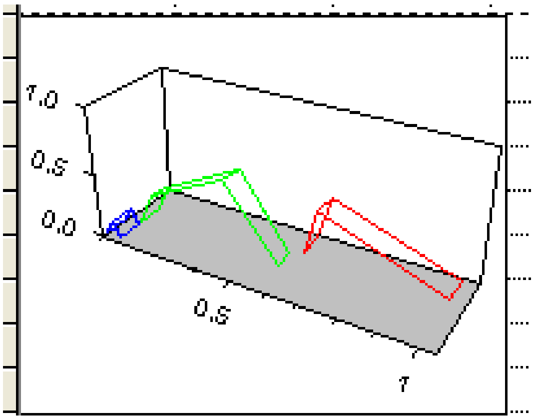
Suppose that a branch of fuzzy decision tree $\tau_f \in T$ (where T is the set of branches, $f = [\overline{1, F}]$), contains N_f nature states and H_f assessments of alternatives. Then a fuzzy set, that represents the evaluation of the alternative solutions, corresponding with the f branches number, may be defined as:

$$M_f = \bigcap_{\text{for all } j\in[1,N_f],\ i\in[1,H_f]} (\mu_{p,j}, \mu_{k,i}), \tag{3}$$

where M_f is a membership function, corresponding to the fuzzy set that represents an integral estimate of *f*-th branch of the tree.

The considered variant for finding the best alternative solutions by using fuzzy decision tree allows to realize fully the concept of the expected values. However, it is possible that in some nature states and assessment of alternatives, especially when they use only quality assessments, for some tree branches fuzzy sets, obtained from equation (3), will be empty.

At the same time, this situation will not necessarily take place only for the previously known bad alternatives. In addition, it can take place for a large number of alternatives from the considered set that would naturally reduce the level of validity of the constructed decisions. Fig. 4 shows the corresponding example of this situation for fuzzy decision tree, shown in Fig. 2. Here, presented alternative solutions for 1,2,3,6,7,9 – branches, which got zero estimates not because they are automatically bad, but as results of an empty crossings.



crossings			
branch 1	0	0	0
branch 2	0	0	0
branch 3	0	0	0
branch 4	0.73	0.27	0.19
branch 5	0.36	0.48	0.17
branch 6	0	0	0
branch 7	0	0	0
branch 8	0.12	0.11	0
branch 9	0	0	0

Figure 4. Results of crossing for branches of decision tree

The problem of empty crossings may be overcoming as follows steps [1]. Segments of each branch of the tree (except the last one representing the solution) are divided into subsets, giving a non-empty crossing. As a result, for each branch there will be received certain groups of non-empty fuzzy sets with corresponding membership functions: $M_f = \{\mu_{f1}, \mu_{f2}, ..., \mu_{fr}\}$, where r is the number of not empty subsets, which can be obtained on the set of segments of a tree branch with *f* number; $\mu_{fi} \neq 0$, but $\bigcap_i \mu_{fi} = \varnothing$.

3.4. Operation of Constructing the Fuzzy Set Geometric Projection

To obtain a solution, an operation on fuzzy sets proposed in [4] and called "geometric projection of fuzzy sets" is used.

It should be noted that this title is not entirely successful, because it is call an analogy with the famous "Operation of projection of fuzzy sets", which led to various misunderstandings.

Therefore, in the future we propose to use the name "shadow of a fuzzy set" for this operation and define it as a shadow (shade, *Sh*).

We define this operation as follows.

Shadow of a fuzzy set $\tilde{A}$ to fuzzy set $\tilde{B}$ must satisfy the following conditions: $Sh(\tilde{A},\tilde{B})$ also will be fuzzy set, $Sh(\tilde{A},\tilde{A}) = \tilde{A}$, $Sh(\tilde{A},\tilde{B}) = 0$ if ,at least, one of the sets $\tilde{A}$ or $\tilde{B}$ is empty, or sets $\tilde{A}$ and $\tilde{B}$ are orthogonal.

Procedure for constructing a shadow of a fuzzy set $\tilde{A}$ on fuzzy set $\tilde{B}$ is defined as follows (Fig. 5):

$$Sh_{\varphi}(\widetilde{A},\widetilde{B}) = \{\varphi[\mu_{\widetilde{A}}(y), \mu_{\widetilde{B}}(x)]/[y, x' = f(y)]\},$$

where $f(y) = \dfrac{CG[\mu_{\widetilde{B}}(x)]}{CG[\mu_{\widetilde{A}}(y)]} y$ – is a projection function; $CG[\mu_{\widetilde{B}}(x)]$ and $CG[\mu_{\widetilde{A}}(y)]$ are coordinates of the centers of gravity of the figures, which are limited by membership functions $\mu_{\widetilde{A}}(y)$, $\mu_{\widetilde{B}}(x)$; φ – functional, giving the appearance for transformations of the membership functions.

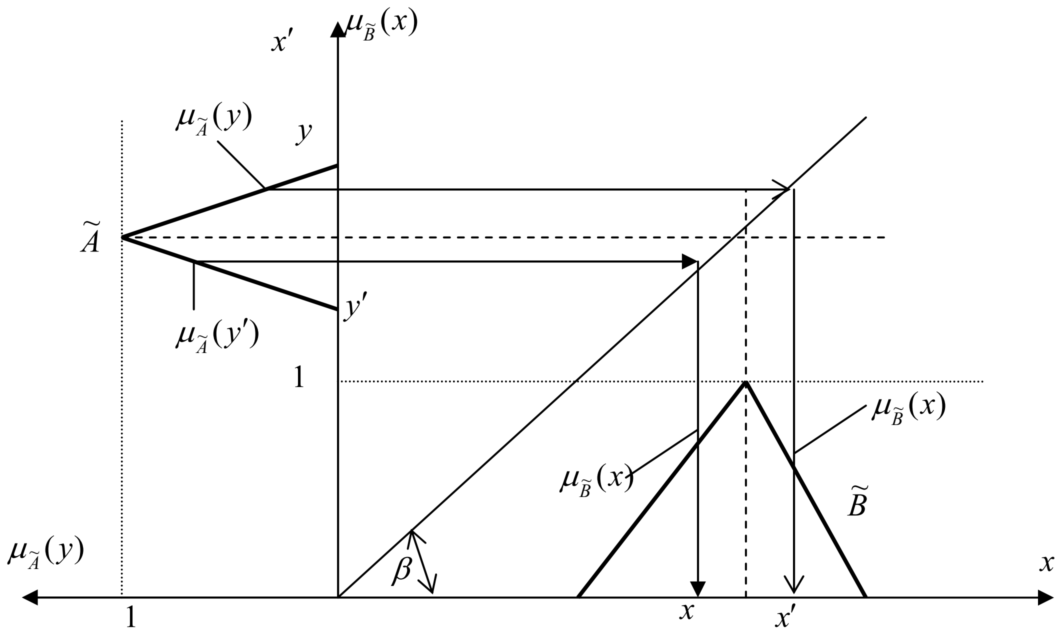


Figure 5. Procedure of fuzzy set shadow constructing

The meaning of this operation is the following: depending on the relative position of fuzzy sets and consequently, the slope of the projection line change the "shadow" of a fuzzy set, is superimposed on another one.

Results of this operation will represent a degree of interaction of estimations of the concepts represented by fuzzy sets. We shall name a fuzzy set $\widetilde{A}$, which is projected on other fuzzy set $\widetilde{B}$ as a source of a shadow. We shall name a fuzzy set $\widetilde{B}$ on which the shadow of fuzzy set $\widetilde{A}$ is projected, as a receiver of the shadow.

The further transformations are carried out in the following sequence. For each indistinct set represented by membership function μ_{fi}, the shadow on the indistinct set representing the required decision is under construction.

As a result for every μ_{fi} we shall receive a corresponding shadow Sh_{f_i}, which, by definition ,will be indistinct set with corresponding membership function $\mu_{Sh_{f_i}}$.

The integrated decision for a branch with number *f* we shall define as crossing $\mathrm{M}_{Sh_f} = \bigcap_i \mu_{Sh_{f_i}}$. Similar transformations are carried out for other branches of a tree.

If to consider $\mu_{Sh_{f_i}}$ as a function of validity distribution, we shall define the best decision as $\max_f M_{Sh_f}$. If unequivocal definition of a maximum is impossible, the value of corresponding coordinate of the centre of gravity CG of membership function M_{Sh_f} is determined and then we find a maximal value as $\max_f M_{Sh_f}(CG)$.

3.5. Graphical and Numerical Results for the Described Example

Below (figs. 6-8 and tab. 1) we show (not losing a generality) the separate graphic and numerical results of calculations for analyzed decision tree from the example.

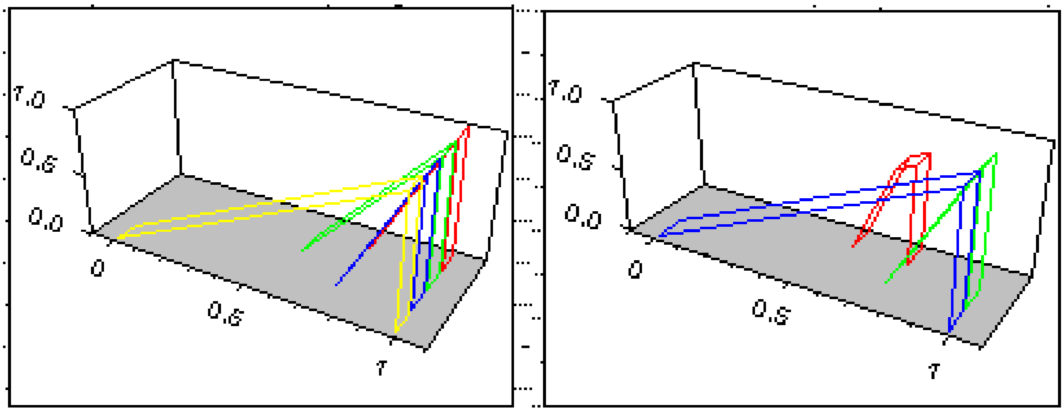


Figure 6. The first individual convolution of conditions for branch B1 (on the left) and its shadow (on the right)

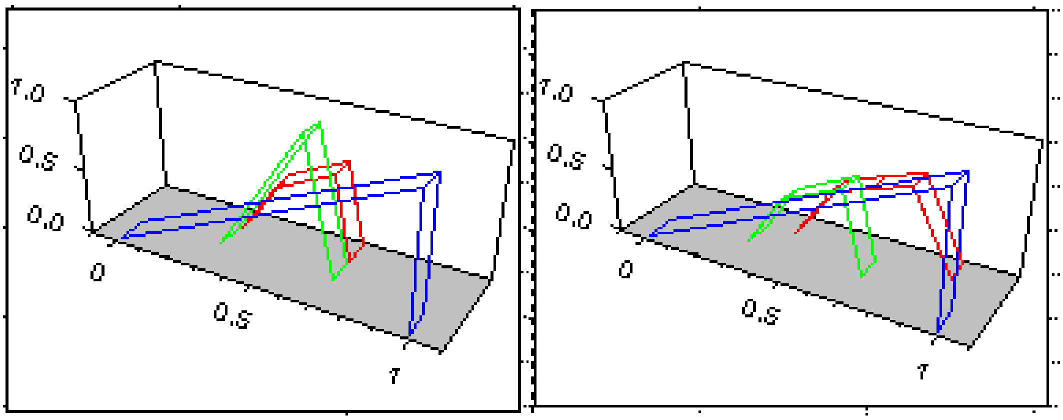


Figure 7. The second individual convolution of conditions for branch B1 (on the left) and its shadow (on the right)

On both figures (6 and 7) we can see on the left the following: red line – membership function which is a result of convolution, other colours – membership functions of convolution participants; and on the right: red line – shadow of individual convolution, green line – source of shadow, blue line – receiver of shadow.

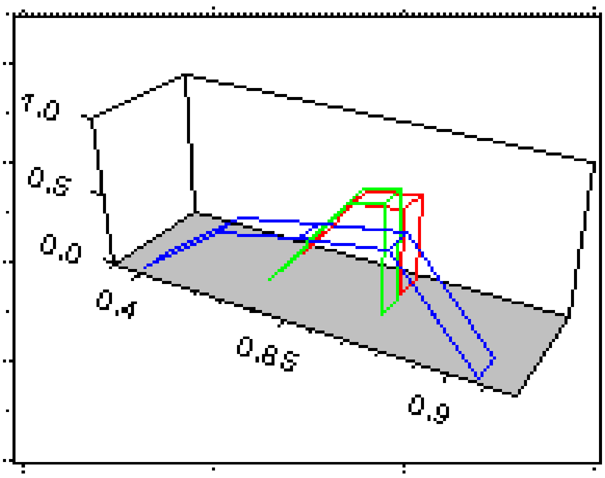


Figure 8. The crossing of shadows of individual convolutions

In this figure the red line is the result of crossing, dark blue and green lines are the sources of shadow.

Calculation results by proposed approach for the decision tree, presented in Fig. 1, are shown in tabl. 1.

Table 1. Results of ranging for branches of the decisions tree

Number of a branch of decision tree	B1	B5	B4	B6	B3	B9	B2	B7	B8
Estimation of the validity of decision	0.56	0.48	0.27	0.19	0.16	0.15	0.13	0.13	0.12

For an examined numerical example the development of a situation on the first branch (B1=0.56) is the most expected and comprehensible.

4. Conclusions

Thus, the offered method for an alternative choice of the decision on the basis of an fuzzy decision tree allows to consider the uncertainty of estimations of decisions and conditions of the nature, and also supposes the use of their qualitative representations.

The method was repeatedly used in practice at an estimation of various alternative technical and investment projects. The received results have been confirmed by the subsequent practice.

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OPTIMIZATION OF RELATIVE TRANSPORT COSTS OF A HYPOTHETICAL DRY PORT STRUCTURE

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Decreasing environmental emissions originated from transportation sector plays a big role in the strategies of EU. One way to decrease emissions is to shift freight transport from unimodal road transport to intermodal solutions. Dry port concept aims at increasing rail transport between seaports and inland intermodal terminals, which are called dry ports. Such a concept is in infancy in Finnish transportation network. The main transport mode used in Finland is unimodal road transport. The aim of this research is to study the effects of a hypothetical dry port structure in Finnish transportation network. The effects are researched with different gravitational models. They apply linear integer programming, and heuristics to find relative transport costs in each situation. Differences in road and rail network, and road and rail transport modes are taken into account. The results of the models argue that Finland could benefit from dry port network. Cost-efficiency of the Finnish transportation network could be enhanced by using up to five or six dry ports. In addition, by replacing road transport with rail transport the environmental impacts can be lowered considerably. However, by alternatively utilizing within wider scale dense seaport network of Finland, we could achieve even better environmental results – approach which has been neglected so far in the dry port literature.

Keywords: Dry port concept, Finnish transportation network, gravitational models, costs of transport, intermodal transport, optimization, linear integer programming

1. Introduction

Transportation is one of the major polluting sectors [1]. The difference between transportation sector and other polluting sectors is that emissions originated from transportation have risen steadily during the last decades, whereas other sectors have been able to decrease or at least stop the increase of their pollution [2, 3]. The aim of the EU is to encourage and increase the use of intermodal transport [4, 5]. One important reason for this is environmental friendliness of intermodal transport, if compared to road transport [6, 7].

Dry port concept is one way to increase the use of intermodal transport. Because the implementation of dry ports increases the use of intermodal transport, especially rail transport, it can decrease the environmental impacts of the whole transportation system. Many studies support the assumption that rail transport is environmentally friendlier mode of transport than road transport [6, 7, 13-17]. The main transport mode between seaport and dry port (inland intermodal terminal) is rail transport in dry port concept [8, 9]. The possible advantages of the concept are the decrease of environmental emissions, and improved cost-efficiency of transportation system [8, 9]. Dry port concept is still in its infancy in Finland. Based on tons being transported (domestically), road transports holds roughly 85 % share in transportation market of Finland, and railways have 11 % (year 2010). However, situation is a bit better, if tonnekms are used as then road transports have share of 67 %, and railways 21.7 %. [10-12]. The aim of this manuscript is to research, what effects a hypothetical dry port network in Finland could have in terms of relative transport costs, and literally improving railways competitiveness.

Gravitational models of distribution based on population areas in Finland are used as main research method. Models are based on populations of chosen cities, rail and road network distances between chosen seaports, chosen dry ports and chosen cities. Models are quantitative, because all the different inputs are numerical. The aim of the gravitational models is to research, how relative costs evolve by using different number of dry ports and different settings concerning choosing of dry port locations in Finland. Linear integer programming is used to find out optimal routes and locations for each setting and for each model. First model uses heuristic approach, when choosing what dry port is dropped out of the model. Other models utilize optimization software package called IBM ILOG CPLEX Optimization Studio (CPLEX) to optimize the model and choose what dry port is dropped out i.e. no heuristic decision-making is then used.

2. Research Environment and Methodology

Physical research environment includes domestic Finnish inland transportation. Different actors that are taken into account are 50 largest cities of Finland with population, different chosen seaports and different chosen dry ports. The chosen dry ports in different models are chosen from the group of 50 largest Finnish cities. Transportation between seaports and dry ports is accomplished by rail transport, whereas transportation between dry ports and the largest Finnish cities is accomplished by road transport. The difference in costs between road and rail transport in Finnish transportation network is taken into account. Henttu et al. [7] calculated cost estimations for both the road and the rail transport modes in Finnish transportation network. Relative road and rail transport costs calculated my gravitational models are multiplied with costs estimations by Henttu et al. [7], so that difference in road and rail transport in gravitational models is detected.

In our approach gravitational models start with nine different dry port cities. After that models drop one dry port out of the model, so that there are now eight different chosen dry port cities. This process is continued until there is only one dry port city left to serve the entire country. In the first model the dry port cities are dropped out by with heuristic decision-making. Logic in selecting, which dry port location "drops from the list" at each time, is relatively straight forward: dry port, which is serving the lowest amount of TOP50 cities, and has the least transportation activity (distance times population). Three other gravitational models are optimized with CPLEX, which makes decision on what dry port is eliminated.

Nine different cities are chosen according to their geographic location and attractiveness in the first two gravitational models. Chosen possible dry ports in first model are cities of Jyväskylä, Kokkola, Kotka, Kouvola, Oulu, Rovaniemi, Tampere, Turku and Vantaa. Dry port cities were selected basing on their locations to serve 50 largest Finnish cities as well as with appropriate access to railway network as well as preparedness for needed infrastructure. The first model includes four different seaports, and they are ports of Helsinki, Kotka, Oulu and Pori. These ports are chosen, because they have high capacity for intermodal transport and they cover Finnish coastal efficiently. This group is studied with both the heuristic approach and optimization software CPLEX. Both the heuristic and CPLEX optimized approaches use linear integer programming to achieve the most cost-efficient environment. Heuristic approach is used, when dry port amount is reduced. Figure 1 clarifies physical environment of two first gravitational models (upper part).

	TEUs				
Seaports	2008	2009	2010	Average	Share
Kotka	627,769	345,939	397,286	456,998.00	34.5%
Helsinki	419,809	357,204	399,903	392,305.33	29.6%
Oulu	30,921	30,224	31,054	30,733.00	2.3%
Pori	37,454	29,087	22,390	29,643.67	2.2%
Total	1,600,925	1,125,450	1,245,869	1,324,081.33	

Shortest distance to dry port as selection criterion (railway network).

Dry ports
Kouvola
Kotka
Vantaa
Tampere
Oulu
Turku
Jyväskylä
Kokkola
Rovaniemi

Criterion for dry port distribution cities - using lowest distribution cost in linear integer programming (road network).

TOP50 Cities	Population
Helsinki	583,995.00
Espoo	244,695.00
Tampere	211,643.00
Vantaa	198,203.00
Turku	176,310.00
Oulu	139,379.00
Jyväskylä	129,749.00
Lahti	101,022.00
Kuopio	92,663.00
Kouvola	88,175.00
Pori	82,859.00
Joensuu	72,753.00
Lappeenranta	71,929.00
...	...
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	TEUs				
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Kotka	627,769	345,939	397,286	456,998.00	34.5%
Helsinki	419,809	357,204	399,903	392,305.33	29.6%
Rauma	172,155	143,269	164,904	160,109.33	12.1%
Hamina	178,804	108,133	115,388	134,108.33	10.1%
Oulu	30,921	30,224	31,054	30,733.00	2.3%
Pori	37,454	29,087	22,390	29,643.67	2.2%
Total	1,600,925	1,125,450	1,245,869	1,324,081.33	

Criterion for distribution cities - using lowest distribution cost in linear integer programming (road network).

TOP50 Cities	Population
Helsinki	583,995.00
Espoo	244,695.00
Tampere	211,643.00
Vantaa	198,203.00
Turku	176,310.00
Oulu	139,379.00
Jyväskylä	129,749.00
Lahti	101,022.00
Kuopio	92,663.00
Kouvola	88,175.00
Pori	82,859.00
Joensuu	72,753.00
Lappeenranta	71,929.00
...	...
...	...
...	...

Figure 1. Modelled hypothetical dry port structure of Finland using four seaports, nine alternative locations for dry ports and 50 largest cities as consumption places (upper part) and alternative hypothetical structure, where six different container sea ports are used as dry ports (lower part). Source: (TEU volume): [18]

By using the chosen ports (Ports of Helsinki, Kotka, Oulu and Pori), the coastline of Finland is effectively used. Most of the chosen dry port locations are situated in the south, because population is concentrated over there. The Northern Finland is very sparsely populated. Figure 1 above illustrates research environment only for two first gravitational models (upper part). Two other gravitational models have different settings concerning the chosen seaports and dry ports, and they are described more carefully later in this Section. Rail network distances from seaports to different dry ports are gathered from Finnish Transport Agency sources [20]. Distance to each dry port is from the nearest seaport. Road network distances from different possible dry ports to 50 largest Finnish cities are gathered from Google Maps [21] and ViaMichelin [22]. Populations of the 50 largest Finnish cities are gathered from Finnish population register centre [23].

Third gravitational model does not include any inland cities as dry ports. Only Finnish most used container seaports are used for export and import (Figure 1 lower part). Inland transportation in Finland is performed by the road transport in this model. The chosen Finnish container seaports in this group are ports of Hamina, Helsinki, Kotka, Oulu, Pori and Rauma. This group is researched only by using CPLEX. The fourth and final gravitational model includes all the largest Finnish cities as possible dry port solutions. Only those cities are included that has railway connection. This group is the most versatile due to many possible dry port locations. This group is researched only with CPLEX. The aim of these gravitational models is to study if Finnish transportation network could achieve cost saving by implementing dry port network, which is having entirely flexible setting (optimization is allowed to make selection). Furthermore, models include different number of dry port locations to find out, what is the effect if dry port amount is decreased or increased i.e. to research, if there is an optimal amount of dry ports in Finnish transportation network according to gravitational models.

In the used CPLEX model the model is done using integer programming (various optimization methods, see [28]). The model is optimized by modifying variables s_{ij} and d_j. They are binary variables, which represent whether a city is using a particular dry port and whether a specific dry port is used. The model minimizes the total costs, which consists of road costs, road environmental costs, railway costs, and railway environmental costs.

In their research, Henttu et al. [7] calculated the total cost estimations for road and rail transport in Finnish transport network. Costing includes both the internal and external costs of both transport modes. Internal costs are further divided into fixed and variable costs. External costs contain accidents, noise, congestion and CO_2 emissions. Estimated internal costs of road and rail transport calculated by Henttu et al. [7] are based on various sources e.g. Finnish Transport and Logistics [24], Finnish Transport Agency [25] and LIPASTO [26], which is a calculation system for traffic exhaust emissions and energy consumption in Finland. Estimated external costs for both the road and rail transport are based mainly on calculations by Maibach et al. [27] and LIPASTO [26]. Estimated total costs by Henttu et al. [7] are 0.0506 € per ton-kilometer for road transport and 0.0270 € per ton-kilometer for rail transport. Increasing use of rail transport can decrease the total costs of the transportation, because the total costs of rail transport are less than same costs of road transport. These costs are used in all groups of gravitational models.

3. Results of Gravitational Models

All the results of different gravitational models are illustrated in Figures 2-7. Relative transport costs incurred by varying number of dry ports or seaports are described in y-axis. Costs are relative, because they are calculated by multiplying population and distance with each other. They are not real costs of transportation. The aim of the relative costs is to find out different possible benefits or disadvantages. X-axis describes the number of dry ports or seaports being used depending on the model (the third model uses only seaports as terminals). Relative rail costs between seaports and dry ports are represented with the lightest line, which has continuously increasing tendency, if additional dry ports are being added into system. Possible positive tradeoff from this increase could be detected from the darkest line, in which the relative road transport costs decrease by adding dry ports. The line in the upper part of Figure 2 represents the total relative transport costs of the dry port system.

Figure 2 illustrates the results of the first group of gravitational models using heuristic approach, when choosing what dry ports are eliminated from the model. In this group, as in all other groups, the difference of costs between road and rail transport is taken into account. The relative road transport costs calculated with gravitational models are multiplied with 0.0506. The relative rail transport costs are multiplied with 0.0270. These multipliers are estimated total costs per ton-kilometer (internal and external costs) for Finnish road and rail transport calculated by Henttu et al. [7]. Cost estimations include internal and external costs i.e. models take the most important environmental impacts into account. Different environmental impacts are accidents, CO_2 emissions, noise and congestion.

The first model was created mainly with Microsoft Excel. Solver of Microsoft Excel was used for linear integer programming. The model starts with settings of nine different dry ports. Solver is used to optimize the most inexpensive routes between seaports and dry ports and dry ports and 50 largest Finnish cities. After that one dry port location is eliminated from the model to research the effect of smaller amount of dry ports. Elimination is based on heuristic approach. Dry port that has the least connections is dropped out of the model. In future this city is counted as one of the consignees or consignors. This process continues until there is only one dry port left in the model. Figure 2 summarizes the results concerning the costs of the first gravitational model.

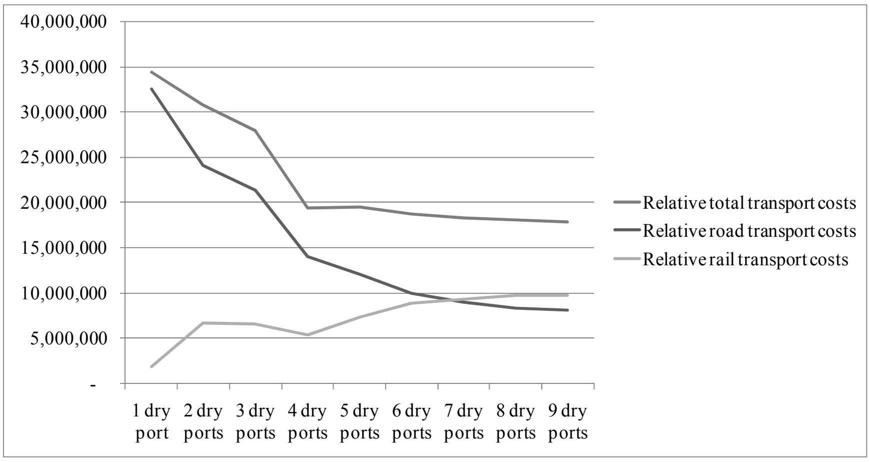

Figure 2. Relative transport costs of a dry port network with different number of dry ports (Heuristic approach)

As Figure 2 shows, the relative total transport costs can be decreased by using dry port network according to the first gravitational model. Significant cost reductions can be achieved by adding up to four dry port solutions. By adding more than four dry ports in the Finnish transportation network, cost saving becomes much less i.e. according to this model, four to six dry ports in Finnish transportation network allow the most cost-efficiency for the whole transportation system. As can be seen from Figure 2, the slope of the relative total transport costs line does not become smaller evenly. The reason for this is the heuristic approach, when choosing that dry port is dropped out of the model.

Next model uses the same possible dry port cities as the previous model. Difference between these models is that next model uses optimization software CPLEX for the whole process. No heuristic decision-making is used in this model. The results are shown in Figure 3.

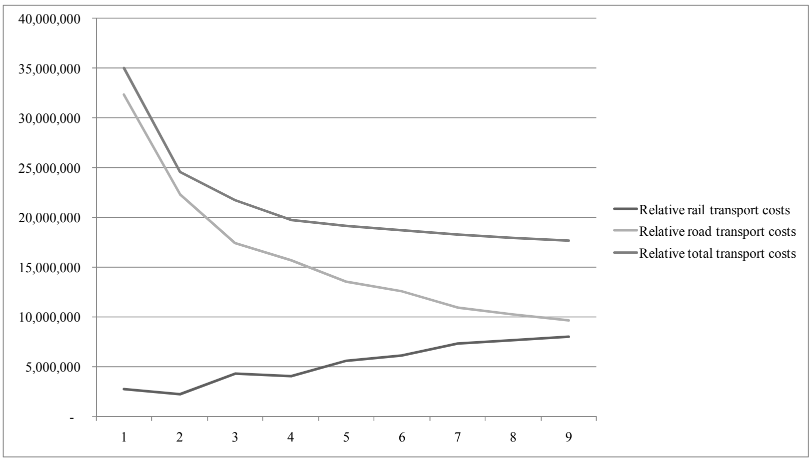

Figure 3. Relative transport costs of a dry port network with different number of dry ports (CPLEX optimized)

According to CPLEX optimized gravitational model, the relative transport costs can again be decreased. The major cost savings can be achieved by adding up to four to six dry ports. By adding more than six dry ports, costs can further be decreased, but decrease in costs becomes smaller. With nine dry port implementations, the total relative costs of road and rail transport are near each other.

Figure 4 summarized differences between two previously presented models. Both models have the same chosen possible dry ports and seaports, but the method for dropping a dry port is different. The first gravitational model uses heuristic decision-making, whereas the other usefull software optimization (CPLEX).

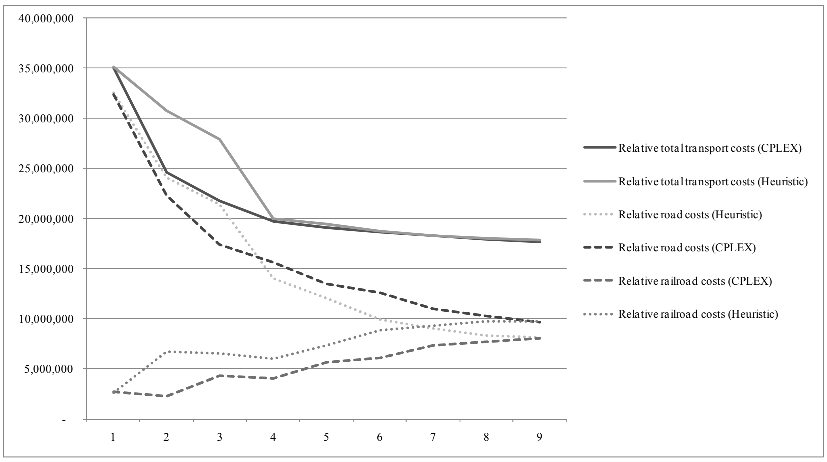

Figure 4. Comparison of relative transport costs between two similar gravitational models with different decision-making method

Figure 4 illustrates that CPLEX optimized model is having lower costs with two and three dry ports. If models use one, five, six, seven, eight or nine dry ports, then the relative total transport costs are similar in heuristic and CPLEX optimized models. So, it seems that total software optimization does not give much benefit, if different possible dry ports are restricted to nine pieces. There is almost no difference in relative total costs between models at number of four to nine dry ports. The main difference in researching hypothetical dry port network with heuristic approach and CPLEX optimization software is the amount of work that has to be done. Both models need both road and rail distances between dry ports, seaports and 50 largest cities of Finland, and population of these cities. After collecting these input data, the heuristic approach took one to two work days to create models. CPLEX optimization was able to run in one or two hours. After first CPLEX model, the others can be run in considerably less time (new models can be created in less than five minutes). The main difference in used dry ports between these models is that one with heuristic decision-making utilized city of Kouvola between three to nine dry port networks, whereas CPLEX optimized model utilized Kouvola only with nine dry port network. CPLEX optimized model utilized cities of Oulu and Kotka instead of Kouvola.

Next results are about gravitational model that does not include any dry port solutions i.e. all intermodal terminals are container seaports, and no inland terminal is used. All the inland transportation is accomplished by road transport. Figure 5 summarizes the results of this gravitational model. Numbers at x-axis describe the number of seaports used. Different possible seaports in this model are ports of Hamina, Helsinki, Kotka, Oulu, Pori and Rauma.

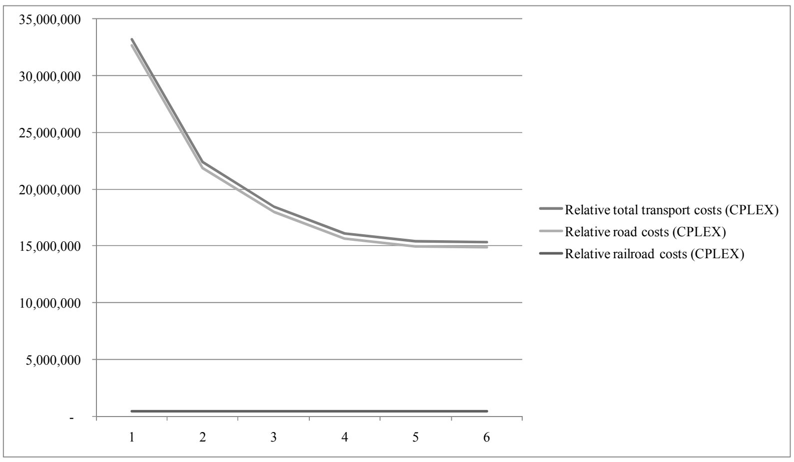

Figure 5. Relative transport costs of a transportation network, which utilized only main Finnish container seaports (CPLEX optimized)

If the main container seaports of Finland are used instead of any dry ports, costs saving can still be achieved by increasing the number of seaports. According to this model, costs saving is even larger in this model. One explanation is the difference of road and rail network structure. Road network distances between different geographical locations in Finland are quite straight, whereas many rail connections between different cities are more distant than road connections.

All the Finnish largest cities are possible dry ports in the last gravitational model, if they have railway connection (not all 50 largest Finnish cities have railway connection). This model is the most versatile one with the most available configurations. The results are illustrated in Figure 6.

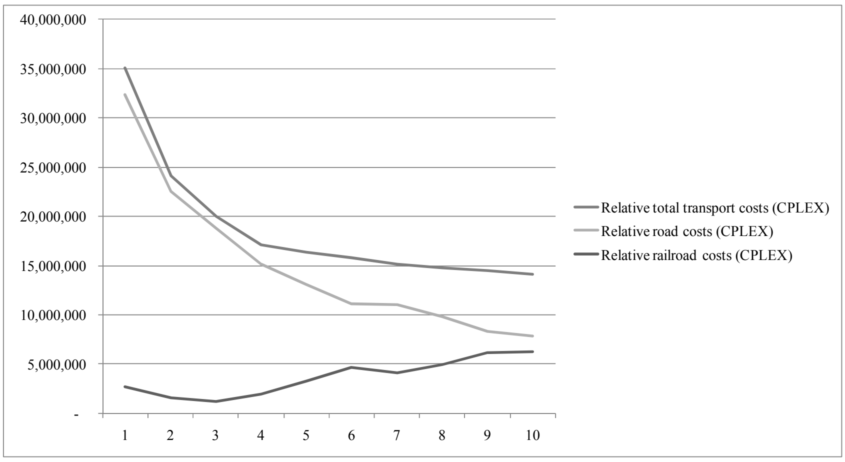

Figure 6. Relative transport costs of a dry port network with all 50 largest Finnish cities as possible dry ports (CPLEX optimized)

Lines in this model look very similar to the first two models. The difference is that costs can be decreased little bit more than in the first two models by using more possible dry port locations. Final Figure 7 illustrates the total relative transport cost results of all four different gravitational models.

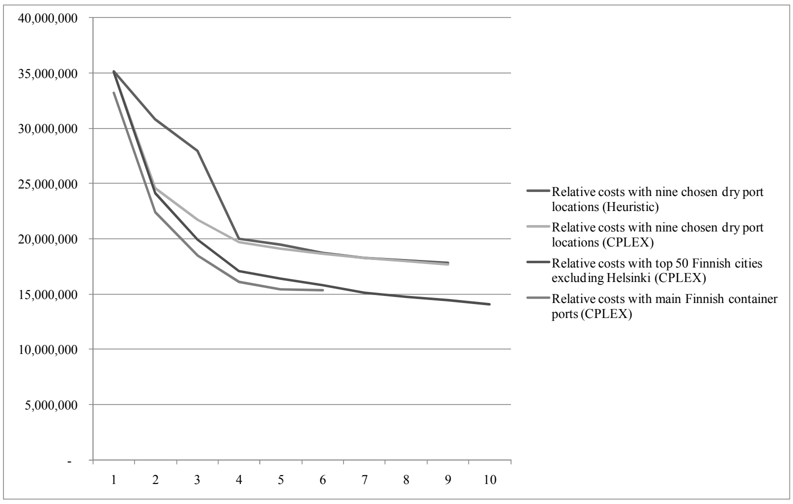

Figure 7. Comparison of all presented gravitational models

According to both heuristic and CPLEX optimized models, the relative total costs of transport can be decreased by using limited dry port network of at most nine different chosen dry ports (Jyväskylä, Kerava, Kokkola, Kotka, Kouvola, Oulu, Rovaniemi, Tampere and Turku). By using up to four or five dry ports the relative costs can almost be minimized. By adding more dry ports, the costs savings become very small. Surprising conclusion is that CPLEX optimized model that uses major Finnish container ports excluding all inland dry ports can reduce costs significantly. The main reason could be a better attainability of the road network. Slight relative cost reductions can be achieved compared to first two models, if number of possible dry ports is increased.

4. Conclusions

CPLEX software can be efficiently used to minimize model creation time. By using heuristic approach, the results can almost be optimized (at least by small number of possible variations), but creating such model takes a lot of time (one to two days). Furthermore, changing heuristic model (e.g. changing seaports, dry ports, number of seaports, number of dry ports etc.) needs much work, whereas changing CPLEX model takes almost no time, once the original model is created (although learning to use the optimization software might take months).

Objective of this research was to research the effect of a hypothetical dry port network in Finland. The research has been conducted with different gravitational models that use linear integer programming to achieve the least possible transport costs. Difference between models is different methods (heuristic approach versus full software optimization), when dropping dry ports out of the models. Other difference is different possible dry ports and seaports between different gravitational models.

The results of gravitational models show that the cost-efficiency of transport system can be enhanced by implementing dry port structure to Finnish transportation network. With four to six dry ports the most cost savings can be achieved. By adding more than six dry ports, costs savings become very small i.e. gaining enough profit to cover possible investment costs of dry port (inland intermodal terminal connected to seaport by rail) will take many years with too many dry port solutions in the system. Surprising result is that unimodal road transport costs can be decreased significantly by using numerous seaports that cover the whole coastal of Finland. By using only one or two seaports, relative transport costs are relatively high. If all 50 largest Finnish cities (cities with no rail connection are excluded) are included, the total relative costs can be decreased. Decrease in costs is not much larger than in other gravitational models that have limited dry ports or seaports. It seems that by choosing possible dry port locations by heuristic approach in Finnish transportation network, the total relative transport costs can be minimized quite accurately. The main reasons for this are small number of appropriate cities that could be dry ports and centralization of Finnish population in the area of capital city.

The practicality of the results shown in this research work establishes a route for further research. For example, using numerous sea ports in decreasing overall emissions could be questionable in the future due to IMO’s strict sulphur emission restrictions of sea vessels (e.g. Entec, 2010), which are mostly harmful for Finnish shipping industry (they are taken with the most strictness from in use in northern Baltic Sea). So, this would in turn restrict the use of low volume sea container sea ports. Besides emission control, another question arises from current level of capacity in smaller sea ports, and secondly their readiness to continue investments in the future. Similar lack of capacity and willingness of investing in future concerns selected railway based dry ports of entirely “flexible” optimization model. This does not only include arrangement yards, but terminals with appropriate railway yards, railway connections, loading/unloading places and lifts for container handling.

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SHORT-TERM TRAFFIC FORECASTING WITH NEURAL NETWORKS

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The paper is dedicated to an advanced algorithm aimed at short-term forecasting of electronic communications traffic by applying non-linear neural networks. The algorithm incorporates three procedures, which allow automating the process of determining an optimal solution with minimal involvement and influence of expert assessment and human factors.

Keywords: telecommunications, electronic communication networks, traffic, neural networks, multilayer perceptron, algorithm, forecasting

1. Introduction

Traffic forecasting plays an important role in design, management and optimization of modern telecommunications systems. Accurate and reliable forecasts allow planning the capacity of a network on time and sustaining the required level of quality of service. Besides, the properties of network traffic directly influence both capital costs of equipment and expected income of an operator.

The emergence of the packet-switched Internet networks as well as transformation of traditional telephone networks into multi-service systems provides new opportunities to a user in the sphere of his/her activities. It has changed not only the architecture of a network but also statistical nature of teletraffic, which is now characterized by the effects of self-similarity and strong long-range dependence [1, p. 150; 2]. Therefore, new approaches to the analysis and forecasting of states and parameters of the packet-switched networks are strongly required. A *non-linear artificial neural network* is one of these methods, which is rapidly gaining recognition in this field.

An *artificial neural network* is a massively parallel-distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use [3, p.2]. Neural networks have been developed as a generalization of the mathematical models of human cognition and neural biology. A special type of neural networks, *time-lagged feed-forward networks* (Fig. 1), is usually applied for the purposes of time series modelling and forecasting. A time-lagged feed-forward network is a powerful nonlinear filter consisting of a tapped delay memory of order Ω and a multilayer perceptron. The standard back propagation algorithm can be used to train this type of neural networks. More details on the operation of multilayer perceptrons and time-delayed neural networks can be found in [3, 4].

The main advantage of the neural networks in comparison with classic linear methods is their ability to model functions characterized by non-linear dynamics. High adaptive ability, tolerance to various outer noises as well as the influence of "heavy-tailed" distributions are the other frequently mentioned advantages of neural networks.

However, we can often hear that *neural networks are more art than science*. This is primarily due to the lack of a functional algorithm for applying the neural networks to time series forecasting. Because of that, the active expert assessment is still necessary at all the stages of implementation, which prevents the automation of a forecasting process. It is also important to understand that, in contrast to some classic linear models, the method of neural networks has not been initially aimed at time series modelling and forecasting. The attempts to predict traffic loads of both a conventional telephone network and a packet-switched Internet network by means of neural networks have been made many times in the past. However, most of these research papers solve a trivial task of time series approximation, with more or less success, without taking into account the general theory of neural networks and time series forecasting.

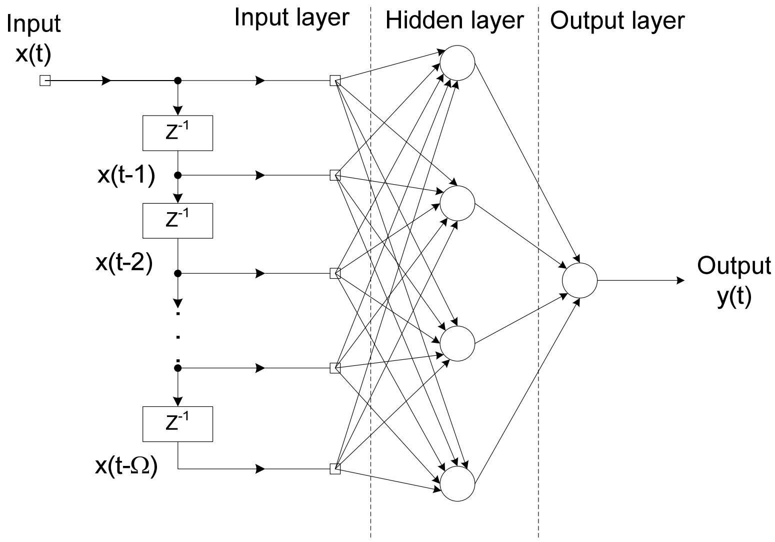


Figure 1. Time lagged feed-forward network [3, p.644; 4]

2. Brief Description of the Algorithm for Short-Term Traffic Forecasting

In order to facilitate and automate the process of time series modelling and forecasting, and compensate for the problems associated with instability of a produced solution, an advanced algorithm has been developed, the core diagram of which in shown in Fig. 2. The algorithm is especially aimed at producing the operative (24 hours ahead) and short-term (up to two weeks ahead) forecasts of network traffic represented as univariate / multivariate time series.

A forecasting task is solved under the assumption that optimal training parameters and an appropriate training algorithm are already selected according to some rules or procedures, and stay invariable during the whole training process.

Such parameters of network architecture as the number of input and output neurons are also constant during all the stages of training and forecasting. Moreover, the number of hidden layers of a regression network does not usually exceed one in accordance with the universal approximation theorem [5, 6]. Thus, the optimal value of only one variable parameter, the number of hidden neurons, has to be determined through test-and-trial routine.

Only few hidden neurons are often satisfactory for the purposes of traffic modeling and forecasting. Therefore, in order to identify the optimal number of hidden neurons, it is advised to apply a constructive method, which is implemented in the proposed algorithm. It involves a gradual increase of the number of hidden neurons with subsequent testing and verification of each network architecture.

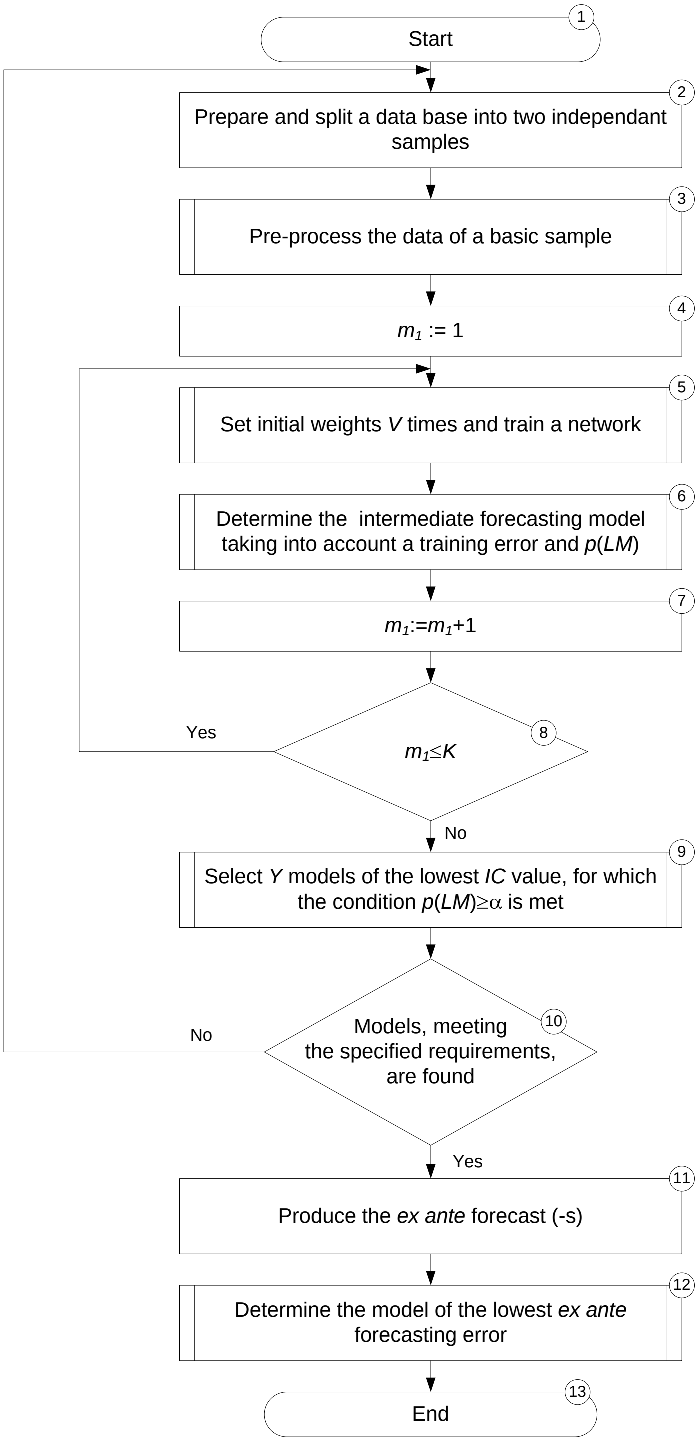
The important stage of the algorithm is pre-processing of input data. Some procedures of pre-processing are discussed in [7] and include reducing a time series to stationary behaviour, identifying seasonal and / or cyclic components, etc.

3. Novelty of the Algorithm

In contrast to some classic algorithms for accomplishing a pre-defined task (see, for example, [8; **Error! Reference source not found.**, p.84]), the proposed algorithm incorporates three procedures:

- implementation of multiple cycles of weight initialization of a neural network during a training process;
- method of selecting the intermediate forecasting models, taking into account the level of residual autocorrelation and the estimates of information criteria;
- method of selecting the final forecasting model, taking into account the accuracy of *ex ante* forecasts.

Let us consider the theoretical arguments in defence of the necessity of implementing these procedures to identify a relevant forecasting model.



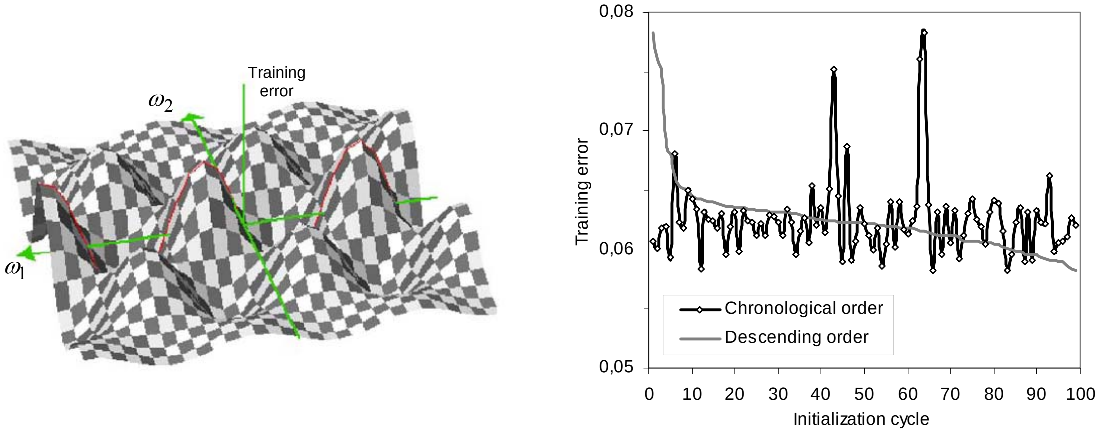
Legend

m_1 – number of hidden neurons of a two-layer perceptron
K – maximum number of hidden neurons
V – total number of weight initialization cycles
IC – information criterion
LM – Lagrange multiplier type test
p(*LM*) *– p-value* (*observed significance*) *of the LM-type test*
α – significance level

Figure 2. Advanced algorithm for solving a traffic forecasting task by means of neural networks

3.1. Implementation of Multiple Cycles of Weight Initialization of a Neural Network

It is required to set some initial values to all the weights and biases of a neural network before a training process starts. The aim of initialization is, probably, to find the best approximation to an optimal solution and, in this way, to decrease training time and facilitate the convergence of a training algorithm.



(a) (b)

Figure 3. Illustration of the necessity of implementing multiple initialization cycles: (a) a simplified example of two-dimensional error surface, which demonstrates a key problem – several local minima can exist on the training error surface; (b) the training errors of a neural network (without applying cross-validation) produced as a result of a hundred cycles of weight initialization[1]

If the initial weights and biases are set to large values, then neurons usually approach the saturation level very quickly. In this case, the local gradients, calculated according to the back-propagation algorithm, take small values, which, in turn, would significantly increase training time. If the initial values are set to small values, then the algorithm works very slowly about the origin of the error surface. This is specifically true in the case of anti-symmetric activation functions such as hyperbolic tangent.

During two last decades many heuristic methods of weight initialization have been proposed (see [10] for more details). Despite this, the optimal solution of this issue has not still been found. Due to its simplicity, the most common method is the random initialization of weights and biases from a uniformly or normally distributed narrow range of small values.

Regardless of the initialization method, starting values of weight coefficients influence the final result of training. This is due to the properties of a training algorithm as well as the fact that several local minima do exist on the error surface (see Fig. 3-a). Therefore, in order to find an actual global minimum, it is necessary to train one and the same neural network multiple times under the same conditions, changing only the initial values of weights and biases.

In spite of these problems, most researchers still do not pay a proper attention to this aspect. It is possible to find references to 5 [11], 10 [12], 25 [13], 50 [14; 15] and 100 [13] cycles of initialization. However, the most practical studies restrict the number of initialization cycles to one, and this can mislead a researcher regarding the adequacy of a produced solution.

The example shown in Fig. 3-b illustrates the uncertainty in producing a final solution and its dependence on the starting values of weights and biases. The training errors shown here are produced as a result of training a neural network of the same architecture and applying the same training parameters but changing the initial values of weights and biases. It is easy to notice that the difference between the highest and lowest errors comprises more than 25 per cent, which can significantly influence the accuracy of final forecasts.

The number of initialization cycles is usually chosen mandatory, and depends on the complexity of a task as well as on time resources a researcher has on his / her disposal.

[1] The values of training errors are displayed in chronological order of their evaluation at the end of each training epoch as well as sorted in descending order to facilitate their comparison.

3.2. Selection of the Intermediate Forecasting Models Taking into Account the Residual Autocorrelation and Estimates of Information Criteria

According to the developed algorithm, the selection of the intermediate forecasting models among the trained networks is carried out taking into account the level of r*esidual autocorrelation* and the value of *information criterion*.

Some standard parameters, such as a correlation coefficient (R), mean squared error (MSE), mean absolute error (MAE) are traditionally used to evaluate a general forecasting ability of forecasting models. However, these parameters provide little information about the accuracy of a fitted model, and are also useless in identifying statically significant differences between the forecasts produced by various methods [16, 17, 18].

The most accurate indicator of the adequacy of a forecasting model can be the absence of *autocorrelation in residuals*. The residuals of a fitted model are defined as *n* differences given by $\varepsilon_t = x_t - \hat{x}_t,\ t = 1, 2, \ldots, n$, where x_t is the observed value and $\hat{x}_t$ is a corresponding predicted value produced by means of a fitted statistical model [**Error! Reference source not found.**, p. 94]. These differences cannot be explained by a produced forecasting model. Therefore, we can consider residuals ε_t to be observed errors.

The acceptance of the hypothesis of no autocorrelation in residuals at a pre-defined significance level means that the residuals are similar to *white noise* and further analysis will not discover any statistically significant dependencies. In classic regression analysis, the *Durbin-Watson* criterion [**Error! Reference source not found.**, p.245] is traditionally used for testing the autocorrelation of residuals. However, this test is not suitable for testing the autocorrelation if the regressor is a lagged explanatory variable [**Error! Reference source not found.**, p.256]. For the same reason, the *Box-Pierce* and *Ljung-Box* [21] criteria cannot be applied to neural networks, although the last one is widely used and, despite its theoretical inconsistence, is still included in most statistical and econometric software packages.

At present, the most relevant estimate of the residual autocorrelation of neural networks is a powerful *Lagrange Multiplier* (*LM*) *type test* [22]. The LM-type test belongs to classic asymptotic tests and is capable of identifying the autocorrelation of any order.

In turn, the use of *information criteria* is based on one of the main idea of time series forecasting – “choice a parsimonious model” (known as the *Ockham’s razor principle*). It means that, all other things being equal, one should prefer the model with the fewest free parameters.

The mean squared residuals usually decrease once the model becomes more “complicated” with addition of new free parameters. Increasing the number of free parameters of a neural network (which is associated with the addition of new neurons / layers of neurons), one can fit a model to historical data with infinite accuracy. The *universal approximation theorem* [5, 6] explains this property of neural networks. However, such a neural network may have a poor ability to make generalizations due to *over-training* [3, p.206]. Besides, once a certain limit is reached, the gain in accuracy of fitting with addition of new parameters tends to be insignificant. On the other hand, time required for selecting the optimal values of free parameters can lead to a sharp decrease in the performance of a network. Therefore, it is very important to seek for the balance between the preciseness of approximation and the complexity of a statistical model.

Information criteria have been found to be quite useful in solving this problem. The estimate of the criterion consists from the penalty for poor fitting and the penalty for over-parameterization. The most popular criteria of this type are the *Akaike’s information criterion* (AIC) and the *Bayesian information criterion* (BIC) given by [23, p.38; 24, p.373]:

$$AIC(l) = N_{ef} \ln \hat{\sigma}_\varepsilon^2 + 2l \,, \tag{1}$$

$$BIC(l) = N_{ef} \ln \hat{\sigma}_\varepsilon^2 + 2l + l \ln(N_{ef}) \,, \tag{2}$$

where

N_{ef} – number of effective observations, to which the model is fitted;

l – number of adjusted parameters;

$\hat{\sigma}_\varepsilon^2$ – estimate of the residual variance, $\hat{\sigma}_\varepsilon^2 = {}^{1}\!/_{N_{ef}} \cdot \sum_{t=1}^{Nef} \varepsilon_t^2$.

Information criteria are evaluated separately for each analyzed specification (architecture) of neural networks. The models that possess the lowest value of the criterion should be selected for further analysis. It has been also noticed that, in practice, the BIC "selects" very parsimonious models with only few parameters. Therefore, this criterion is often used for non-linear models, where insignificant gain in fitting quality hinges upon the necessity of calculating many additional parameters.

3.3. Selection of the Final Forecasting Model Taking into Account the Accuracy of *Ex Ante F*orecasts

If the models, meeting the above specified conditions, are found, it is required to test their generalization ability (i.e., the ability to produce reliable forecasts) for an independent test set, which is not involved in training. The forecast developed for an independent test set we will call an *ex ante forecast*. The necessity of *ex ante* forecasting is related to the fact that even if a neural network provides a high accuracy of approximation and uncorrelated residuals, it would be still over-trained on historical data.

The approach of splitting a time series into two independent subsets has gained wide acceptance in the practical studies dedicated to time series forecasting (see, e.g., [25; 26]) but it is still rarely used in the case of neural networks. The first, largest data subset, called the *basic* or *retrospective sample*, is used to select and verify a statistical model. The second, *ex ante forecasting sample* is used to examine the quality of *ex ante* forecasts, comparing them against historical data. The latter provides the opportunity to evaluate independently the forecasting abilities of the model fitted to the basic sample.

The last historical values of an analyzed time series are traditionally used for developing the *ex ante* forecasting sample. However, it is necessary to keep in mind, that these observations influence the direction of the actual *real-life* forecast much more than the earlier ones. Therefore, the last historical data are the most valuable for the process of selecting an appropriate forecasting model, and using them as a testing sample is not always reasonable.

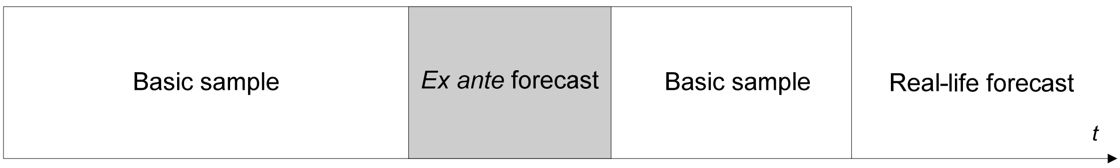


Figure 4. Chronological division of a time series into the basic and ex ante forecasting samples

According to the proposed algorithm, it is recommended to divide a time series into the basic and *ex ante* forecasting samples in the way shown in Fig. 4. This original approach allows increasing the quality of real-life forecasts, since the last historical observations are used for fitting a statistical model rather than testing.

The accuracy of *ex ante* forecasts is evaluated by one of the standard error parameters. In the practical studies of [10], the mean absolute percentage error (*MAPE*) was applied, given by [27, p. 347]:

$$MAPE = \frac{\sum_{t=1}^{L}\left|\frac{x_t - \hat{x}_t}{x_t}\right|}{L} \cdot 100\%, \tag{3}$$

where L – the size of an *ex ante forecasting* sample (i.e., forecasting horizon).

The *MAPE* is a relative, dimensionless measure of the accuracy of approximation or forecasting. It is helpful in comparing forecast performance across different data sets, or comparing the performance of different forecasting methods.

The lower the *MAPE*, the more accurate is a forecast. The model of the lowest *MAPE* is the final model assigned to further *real-life* forecasting. The interpretation of *MAPE* introduced in [28] allows judging about the accuracy of a forecast: less than 10 per cent is a highly accurate forecast, 11 to 20 per cent is a good forecast, 21 to 50 per cent is a reasonable forecast, and 51 per cent or more is an inaccurate forecast.

Thus, the choice of a final forecasting model is based on the results of multiple consecutive procedures and tests. The final model is characterized by the lowest value of the information criterion, uncorrelated residuals and the lowest error of an *ex ante* forecast.

4. Conclusion

The use of neural networks traditionally involves expert assessment at all stages of application. The proposed algorithm allows minimizing the influence of human factor and helps identifying the neural network solutions resulting in reliable forecasts with a minimum level of errors.

The effectiveness of the developed algorithm was examined on real data sets represented as ten time series of different lengths and averaging degrees, which characterized:

- the intensity of total carried traffic of a conventional telephone network;
- the transmission rate of outgoing international traffic measured at a transport level of a packet-switched Internet network.

The results of this practical study are summarized in [10]. It was shown that the MAPE estimates of examined *ex ante* forecasts varied from 10 per cent to 30 per cent. This confirms the possibility of applying these models in real-life conditions.

The criteria for selecting a final forecasting model proposed in the thesis – the lowest estimate of the information criterion and statistically insignificant residual autocorrelation – can be successfully applied to linear statistical methods as well.

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APPLICATION OF THE SPATIAL STOCHASTIC FRONTIER MODEL FOR ANALYSIS OF A REGIONAL TOURISM SECTOR

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This research is devoted to an econometric analysis of competition and cooperation on the regional tourism market between regions within the Baltic States (Estonia, Latvia, Lithuania). We estimate the relative regional efficiency levels of tourists' attraction and discovered factors affecting them. We propose an econometric approach called Spatial Stochastic Frontier, which corresponds to a spatial modification of a stochastic frontier model. The study includes three alternative specifications of the spatial stochastic frontier model: distance-based, travel-time based, and border-based. It is intended to identify the influence of existing transport networks on research results.

On the base of the models' estimation results we analyse region-specific factors (tourism infrastructure, employment, geographical position and natural attractions) which affect the numbers of visitors and estimate regions' efficiency values.

We discover a significant level of inefficiency of tourists' attraction in Baltic States region and propose some ways to improve the situation.

Keywords: spatial stochastic frontier, efficiency, competition, cooperation, regional tourism, transport network

1. Introduction

The growing importance of the tourist industry and its influence on the overall development of destination countries and regions mean that tourism policy is now strategically very important. The European Community has no direct tourism competence, but its policies in some areas have a considerable impact on tourism. The EU Commission funds sustainable tourism-related projects through the European Regional Development Fund (ERDF) in support of social and economic development. Objectives of the ERSF include a support of sustainable patterns of tourism to enhance cultural and natural heritage, develop accessibility and mobility of the related infrastructure. Environment and transport infrastructures, both of utmost importance for tourism, are also financed. All these financial instruments require an approach to regional efficiency estimation and comparison of regions' in respect of tourist's attraction.

There are many economic studies devoted to the positive effects of competition between companies in markets. Recently researchers have applied the same approach to competition between countries, administrative regions, and cities. Over the last decade tourism has increasingly become an area of competition [1, 2] between countries or regions for visitors. Competition forces regions to be more attractive for tourists and to use their resources more efficiently. Now regions can be examined not as a geographical areas with natural or heritage attractions, but as businesses, which should use all possible resources to beat their competitors and attract more tourists.

The completion between regions for tourists is growing, firstly because of increasing mobility of the population. Significant part of the population (at least in the EU) has a free choice of where to travel and spend their savings. Also the integration of the EU countries as well as EU border politics are significantly improved during last years, so the market of tourist destinations is partly in the making stage and quite flexible and mobile.

When we consider regions within a country (or several adjacent countries) as competitors, indicators of efficiency should be brought to the forefront. Being the economic units in a competitive environment, regions should be examined in terms of the efficiency of their use of resources and how this can be improved. There is very little analysis of region efficiency in the tourist literature. The majority of research in this area is at the microeconomic level, and contains efficiency analyses of hotels, restaurants, and other business units. There is little research designed to analyse efficiency at a regional level. One of the few studies in this area, that can be referred to, is the analysis of Italian tourist destinations [3], conducted by means of DEA and the Malmquist Index.

This research is intended to analyse the competitiveness and efficiency of regions within the Baltic States (Estonia, Latvia, and Lithuania). Tourism is one of the most important industries for these countries, but there is no research, known to us, which analyses the competition between regions in this area. In all three Baltic countries the pattern of tourism is quite conservative – the capital cities (Tallinn, Riga, and Vilnius) attract the majority of tourists, and leave a small part of tourist flows for regional destinations. But the mild climate, relatively good level of service and transport network support the potential of regional tourism and provide a good source of regions' development.

One of the most important sources for development of regional tourism attractiveness is a transport network, so modelling of regional competition and efficiency requires consideration of regional spatial structure and existing transport networks. In this research we provide a spatial modification of the standard stochastic frontier model for efficiency estimation. The proposed models are based on the well-known stochastic frontier approach, frequently used for estimation of unit's relative efficiency levels, and amend it by adding a spatial component, reflecting dependencies between neighbour regions. We have applied the proposed approach to the Baltic state regional data and carried out empirical analysis of estimated results to provide some recommendations.

2. Spatial Stochastic Frontier Model

Stochastic Frontier Model

The well-known stochastic frontier model is usually presented as (in the matrix form) [4]:

$$y = f(x, \beta) + \varepsilon,$$
$$\varepsilon = v - u, v \sim N(0, \sigma_v^2), u \geq 0,$$

where
- y – an output;
- x – a vector of resources;
- f – a production function;
- β – a vector of unknown coefficients;
- ε – a composite error term.

The first component of a composite error term, v, shows the random variation of the efficiency frontier. The second one, u, shows the technical inefficiency of regions (as a distance from the efficiency frontier). An efficiency level of a given region i can be estimated as [5]:

$$TE_i = e^{-E(u_i|\varepsilon_i)},$$

where $E(u_i|\varepsilon_i)$ – conditional expectation of u_i given estimated ε_i.

Selection between the classical regression and the stochastic model is based on variances of u and v error terms. If the variance of u is significantly large relative to the total variance of the error term, then inefficiency presents in data. A γ statistic is used to check this hypothesis:

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$$

If a value of γ statistics is far from 0, we accept the hypothesis about the presence of inefficiency in the data and the preference for the stochastic frontier model.

There are some different approaches to estimation of stochastic frontier model parameters, and the maximum likelihood estimator is one, which is used frequently. The classical maximum likelihood approach requires an exact distribution law for the composite error term, inherited from the stochastic model. In this research we assume a truncated normal distribution law of the inefficiency term u:

$$u \sim N^+(\delta z, \sigma_u^2)$$

The error term distribution function for the normal-truncated normal specification of the stochastic frontier model is presented in [4]:

$$f(\varepsilon)=\frac{2}{\sigma}\varphi\left(\frac{\varepsilon+\delta z}{\sigma}\right)\frac{\Phi\left(\frac{\delta z}{\sigma\lambda}-\frac{\varepsilon\lambda}{\sigma}\right)}{\Phi\left(\frac{\delta z}{\sigma_u}\right)},$$

where

$$\sigma=\sqrt{\sigma_u^2+\sigma_v^2},\lambda=\frac{\sigma_u}{\sigma_v},$$

φ and Φ are standard normal probability density and distribution functions accordingly.

Spatial Modification of the Stochastic Frontier Model

Spatial econometrics considers the possibility of geographic interaction between the economies of neighbouring regions. The general spatial autoregressive model is specified [6, 7] as:

$$y=\rho Wy+\beta X+\varepsilon,$$
$$\varepsilon=\lambda W\varepsilon+\upsilon,\ \upsilon\sim N\left(0,\sigma^2\right)$$

where
y – a vector of dependent variable values;
x – a matrix of explanatory variables' values;
ε – a vector of residuals;
W – a matrix of contiguity.

The feature of the model is designed in the components with the contiguity matrix W. This square matrix contains the information about inverse distances between data points, so a higher value means closer points, and zero values on the main diagonal (to exclude y values self-dependence). The authors assume that a value of the dependent variable y at a given data point depends on its own neighbour values, and closer neighbours have stronger influence. The same assumption is specified for the residuals ε.

One possible spatial modification of the stochastic frontier model [8] with the Cobb-Douglass form of the efficiency frontier and the truncated normal inefficiency component is:

$$\ln(y)=\rho W\ln(y)+\beta\ln(X)+v-u,$$
$$u\sim N^{+}(\lambda Wy+\delta z,\sigma_u^2),$$
$$v\sim N(0,\sigma_v^2)$$

The definition of the W contiguity matrix can be different and vary between research studies. Usually distances are specified as geometrical Euclidean distances, or as great-circle distances (in the case of significant geographical remoteness of data points). This specification is the most popular, but not the only one. In some researches (including this paper) it is necessary to include real journeys within the model, so the matrix with inverse travel time or cost values matches the real situation better. In our research we have used and compared both approaches. The dDetailed analysis is presented in the Model Specification section.

One of the main points of the research is the values of ρ and λ parameters. Parameter ρ shows the influence of model output values (the number of tourists) in neighbouring regions on the output in a given region. Our reasoning states that this influence can be regarded as positive (cooperation of regions), or as negative (competition between regions) [9]. The analysis of the ρ value will answer this major research question.

Parameter λ shows the influence of output values in neighbouring regions on efficiency in a given region. We expect a positive influence here, because both cooperation and competition should improve an economic unit's efficiency in a healthy economy.

3. Data

Panel data used in the research includes information about regions of Latvia, Estonia and Lithuania between 2005 and 2008 (data for 2009 are not yet completely available).

The division of these countries into regions is not well-defined and can cause some problems. We used the Nomenclature of Units for Territorial Statistics level 3 (NUTS 3) approach to define regions in Estonia and Lithuania (15 and 10 regions respectively), but not for Latvia. In NUTS3 Latvia comprised only 4 regions, which are significantly larger than the regions in Estonia and Lithuania, and appear to bevery heterogeneous. For this reason we used the same approach as the National Statistical Office of Latvia to divide the regions. 26 regions of Latvia correspond in terms of size and population with NUTS3 regions of Estonia. The regions of Lithuania are significantly larger (approximately twice the size, see Table 1), but their separation was impossible due to a shortage of information. Statistical data about smaller Lithuanian regions (municipalities) were provided by the National Statistical Office starting from 2009 only. We think that this discrepancy is a matter of scale only and is not a matter of 'production' differences (which are critically important for a frontier model) and that the discrepancy does not affect the received results significantly. We have incorporated dummy variables into the model to capture a possible effect of the difference in Lithuanian regions' definition.

The statistical information was collected from the following sources:

- National statistical offices of the Baltic states provided information about the number of tourists visiting a given region, the number of hotel beds, the number of enterprises in tourism-related sectors (according to NACE rev.2 classification), and also information about the area of the region, its population and road coverage. These parameters are described in detail in the Model Specification section.
- Schedules of railways and regional coach services are used for collecting data regarding travel time between regional centres.
- TomTom (a digital mapping and routing company) is used for information about road distances and travel time by car between regional centres.
- The Museums Associations of Latvia, Lithuania, and Estonia supplied information about the number of museums in each region.
- GIS system (Google Earth) is used for information about the geographical coordinates of regions and natural tourist attractors (sea-side, national parks).

Table 1. Descriptive statistics for used indicators

	Total	**Estonia**			**Latvia**			**Lithuania**		
Variable	*Mean*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Tourists, people	73902	79276	8975	257930	23147	2043	97580	182576	13073	755013
Hotel beds	1609.8	1400.9	184	4752	516.2	71	1673	4766.5	263	16975
Labour, enterprise	1976.4	974.6	183	3019	618.6	177	2364	7009.3	1395	23987
Museums, count	15.9	16.5	4	38	4.8	1	14	43.8	22	86
Area, sq. km	3390	2895	1023	4806	2467	1628	3652	6530	4350	9731
Population, people	113713	62887	10118	170719	57613	24159	167774	335811	126717	848956
Roads/area ratio, km/sq.km	0.706	0.397	0.273	0.546	0.805	0.549	1.081	0.911	0.652	1.128

Capital cities (Riga, Tallinn, Vilnius) were excluded from the analysed data set as outlier – numbers of tourists, attracted in these cities, exceed number of tourists in all the other regions put together. Also Jurmala city was excluded using the same logic. The distribution of a number of visitors per capita is presented on Figure 1.

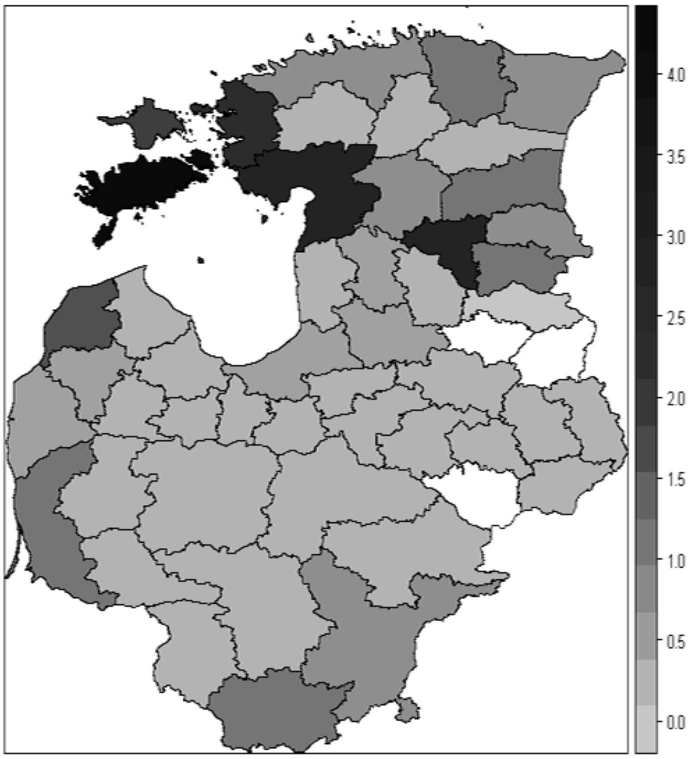

Figure 1. Number of tourists per capita in Baltic States regions

The distribution of tourists is not uniform – sea-side regions have expected larger values due to natural attractors for leisure and significant numbers of international businesses and volumes of passenger and cargo traffic (generally, via sea-ports).

4. Model Specification

The specification of the spatial stochastic frontier model includes output and resource parameter selection and definition of the contiguity matrix.

In this research we consider a region as an economic unit, which uses its own resources to attract and service tourists. The term 'tourists' can mean different things. It can refer to people who are accommodated in a region, but also to people who are just visiting the region; day-trip tourists or people in transit through the region. Tourists can be classified according to the purpose of their trip – business or private. We assume (and data collected by national statistical offices support this assumption) that the most important tourists for a region economy are those who are accommodated in the region. Usually a tourist who is accommodated in a given region spends a significant amount of time in that region and "supports" the region economy through spending money and using local services. For this reason, as a dependent variable, we chose the number of tourists (*tourists*) staying at least one night in a hotel, motel or any other kind of accommodation establishment. This definition of the dependent variable should add a value to the 'competition' scale pan of the 'competition-cooperation' scales.

The set of explanatory variables includes resources used in a given region to attract and service tourists. We include a region tourism infrastructure in the model in the form of a number of beds available in hotels and other types of accommodation (*beds*). This conforms to our definition of tourists. We also assume a strong relationship between the number of beds offered and other tourism facilities.

We have included the number of enterprises in tourist-related sectors as a service quality and labour force parameter. Generally, it is impossible to separate enterprises serving tourists and residents, therefore we have used the total number of enterprises in chosen sectors of the economy. We have used the NACE rev.2 classification and selected the following economic sectors as related to tourism: wholesale and retail trade; repair of motor vehicles and personal and household goods (class G); transportation and storage (H); accommodation and food services (I), information and communications (J). The final parameter used (named *services*) was calculated just as the total number of enterprises in the chosen sectors.

Transport infrastructure was included in the model in two different forms. The first one is related to the level of region accessibility for international tourists. We have considered the distance to the nearest airport/sea port (*nearestGate*) as an accessibility metric. The distance was measured in kilometres, travel time by car, train and coach. Usually regions in the Baltic countries have good connections of all types with the nearest airport, so all 4 parameters were highly correlated. We chose only one region's accessibility parameter (travel time by car) to avoid the multi-colleniarity problem. No distance decay functions were applied.

The second transport-related parameter was constructed to include local transport infrastructure in the model. We haveused a ratio of the total road lengths of a region and the regionarea as a metric (*road_coverage*), because usually all tourist movements within a region in the Baltic states are done by car or bus.

We have considered museums, castles and palaces as man-made tourist attractions. After data collection we have discovered a strong relationship between the numbers of this kind of attraction. Therefore, we have used only one of them (the number of *museums*) in the final model specification.

Natural attractions were included in the model in the form of a dummy variable for the sea-side (*sea*, yes/no) and the number of national nature parks (*natparks*) in a region.

An important parameter of the spatial stochastic frontier model is a contiguity matrix W. This matrix presents distances between regions in the model and can be defined in different ways [10].

The simplest method of defining the W matrix is as an inverse Euclidian distance between the regional centres. According to this approach we calculate the distances between regions in terms of kilometres between their main cities. The method can be modified by taking the spherical surface of the Earth into account (a great-circle distance). In this study we have filled this matrix with simple Euclidian distances between regional centres and restricted the distance with 1 (about 110 km). The model with this continuity matrix is called Model DIST.

The main disadvantage of this approach is obvious – being geographically close generally does not mean being accessible easily. There may be no road between two points or the road distance may be significantly longer than the direct distance. Matrix definition is a critical point for spatial models, so we have used an alternative approach to compare the estimation results. We have defined an alternative contiguity matrix on the basis of travel time between regional centres by car. This alternative model specification is noted as Model ROAD. Travel time reflects the real distance between regions more precisely and differs significantly from the geographical distance (see Figure 2). We calculate the coefficient of correlation between the models distance and travel time spatial components ($W \cdot tourists$) and discovered an absence of a significant relationship (correlation = 0.06, p-value = 0.37).

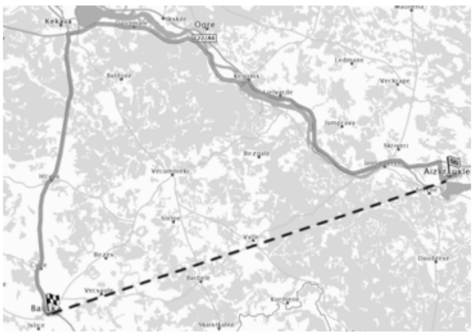

Figure 2. Geographical and road distances

The travel time-based contiguity matrix is adequate for use in cases of point-type economic units. Obviously, regions have areas, so the distance between the regional centres does not always reflects the distance between regions fairly.

Another possible approach is based on a binary contiguity matrix, which is constructed solely on the basis of direct borders between regions. There are two most frequently used border-based approaches – Rook and Queen. The names of approaches are derived from the chess terminology and are self-explaining – the Rook definition of contiguity is a direct edge-to-edge contact of units, and the Queen definition includes both edge-to-edge and vertex-to-vertex contact types. In this research we haveapplied a distance based modification of border-type contiguity. Two regions are considered as neighbours if the distance between their two nearest points is less than a predefined limit. The limit can be chosen in different ways, we have chosen a minimal distance, which provides at least one neighbour for all objects in the sample. The relevant model is called Model BORDER.

An efficiency frontier form can vary during the observable time interval (2005-2008). This variation can be caused by changes in the economies of the Baltic States and other general factors. We have included the time variable (*years*) in the specification of the efficiency frontier and as an explanatory variable for a regions inefficiency level. We have received insignificant values of the considered parameters in both cases and decided to exclude the time variable from the model. Therefore, we conclude that no significant changes in regional tourism efficiencies occurred during the period of the study.

Another model specification hypothesis was related to the different countries specifics. Estonia, Latvia, and Lithuania are significantly different in terms of economics and politics, and differences in regional tourism are also possible. We have included dummy variables for Estonia (*EE*) and Lithuania (*LT*) into the models to check for permanent differences of regional tourism efficiency frontiers between countries.

In addition to country-specific differences in the efficiency frontier position, we have investigated the possible differences in the main 'competition-cooperation' area. It is possible that the level of competition (or cooperation) between regions varies between countries. We have included cross dummy variables $EE\cdot\ln(W\cdot tourists)$ and $LT\cdot\ln(W\cdot tourists)$ to test this hypothesis.

The final model specification with the Cobb-Douglass form of the efficiency frontier and truncated normal distribution of the inefficiency component after removing insignificant explanatory variables is:

$$\begin{aligned}\ln(tourists) = {} & \rho W \ln(tourists) + \beta_1 \ln(beds) + \beta_2 \ln(services) + \beta_3 \ln(museums) + \\ & + \beta_4 \ln(nearestGate) + \beta_5 sea + \beta_6 EE + \beta_7 LT + \\ & + \beta_8 EE \cdot W \cdot \ln(tourists) + \beta_9 LT \cdot W \cdot \ln(tourists) + v - u,\end{aligned}$$

$$u \sim N^+(\lambda W \cdot \ln(tourists), \sigma_u^2), v \sim N(0, \sigma_v^2)$$

5. Empirical Results

Using the presented specification of a spatial stochastic frontier model we have constructed four alternative models:

1. Model NOSPAT – stochastic frontier model without spatial components;
2. Model DIST – spatial stochastic frontier model with distance-based contiguity matrix;
3. Model ROAD – spatial stochastic frontier model with travel time-based contiguity matrix;
4. Model BORDER – spatial stochastic frontier model with border-based contiguity matrix.

The Models' estimation results are presented in Table 2.

Table 2. Estimation results of three alternative models: Model NOSPAT (without spatial components), Model DIST (distance contiguity matrix), and Model ROAD (travel time contiguity matrix)

	Model NOSPAT		**Model DIST**		**Model ROAD**		**Model BORDER**	
Dependent variable	ln(*tourists*)		ln(*tourists*)		ln(*tourists*)		ln(*tourists*)	
Frontier Estimates	*Coefficient*	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*
ln(*beds*)	0.878	0.000	0.890	0.000	0.843	0.000	0.885	0.000
ln(*nearestGate*)	0.003	0.896	0.043	0.027	0.028	0.307	0.341	0.009
ln(*services*)	0.300	0.000	0.387	0.000	0.306	0.000	0.018	0.700
ln(*museums*)	-0.107	0.094	-0.264	0.000	-0.214	0.002	-0.170	0.114
$W\cdot\ln(tourists)$, ρ			-0.091	0.002	-0.094	0.014	-0.002	0.981
Sea	0.163	0.043	0.099	0.078	0.271	0.000	0.320	0.019
EE	0.502	0.000	3.706	0.000	1.579	0.025	0.505	0.016
LT	-0.271	0.087	2.213	0.000	0.610	0.120	-0.031	0.914
$EE\cdot W\cdot\ln(tourists)$			-0.227	0.002	-0.114	0.132		
$LT\cdot W\cdot\ln(tourists)$			-0.174	0.000	-0.066	0.083		
Constant	2.841	0.000	3.682	0.000	4.161	0.000		
Inefficiency component								
$W\cdot\ln(tourists)$, λ			-0.491	0.000	-0.152	0.011		
Constant	-1.179	0.745	6.603	0.000	1.753	0.001		
Statistics								
Log likelihood	-78.393		-50.518		-59.226			
γ	0.921		0.983		1.000		1.000	

Firstly, we need to test the validity of the usage of the stochastic frontier and their dominance over the simple regression. The γ-statistic values for all models are near to 1 (significantly higher than 0), so we state the presence of inefficiency in the data, and prefer the stochastic frontier models.

We have used the likelihood-ratio test to compare spatial and non-spatial model specifications:

$$P\{LR > \chi^2_{crit}(4)\} = P\{2(Ln(H_1) - Ln(H_0)) > \chi^2_{crit}(4)\} =$$
$$= P\{2(-59.226 - (-78.393)) > \chi^2_{crit}(4)\} = P\{38.334 > \chi^2_{crit}(4)\} = 0.000$$

Therefore, we reject the model without the spatial components and accept the spatial stochastic frontier models. A difference in efficiency estimates between spatial and non-spatial models will be discussed later in this section.

The Model BORDER is the only model with the spatial component, which shows insignificant spatial effects in data. This result can be explained by incorrectness of the border-based approach for this data sample. The problem of a correct formulation of contiguity is well-known in spatial econometric literature. The comparison of two other alternative spatial model specifications (Model DIST and Model ROAD) is not only a statistical task, but also a matter of interpretation. The essence of these two models is different, and a researcher can choose one or the other depending on the goals of his research. We havechosen the model based on travel time (Model ROAD) for analysis in this research.

The majority of Model ROAD coefficient estimates are significant and match our expectations. The number of beds in hotels and the number of enterprises in tourism-related sectors have a significant positive influence on the number of tourists, so these predictably can be considered as important resources for regional tourism. This relationship is bidirectional; businesses adapt to the real economic situation and develop in regions with higher numbers of tourists.

The locational characteristics of regions also influence significantly the tourist numbers. The sea-side is one of the most powerful attractions in the Baltic States and has, as expected, a significant positive value. The influence of travel time from the nearest airport/port is significant in the Model DIST, but not significant in the Model ROAD. This can be easily explained using the fact that the travel time is already included in the Model ROAD for regions located near to main gates (in form of the contiguity matrix), and possibly there is no significant difference for other regions (due to the law of distance-decay).

The only unexpected parameter value is the negative influence of the number of museums in a region. The fact that having a large number of specialised museums may not act as a tourist attractor is predictable, but the negative sign is more difficult to explain. We do not make any assumptions or conclusions about this result in this study. It is a point that requires additional investigation.

The dummy variable *EE* (specifics of Estonia) has a significant positive sign, so we conclude that Estonian regions have a higher level of efficiency. This can be explained by the strong relationships between Estonia and Finland (including the tourism sector). More than 35% of tourists, visiting Estonia in 2008, arrived from Finland. In addition the lower crime rate and more stable political atmosphere can be considered as a reasons for the positive distinction in favour of Estonia (for example, according to Transparency International's Corruption Perception Index 2009, Estonia occupies 27th place while Lithuania and Latvia are 52nd and 56th respectively). The dummy variable for Lithuania also tends to be positive, but in the Model ROAD it is insignificant, so we do not distinguish between Latvia and Lithuania in terms of tourist attraction.

Analysis of competition and cooperation between regions in the Baltic states is one of the main points of this research. The spatial component W·ln(*tourists*), included in the models, has a significant negative value (ρ) for both cases. This means that tourists accommodated in a neighbouring region cannot be considered as a resource for a given region, but quite the contrary. They have a negative influence on the region tourists numbers. So we state that **competition between regions for tourists is present in all Baltic states**.

This fact can be explained in different ways. Firstly, as we have used the number of accommodated tourists as a dependent variable, this conclusion shows that tourists prefer to stay in one particular region and visit neighbouring regions (if at all) as one-day trips.

The second reason for competition between regions is a shortage of organised tours in the Baltic States. Most of these tours are still country-oriented and usually have a base region where the tourists stay, several one-day trips to neighbouring regions. The development of tours, offering several nights stay in different regions, would improve the level of regional cooperation.

In addition we haveanalysed the cross-dummy variables to discover the differences in competition levels between the countries, but in our final model these effects are insignificant (though with a tendency to higher competition levels in Estonia and Lithuania).

As we have stated, for competition between regions for tourists we expect a relation between spatial component and regional efficiency levels. Economic theory postulates that a higher level of competition leads to a higher efficiency of economic units. In our case, we observe this effect via the value of λ coefficient. According to the stochastic frontier model specification, the negative sign of this coefficient decreases the value of region inefficiency u, and so has a positive influence on its efficiency. This can be stated as another very important conclusion of this research.

The stochastic frontier approach allows us to calculate efficiency level values for a given region for every time point. We have presented the average efficiency values (2005-2008 years) in Table 3 and their geographical distribution in Figure 3.

Table 3. Model ROAD and Model NOSPAT estimates of region efficiency levels

Latvia			**Estonia**			**Lithuania**		
Region	*Model ROAD, %*	*Model NOSPAT, %*	*Region*	*Model ROAD, %*	*Model NOSPAT, %*	*Region*	*Model ROAD, %*	*Model NOSPAT, %*
Ventspils	93	93	Laane	93	93	Taurage	87	92
Valmiera	89	89	Saare	82	81	Siauliai	84	87
Cesis	80	80	Viljandi	77	82	Alytus	79	82
Ogre	75	83	Parnu	73	78	Vilnius	79	80
Jekabpils	70	79	Polva	70	72	Marijampole	61	78
Preili	68	74	Voru	69	72	Kaunas	59	69
Bauska	68	79	Tartu	69	74	Klaipeda	41	56
Saldus	68	80	Jarva	67	78	Utena	38	61
Kuldiga	67	81	Jogeva	66	75	Telsiai	32	54
Riga region	64	67	Harju	65	67	Panevezys	27	39
Madona	58	73	Hiiu	64	77			
Jelgava	57	74	Laane-Viru	62	75			
Valga	56	62	Valka	48	64			
Liepaja	54	83	Rapla	40	53			
Limbazi	48	76	Ida-Viru	38	56			
Aizkraukle	46	62						
Daugavpils	46	63						
Talsi	45	65						
Kraslava	41	64						
Tukums	39	54						
Aluksne	34	50						
Ludza	30	49						
Rezekne	20	31						
Average	**59%**			**70%**			**60%**	

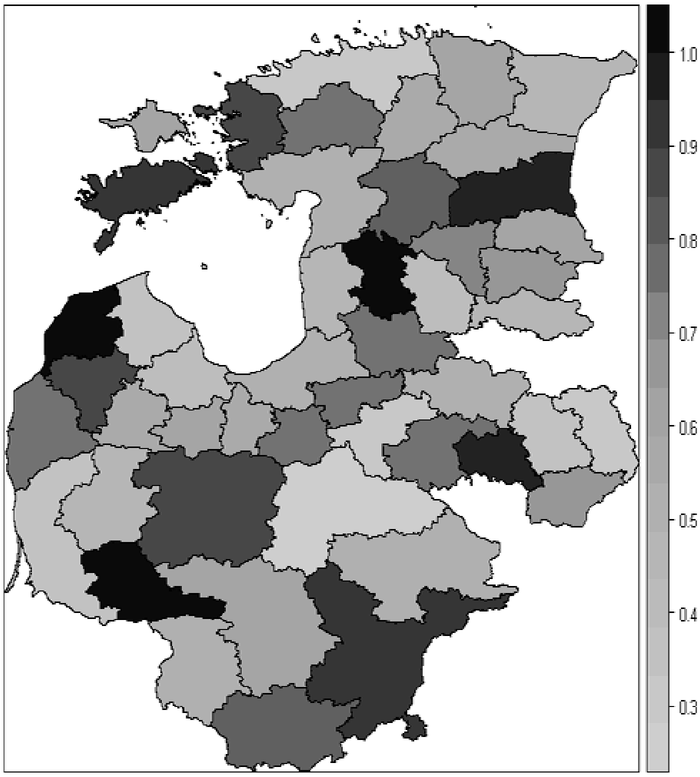

Figure 3. Map of regions' efficiency levels (Model ROAD)

The average value of the region efficiency levels is 63%, so regions have a significant internal potential and could attract 58.7% tourists more (37/63 = 0.587) using the available resources and increasing the efficiency of their utilization.

Estonian regions are relatively more efficient (70%) than the regions in Latvia and Lithuania (59% and 60% respectively), and there is no significant difference between Latvian and Lithuanian regions. Also it can be noted that Latvian and Lithuanian regions are more heterogeneous than regions in Estonia. A complete analysis of regions is beyond the scope of this research.

One of the main goals of this research is the comparison of spatial and non-spatial stochastic frontier models. Estimates of parameters (Table 2), included in both models, correlate to each other and the models look similar. Differences between the models efficiency estimates are presented in the Tables, but they should not be analysed directly, because generally efficiency estimates of different model specifications are non-comparable. Values, presented in the tables, allow conclusions about the patterns of the efficiency estimates to be made, not the numbers themselves. We can conclude that the application of the spatial model does not affect the central regions (Riga, Vilnius, Harju) and regions without powerful neighbours (Saare) significantly. However, efficiency estimates for regions located near the popular centres for tourists accommodation are changed significantly under the influence of a spatial structure inclusion (Liepaja, Rapla, Telsiai). This result is economically explainable and can be considered as evidence for the utility of spatial stochastic frontier models.

6. Conclusions

In this paper we have proposed a spatial modification of the stochastic frontier model for estimation of efficiency of units with strong spatial dependencies. The model is a combination of stochastic frontier approach, frequently used for econometric estimation of efficiency, and a spatial autoregressive model. This enhancement allows including spatial relationships as a possible resource used by an economic unit for its purposes. Also the spatial relationships can be used to explain the observed levels of inefficiency. The proposed model was applied to data sample of regions in the Baltic States as places for tourists accommodation. We have used information about the regional spatial structure to estimate the effects of competition for tourists between regions and its influence on the relative efficiency levels.

We have estimated parameters of the suggested model for data about Estonian, Latvian, and Lithuanian regions between 2005 and 2008. This model allows us to distinguish the effects of different factors (inputs) on the regions attractiveness for tourists and efficiency levels. We have discovered a significant positive relationship between a number of tourists attracted and infrastructure objects (hotels) and transport ways (travel time to the nearest airport). Also significant positive effects of a sea-side have been confirmed.

The suggested model was estimated using three different approaches to the spatial contiguity – geographical distance-based, travel-time based, and border-based. We have also investigated unobservable country-specific effects via including dummy variables for the countries in the model. We have compared the spatial models against the model without spatial components and have noted the considerable advantages (theoretical and empirical) of the spatial models.

We have discovered that the competition effects in the Baltic States are stronger than the cooperation ones. Regional tourism in the Baltic countries is still separated significantly, and the development of transport networks and international holiday tours is highly desirable. We have found a significant positive relationship between competition between adjacent regions and those regions efficiency levels. This matches our economic expectation.

We have also estimated the efficiency levels of the regions and found a significant level of inefficiency in all three Baltic States.

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CONDITIONS AND PROPOSALS OF TARIFF INTEGRATION FOR THE INTEGRATED TRANSPORT SYSTEMS IN THE SLOVAK REPUBLIC

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The integrated transport systems are the solution of decreasing utilization of public passenger transport in many cities and areas around the cities not only in the countries of the European Union. The statistics figures of using the public passenger transport in Slovakia have the decreasing tendency in the last 10-15 years. There were performed some experiments to create the integrated transport systems in Slovakia but they were not developed anymore. The presented article analyses the conditions for implementing the integrated transport systems in Slovakia with focusing on tariff integration. It points out the key elements in creation of integrated transport system to be attractive for passengers and to be advantageous to the transporters.

Keywords: integrated transport system, public passenger transport, tariff system

1. Introduction

The number of passengers using the public transport for their everyday trips has been decreased during the last years in the Slovak Republic. This development is very similar to the development in most of countries in Europe last decades.

Table 1. Comparison of passenger transport by mode in the Slovak Republic

	1995	2000	2004	2005	2006	2007	2008
Rail public transport	89 471	66 806	50 325	50 458	48 438	47 070	48 744
Road public transport	722 510	604 249	461 772	449 456	403 270	384 637	365 519
Urban public transport	515 593	404 539	383 118	395 064	400 673	403 466	399 425
Individual road transport	1 333 334	1 664 342	1 750 171	1 769 147	1 792 000	1 812 245	1 847 112
Passenger cars registered in the Slovak Republic	1 015 794	1 274 244	1 197 030	1 303 704	1 333 749	1 433 926	1 544 888

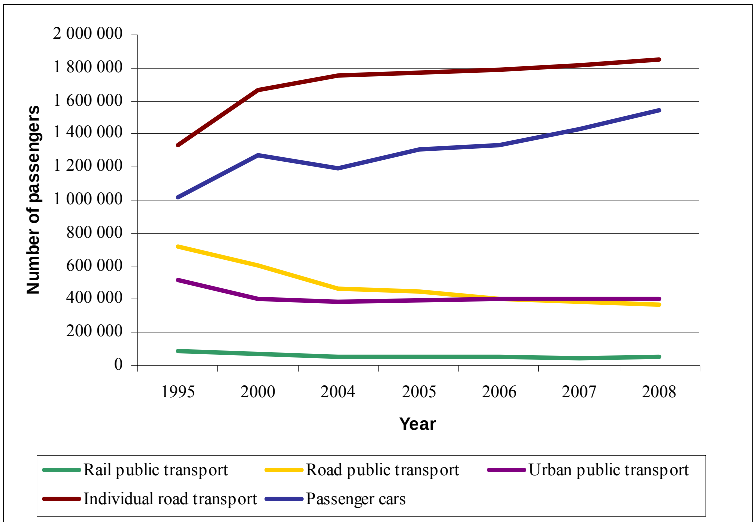

Figure 1. Development of passengers’ number in public passenger transport in Slovakia

The development of number of passengers has decreased in railway public transport, road public transport as well as in urban public transport. On the other hand, the individual road transport has increased. This development is caused by the increasing level of living standards. The individual road transport offers more advantages for inhabitants while the public passenger transport services are not so attractive because of travel time, accessibility (time, space) but mainly the quality of travelling. The preference of public passenger transport is still remaining at a low level. Last but very important thing for passenger decision-making to use or not the public transport is the price. The prices in the case of all modes have increased dramatically last 15 years. All these facts influenced the changeover of passengers from public to individual transport.

2. Experiments of Integrated Transport Systems in Slovakia

Last ten years the experiments to create the integrated transport system have been done in some cities. Some of them are still continuing and even there are the plans for their full operation. These days there is the integrated transport system in the different stages of development in 2 cities – Bratislava and Žilina. The experiment of the integrated transport system has been done in Košice but it is not in service for now.

The common features for all the experiments of integrated transport systems in Slovakia are as follows:

- the integration was applied only to the chosen lines of urban transport, railway transport and bus transport,
- the integration covered only small part of area,
- the integration was based mainly on using one tariff for time ticket, the transport integration and tariff integration was not developed further.

On the base of the above mentioned it can be concluded that the integrated transport systems in Slovakia are not the integrated transport system in the true sense.

2.1. Bratislava

The first attempt of integration on the area of Bratislava was in year 2000. That time the passengers could use the net season ticket for trips by urban public transport and railway transport. Later the suburban bus transport has been integrated but only a few lines. This situation has been lasting out practically till now. In 2005 the company "Bratislava Integrated Transport" proposed the aim to create and operate the integrated transport system on the area of whole Bratislava region. In 2007 the document "The Concept of Bratislava Integrated Transport" was processed. The process of integration (such operations as as the tariff setting, transport integration, the technical equipment, economic integration and system with main focus on revenues dividing) is elaborated in this document.

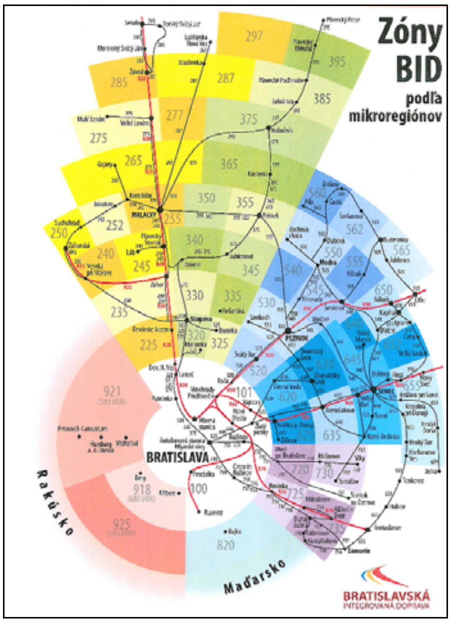

Figure 2. Proposal of zones in Bratislava integrated transport [5]

Last two years the preparations for the system start have been implemented but the start as such is still postponed. There are mainly political and economic reasons, which have the influence on the system start-up.

2.2. Žilina

Žilina regional integrated transport system has been created mainly for the reason to revive the railway line from Žilina to Rajec (the town about 20 km southwards). This line is interconnected with the urban public transport. The passengers can use single tickets and also tickets for a season. The area is divided into 7 zones (Fig. 3). The integration is oriented mainly on tariff integration.

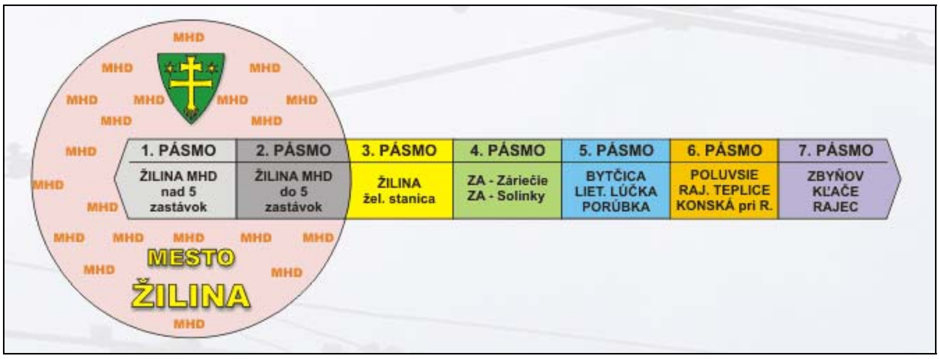

Figure 3. Zones in integrated transport system in Žilina [6]

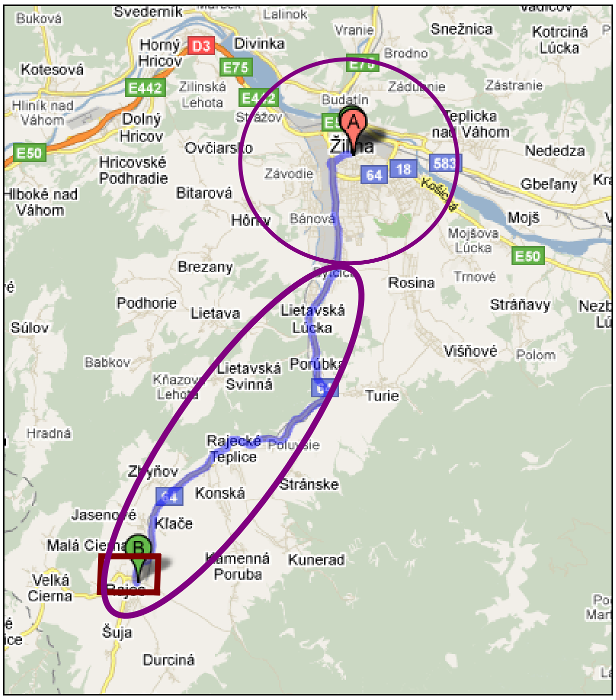

Figure 4. Žilina area integrated transport system

2.3. Košice

In Košice, the second largest city of Slovakia, the experiment of integrated transport system was focused on the employees of US Steel. Similar to the one in Žilina, first of all the urban public transport and railway transport was integrated; later the suburban bus transport was integrated too. But the project was terminated because of unfavourable economic results.

3. Current Conditions for Integrated Transport System Creation

3.1. Legislation on Passenger Transport in Relation to the Integrated Transport Systems

Until recently, the law of the Slovak Republic did not support the creation of the integrated transport systems. The amendment of Act 168 from 1996 about the road transport from year 2007 defines the integrated transport system and sets the duty for regions and municipalities to support the creation of the integrated transport systems.

"The region or municipality supports the creation of the integrated transport system in the passenger transport. The integrated transport system means the connection of the railway transport services with urban transport system and suburban bus transport into one system of lines in the way that it brings the advantages of unified tariff, transport conditions and unified transport documents."

The similar new passage containing the support for the integrated transport systems is included in the act for railway transport:

"The integrated transport system means the connection of the railway transport services with the system of urban transport and suburban bus transport into one system in which the lines are interconnected and the connections are harmonized. This is based on the unified time-table. The ticket sell system is unified as well. The integrated transport system has to be able to perform the trips on the interconnected lines with only one transport document."

It appears from above mentioned that for now there are only basic support defined. More detailed elaboration of each part of integration, the process of integration, the conditions for all involved parts are absent in both acts.

The government of the Slovak Republic issued some documents relating to the public passenger transport. In 2002 it was the conception of regional transport policy creating. The integrated transport system is mentioned there as one of the most effective ways for the share of public passenger transport to be maintained or increased.

Another support of the integrated transport system is included in the document "Transport Policy of the Slovak Republic till 2015" from 2005. One of the aims is to provide the support of inhabitants' mobility by developing and operating of integrated transport systems. The integrated transport should provide suitable, safe and economical transportation of passengers. It is necessary to create the unified transport conditions, tariff, transport documents, coordinated timetables, complex information transport systems and relevant transfer terminals. The implementation of the integrated transport systems can be at two levels, either in the area of city and the suburban area, or in the region area.

In 2007 the Ministry of Transport, Posts and Telecommunication of the Slovak Republic agreed the Operational programme Transport 2007 – 2013. It is the programme document for drawing from EU funds in the transport segment. The infrastructure of the integrated transport system is one of preferred axis in this document. As the more exact fact it is mentioned that the strategy is focused mainly on the integration of the public railway passenger transport, its support and preference in two largest cities of the Slovak Republic – Bratislava and Košice. The railway infrastructure should be the base for transport system and the other transport modes.

The government of the Slovak Republic adopted the Resolution on the development of public passenger transport. The integrated transport system is proposed as one of the provisions whereas the legislative support and the creation of the transport integrators are the other provisions included in this document. The legislative support means:

- to set down the duty to integrate the public passenger transport at the regional level and the subsidies determined by integration;
- to set down the method of allocating the financial resources for integrated transport systems and to limit the number of parallel lines according to the transport area service;
- to enable to create the transport integrator including setting down its competences;
- to adjust the competences of regions in the area of regional railway transport.

The activities which should be provided by integrator should be also set down by legislation.

3.2. Tariff Legislation

The tariff integration has the key role in the integration process. On one hand the tariff and tariff conditions should be set to make the system attractive for passengers, on the other hand it should provide the revenues for all the involved transporters. Within the tariff integration it is necessary to integrate the different tariffs of all involved transporters, the tariff documents and the transport conditions.

The integration of different tariffs has to be in compliance with the legislative framework. The key problem in the Slovak Republic regarding the tariff is the fact that the maximum prices for suburban bus transport, railway transport and urban transport are fixed by different administration. From 2005 the prices for suburban bus transport are regulated by regions. The prices for railway transport are regulated by the office for regulation of railway transport. Now the process of movement of the competences from the office to the regions is implemented. But in this time the regions do not have the full competence to set the prices for railway transport. The urban transport is regulated by the municipalities.
In Table 2 the differences in the current prices are shown between the suburban bus transport (SBT) and the railway transport (RT). There are also shown the prices when the passenger uses the transport card in the suburban bus transport (SBT-TC). In this case the prices are lower.

The prices are presented for single ticket. Also there are more differences regarding the assortment of season tickets, special tickets and their prices in the tariffs of each transporter.

Table 2. Comparison of prices between suburban bus and railway transport

The comparison of prices in suburban bus transport and railway transport			
Distance (km)	SBT (Eur)	SBT – TC (Eur)	RT Eur)
1 - 5	0,50-0,60	0,37-0,43	0,26
6 - 10	0,60-0,65	0,43-0,53	0,40
11 - 15	0,80-0,90	0,66-0,80	0,60
16 - 20	0,90-1,00	0,80-0,86	0,80
21 - 25	1,20	1,06	1,06
26 - 30	1,50	1,36	1,18
31 - 35	1,70	1,59	1,38
36 - 40	1,80	1,69	1,58
41 - 45	2,00	1,86	1,92
46 - 50	2,30	2,12	2,18
51 - 55	2,50	2,36	2,52
56 - 60	2,60	2,49	2,72
61 - 65	3,00	2,85	2,98
66 - 70	3,00	2,85	3,18
71 - 75	3,40	3,19	3,72
76 - 80	3,40	3,19	3,72
81 - 85	3,90	3,75	4,18
86 - 90	3,90	3,75	4,18
91 - 95	4,30	4,15	4,78
96 - 100	4,30	4,15	4,78

Data sources: [3][4]

3.3. Present Conditions - Conclusion

As resulted from the above facts the legislation gives the very common base for the creation of integrated transport systems in the Slovak Republic. There are still many areas and problems, which have to be solved and which have to have the support in legislation. The other problem is the goodwill of transporters, regions, municipalities for cooperation and agreement in the key parts in the process of the creation of integrated transport process.

4. Proposal of Basic Parts of Tariff Integration for ITS in the Slovak Republic

The basic task of integrated transport system is to offer the advantages for passengers to prefer the public transport against the individual automobile transport. The main advantages should be:

- simple and intelligible system for passengers,
- the sequence of all the lines and coordinated timetable,
- the one ticket from origin to destination regardless of the transport mode or transporter,

- the advantageous ticket prices,
- unified selling, dispatching and information system.

The experiences of the countries where the integrated transport systems are operated for many years show that these advantages are very attractive for passengers. When the system is clear and intelligible for the inhabitants and it brings mainly the price and time advantages, the increasing number of passengers is the result.

4.1. Legislation Support

The basic problems of creating the integrated transport systems were mentioned in the previous chapter. The following two main aims should be achieved:

1) more detailed support for integrated transport systems,
2) one decision-making place for setting the prices.

1. For more detailed support it is necessary to create and admit the act about the public passenger transport. This act would solve the issue of the public passenger transport and also it would include the issue of integrated transport systems. There were some attempts inthe act about public passenger transport but they were not successful. Till this time the act about road transport and railway transport have been only revised.

The act about the public passenger transport should include the following parts regarding the integrated transport systems (ITS):

- the process of creating the integrated transport system:
  - the creation of society which will provide the management of ITS,
  - the legal form of society,
  - the necessary steps for creating ITS,
  - the discretions and duties for all involved in the process of preparation, etc.;
- the operating of integrated transport system:
  - the tasks and competences of ITS coordinator,
  - the creation of prices and tariff and transport conditions,
  - the transport coordination,
  - the discretions and duties for all involved,
  - the way of revenues diving, etc.

2. The coordinator (society or region) should have the competence to set the prices for all transport modes involved in the integrated transport system. In Fig. 5 the present state is shown; in Fig. 6 the proposal of solution is displayed.

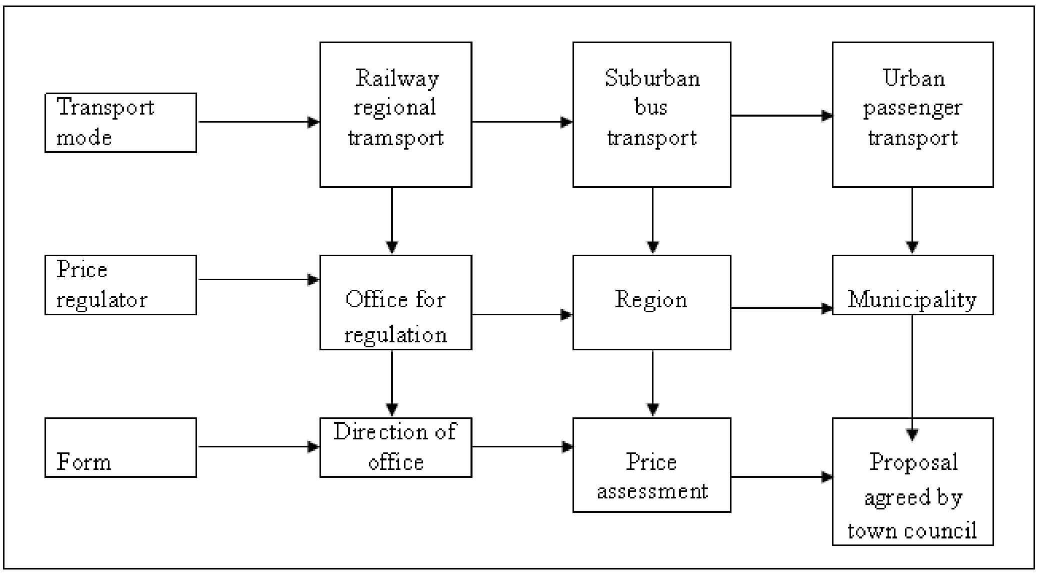

Figure 5. Present state of the price setting

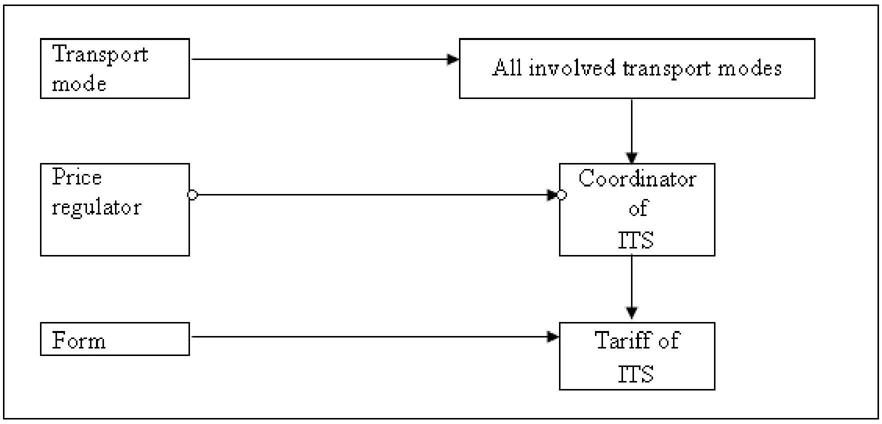

Figure 6. Proposal for tariff coordination

4.2. Proposed Area

The basic step in the first phase of preparation is to choose the area where the integrated transport system will provide the transport services. This issue is important from two points of view: first, the chosen area has an influence on the other parameters of ITS, such as tariff structure and operation of ITS. The second reason is that this issue is related to the competences of state and local authorities and to the tasks of ITS coordinator.

Generally, two different principles can be used:

1. ITS will cover the whole chosen area – so called “complex integration from the first moment” – ITS covers the whole area from the first moment of the system start-up.
2. The parts of area will be gradually integrated to ITS – so called “gradual integration” – it can be planned or it can be “spontaneous” (e.g. the later decision of municipalities to join in).

The administrative division is another important factor in terms of the area extent selection process. It is also related to the competencies of local authorities and it can influence the fact who will have a role of coordinator.

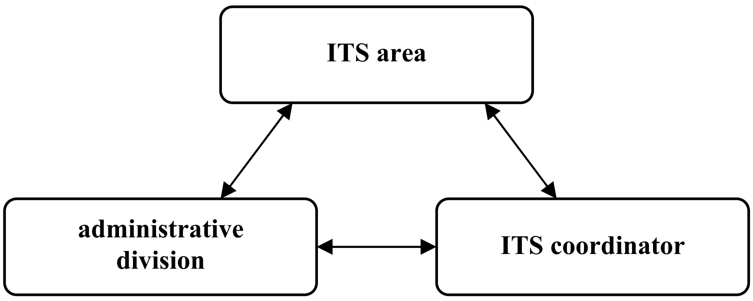

Figure 7. Mutual interconnection of elements

The territory of Slovakia is divided into 8 large regions and 79 smaller districts/counties. Regarding this fact the following possibilities of ITS creation can be defined:

1. ITS will cover only the part of region, which includes the following possibilities:
   a) the area of the city and its attraction zone – it results from the need to provide the integration of different transport services;
   b) the area of more cities and their attraction zones – these districts are usually strongly interconnected;
   c) the area with specific character (e.g. the tourist area of High Tatras).
2. ITS will cover the whole region – usually there is one authority, which can act as the coordinator regarding its competencies.

3. ITS will cover the area of more regions – the strong interconnection between the regions exists, for example two big cities of two regions are situated close to each other and it has the influence on the trips of people in these regions.
4. ITS will cover the chosen area and also it will be connected with ITS in the area of adjacent state.

It is supposed that the second possibility – ITS covering the whole region – will be used in the conditions of Slovakia. There are also the government resolutions, which recommend this type of integration. It is related to the region authority and its present and future competences regarding the public transport. Today the regional authority has the competences to order the local bus transport. The competences for regional railway transport are expected to be moved to the regional authority next year (2012). It will give more possibilities to provide the integrated transport in the area of regions.

The integrated transport system covering the area of more regions is another suitable possibility which could be considered in the case of Slovakia. It is considered in the case of Bratislava and Trnava region in the south-west and Košice and Prešov region in the east (Fig. 8).

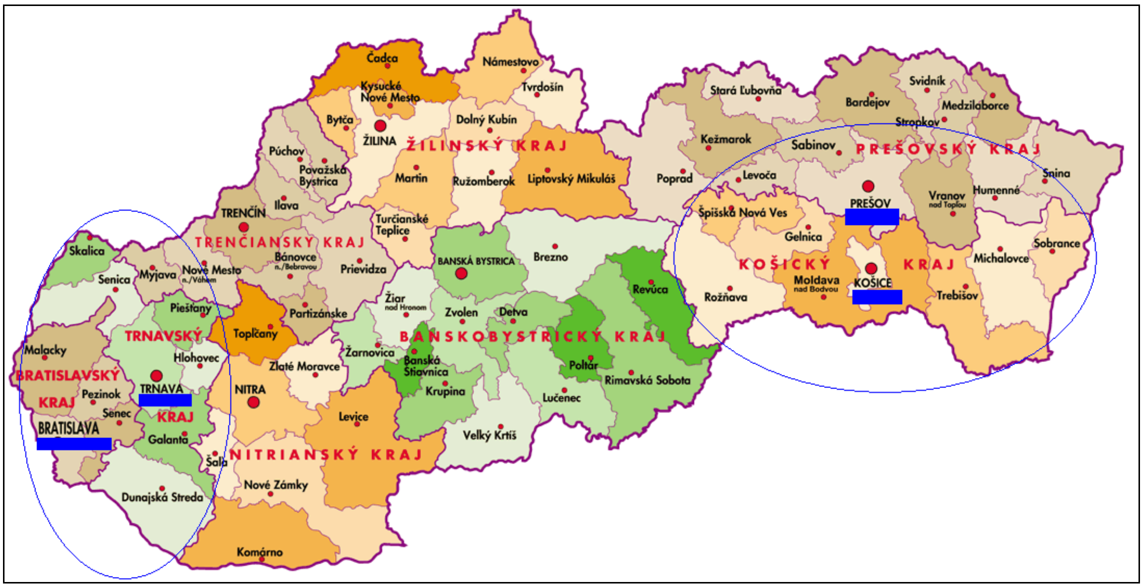

Figure 8. Regions, which can be considered for common integration

As it was already mentioned in chapter 2.1, the integrated transport system of Bratislava has been prepared for several years. Bratislava region is neighbouring to "South Moravian integrated public transport system" in Czech Republic and "Vienna region integrated transport system" in Austria. The representatives of these two ITS have already negotiated with the representatives of Bratislava ITS about the possibility to interconnect all these systems in the future regarding the inhabitants existing trips between these three regions.

4.3. Tariff Structure

The choice of tariff structure is another very important part of integration and it should be considered carefully because it is recommended that during the first years of ITS operation there should not be an extensive changes in the tariff structure.

The tariff structure can be:
a) irregular form of zones,
b) regular form of zones – honeycombs,
c) concentric circles, which can be also radially divided into so called sectors.

Each of these forms has its own advantages and disadvantages and many important factors have to be taken into account in the process of preparing the phase of ITS.

From the passengers' point of view two cases can happen:

1. The size of the zone is equal or approximates to the original zone margins of transporters. This means the changes will have the minimal influence on the ticket prices.
2. The sizes of zones are different from the original margins, and this fact can have a positive or negative influence on the ticket prices.

The planned tariff structure should meet the following aims:

– not to cause the disadvantage ticket prices based on the tariff structure for passengers, and if there is any disadvantage, it should touch as few passengers as possible and should not touch mainly the regular passengers,
– to create the tariff structure on the base of which the tariff and tariff conditions will be created and will be intelligible for passengers,
– to support the passengers' interest to use the integrated transport system in combination with the ticket range.

If it is considered, that the integrated transport system will cover the area of region in Slovakia it is supposed, that the irregular zones will be proposed as the tariff structure. The main advantage of this type of tariff structure is that the zones can be created depending on the habitation density, railway and road infrastructure density, existing passengers' trips in the area, original tariff margins of involved transporters.

The process of tariff zone creation is the following:

1. Analyses of the current tariff margins of transporters involved in projecting the future integrated transport system.
2. Identifying the municipalities, which will be included in one zone. It is supposed that if there is the city with public passenger transport, the area of this city will represent one zone, which can be divided even to more zones regarding the size of the city.
3. Verifying of created zoning – after elaborating of all proposed ticket prices the analyses of the impact of prices on passengers should be done.

4.4. Integrated Tariffs

The transporters enter the integrated transport system not only with different tariff margins, but also with different price levels and tariff conditions. In the case of the Slovak Republic, it can be said that the most "conflicted" part will be to integrate the prices of suburban bus transporters and railway transporter. This "conflict" can be perceived from the following points of view:

- **orderer's standpoint** – ITS coordinator will have a role of an intermediary between the supply and demand. It provides the operation of linkings by ordering them. They have to pay the subsidies for transporters and so they try to optimize the number of links. On the other hand, they have to provide a basic transport connection on the area for the inhabitants and provide the social discounts for some categories. They have to provide the socially sufferable prices for the passengers.

- transporter's standpoint – Each of transporters enters the ITS with its own expectations. The main aim is to make the public passenger transport more attractive for inhabitants to use it for their everyday trips. The price is one of the key issues and the transporters have to agree on the unified prices.

- passenger's standpoint – the passengers are accustomed to the certain price level. They are willing to accept its increase only to the certain level. If the increase is larger the passengers start to think about other possibilities or they are willing to accept the higher price but with some compensation as a higher quality of services. It can be said that on the contrary the passengers will expect prices that are more favourable when the integrated transport system is already running. Generally, the passengers and their acceptance of price level is the key part of later ITS success.

When the integrated tariff is prepared, first the prices of single tickets have to be set as the basis for the time tickets. In addition, the analysis of the discounts has to be done regarding the horizontal and vertical price digression of all the tickets. Two parameters have to be set:

- parameter of fare advantage regarding the number of trips (the validity of time of the ticket),
- parameter of fare advantage regarding the travel distance.

The proposal of parameter regarding the number of travelled zones:

- it will be based on the tariff structure and the size of zones,
- the value of parameter will be decreasing with increasing number of travelled zones, or its value is constant from the certain distance,
- in case of season tickets the value of parameter will be lower than in case of single tickets. It is the way of supporting the season tickets selling.

The proposal of parameter regarding the number of trips:

- it will be based mainly on the range of season tickets,
- its value will be constant for trips independently of the number of travelled zones,
- the value of the parameter will decrease with increasing time of season ticket validity,
- if it is economically acceptable, the value of the year season ticket will be 10 – for the reason of marketing activities,
- the value of parameter for season tickets will be set to provide using of season tickets.

Table 3. Proposal of parameter

Season ticket	Parameter
day	2 - 3
week	3 - 5
month	10 - 20
year	10

In case of transporters which are considered to be involved in the integrated transport systems in Slovakia, there are differences in the ticket ranges and current parameters between the suburban bus transport, railway transport and urban public transport. There are no season tickets for the trips within suburban bus transport and in case of railway transport there is only the week tickets, used as the season tickets. The season tickets are very important part of ITS tariff so it is evident that the preparation of the integrated tickets and prices will be a difficult process, which will include setting up of the parameters for season tickets.

4.5. Integrated Tariff Conditions

The tariff conditions mainly include the reduced fares for the various categories of passengers, the conditions for applying the claim for the reduced fare, for free transportation.

The discounts can be divided from the following point of view:

- social – they support the passengers with lower incomes,
- public interest – for pupils and students, the support of certain groups of inhabitants who help society in some way (e.g. blood donors),
- transport-technological – e.g. the support of trips out of traffic peak for better capacity utilization,
- employees – for employees of transport companies and their family members.

The main aim of the reduced fares is to support the regular or irregular passengers for more trips and to attract more inhabitants for using public passenger transport for their everyday trips.

5. Conclusions

The process of integration is very difficult. The tariff system is the key part of it because it has the financial impact on the passengers and their decision to use or not to use the public passenger transport for their regular but also irregular trips. The tariff system has to be solved comprehensively. Each part of the tariff system follows the other one and they influence each other. It is necessary to analyze the current tariff system of transporters, involved in the integrated transport system. The following proposal of tariff system should be attractive for the passengers and simultaneously financially interesting for the transporters and municipalities. The tariff integration together with the transport integration should make the public passenger transport more attractive and should provide increasing number of passengers.

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COMPARATIVE ANALYSIS OF APPROACHES TO ANALYTICAL MODELLING OF TRAFFIC FLOWS AT AN INTERSECTION

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Different approaches to analytical modelling of traffic flows at an intersection are considered. The general principles are outlined, the set of existing models is presented. Results obtained by different models are compared to the data received from the experiment. The recommendations for practical usage of the presented models are made.

Keywords: highway intersection, queuing models

1. Introduction

In recent years the increase in the number of vehicles has led to traffic flows intensity growth. As a result, vehicle delay on intersections has increased. Delay reduction has become the prior goal of researchers in traffic engineering. Obviously, this problem is solved by regulation of the traffic lights for appropriate traffic control. For calculating performance measures of traffic control, analytical models are being utilized. There are several approaches, the majority of which are based on queuing theory and have the following general principles.

The entire intersection is so called queuing system with “vacations” of the servers, i.e.

- the intersection is being modelled by the server (i.e. vehicles passing through the intersection is the service process), and only one request can be processed at the particular time,
- the server is being switched off periodically and then, after some time interval it resumes processing (this models prohibition and permission of movement),
- traffic flow is a service request flow,
- quantity of vehicles, that physically can be located on the portion of the highway to the previous intersection, is maximum queue length.

It should be pointed out that in whole these principles are applicable only for non-conflicting traffic flows modelling (through- and right-turning flows particularly, unlike left-turning flows, when vehicles have to wait for gap appearances in the contra flow to pass the intersection). Precisely this case is considered in this paper. Since mutual influence of flows is exempted, they can be analyzed separately.

Different approaches to modelling use various presentations of incoming request flows and service disciplines. Interarrival and service time may be deterministic or random values having certain distributions.

A large amount of researches is devoted to the considered problems, particularly the following: Haight F.A. (1963) [1]; Mannering F.L., Kilareski W.P.и Washburn S.S. (2005) [2]; Afanaseva L., Bulinskaya E. (2009) [3] etc. Interesting variants of M/G/1 queuing with vacations applied to the Internet protocol analysis are considered in research paper by Saffer Z. and Telek M [4].

The goal of the present research is the comparison of the results obtained by different models with experimental delay data, measured on a real traffic flow.

2. Description of Models

2.1. General Terms

One flows movement at an intersection is being defined by the following parameters.

Transport flow intensity is denoted by the symbol λ and is expressed in vehicles per second.

Service intensity (vehicle amount that can pass the intersection with continuous flow in a time unit, assuming the movement permitted) is denoted by the symbol μ and is expressed in vehicles per second as well.

Queue length limitation is denoted by the symbol r and is expressed in vehicle units.

Cycle – one complete sequence of signal indications (greens, yellows, reds) [2].

Traffic signals cycle length (henceforth *cycle length*) is the total time for the signal to complete one cycle. This measure is denoted by the symbol C and is expressed in seconds [2].

Effective green time for the flow is the time per cycle during which a traffic movement is effectively utilizing the intersection (this time is most likely different from the green signal indication displaying time). This measure is denoted by the symbol g and is expressed in seconds [2].

Likewise, it may be given the *effective red time* – the time per cycle during which a traffic movement is not utilizing the intersection efficiently. However, this is not necessary, because its value can be calculated as $C - g$ [2].

2.2. Model Based on the D/D/1/∞ Queuing System with Vacations

F.L.Mannering, W.P.Kilareski and S.S.Washburn in their research "Principles of Highway Engineering and Traffic Analysis" offer the following approach to the traffic movement modelling at an intersection [2].

The intersection is being considered as a D/D/1/∞ queuing system with the servers vacations in the following fashion:

- Interarrival time is deterministic (constant),
- Service time is deterministic,
- There is one server, which switches off periodically,
- The queue length is unlimited.

The following parameters are given.

- λ – intensity of traffic flow, consequently $1/\lambda$ is a constant vehicle interarrival time interval,
- μ – intensity of service, consequently $1/\mu$ is a constant time interval, needed by vehicles to pass through the intersection,
- g – efficient green time allocated to the considered flow,
- C – cycle length,
- the cycle start instance matches the efficient green time start.

Let us consider the calculation of efficiency measures of the intersection's operation, according to this model.

Authors point out, that their suggested method is the only applicable in case where the intersection capacity exceeds arrivals for all cycles. Consequently, the queue is always empty at the start of the efficient red. Such queuing system is shown in Fig. 1.

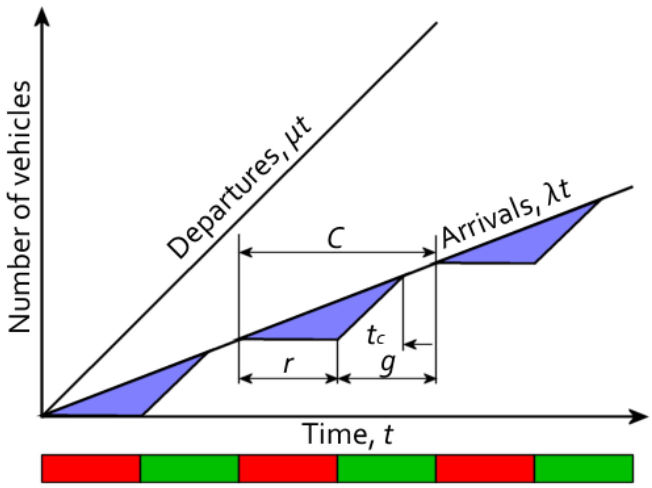

Figure 1. D/D/1/∞ signalized intersection queuing

In this figure, in addition to the previously defined, the following terms are used:

t – total transpired time in seconds,

t_c – time from the start of the efficient green until queue clearance in seconds,

r – efficient red time in seconds.

The "arrivals, λt" curve gives the total number of vehicle arrivals at time t, and the "departures, μt" curve gives the slope of vehicle departures during the efficient green. Note that the per-cycle arrivals will be λC, and the capacity will be μg.

Basing on this approach, the authors suggest the following calculations of the queuing system efficiency measures.

The time to queue clearance after the start of effective green, t_c:

$$t_c = \frac{\rho r}{(1-\rho)}, \tag{2.1}$$

where $\rho = \lambda / \mu$ – traffic intensity and it should be pointed out that

$$\lambda(r + t_c) = \mu t_c .$$

The proportion of the cycle with a queue P_q:

$$P_q = \frac{r + t_c}{C} . \tag{2.2}$$

The proportion of vehicles stopped P_s:

$$P_s = \frac{\lambda(r + t_c)}{\lambda(r + g)} = \frac{\mu t_c}{\lambda C} = \frac{t_c}{\rho C} . \tag{2.3}$$

The maximum number of vehicles in queue Q_{max}:

$$Q_{max} = \lambda r . \tag{2.4}$$

Total vehicle delay per cycle D_t:

$$D_t = \frac{\lambda r^2}{2(1-\rho)} . \tag{2.5}$$

The average delay per vehicle d_{avg}:

$$d_{avg} = \frac{\lambda r^2}{2(1-\rho)} \times \frac{1}{\lambda C} = \frac{r^2}{2C(1-\rho)} . \tag{2.6}$$

The maximum delay of any vehicle d_{max}:

$$d_{max} = r . \tag{2.7}$$

Of great interest here is the average delay per vehicle d_{avg}, because it is the most direct indicator of the intersection operation efficiency. As well as the proportion of vehicles stopped P_s; as the signal operation optimization is usually directed towards the minimization of this value. However, we are also interested in the maximum queue length Q_{max}, which is actually the average queue length at the efficient green start Q_g (for this model, also at the cycle start).

Authors point out that this approach provides reasonably accurate results for intersections with low or moderate flow rates, generally up to $\lambda C / \mu g$ ratios of about 0.5. Otherwise, it is recommended to use models based on Poisson flows, as it is described further.

2.3. Model Based on the M/M/1/∞ Queuing System with Vacations

L.G.Afanaseva and Y.V.Bulinskaya in their research paper "Stochastic models of transport flows" [3] present the following approach to the traffic movement modelling at an intersection. The intersection is being considered as a M/M/1/∞ queuing system with the servers vacations in the following fashion:

- vehicle interarrival intervals are independent exponentially distributed random values,
- service times are independent exponentially distributed random values,
- there is one server, which switches off periodically,
- the queue length is unlimited,
- efficient green time g is an exponentially distributed random value,
- efficient red time r is an exponentially distributed random value.

The following parameters are given.

- λ – traffic flow intensity,
- μ – service intensity,
- γ_1 – parameter, which defines the effective green time g duration,
- γ_2 – parameter, which defines the effective red time r duration.

Since the efficient green g and the efficient red r times are exponentially distributed random values with parameters γ_1 and γ_2, their mean values are equal to $1 / \gamma_1$ and $1 / \gamma_2$ respectively.

For average stationary queue length through the cycle, the following expression is suggested:

$$m = \frac{\lambda\left(1-\frac{1}{\theta\gamma_1}\right)\left[1+\frac{\mu}{\gamma_1}\left(1-\frac{\lambda}{\mu}\right)\left(1-\frac{1}{\theta\gamma_1}\right)\right]}{\mu\left(1-\frac{\lambda}{\mu}\right)\left(\frac{1}{\theta\gamma_1}-\frac{\lambda}{\mu}\right)}, \tag{2.8}$$

where

$$\theta = \frac{1}{\gamma_1}+\frac{1}{\gamma_2} \tag{2.9}$$

is the average cycle length.

2.4. Model Based on the M/G/1/r Queuing System with Vacations

A.M.Andronov offers the following approach to the traffic movement modelling at an intersection [5]. The intersection is being considered as a M/G/1/r queuing system with the servers vacations in the following fashion:

- vehicle interarrival intervals are independent exponentially distributed random values, consequently the respective traffic flow is a Poisson flow,
- service process is defined by giving the maximum number of services per cycle,
- there is one server, which switches off periodically,
- the queue length is limited by the number r.

The following parameters are given.

- λ – traffic flow intensity,
- k – maximum number of services per cycle, $k \le r$,
- g – efficient green time allocated to the considered flow per cycle,
- C – cycle length,
- the cycle start instance matches the efficient red time start.

Since vehicle interarrival intervals are distributed exponentially, number of vehicles arriving per cycle has Poisson distribution with parameter λC.

Let us consider two cycles of the intersection operation: the current (new) and the preceding. We will give the symbol p_i to the stationary probability of i requests present in the system at the start of the current cycle. If at the beginning of the preceding cycle there were less than k vehicles in the queue, then they have all passed and the queue is empty at the current cycle start. Obviously,

$$q = \sum_{i=0}^{k} p_i \tag{2.10}$$

is the probability of all arriving vehicles passing through during the current cycle and no queue will be left for the one that follows. Then,

$$p_0 = q \cdot \frac{\lambda^0}{0!} \cdot e^{-\lambda} = qe^{-\lambda} \tag{2.11}$$

is the probability of an empty queue at the start of the new cycle.

If there were $k + j$ vehicles, then k of them would have passed through and j would be left in the queue. Then for the new cycle start, taking into account the newly arrived vehicles, the probability of the presence of i vehicles on the current cycle can be calculated using the following formulae:

$$\begin{aligned} p_i &= q \cdot \frac{\lambda^i}{i!} \cdot e^{-\lambda} + \sum_{j=1}^{i} p_{k+j} \cdot \frac{\lambda^{i-j}}{(i-j)!} \cdot e^{-\lambda}, \quad i = 1,\ 2, \ldots, r-1, \\ p_r &= q \cdot \frac{\lambda^r}{r!} \cdot e^{-\lambda} + \sum_{j=1}^{r-k} p_{k+j} \cdot \left(1 - \sum_{n=0}^{r-j-1} \frac{\lambda^n}{n!} \cdot e^{-\lambda} \right). \end{aligned} \tag{2.12}$$

Formulae (2.11) and (2.12) allow the application of an iterative method for calculating stationary probabilities $\{ p_i \}$. Uniform distribution can be used as initial probability values

$$p_i = \frac{1}{1+r}, \quad i = 0,\ 1, \ldots, r. \tag{2.13}$$

If for the queuing system being analyzed there is a steady state, then results of each iteration will differ less from the previous one. Given any precision $\varepsilon > 0$, it is possible to obtain the stationary probability distribution. Convergence of the iterative procedure is ensured by existence of a steady state, which holds true if

$$\lambda C < k\ . \tag{2.14}$$

Having obtained the stationary probability distribution of queue lengths for the cycle start instance, we can calculate the rest of the efficiency measures listed in section 2.2. Particularly, an average queue length at the start of the efficient red Q_r:

$$Q_r = \sum_{i=0}^{r} i p_i\ . \tag{2.15}$$

An average queue length at the start of the efficient green will be greater by $\lambda(C - g)$ in average. Hence, an overall (during the cycle) average queue length m can be calculated as

$$m = Q_r + \frac{1}{2} \lambda \cdot (C - g)\ . \tag{2.16}$$

2.5. Model Based on the M/M*/1/∞ Queuing System with Vacations

Below there is one more approach to the traffic movement modelling at an intersection based on a M/M/1/∞ queuing model with vacations [5]. The model assumes that

- vehicle interarrival intervals are independent exponentially distributed random values,
- service time is distributed exponentially,
- there is one server, which switches off periodically,
- the queue length is unlimited.

The following parameters are given.

- λ – traffic flow intensity,
- μ – service intensity,
- g – efficient green time allocated to the considered flow per cycle,
- C – cycle length,
- the cycle start instance matches the efficient red time start.

Thus, here, unlike in the model from section 2.3, the g and C parameters are constant.

Let us denote the number of vehicle arrivals per cycle by the symbol L. Since vehicle interarrival intervals are distributed exponentially, the number of vehicles arriving per cycle L has Poisson distribution with parameter λC:

$$P\{L=l\}=\frac{(\lambda C)^l}{l!}e^{-\lambda C},\ l=0,\ 1,...$$

Let us denote the number of vehicles passing through the intersection per cycle by the symbol K. Likewise, the value K has Poisson distribution with parameter μg. However, this time the Poisson distribution is truncated from the right by the number of vehicles at the intersection.

Let us consider two intersections operation cycles: the current (new) and the preceding cycles. We will denote the number of vehicles at the intersection on the current and previous cycles by the symbols I and J respectively. The probability distributions of queue lengths on these two cycles are related by the following system of equations.

$$\begin{aligned}
&P\{I=0\}=\sum_{j=0}^{\infty}P\{J=j\}\sum_{l=0}^{\infty}P\{L=l\}P\{K\ge j+l\},\\
&P\{I=i\}=\sum_{j=0}^{i}P\{J=j\}\sum_{l=i-j}^{\infty}P\{L=l\}P\{K=j+l-i\}+\\
&+\sum_{j=i+1}^{\infty}P\{J=j\}\sum_{l=0}^{\infty}P\{L=l\}P\{K=j+l-i\},\\
&i=1,\ 2...r.
\end{aligned} \tag{2.17}$$

Thus, we have a system of equations for the probabilities $\{p_i=P\{I=i\}=P\{J=i\}\}$.

$$\begin{aligned}
&p_0=\sum_{j=0}^{\infty}p_j\sum_{l=0}^{\infty}\frac{(\lambda C)^l}{l!}e^{-\lambda C}\sum_{k=j+m}^{\infty}\frac{(\mu g)^k}{k!}e^{-\mu g},\\
&p_i=\sum_{j=0}^{i}p_j\sum_{l=i-j}^{\infty}\frac{(\lambda C)^l}{l!}e^{-\lambda C}\frac{(\mu g)^{j+l-i}}{(j+l-i)!}e^{-\mu g}+\\
&+\sum_{j=i+1}^{\infty}p_j\sum_{l=0}^{\infty}\frac{(\lambda C)^l}{l!}e^{-\lambda C}\frac{(\mu g)^{j+l-i}}{(j+l-i)!}e^{-\mu g},\ i=1,\ 2...r.
\end{aligned} \tag{2.18}$$

Like the system of equations from the previous section, it can be solved using an iterative method. Here, infinite queue length can be replaced by a finite number, providing the adequate result precision.

Convergence of the iterative procedure here, like in the previously described model, is ensured by the existence of the steady state. Here, it holds true if

$$\lambda C<\mu g\,. \tag{2.19}$$

Further, like in the method from the previous section, an average queue length for the efficient red start instance Q_r and an overall average queue length m can be calculated, using expressions (2.15) and (2.16) respectively.

3. Comparison of Analytical and Experimental Results

To obtain the experimental data, the traffic movement was monitored within an hour at the intersection of Gogolya and Lachplesha streets of the city of Riga. The monitored flow was allocated 30 seconds of the efficient green (g = 30) in C = 90 seconds signal cycle. The traffic flow had an intensity of λ = 0.109 vehicles per second, but the service intensity was estimated at μ = 0.4 vehicles per second. At the same time, the average queue length at the cycle start (start of the efficient green) was equal to 7.767 vehicle units. The average queue length at the start of the efficient red was less by $\lambda(C - g)$ in average. Then, the overall average queue length can be calculated as

$$m = Q_{max} - \frac{1}{2}\lambda \cdot (C - g)\,. \tag{3.1}$$

In our case m = 4.497 vehicle units.

Now, using this data, let us calculate the delay measures at the intersection using the previously described methods. To link efficiency measures of different types, we will use the Little's formula

$$m = \lambda \cdot T\,, \tag{3.2}$$

where m – average number of vehicles in the system,
λ – incoming flow intensity,
T – average sojourn time in the system.

The results of the calculations are shown in the Table 1.

Table 1. Efficiency measures of the intersection operation

	D/D/1/∞	M/M/1/∞	M/G/1/r	M/M*/1/∞	Experiment
Q_{max}	6.540	31.265	6.649	9.273	7.767
m	2.997	27.995	3.379	6.003	4.497
T	27.491	256.838	31	55.077	41.257

Here: Q_{max} – average maximum queue length,
m – average queue length (overall),
T – average sojourn time in the system (in seconds).

As it can be seen from the results of the calculations, none of the considered models gives sufficiently precise results. The closest to the experimental data were calculations based on the D/D/1/∞ and M/G/1/r queuing systems.

The least accurate calculations were those based on the M/M/1/∞ queuing system. This is natural, since according to this model, the time intervals, when movement is permitted and prohibited, are exponentially distributed random values. In reality, these intervals are deterministic, and judging by the considerable difference between the calculated and measured results, such assumption is unreasonable.

Most likely, when solving practical tasks, it is reasonable to choose the model based on the M/G/1/r queuing system, since it gives the most accurate results. As it was mentioned above, D/D/1/∞ based queuing systems are reasonably accurate in cases of relatively low intersection load. In the considered example the load ratio was $\lambda C / \mu g$ = 0.109×90/(0.4×30) = 0.8175.

4. Conclusion

In this paper, the common principles of analytical modelling of the operation of intersections were considered. Several known models, based on queuing theory were presented. The basic efficiency measures of its operation were as follows: the average sojourn time in queue by vehicles, the average queue length (overall), the average queue length at the start of the efficient green (average maximum length). These measures were calculated for all presented models on the basis of experimentally obtained data. The calculated results were compared to the measured ones. Basing on this, the recommendations concerning the practical use of the considered approaches were made.

Author expresses his gratitude to professor A.M.Andronov for his attention and significant help in preparation of this paper.

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Transport and Telecommunication Institute, Lomonosov 1, Riga, LV-1019, Latvia

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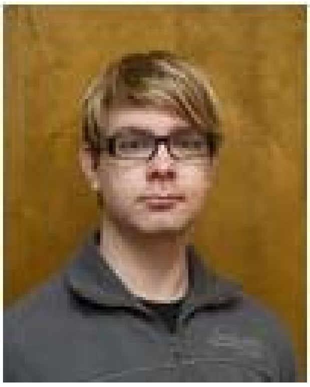

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 12, No 2, 2011 (Abstracts)

Dorokhov, O., Chernov, V. Application of the Fuzzy Decision Trees for the Tasks of Alternative Choices. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 4–11.

The article deals with solving the alternative choice problem on the base of fuzzy decision trees or fuzzy positional games, which peculiarity lies in using fuzzy quality estimation of decisions consequence and nature states. The proposed approach and numerical algorithm can be used for a large number of transport services problems. Among them, there are the investment decisions in the transport sector, the choice of types of trucks, cars, buses etc, the choice of variants for transportation organization, financial services problems and others. Corresponding example of practical calculations in the specialized program *Fuzicalc* for fuzzy numbers has been given and described.

Keywords: alternative choice problem, fuzzy decision trees, fuzzy positional games, *Fuzicalc* program

Henttu, V., Lättilä, L. and Hilmola, O.-P. Optimization of Relative Transport Costs of a Hypothetical Dry Port Structure. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 12–19.

Decreasing environmental emissions originated from transportation sector plays a big role in the strategies of EU. One way to decrease emissions is to shift freight transport from unimodal road transport to intermodal solutions. Dry port concept aims at increasing rail transport between seaports and inland intermodal terminals, which are called dry ports. Such a concept is in infancy in Finnish transportation network. The main transport mode used in Finland is unimodal road transport. The aim of this research is to study the effects of a hypothetical dry port structure in Finnish transportation network. The effects are researched with different gravitational models. They apply linear integer programming, and heuristics to find relative transport costs in each situation. Differences in road and rail network, and road and rail transport modes are taken into account. The results of the models argue that Finland could benefit from dry port network. Cost-efficiency of the Finnish transportation network could be enhanced by using up to five or six dry ports. In addition, by replacing road transport with rail transport the environmental impacts can be lowered considerably. However, by alternatively utilizing within wider scale dense seaport network of Finland, we could achieve even better environmental results – approach which has been neglected so far in the dry port literature.

Keywords: Dry port concept, Finnish transportation network, gravitational models, costs of transport, intermodal transport, optimization, linear integer programming

Klevecka, I. Short-Term Traffic Forecasting with Neural Networks. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 20–27.

The paper is dedicated to an advanced algorithm aimed at short-term forecasting of electronic communications traffic by applying non-linear neural networks. The algorithm incorporates three procedures, which allow automating the process of determining an optimal solution with minimal involvement and influence of expert assessment and human factors.

Keywords: telecommunications, electronic communication networks, traffic, neural networks, multilayer perceptron, algorithm, forecasting

Pavlyuk, D. Application of the Spatial Stochastic Frontier Model for Analysis of a Regional Tourism Sector. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 28–38.

This research is devoted to an econometric analysis of competition and cooperation on the regional tourism market between regions within the Baltic States (Estonia, Latvia, Lithuania). We estimate the relative regional efficiency levels of tourists' attraction and discovered factors affecting them. We propose an econometric approach called Spatial Stochastic Frontier, which corresponds to

a spatial modification of a stochastic frontier model. The study includes three alternative specifications of the spatial stochastic frontier model: distance-based, travel-time based, and border-based. It is intended to identify the influence of existing transport networks on research results.

On the base of the models' estimation results we analyse region-specific factors (tourism infrastructure, employment, geographical position and natural attractions) which affect the numbers of visitors and estimate regions' efficiency values.

We discover a significant level of inefficiency of tourists' attraction in Baltic States region and propose some ways to improve the situation.

Keywords: spatial stochastic frontier, efficiency, competition, cooperation, regional tourism, transport network

Poliaková, B. Conditions and Proposals of Tariff Integration for the Integrated Transport Systems in the Slovak Republic. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 39–49.

The integrated transport systems are the solution of decreasing utilization of public passenger transport in many cities and areas around the cities not only in the countries of the European Union. The statistics figures of using the public passenger transport in Slovakia have the decreasing tendency in the last 10-15 years. There were performed some experiments to create the integrated transport systems in Slovakia but they were not developed anymore. The presented article analyses the conditions for implementing the integrated transport systems in Slovakia with focusing on tariff integration. It points out the key elements in creation of integrated transport system to be attractive for passengers and to be advantageous to the transporters.

Keywords: integrated transport system, public passenger transport, tariff system

Ruskevich, I. Comparative Analysis of Approaches to Analytical Modelling of Traffic Flows at an Intersection. *Transport and Telecommunication*, Vol. 12, No 2, 2011, pp. 50–57.

Different approaches to analytical modelling of traffic flows at an intersection are considered. The general principles are outlined, the set of existing models is presented. Results obtained by different models are compared to the data received from the experiment. The recommendations for practical usage of the presented models are made.

Key words: highway intersection, queuing models

TRANSPORT and TELECOMMUNICATION, 12.sējums, Nr.2, 2011 (Anotācijas)

Dorohovs, A. Černovs, V. Fazi lēmumu pieņemšanas shēmu piemērošana alternatīvu izvēļu uzdevumiem. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 4.–11. lpp.

Rakstā tiek izskatīta alternatīvas izvēles problēmas risināšana uz fazi lēmumu pieņemšanas shēmas vai fazi pozicionālās spēles pamata, kuras īpatnība ir lēmumu konsekvences un dabisku stāvokļu fazi kvalitātes novērtējuma pielietojums. Piedāvātā pieeja un skaitliskais algoritms var tikt pielietots lielam transporta pakalpojumu problēmu skaitam. Starp tiem ir investīciju lēmumi transporta sektorā, smago mašīnu tipu, automašīnu, autobusu u.c. izvēle, transporta pārvadājumu organizācijas variantu izvēle, finansu pakalpojumu problēmas utt.

Rakstā tiek dots un aprakstīts atbilstošs praktisko aprēķinu piemērs specializētā programmā *Fuzicalc* fazi skaitļiem.

Atslēgvārdi: alternatīvās izvēles problēma, fazi lēmumu pieņemšanas shēmas fazi pozicionālās spēles, *Fuzicalc* programma

Hentu, V., Latila, L., Hilmola, O.-P. Hipotētiskās sausās ostas struktūras relatīvu transporta izmaksu optimizācija. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 12.–19. lpp.

Samazinot vides piesārņojumu, kas rodas no transporta pārvadājumu sektora ieņem nozīmīgu vietu ES stratēģijās. Viens veids, kā samazināt emisijas, ir novirzīt kravu transportu no viena veida autotransporta uz pārvadājumu risinājumiem. Sausās ostas koncepta mērķis ir dzelzceļa pārvadājumu palielināšanās starp jūras ostām un iekšzemes intermodāliem termināļiem, kuri tiek saukti par sausām ostām. Šāds koncepts Somijas pārvadājumu tīklā ir jaunums. Galvenais pārvadājumu veids, kāds tiek lietots Somijā, ir viena veida autotransports. Šī pētījuma mērķis ir noteikt hipotētisko sauso ostu uzbūves efektu Somijas pārvadājumu tīklā. Efekti tiek pētīti ar dažādiem gravitācijas modeļiem.

Tomēr, alternatīvi, izmantojot plašāk blīvo jūras ostu tīklu Somijā, mēs varētu sasniegt vēl labākus rezultātus vides aizsardzības jomā – pieeja, kas līdz šim bija neievērota, literatūrā par sausām ostām.

Atslēgvārdi: sausās ostas koncepts, Somijas transportēšanas tīkls, gravitācijas modeļi, pārvadājumu izmaksas, intermodālais transports, optimizācija, lineārā veselā skaitļa programmēšana

Kļevecka, I. Noslodzes īstermiņa prognozēšana ar neironu tīkliem. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 20.–27. lpp.

Raksts ir veltīts inovatīvajam algoritmam, kas domāts elektronisko sakaru tīklu noslodzes īstermiņa prognozēšanas uzdevuma risināšanai ar nelineārajiem neironu tīkliem. Algoritms ietver trīs procedūras, kuras ļauj automatizēt optimālā risinājuma meklēšanu ar minimālu eksperta vērtējumu un cilvēka darba iesaisti.

Atslēgvārdi: telekomunikācijas, elektronisko sakaru tīkli, noslodze, neironu tīkli, daudzslāņu perceptrons, algoritms, prognozēšana

Pavļuks, D. Telpas stohastiskās robežas modeļa pielietojums reģionāla tūrisma analīzēm. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 28.–38. lpp.

Šis pētījums ir saistīts ar konkurences un sadarbības tūrisma sektorā starp Baltijas valstu (Igaunijas, Latvijas, Lietuvas) reģioniem ekonometrisko analīzi. Mēs izvērtējam valstu reģionu efektivitātes līmeņus un arī faktori, kuri nozīmīgi ietekmē šo līmeņus. Mēs ierosinām jauno pētīšanas pieeju – Telpas Stohastisko Robežu, kura balstās uz pazīstama stohastiskās robežas modeļa telpas modifikāciju. Šajā pētījumā tika formulēti trīs alternatīvi telpas stohastiskās robežas modeļi – ar distances, ar ceļojuma laika un ar robežas tuvuma matrici, un atklāta transporta tīkla ietekme uz pētījuma rezultātiem.

Izmantot telpas stohastiskās robežas modeļi tiek analizēti reģionu zīmīgie raksturojumi (tūrisma infrastruktūra, nodarbinātības struktūra, atrašanas vieta un dabas pievilcīgums), kuri ietekmē ataicinātu tūristu skaitu. Tāpat tiek izvērtēts reģionu efektivitātes lielums.

Šajā pētījumā tika atklāti Baltijas valstu reģionu nozīmīgie neefektivitātes līmeņi un ieteikti situācijas uzlabošanas ceļi.

Atslēgvārdi: telpas stohastiskā robeža, efektivitāte, konkurence, sadarbība, reģionāls tūrisms, transporta tīkls

Poļakova, B. Tarifu integrācijas apstākļi un piedāvājumi integrētai transporta sistēmai Slovākijas republikā. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 39.–49. lpp.

Integrētās transporta sistēmas ir risinājumi sabiedriskā pasažieru transporta izmantošanas samazināšanai daudzās pilsētās un reģionos ap pilsētām ne tikai Eiropas Savienības valstīs. Statistiskie skaitļi par sabiedriskā transporta izmantošanu Slovākijā liecina par samazināšanās tendenci pēdējos 10-15 gados. Tika veikti daži eksperimenti, lai radītu integrētu transporta sistēmu Slovākijā, bet tie netika attīstīti. Dotais raksts analizēs apstākļus integrētās transporta sistēmas ieviešanai Slovākijā, galveno vērību veltot tarifu integrācijai. Tas liks uzsvaru uz galveniem elementiem integrētās transporta sistēmas izveidē, kurai ir jābūt pievilcīgai pasažieriem un mūsdienīgai pārvadātājiem.

Atslēgvārdi: integrētā transporta sistēma, sabiedriskais pasažieru transports, tarifu sistēma

Ruskevičs, I. Pieeju salīdzinošā analīze transporta plūsmu krustojumos analītiskai modelēšanai. *Transport and Telecommunication,* 12.sēj., Nr.2, 2011, 50.–57. lpp.

Rakstā tiek izskatītas dažādas pieejas analītiskai modelēšanai transporta plūsmām krustojumos. Tiek atzīmēti vispārējie principi un rakstā tiek parādīta eksistējošo modeļu rinda. Rezultāti, kas iegūti ar dažādu modeļu palīdzību, tiek salīdzināti ar datiem no eksperimentiem. Tiek dotas rekomendācijas modeļu praktiskai lietošanai.

Atslēgvārdi: ātrumceļu krustojumi, rindu modeļi

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