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A GIS AND MULTI-CRITERIA-BASED ANALYSIS AND RANKING OF TRANSPORTATION ZONES OF VILNIUS CITY

Marius Jakimavičius[1], **Marija Burinskienė**[2]

Dept of Urban Engineering, Vilnius Gediminas Technical University, Saulėtekio al.11, LT-10223 Vilnius, Lithuania
E-mail: [1]mjakimavicius@hnit-baltic.lt; [2]marbur@ap.vgtu.lt

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Abstract. Fixing the accessibility is a standard issue of transport analysis, which can be of interest to many socioeconomic applications. In the paper we propose and discuss accessibility and other indicators-based urban transport system analysis and GIS (geographic information systems) calculation method for indicating problematic transportation zones in Vilnius city. The main parameter is time-based accessibility from/to the central part of Vilnius and other transport zones in the city. Created GIS application computes the ranks for transport zones of Vilnius city according to accessibility and Vilnius statistics in these zones (street network density in city zones, number of working places, number of equipped parking places, number of attractive objects in transportation zones). The GIS decision support system is based on 2 calculation methods *TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and SAW (Simple Additive Weighting)*. Application of transportation zones analysis improves the quality of basic environment statistics and fills many data gaps related to urban statistics, providing information to decision-makers and the general public concerning key factors determining the state of urban transportation environment. This paper outlines criteria and models used in Vilnius to develop urban transportation indicators and the reasons why the selected indicators represent the first important step to achieve a comprehensive system of indicators of urban transportation sustainability in Vilnius city. This model could be integrated in systems of urban transport planning and sustainable development planning.

Keywords: urban transportation, geographic information system, sustainable transport, transport planning, traffic analysis zone, decision support system.

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1. Introduction

The motivation for this research arose from an effort to assess transportation system performance in Vilnius city. The approach taken in that research (Casello 2003) was to preselect a series of origin destination pairs for which public transportation might compete well with private automobile, and test the sensitivity of modal split, and overall system performance, to changes in transit service provided and the cost of auto travel. A review of the literature suggests that transit is most competitive in high-density commercial areas and to a lesser extent in residential ones (Pushkarev and Zupan 1982). To preselect the origin and destination pairs, it was necessary to have a quantitative definition of "high-density" areas.

The urban studies contain definitions of activity centres, typically defined as areas with higher than adjacent concentrations of employment at the traffic analysis zone (TAZ) level. This definition has proven satisfactory in the analysis of polycentric areas' employment patterns, residential location theory, and overall economic analysis.

The accessibility concept can be applied to many spatial problems: e.g. service centre location, hospital-sitting, school closure and many others. The analysis based on the concept of accessibility is therefore ideally suited to be integrated within geographic information systems (GIS). This paper expands the work in modelling accessibility fields taken by Donnay and Ledent (Donnay and Ledent 1995) for the urban region of Liège (Belgium) and Julião (Julião 1999) for Tagus Valley Region (Portugal), as well as one-stage model for Slovene municipalities (Drobne 2003; Black *et al.* 2002). In this paper, travel time (by car) and territorial allocation to the Lithuanian administrative regions have been modelled using the road network and GIS approach.

Accessibility matrix was implemented with origin-destination (OD) matrix computation used in travel demand analysis in transportation geography. In both cases, GIS is used in determination of user-defined arbitrary analysis zone or area of interest (AOI), corresponding to TAZ (Miller and Shaw 2001).

The research presented here proposes an extension to a commonly used activity centre definition to improve that definition's applicability to transportation research. This extension involves identifying activity centres based on the trip-attracting strength of disaggregate employment types within TAZs. This approach identifies areas that are responsible for a disproportionate number of regional trips. The proposed methodology has 2 positive characteristics. First, the approach computes attraction strengths using standard socio-economic data available at the municipality planning organization level. Second, employment is still the fundamental unit of the activity centre definition, and the pedagogical approach of identifying sub areas that exceed certain thresholds remains unchanged.

The efficiency of urban transportation 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).

Accessibility from the centre of traffic analysis zone to the central part of Vilnius was taken as the main factor for transport system analysis in Vilnius city. Also, other factors have been included, like population density in TAZ, number of working places in TAZ, street network density in traffic zone, public transport density, average number of daily trips in each analysis zone. By comparing the georeferenced data like street network, the territorial allocation and statistical data for each traffic analysis zone in Vilnius can argue about the equity of investments distribution for each TAZ. Also the created GIS application could be used for transport analysis zones ranking by various aspects and problematic zones identification.

2. Case in Vilnius city

Growing Lithuanian economy and increasing quality of the living conditions prompts population's mobility, the motorization level and increasingly high transport flow on the countries streets and roads (Burinskienė and Paliulis 2003).

Average percentage of Vilnius city automobiles quantity is increasing per year about 3%. Number of personal cars in Vilnius city rose from 265 automobiles for 1000 inhabitants in 1999 till 450 in 2005. Sharp bounce of motorization level invokes a lot of transportation problems. Many researchers analyze transportation system from the point of system sustainability, which influences economical, social and environmental implications (Black *et al.* 2002; Camagni *et al.* 2002; Grigonis and Burinskienė 2002). Other scientists also indicate political and institutional aspects (Čiegis and Gineitienė 2008).

Number of public transport passengers rose from 229.5 mln. in 1999 year till 277.1 till 2004 year. This indicator increases by about 3.7% each year. The main Vilnius city transport system indicators are in Table 1.

Table 1. Transport system indicators in Vilnius city, 1999, 2005

Indicator	1999	2005
Street network density (km/km^2)	1.9	2.4
Public transport network density (km/km^2)	0.55	0.62
Bicycle paths network density (km/km^2)	0.10	0.16
Average traffic flow in peak hours (aut./h)	1275	1521
Percentage of trucks in average flow	3.4	2.4
Average speed in peak traffic flow (km/h)	37.5	29.3
Modal split		
– pedestrian trips %	31.3	34.8
– trips by bicycles %	0.3	0.3
– trips by public transport %	45.4	34.2
– trips by car %	23.0	30.7
Maximum number of public transport passengers in peak hours	5300	3600
Transit of trucks in peak hours %	21.3	13.2
Number of traffic accidents for 1000 inhabitants	1.07	1.77

Vilnius city is divided into 51 traffic analysis zones. TAZ and population density (inhabitants in hectare) in each zone are shown in Fig. 1.

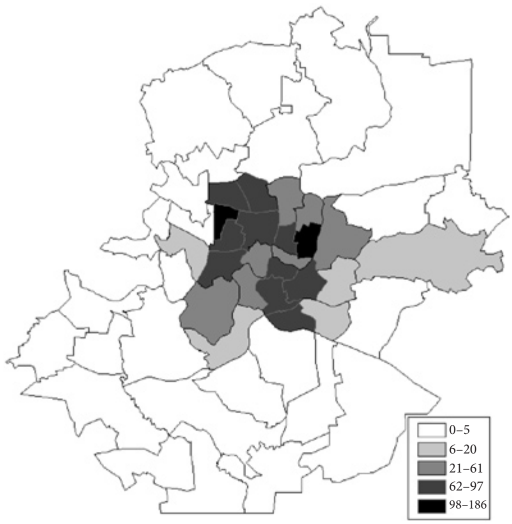

Fig. 1. Traffic analysis zones and population density in Vilnius city

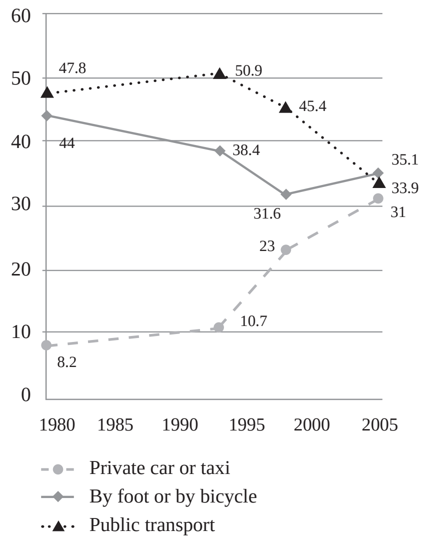

Fig. 2. Trips modal split tendencies in Vilnius city

Analysis of modal split of Vilnius city transportation system showed that trips by public transport decreases (Fig. 2) and trips by private transport are increasing.

The most concentration of working places is in the central part of Vilnius city (Fig. 3). Largest density of working places in the central part of Vilnius involves parking and traffic flow problems.

Fig. 3. Working places density in Vilnius city

3. Methodology

For this research, several changes to the Bogart and Ferry model are implemented. First, three "levels" of activity centres are defined (Bogart and Ferry 1999): major urban centres of large cities, secondary urban centres of smaller cities, and suburban centres. Decreasing employment and employment density thresholds are utilized in each case. Establishing differing thresholds for inclusion ensures that the method will identify those TAZ's with higher than adjacent employment characteristics, the essence of an activity centre. The second set of modifications involves formation of activity centre clusters. Recall that in the Bogart and Ferry method, those zones which by themselves do not meet the activity centre employment thresholds may be clustered with adjacent zones and so meet the criteria to form larger areas. Bogart and Ferry added zones until the whole cluster density fell below the threshold. The authors have adopted this method, but only for suburban activities centres, to avoid the case where a single ultra-high density zone in an urban centre dominates that all adjacent zones would be included to form a "superzone." Further, we require that individual zones being added to meet a minimum employment density threshold. This requirement avoids the case where an open space adjacent to a high density employment centre is considered a part of a suburban activity centre. Finally, we relax the adjacency requirement such that any two zones are considered adjacent if they share a common border of any length. The most significant change we propose is motivated by the following observation. A hypothetical TAZ with a 100 mining jobs attracts far fewer trips than a TAZ with sufficient retail development to employ 100 persons. Furthermore, Targa has shown that different employment types tend to respond to agglomerative location forces more readily than others, with retail among the most responsive (Targa 1990). Transportation models specifically for retail activity have been developed by Hamed and Easa. Generally, retail activities produce more trips, are more likely to agglomerate, and therefore are likely to have stronger impact on regional transportation patterns (Hamed and Easa 1998). For transportation analysis, then the method to identify transportation activity centres TACs should not be based solely on employment density, but rather on the trip-attracting strength of the disaggregate employment types present in a TAZ. To incorporate trip attraction strength into the TAC definition, one could compute the product of employment and trip attraction rate per job for each disaggregate employment type. Those zones that exceeded a threshold value of trips and trip density trips per unit of area would be then considered part of a TAC. The decision statistic, however, would then no longer be the well-established gross employment and employment density thresholds frequently used in the literature. The approach advanced here is to define a hypothetical "mean trip-attracting" MTA job. Suppose that there is a TAZ with exactly one job in each of the 11 standard disaggregate employment types: agriculture, mining, construction, manufacturing, transportation, whole sale, retail, fire, service, government, and military employment. In this case, a total number of daily trips would be attracted to this zone, and an average number of trips per job could be computed. The relative strength of each employment type can be calculated as the ratio of each employment type's attraction rate to the mean attraction rate. This ratio can be used to express each *actual* job in terms of *equivalent* MTA jobs. A zone that exceeds the gross employment and employment density levels in terms of MTA jobs would then be considered for inclusion in a TAC.

Trip attraction to TAZs in their metropolitan region equals:

$$TA = 1.4Ag + 1.2Mi + 3.0Re + 2.4Se, \tag{1}$$

where:

TA – number of trips attracted; Ag – number of agricultural jobs; Mi – number of mining jobs; Re – number of retail jobs; Se – number of service jobs.

If a TAZ had only 4 jobs, one of the above categories, the zone would attract 8 trips, or 2 trips per job. Thus, an MTA job would attract 2 trips. Retail, in contrast, attracts 3 trips per job; thus, a retail job can be considered 3/2 or 1.5 MTA jobs. Similarly, an agricultural job attracts only 1.4 trips per job, and therefore can be considered 1.4/2 0.7 MTA jobs. The example is generalized as follows. If α_k is defined as the trip attraction rate for employment type *k*, then:

$$\chi_k = \frac{\alpha_k n}{\sum_{k=1}^{n} \alpha_k} \forall k \,, \quad (2)$$

where χ_k – MTA factor for each employment type, *k*; and *n* – total number of employment types. A TAZ would be considered as a TAC if:

$$\sum_k E_k \chi_k \geq \xi \,, \quad (3)$$

and

$$\frac{\sum_k E_k \chi_k}{A} \geq \varphi \,, \quad (4)$$

where E_k – actual employment of type *k*; ξ – gross employment threshold (MTA jobs); *A* – area of the TAZ (hectares) and φ – employment density threshold (MTA jobs per hectare). Thus, TAZs that meet or exceed the employment and employment density thresholds using MTA jobs are considered TACs. The creation of TAC clusters is done by adding adjacent candidate zones (those with MTA employment density greater than 3.0 MTA jobs per acre), such that the total cluster remains above the threshold level. For our research, we utilized MTA employment and MTA employment density thresholds equal to gross employment thresholds typically used in the literature.

Fig. 4. Traffic activity centres in Vilnius city

The following sections demonstrate the analysis of the Vilnius city area using standard activity centre definitions and the TAC method presented here.

The map of traffic analysis zones of Vilnius city (Fig. 4) presents the areas where traffic analysis zones could be considered like transport activity centres (these zones are presented in black colour).

This analysis showed that TAZ could not considered like TAC that in the central part and old town of Vilnius, also in areas of Vilnius city which are in a distant of central part of Vilnius city. The main reason is that in the central part of Vilnius there is a big concentration of working places and in areas around Vilnius city residential houses are dominating, with less working places.

The second stage is to perform an estimated traffic analysis zones ranking using various transportation indicators. For TAZ ranking 2 methods of decision support system were used – Topsis and SAW. GIS-based application computes the ranks of transport analysis zones.

3.1. SAW (Simple Additive Weighting) method in GIS application

For a fragment of input from Vilnius traffic analysis zones socio-economic data for GIS application (Fig. 5).

Input data for calculation is the criteria and their values of importance; criteria matrix is normalized according to these conditions (Shevchenko *et al.* 2008):

X_{ij}	**Criteria for analysis of automobiles transport system in Lithuania** *1, 2 … i*
1 *2* . . . *j*	Attributes of vilnius_lks

RAJ PAVAD	PLOTA	Z999 GYV	Z005 GY	Z015 GY	Z999 DARB	Z005 DARB	Z015 DARB	GYV
Senamiestis	399,8	26495	25000	23000	45037	43000	41000	66
Centras II	104,4	9485	9000	8000	39146	38000	37500	91
Naujamiestis	346,9	27657	30000	32000	32978	35000	37000	80
Ž. Paneriai	740,7	14547	12000	11500	17038	16500	16000	20
Antakalnis	837,3	30301	28000	27000	12856	13000	13500	36
Šnipiškės	195,7	14142	15500	16500	8488	10000	13000	72
Santariškės	2010	10301	11500	12700	10554	11000	12100	5
Centras I	156,7	6049	7000	7500	7749	8650	11000	39
Žirmūnai II	262,7	40979	38500	38000	14925	11000	10500	156
Žirmūnai I	264,8	16111	16000	15500	6328	7500	8700	61
Kirtimai	1477,6	4599	4000	3500	9596	9000	8700	3
Žvėrynas	260,8	13519	14000	14000	7573	8000	8000	52
Karoliniškės	398	38407	34500	32000	7405	7700	7900	97
Nauja Vilnia	2369,4	29338	31600	37500	5314	6000	7800	12
Vilkpėdė	335	12656	13000	13500	6129	7000	7500	38
Gariūnai	2026,2	1887	2000	2000	6427	7000	7500	1
Naujininkai	311,4	26626	24000	23000	6725	7100	7300	86

Fig. 5. Socio-economic Vilnius TAZ data

If the criterion is maximized:

$$X_{ij} = \frac{X_{ij}}{X_j^{max}} . \tag{5}$$

If the criterion is minimized:

$$X_{ij} = \frac{X_j^{min}}{X_{ij}} . \tag{6}$$

A normalized matrix for each criterion of concrete municipality is multiplied with its importance. Multiplied criteria are summed for each row (for each TAZ). The biggest value means the best transport situation in certain traffic analysis zone.

3.2. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method in GIS application

Criteria matrix is normalized by formula

$$X_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} . \tag{7}$$

It is multiplied by matrix of importance values (Ustinovichius *et al.* 2007):

$$P^{*}=[X]\times[q], \tag{8}$$

where: q – matrix of creations importance values.

Normalized matrix is used for calculating ideal positive (f_j^+) and negative (f_j^-) variants. Calculation of variant's deviation to ideal positive variant is based on:

$$L_i^+ = \sum_{j=1}^{n} (f_{ij} - f_j^+)^2 . \tag{9}$$

Calculation of variant's deviation to negative variant is based on:

$$L_i^- = \sum_{j=1}^{n} (f_{ij} - f_j^-)^2 . \tag{10}$$

Calculation of proportional variant's deviation to ideal variant K_{BIT} is based on:

$$K_{BIT} = \frac{L_i^-}{L_i^+ + L_i^-} . \tag{11}$$

The best variant of transport system situation in TAZ is the one with the highest K_{BIT} value. Indicators of Vilnius city transport system analysis for each traffic analysis zone are in Table 2.

Table 2. Transport system indicators for Vilnius TAZ analysis

Indicator description	Function	Importance (%)
Street network density (km/km^2) in each TAZ	maximize	19
Public transport network density (km/km^2) in each TAZ	maximize	15
Length of streets for 1000 inhabitants in each TAZ	maximize	16
Disproportion for population and employees densities	minimize	22
Density of parking places (parking places/ hectare)	maximize	10
Accessibility from the central part from each transport activities centre to Vilnius city central part	maximize	9
Average number of daily trips in each analysis zone	maximize	9

Importance for each indicator was estimated by a transport specialists' questionnaire.

The results of analysis (Fig. 6) showed that the best transport situation is in Santariškės and Žemieji Paneriai transport activities centres. There are no major disproportion of working places and inhabitants in these zones, there is enough street network density.

4. Conclusions

Research of traffic analysis zones in Vilnius city showed that not all traffic analysis zones could be possible to consider like transport activity centres. Such kind of problematic situation is in the central part of Vilnius and in the TAZ, which are in a distant area of the central part of Vilnius. The main reason is a large disproportion of population and working places density in these areas.

The second stage of this research represents a GIS based methodology for Vilnius city traffic analysis zones ranking. The created GIS application with 2 calculation methods of decision-support system Topsis and Saw performs TAZ ranking. The analysis of Vilnius city TAZ showed that the best transport situation is in Santariškės and Žemieji Paneriai transport activities centres.

Fig. 6. Results of ranking Vilnius TAZ's

The investigation of TAZ identified major car parking and traffic problems in the following traffic zones: Centras I, Centras II, Lazdynai, Karoliniškės, Antakalnis, Senamiestis, Šnipiškės and Naujamiestis. Public transport problems were also identified in these Vilnius TAZ: Verkiai, Dvarčionys, Valakupiai, A. Paneriai and Tarandė.

The created methodology is flexible and could be successfully adopted for TAZ analysis and ranking in other cities. It is necessary to have TAZ GIS and socio-economic statistical data.

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SUSISIEKIMO SISTEMOS ANALIZĖ IR RANGAVIMAS VILNIAUS MIESTO TRANSPORTO RAJONUOSE NAUDOJANT GIS

M. Jakimavičius, M. Burinskienė

Santrauka

Straipsnyje aptariama indikatorių sistema, reikalinga miesto transporto rajonams ranguoti, remiantis sprendimų paramos skaičiavimo metodais ir GIS (geografinės informacinės sistemos) technologijomis. Buvo identifikuojami Vilniaus miesto transporto rajonai, probleminiai susisiekimo sistemos požiūriu. Analizei atlikti buvo naudojami šie rodikliai: gatvių tinklo tankis, visuomeninio transporto tinklo tankis, automobilių statymo vietų tankis, kelionių skaičius kiekviename transporto rajone, gatvių tinklo ilgis, tenkantis 1000 transporto rajono gyventojų, dirbančiųjų ir gyventojų tankių disproporcija transporto rajone, transporto rajono pasiekiamumas nuo miesto centro. GIS aplikacija su integruotais daugiakriteriniais sprendimų paramos sistemos skaičiavimo metodais, kaip paprastųjų svorių sudėjimo SAW ir idealiojo taško TOPSIS, ranguoja Vilniaus miesto transporto rajonus ir leidžia identifikuoti problemines susisiekimo sistemos požiūriu miesto vietas. Plečiant sukurtą aplikaciją, naudojant daugiau indikatorių galima sukurti bendrą indikatorių sistemą miestų planavimo uždavinių sprendimams pagrįsti.

Reikšminiai žodžiai: miesto susisiekimo sistema, geografinės informacinės sistemos, susisiekimo sistemos darna, susisiekimo sistemos planavimas, transporto rajonas, sprendimo paramos sistemos.

Marius JAKIMAVIČIUS. PhD student of Vilnius Gediminas Technical University, Faculty of Environmental Engineering, Dept of Urban Engineering, LT. Member of Association of Lithuanian Surveyors. Research interests include GIS and GPS systems, GIS-based solutions for transport analysis tasks, optimization of transport system according to urban areas.

Marija BURINSKIENĖ. Professor, Dr, Head of Urban Engineering Department and Director of Territorial Planning Research Institute of Vilnius Gediminas Technical University. She was project manager of more than 40 national projects from 1983, participated in more than 30 intern conferences and was involved in 8 Framework 5 and 6 program projects. The main area of research interest is regularities and specificity of urban and regional sustainable development, development of urban transport system as well as creation of decision-support system for implementing engineering solutions.