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ASSESSMENT OF VILNIUS CITY DEVELOPMENT SCENARIOS BASED ON TRANSPORT SYSTEM MODELLING AND MULTICRITERIA ANALYSIS

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Abstract. The paper describes the assessment of 3 Vilnius city development scenarios according to transport system parameters multi-criteria analysis and performing transport system modelling for 2015 and 2025 years. Vilnius city development scenarios such as concentrated development, extensive development and decentralized concentrated development have been evaluated from a transport viewpoint. Vilnius city development scenarios have been evaluated by using SAW (Simple Additive Weighting) multi-criteria method. According to this method development scenarios ranking calculations have been performed using transport system indicators. Urban transport system analysis model was developed for Vilnius conditions, which estimates the fuel consumption, average travel distance and driven time by car in morning peak hours depending on urban areas development scenario and socio-economic data. This model should be used when calculating new projects of the transport infrastructure (by-passes, new bridges) and when evaluating the economic efficiency of traffic organization projects.

Keywords: urban transportation, sustainable transport, urban areas development, transport system modelling, multicriteria analysis.

1. Introduction

The motivation for this research arose from an effort to assess transportation system performance in the Vilnius city. Most of cities in Europe struggle with the problems of urban sprawl and traffic congestion, yet mostly with little success. It is increasingly becoming clear that market forces will continue to lead to ever more dispersed, energy-wasteful urban settlement patterns. Land-use policies like the promotion of higher-density, mixed-use urban forms more suitable for public transport become necessary. But only a combination of land-use policies and transport policies promoting public transport and containing the private automobile can limit further urban dispersion and free metropolitan areas from their increasing auto-dependency. It is therefore necessary to develop modelling approaches in which the two-way interaction between transport and land use is modelled (Alvanides *et al.* 2001; Drobne 2003; Black *et al.* 2002).

Sharp bounce in motorization level invokes a lot of transportation problems. Many researches analyze urban areas development from the point of transportation system sustainability, which influences economical, social and environmental implications (Camagni *et al.* 2002; Grigonis and Burinskienė 2002; Burinskienė and Paliulis 2003). Other scientists also indicate political and institutional aspects (Čiegis and Gineitienė 2008).

Chosen urban areas development scenario invokes reorganization of the transportation system. Urban areas development should not precede without either adequate existing public transport provision or new public transport provided in tandem with the development (Anderson 1999; Siewczyński 2004).

The efficiency of urban transportation modelling is getting more and more important because of the increasing rate of mobility demand. To plan, control and organize urban transportation in the most efficient way, we also need to consider the aspects of land use (Tanczos and Torok 2007).

If sustainability is defined only in terms of energy consumption and air pollution emissions, the best solution may be more efficient and alternative fuel vehicles. But these strategies do not help achieve other planning objectives such as congestion reduction, facility cost savings, increased safety, improved mobility for non-drivers, or more efficient land use development; in fact, by reducing vehicle operating costs, it tends to increase these problems (Litman 2004). When all impacts are considered, strategies that improve travel options, encourage reduced driving, and create more accessible land use patterns are generally more sustainable overall.

Also multicriteria methods could be used for urban areas development scenarios evaluation. There is a wide range of methods based on multicriteria utility theory: SAW – Simple Additive Weighting (Ginevičius *et al.* 2008a; Sivilevičius *et al.* 2008); TOPSIS – Technique for Order Preference by Similarity to Ideal Solution (Zavadskas *et al.* 2006; Jakimavičius and Burinskienė 2007);

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COPRAS – Complex Proportional Assessment (Zavadskas *et al.* 2007); COPRAS-G – Complex Proportional Assessment of alternatives with Grey relations (Zavadskas *et al.* 2008). When wide range indicators of urban transport system are known, it is possible to use multicriteria methods for correct urban areas development scenario estimation (Ruichun 2007). Other researcher's analyse the idea that the disadvantages of some particular multicriteria evaluation methods could be compensated by the advantages of others. The integration of methods will be correct if there is a correlation between the values obtained by different methods (Ginevičius *et al.* 2008b). A more thorough analysis reveals that the above methods do not take into consideration the effect of the components of a particular evaluation method on the result obtained. This can be achieved only if multicriteria evaluation is based on graphical-analytical approach (Ginevičius and Podvezko 2008). Other researcher's investigating the application of game theory principles to civil engineering technology and management problems (Zavadskas and Peldschus 2009).

2. Methodology of Vilnius city development scenarios modelling

A common way to produce a transport forecast is to divide the calculations in the following modelling steps: Trip Generation, Trip Distribution, Mode Split and Network Assignments.

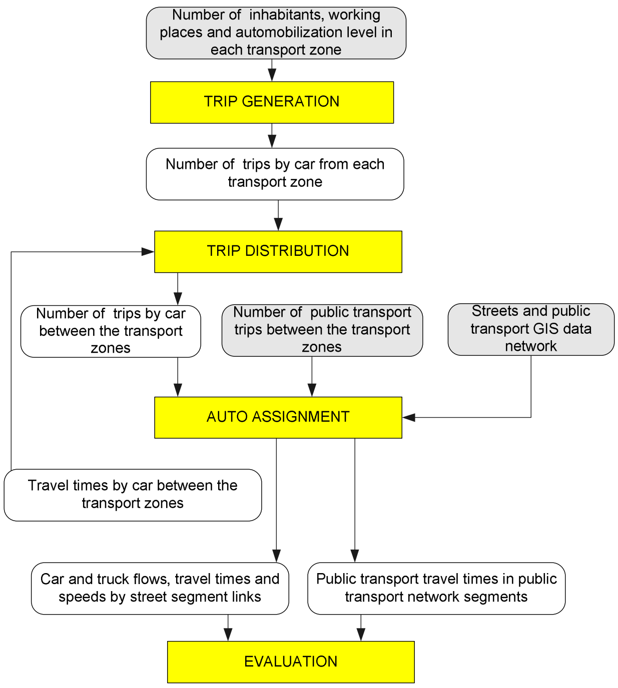

Fig. 1. Transport modelling steps

In a Trip Generation step, the number of car and truck trips that start in each zone and the number of trips that end in each zone are calculated. In the Trip Distribution step, the geographical trip pattern is calculated, which is determined by the number of car and truck trips between each pair of the zones. In Auto Assignment step, the car and truck trips between different zone pairs are simultaneously allocated to the network and travel times by car between the zones that are calculated. Trips by public transport are allocated to the public transport network and travel times by public transport between zones are calculated. In the last step, fuel consumption is calculated for the whole network (Fig. 1).

In the Auto Assignment Step, the car and truck trips between zones are allocated (assigned) to the road network according to the equilibrium traffic assignment. Also are assigned public transport trips to a public transport network segments. The behaviour assumption of the traffic assignment is that each driver tries to choose the route that takes him/her to the destination as fast as possible. The route travel time is calculated as the sum of link's travel times along the route. The link travel times are calculated by using increasing volume delay functions where the travel time along a route increases with the number of users. The consequence is that, between each origin/destination pair, only the routes that have minimal travel time are used. In the Traffic Analyst Model, the distribution of trips by routes is performed as a multi-class traffic assignment with generalized travel cost that is a modification of the traffic assignment based on plain travel times.

3. Description of Vilnius city development scenarios modelling

Forecasting of changes in land-use across the city is quite complicated as many factors are involved: policy packages, private initiatives, infrastructure development and changes in global economics. Consequently, it was decided to operate with developments that are targeted and hypothesized in the Vilnius Comprehensive Plan (Comprehensive plan of Vilnius city 2007).

Hence, other forecast factors were development within Vilnius transport infrastructure according to the Comprehensive Plan and its influence on traffic flows. Also transport system scenarios have been modelled according to infrastructure of the street network (Fig. 2).

Vilnius city transport system development scenarios have been modelled so that these main new projects of Vilnius city transport infrastructure would be developed till 2015:

- Equipment of the South Vilnius city bypass.
- Equipment of the West Vilnius city bypass.
- New segment of G. Vilko st. from Mokyklos street to A14 road.
- New two-level crossing at Žalgirio st. and Geležinio Vilko st.
- New two-level crossing at Ukmergės st. – Ateities st. – Laisvės st.
- Equipment of Šiaurinė st. from new West bypass to Žirmūnų st.
- Equipment of Pilaitės st. follow-up.
- New connection from Ozo st. at Buivydiškių st. to Laisvės st.
- New two level crossings at Kernavės st. – Ozo st. intersection.

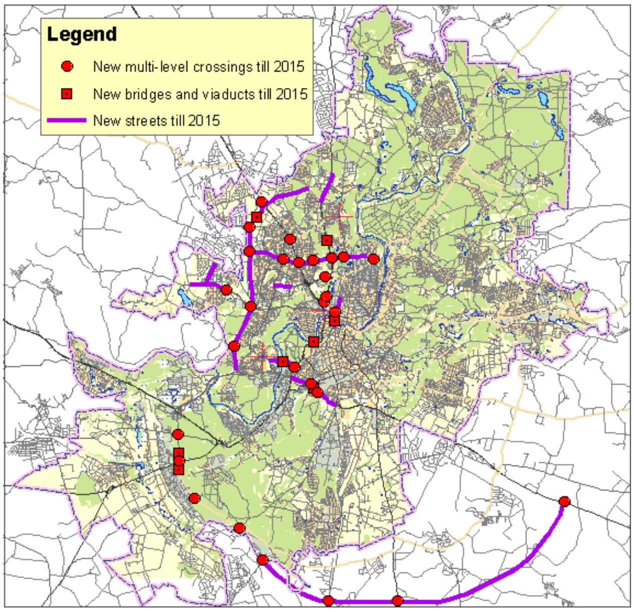

Fig. 2. Development of Vilnius bypasses and two-level crossing according to Vilnius Comprehensive Plan till 2015

- New connection through Bajorai village from Mokslininkų st.
- New connection from Kernavės st. to Tumo-Vaižganto st. through a new bridge.

It is possible to modify car ownership by changing the number of cars per person. The forecasted car ownership in 2015 is 570 cars per 1,000 inhabitants and ownership in 2025 is 590 cars per 1,000 inhabitants. The total number of car trips in the region is calculated as a function of changes in the total population and the car ownership as compared to the base year situation. The consequence is that if the population and car ownership is unchanged as compared to the base year situation, but the total number of workplaces increased, then the total number of car trips will be the same as for the base year situation. If the workplaces are relocated, for example, to more central areas, it will have an effect on the trip's pattern for cars, but not on the total number of trips.

The trip frequencies in the Trip Generation model are estimated and based on the travel behaviour in 2007. Hence, it is the level of car use for the base year situation that is included in the model. If there is a reason to believe that the cars will be used to a higher extent in the future, then the way to implement that in the Model is to increase the car ownership slightly in addition to the increase of the number of registered cars per capita.

Construction of scenarios should reflect expected and desired aspects of developments. There are many factors that could be changed in the model, consequently the number of scenarios will strongly and unreasonably increase. Scenarios were chosen for the comparison, they are in Table 1. Factors used in the scenarios are explained later.

Street Network 2007 – means the current street network and other infrastructure, i.e. length of streets, number of lanes, modes allowed, and volume-delay function index.

Street Network 2015 – means the development of bypasses and two-level crossings according to the Comprehensive Plan of Vilnius (see previous chapter).

Social Data 2007 – current situation, i.e. total number of inhabitants is 554,000, the rough number of workplaces is 310,000.

Social Data 2015 – number of inhabitants that increased to 576,000, the rough number of workplaces will be 409,000. The ratio between workplace and number of residents are more balanced, as were population and employment moves to suburban areas, especially in the Northern direction. The number of inhabitants decreased in the central part of the city, and most of the residents will have to travel towards the centre.

Social Data 2025 – number of inhabitants that increased to 600,000 and the rough number of workplaces will be 426,000.

Car ownership in 2007 – car ownership initially used in model. Such a rate was used in the model's calibration, and therefore it does not fully correspond to the real figures (official statistics could be questioned).

Car ownership 2015 – due to economical growth car ownership will increase rapidly to 570 cars per 1,000 inhabitants and car ownership in 2025 will be 590 cars per 1,000 inhabitants.

4. Discussion results of Vilnius city transport system modelling scenarios

All scenarios were evaluated by combining different factors and planning horizons according to Vilnius city urban areas development strategies. The model produced rational results for a peak-hour and is presented in Table 2. In order to see an effect of new transport system infrastructure development according to Vilnius city

Table 1. Chosen scenarios for Vilnius transport system modelling

Present situation		C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
Street Network	2007	2007	2015	2007	2015	2007	2015	2007	2015	2007	2015	2007	2015
Social dat	2007	2015	2015	2025	2025	2015	2015	2025	2025	2015	2015	2025	2025
Car ownership	2007	2015	2015	2025	2025	2015	2015	2025	2025	2015	2015	2025	2025

C – Concentrated development
D – Decentralized concentrated development
E – Extensive development

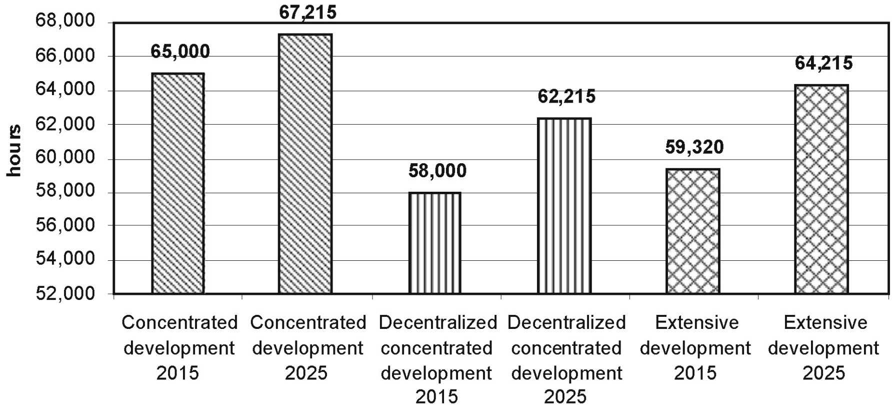

Fig. 3. Driven time by car according to different Vilnius city development scenarios for 2015 and 2025 years

Table 2. Results of Vilnius city development scenarios calculations

Indicator		Concentrated development				Decentralized concentrated development				Extensive development			
	2007	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
Length of street network, km	1,710	1,710	1,790	1,710	1,790	1,710	1,790	1,710	1,790	1,710	1,790	1,710	1,790
Driving time, h	18,250	65,000	45,320	67,215	48,125	58,000	43,421	62,215	45,125	59,320	48,901	64,215	47,225
Driving downtime, h	9,925	38,000	24,135	43,512	32,180	25,451	18,214	29,451	21,451	23,451	17,254	27,861	20,655
Driven distance, km	850,230	1151,250	1100,251	1371,250	1280,251	1291,780	1210,631	1459,560	1368,911	1367,780	1270,631	1589,840	1468,700
Fuel consumption 1 aut-km, litr.	0.0854	0.1077	0.1069	0.1131	0.1119	0.1051	0.1042	0.1122	0.1109	0.1059	0.1048	0.1129	0.1115

Comprehensive Plan, it is necessary to perform a comparison of developments with base scenario and future scenarios with "the worst future" scenario is essential. The "worst future" scenario means that there are no changes in the infrastructure, but car ownership increased and land use pattern changes and so will influence more trips from suburbs to the city centre (in 2015 and 2025).

Travel time by car of "the worst future" scenario is presented in Fig. 3. This figure presents travel time by car in morning peak-hours of the 3 Vilnius city development scenarios in 2015 and 2025, when new transport system infrastructure (two-level crossings and new bypasses) would not be developed.

The next charts shows an average modelled driven distance for one Vilnius inhabitant and an average fuel consumption in litres for one driven kilometre in 2015 and 2025 years according different Vilnius city transport system development scenario (Figs 4, 5).

Fuel consumption and average driven distance have been taken into account that new projects of Vilnius city transport infrastructure according Vilnius Comprehensive Plan would be developed till 2015 year.

Driving pattern is a complex phenomenon, which is influenced by several variables as the drivers' behaviour, the street environment, the traffic flow and the car type, and the driving patterns may vary strongly. A large number of the measures must be employed in order to capture

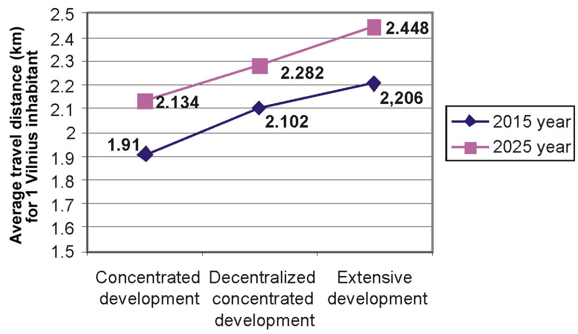

Fig. 4. Average driven distance according to different Vilnius city development scenarios for 2015 and 2025 years

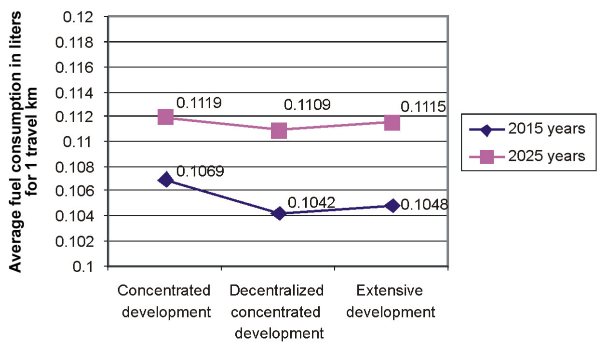

Fig. 5. Fuel consumption according to development scenarios for 2015 and 2025 years of Vilnius city

all these sources of variation (Loukopoulos *et al.* 2004). The aim was to prepare model that would describe a way how to choose the correct city development scenario according to urban transport system conditions.

Modelling results clearly show that all infrastructure developments and changes in land use influence the driven distance and fuel consumption.

Generally, the exact extent of cause and effect between urban areas development scenarios and transport system indicators in transport is not conclusive. Often there is a number of local factors involved, relating to particular people behaviour and the involved localities. A combination of complementary land use planning measures and infrastructure development can provide an integrated package, where each element reinforces the other towards a more sustainable development.

The current situation (social data 2007, i.e. total number of inhabitants is 554,000 and the rough number of workplaces is 310,000 and the street network data for 2007 situation) initially shows that an average driven distance for one Vilnius inhabitant is 1.56 km. The "worst future" scenario for 2015 and 2025 year, when street network infrastructure would not be developed according Vilnius Comprehensive Plan, indicates a huge increase of time spend in traffic jams. Modelling results show that an average time for one Vilnius inhabitant spends in traffic jams without any movement in 2015 would be about 5 min and in 2025 – 7 min for Vilnius city concentrated development scenario. If would be taken into account the prognosis of Vilnius city automobilization level, the average time spend in traffic jams for Vilnius inhabitants, having automobiles, would be 7 and 9 min in 2015 and 2025 years.

In order to calculate the effectiveness of fuel consumption in morning peak hours for each Vilnius city development scenario, according to streets infrastructure projects which are in Comprehensive Plan, it is possible to compare modelling scenarios with the urban areas development scenarios with 2007 year street network (Figs 6, 7).

The biggest difference in fuel consumption in morning peak hours according to new transport network infrastructure has an extensive development scenario. Difference in fuel consumption is 11,686 litres and 15,733 litres according modelling scenarios for 2015 and 2025 years.

Other Vilnius city development scenarios are not so sensitive for the need of new infrastructure development and the results differs by 1%. Decentralized concentrated development scenario for 2015 year and without new street network infrastructure has 135,766 litres and 163,762 litres for 2025 year and respectively concentrated development has 123,990 litres for 2015 year and 155,088 litres for 2025. Development of Vilnius city new street network infrastructure, according to Vilnius city Comprehensive Plan till 2015, gives 6,374 litres economy of fuel consumption according to concentrated development and 9,618 litres according to decentralized concentrated development.

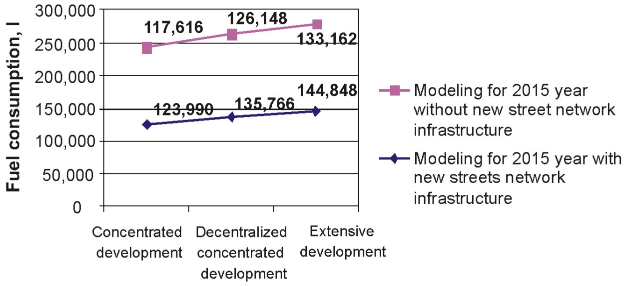

Fig. 6. Fuel consumption according to Vilnius development scenario for 2015 year and street network infrastructure

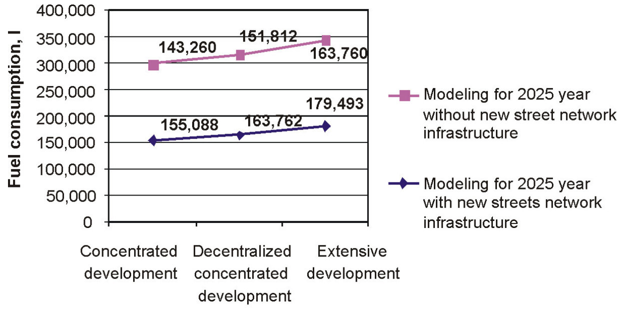

Fig. 7. Fuel consumption according to Vilnius development scenario for 2025 year and street network infrastructure

5. Vilnius city development scenarios ranking

Another goal of this paper is to perform urban areas development scenarios ranking based on SAW multicriteria method. In order to perform a correct analysis, the urban development scenarios ranking should be taken into account indicators system which represents social economical and environmental group sets of indicators (Jakimavičius and Burinskienė 2009).

The best variant of Vilnius city development scenario according to travel time is the scenario of decentralized concentrated development. The modelling results of total travel time by car with evaluated new street network infrastructure are 43,421 h in morning peak hours in 2015 year and 45,125 h in 2025.

Calculation of indicators weights for Vilnius city development scenarios ranking have been performed using ranking method, the input data have been collected by performing 28 experts questionnaire.

Experts from Vilnius municipality and from Vilnius municipality company "Susisiekimo Paslaugos" have filled questionnaires for evaluating criteria importance. The results of ranking method are presented in Table 3.

Calculations in order to find rational variant of Vilnius city transport system development have been performed by computer program WinDetermination. Variants priority row by SAW method: Decentralized concentrated development > Concentrated development > Extensive development = 0.882 > 0.875 > 0.871.

Table 3. Decision support system matrix with criteria importance of Vilnius development scenarios evaluation

Nº	Criterion name	Units	Importance	*	Development scenario		
					Extensive development	Concentrated development	Decentralized concentrated development
Quantitative criteria							
R1	Budget for urban area transport system development	mln. Lt	0.078	–	4,802	4,432	4,535
R2	Necessary land use for building new streets	ha	0.061	–	902	115	300
R3	Fuel consumption for one automobile kilometer	1 aut. km /l	0.071	–	0.1115	0.1119	0.1109
R4	Total driven distance per morning peak hours	km	0.086	–	1468,700	1280,251	1368,911
R5	Total trip by car downtime per morning peak hours	h	0.086	–	20,655	32,180	21,451
R6	Total driving time per morning peak hours	h	0.089	–	47,225	48,125	45,125
Qualitative criteria							
R7	Possibilities of internal trip realization	score	0.052	+	3	4	4
R8	Possibilities of trip realization in out of city area	score	0.061	+	3	4	3
R9	Possibilities of trip realization by public transport	score	0.072	+	2	4	3
R10	Possibilities of transport mobility reduction, influence on traffic flows speed, environmental impact	score	0.069	+	2	3	3
R11	Complicity of urban transport system network development	score	0.031	–	4	2	3
R12	Loaded traffic flows in central part of the city	score	0.044	–	3	4	2
R13	Increase of citizens mobility	score	0.051	–	4	3	4
R14	Noise and air pollution in central part of the city	score	0.064	–	3	4	3
R15	Motivation of city bypass need through: Rudamina, N. Vilnia, Balsiai, Riešė, Grigiškės and Lentvaris	score	0.056	+	4	2	3
R16	Motivation of rail transport usability	score	0.029	+	2	1	4

6. Conclusions

1. The problems of correct selection of urban areas transport system development could be solved by using decision-support system methods and created indicators group of urban transport system. Created indicators system could be used for evaluating urban areas development scenarios according to the sustainability of transport system.

2. Urban transport system analysis model was developed for Vilnius conditions, and estimates the fuel consumption, average travel distance and driven time by car in morning peak hours depending on urban areas development scenario and socio-economic data. This model should be used when calculating new projects of the transport infrastructure (by-passes, new bridges) and when evaluating the economic efficiency of traffic organization projects.

3. The application of model solved several practical problems. Analysis of 3 different Vilnius city development scenarios would determine that a decentralized concentrated development scenario has the lowest fuel consumption per one passenger per kilometre, but it would also lead to longer (but faster) trips and consequently higher total fuel consumption than concentrated development scenario. Meanwhile, reconstruction of current critical intersections will reduce fuel consumption and reduce pollution in highly populated areas. A more concentrated and mixed land use is definitely an advantage to lowering total fuel consumption, but it is not advantage for sustainable transport system. Concentrated land use increases travel time and time spend in traffic jams.

4. For evaluating urban areas land use scenarios according transport system sustainability it could be successfully used the integrated multicriteria decision support system methods with GIS software. Also, for urban areas transport system detailed analysis in order to calculate traffic indicators traffic modelling software could also be applied.

5. Hence, various developments have strengths and weaknesses. Reducing dependency of fuel consumption in urban areas, it is necessary to promote concentrated development in urban areas; however, a concentrated development has enormous positive spin-offs in the overall transportation sustainability and liveability of the Vilnius.

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VILNIAUS MIESTO PLĖTROS SCENARIJŲ VERTINIMAS, NAUDOJANT SUSISIEKIMO SISTEMOS MODELIAVIMĄ IR DAUGIAKRITERĘ ANALIZĘ

M. Jakimavičius, M. Burinskienė

S a n t r a u k a

Straipsnyje analizuojami trys susisiekimo sistemos požiūriu Vilniaus miesto plėtros scenarijai. Miesto plėtros scenarijai, kaip sutelktoji plėtra, decentralizuotai sutelktoji plėtra ir ekstensyvioji plėtra, vertinami daugiakriteriu metodu SAW ir atliekant Vilniaus miesto plėtros scenarijų modeliavimą 2015 m. ir 2025 m. Daugiakriteriu metodu nustatoma plėtros scenarijų prioritetinė eilė, vertinant Vilniaus miesto susisiekimo sistemos rodiklius. Modeliuojant plėtros scenarijų, nustatomi tokie rytinio piko metu rodikliai: kuro naudojimas, suminis nuvažiuotas atstumas, suminis kelionės laikas. Modeliavimas remiasi esamais ir numatytais bendrojo Vilniaus plano miesto gatvių tinklo duomenimis, transportinių rajonų dabartiniais ir prognozuojamais socialiniais bei ekonominiais duomenimis. Sukurtas modelis gali būti sėkmingai naudojamas vertinant transporto infrastruktūros ir eismo organizavimo projektų įtaką miesto susisiekimo sistemai.

Reikšminiai žodžiai: miesto susisiekimo sistemos, gyvenamųjų teritorijų plėtra, susisiekimo sistemos modeliavimas, daugiakriterė analizė.

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