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MODELLING A PASSENGER CAR SYSTEM BASED ON THE PRINCIPLES OF SUSTAINABLE MOBILITY IN VILNIUS CITY

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Abstract. The growing rate of motorization and the use of passenger cars have a worsening effect on traffic conditions in the streets of Vilnius City. Moreover, adverse urbanisation processes (i.e. migration to suburban areas) make a huge effect on the behaviour of travelling. A deeper analysis of these processes requires large data amounts and techniques for analysing transportation. The study is aimed at preparing and assessing the scenarios of developing passenger car transport through the prism of sustainability indicators. A plan for case study-based hypothetical mobility management explores a series of future scenarios improving transportation diversity and changes in modes for travellers. These scenarios are developed with respect to developments anticipated in the Master Plan of the City of Vilnius and aims at identifying the effect of a new public transport network on the motorized transport system during the morning peak in the hypothetical year 2025. Mobility management through transportation diversity increases travelling options, encourages travellers to choose the most efficient mode and tends to eliminate car dependency that otherwise occurs in urban areas. The development of a public transport route network in Vilnius City creates real preconditions for implementing a sustainable transport system thus giving a priority to the development of a new and fast transport mode. The planned routes of the new transport mode allows significantly reducing the necessity for the use of private motorized transport and influencing the total structure of travels thus making it possible for a large number of people to reach destination by public transport.

Keywords: mobility management; transportation diversity; case study-based scenarios; mobility indicators; modal choice; Vilnius City.

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Introduction

Recently, sustainability has become the fundamental component of transport planning and policy implications (Haque *et al.* 2013; Black 2010). The overall objective of sustainable transport system planning in the EU is 'to ensure that our transport systems meet society's economic, social and environmental needs whilst minimising their undesirable impacts on the economy, society and the environment' (Council of the European Union 2006). The main approach that helps with seeking the sustainability of transportation systems is Mobility Management (MM). In particular, MM has been one of Europe's primary approaches to Transport (Travel) Demand Management (TDM) for the past fifteen years. The aim of TDM is to promote sustainable transportation by changing travellers' behaviour against the usage of private vehicles (Kepaptsoglou *et al.* 2012; Santos *et al.* 2013). At the core of MM there are 'soft' measures such as information and communication, organising services and coordinating activities of different partners. 'Soft' measures quite often enhance the effectiveness of 'hard' measures within urban transport (e.g. new tram lines, new roads and new bike lanes) (Hickman *et al.* 2013). The sustainable mobility approach requires actions to reduce the need to travel (less trips), to encourage modal shift, to reduce trip lengths and to encourage greater efficiency in the transport system (Banister 2008; Frändberg, Vilhelmson 2011). While public transport offers significant social and environmental benefits, it is crucial to increase quality, productivity and reduce costs. Indeed, improving the sustainability of public transport would help with realizing the potential environmental

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and social benefits of public transport, since it would make expanded public transport service more affordable, both for the governments who provide it and for the passengers who use it (Buehler, Pucher 2011).

Modelling future transport systems is the cheapest way to predict future changes in traffic and passenger flows as well as modal split. Salonen, Toivonen (2013) has proved that the employment of corresponding models for the car and the calculation of public transport travel time are the key actions to achieve a more reliable analysis of modal accessibility. French scientists (Prud'homme *et al.* 2012) emphasize the modelling and cost-benefit analysis of urban public transport. Public transport quality and tolls are influencing a number of passengers in public transport, and an increase in public transport passengers could be explained by modal shift. The analysis of literature prepared by Swedish scientists indicated that such a shift was not very significant (Redman *et al.* 2013).

The growing rate of motorization continuously increasing traffic flows on the streets of Vilnius City, worsening traffic conditions and increased travel time with fairly intensive urbanization processes require deeper analysis and closer attention to solving the issues of transport and communications (Burinskienė *et al.* 2009). Since in the territory of Vilnius City, like in other Lithuanian cities, no monitoring of transport and communications system is carried out, the above analysis requires the large-scale field measurements of traffic volume, flow composition and speed. Meanwhile, there are usually no financial possibilities for deeper analysis, essential revision and the renewal of the whole database of modelling software used for simulating traffic flows.

The main objective of urban transport flows modelling carried out in the framework of this study is based on perspective infrastructure development anticipated in the Master Plan of the City of Vilnius and assists in identifying the effect of new public transport routes (Tram and Bus Rapid Transit (BRT)) on the motorized transport system during the morning peak in the year 2025.

Thus, the elaborated objectives of modelling are as follows:

- to carry out the macro modelling of a light motorized transport system in case new public transport modes are introduced in Vilnius City;
- to give proposals/scenarios for improving the qualitative parameters of the transport system;
- to assess the light motorized transport system taking into consideration qualitative parameters.

In the course of this study, modelling traffic flows during the morning peak in 2025 was carried out across the whole Vilnius City using *PTV Visum* software aimed at assessing the effect of the planned public transport routes on the motorized transport system. The following aspects of modelling transport infrastructure have been considered:

- the existing and perspective use of a passenger car;
- the existing and perspective transport infrastructure network, the types of intersections and their control;
- the distribution of city inhabitants and working places in different transport regions, the existing and perspective travel structure and relationship matrices.

For assessing the current situation and model calibration, the field measurements of traffic flows during the peak hours in 2010–2011 were used. In the database, the technical parameters of roads and streets were revised. Also, the regimes of traffic lights, the duration of the green phase and relationship matrices were corrected.

1. General Information about the Developed Database and Modelling

This study used a part of the VIDAS database created on the grounds of the modelling system for EMME/2 transport flows. The VIDAS database was created in 2001 by a joint cooperation between the Vilnius City Municipality, Swedish International Development Agency and Stockholm City Municipality. The model took into consideration the main streets of the city, and the work of the transport system was modelled with reference to the morning peak hour. The database was designated for the assessment of the transport system in Vilnius City, the analysis of the interaction between transport infrastructure and urban development, prediction for development scenarios assessing various infrastructure, the redistribution of working and living places and a change in the rate of motorization. The VIDAS database was transferred to *PTV Visum* software where hypothetical data on car use, land use and infrastructure development were renewed.

The introduced transport flow model provides a rather inaccurate description of vehicle manoeuvres at the intersection, and therefore performing micro-modelling is necessary for a more detail description of the geometrical parameters of intersections. Despite the fact, the model is suitable for the justification of transport infrastructure objects having particular importance and a large effect (solutions to the Master Plan of the City).

The number of examples from European and Asian cities are indicate that a good supply of public transport and non-motorized transport infrastructure are crucial for sustainability (Haghshenas, Vaziri 2012). Developing countries, in order to maintain sustainable transport and avoid an environmental impact, should pay close attention to public and non-motorized transport. Such attention would prevent hard-reversible changes in modal split. At a concept stage, the Vilnius City Council approved a vision of sustainable urban development thus giving a priority to public transport and introducing its new modes (Fig. 1).

For clarifying the principles of public transport development in 2025, the initial data during investigations into the transport system of Vilnius City were obtained and a survey of Vilnius inhabitants was made in 2011.

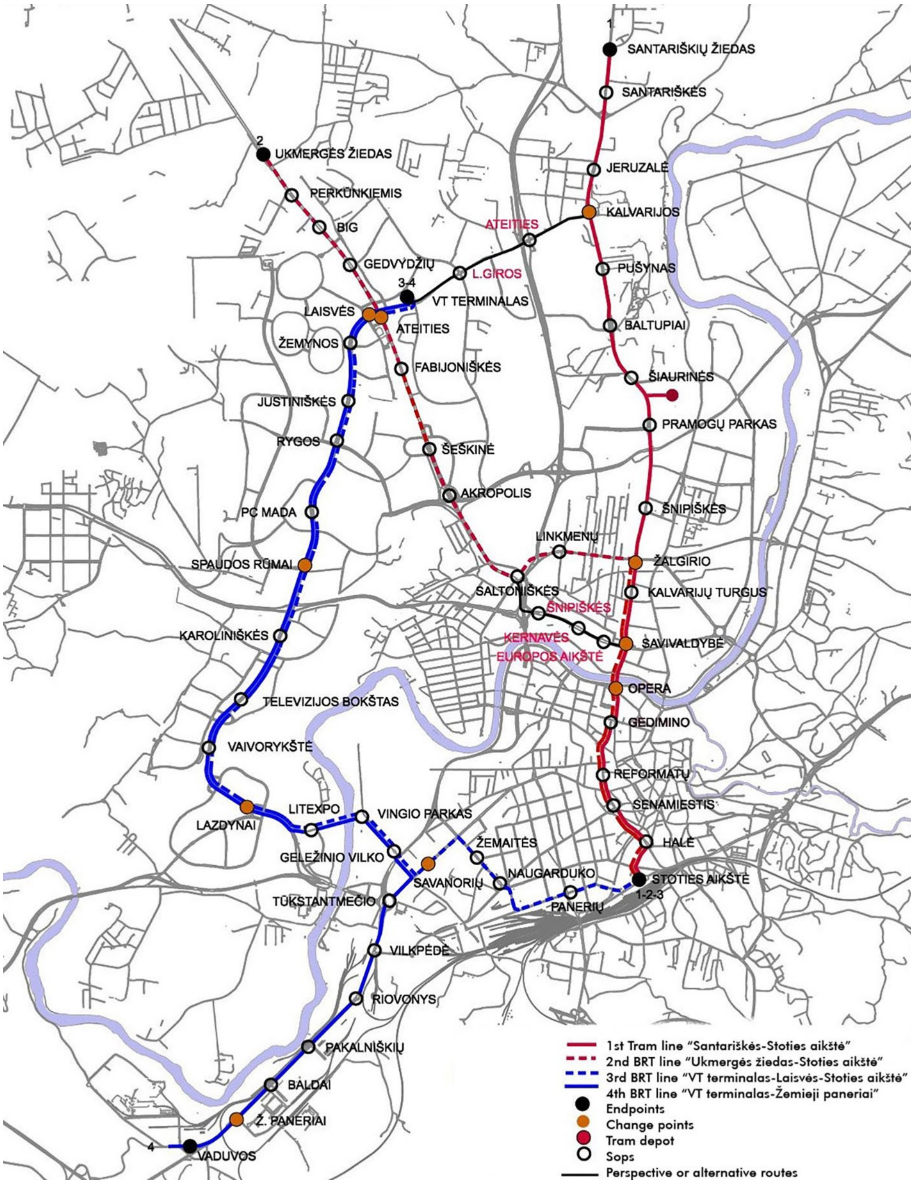

Fig. 1. The network of new public transport modes in Vilnius City in the year 2025

At that time, one statistical inhabitant of Vilnius City made 2.9 travels per day, and the total ratio between travelling by transport modes of public transport and passenger cars was 40% vs 60% respectively. The number of inhabitants in the studied territory in 2011 amounted to 651000, including those of the city, Vilnius district and city guests. During the morning peak hour, one inhabitant accounted for 0.168 travels.

The following main characteristics of the transport system in Vilnius City are predicted during the expert-based survey (Table 1). In 2025, mobility will slightly increase and, during the peak hour, one resident will account for 0.172 travels. The total distribution of travels, if the project of a new transport mode between public transport and passenger cars is implemented, will amount to 47% vs 53% respectively, and the number of inhabitants within the service territory in 2025 will amount to 675200 inhabitants. However, if the project is not implemented, the inhabitants of Vilnius City will use passenger cars and the share of public transport will decrease to 38%.

It is expected that the existing public transport system in Vilnius City and the BRT system, together with a conceptually new public transport mode (most likely Light Tram), will take over about 15% of morning peak-hour passengers from light passenger transport (comparing the alternative '2025, doing a project' to the alternative '2025, doing nothing').

Each urban territory has characteristic economic activities and land use. All these activities determine a certain spatial structure characteristic to each city and form the features of the urban territory. Human activities form potential/demand for working, cultural and domestic journeys, and it is the transport system that realizes (satisfies) this demand. From a long-term viewpoint, the transport system also influences the use of

Table 1. Mobility indices of inhabitants

Year Index	2011, current situation	2025, doing a project	2025, doing nothing
Number of inhabitants in the studied territory	651000	675200	675200
Number of travels by public transport/peak hour	44012	54776	44141
Number of travels by passenger cars/peak hour	65100	61382	72017
The total number of travels by public transport and passenger cars/peak hour	109112	116158	116158
Number of travels per 1 inhabitant/peak hour	0.168	0.172	0.172
Ratio of travels between:			
Public transport	0.403	0.472	0.380
Passenger cars	0.597	0.528	0.620

urban land, since new streets and an increase in their capacity improve the accessibility of territories, and finally, create favourable conditions for developing economic activities (Knoflacher 2007).

When modelling and assessing the volume of traffic flow distribution, the following steps (Fig. 2) like the determination of departing and arriving flows in a transport region (trip generation), the distribution of flows between different pairs of transport regions (trip distribution), the determination of the share of travels per different transport modes (modal distribution) and travels assigned to a transport network (assignment) are commonly taken.

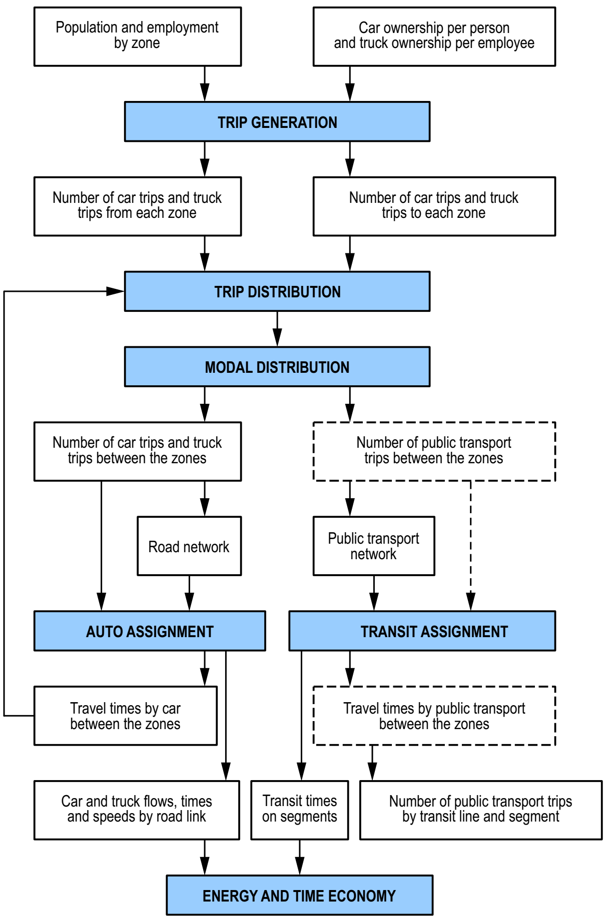

Fig. 2. Modelling steps

The model of the transport network describes the spatial properties of the transport system, its capacity, land use and other characteristics. Therefore, the model consists of several key elements such as zones, nodes, links, manoeuvres, connecting elements, stops, public transport routes.

The integrated network model separates passenger cars and public transport only when calculating modal distribution; however, the currently created public transport and passenger car models are not integrated at present (the models are separate from the first step). The speed of passenger cars depends on the capacity of links, whereas, the speed of public transport depends on timetables. Thus, the transport system consists of several parts described by the type (private or public) and mode (car, bus, trolleybus, etc.).

2. Transport Infrastructure Development in Vilnius City Until 2025

When solving the questions of unloading in the city centre and radial Kalvarijų–Pylimo streets, it is very important to realize the development of the whole street network in Vilnius City, which provides passengers with alternative travel routes bypassing the city centre. Also, in the central part of the city, additional mobility management measures such as pay parking or driving, the prohibition of heavy traffic, etc. could be introduced to eliminate the remaining through traffic flows. This would allow a more rational use of the existing street network to access living, working and tourist service places.

Transport infrastructure development has been defined in the recent Master Plan of the City of Vilnius, and therefore it is assumed that until 2025, a series of the most important projects on the city will be implemented (Fig. 3).

The model took into consideration the following important infrastructure projects on Vilnius City:

- the western fast-speed street (construction of the missing link of transport corridor IXB–Vilnius City western by-pass), (2);
- the reconstruction (construction) of the two-level intersection at Geležinio Vilko–Ukmergės–Žalgirio streets, (5);
- Šiaurinė street from Vakarinė street to Žirmūnų street (including Žvalgų street), (9);

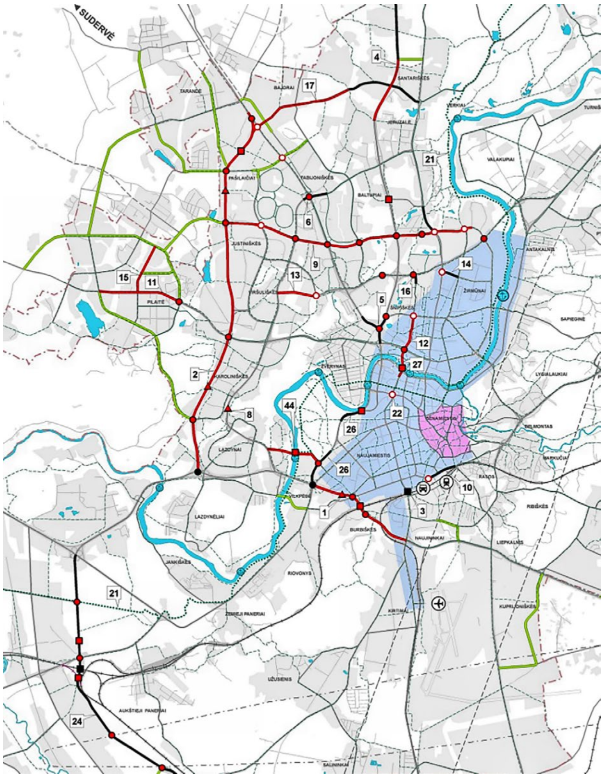

Fig. 3. Transport network development in Vilnius City until 2025 (based on the Master Plan of the City of Vilnius)

– the completion of the Old City by-pass (reconstruction of Geležinkelio street section up to Panerių street), (10);
– Kernavės street between Žalgirio and Lvovo streets, (12);
– the reconstruction of the section in P. Lukšio street from Kalvarijų to Verkių streets, (14);
– the link between Mykolo Lietuvio street, Bajorų village and Mokslininkų street, (17);
– Vilnius City Southern by-pass (Kirtimų street), (24);
– the link of Kernavės street with J. Tumo-Vaižganto street and a new bridge, (27).

While preparing the model, Vilnius City was divided into a finite set of transport regions (Fig. 4). When constructing scenarios, the hypothetical calculations of the number of living and working places in 2011, 2025 and 2040 made by the Municipal Enterprise 'Vilniaus Planas' were used. Data about living and working places for the year 2011 were collected with the help of GIS while data for 2025 were based on forecasted building intensity in transport regions.

3. Description of Scenarios

A scenario is a projected course of events (transport infrastructure, car use coefficients, changes in the distribution of inhabitants and working places) defined for a certain time period (e.g. for the year 2025).

Fig. 4. The division of Vilnius City into transport regions

The European Commission (2011) released its White Paper. This White Paper calls for cities to follow a mixed strategy involving land-use planning, pricing schemes, efficient public transport services and infrastructure for non-motorised modes and charging/refuelling of clean vehicles to reduce congestion and emissions (The State-of-the-Art… 2011). Experience shows (Wefering *et al.* 2013) that isolated measures can only have a limited impact while the packages of measures can make use of synergies and reinforce each other. Furthermore, the finally selected packages should also strive for the integration of transport modes (inter-modality) with land-use planning and other planning activities (e.g. environmental, health or economic measures).

Four perspective scenarios were developed in the course of this study. Fig. 5 gives a summary of the modelled perspective scenarios. Modelling was carried out step by step starting with the calibration of the model for the existing (2011) situation and proceeding to modelling the proposals made by the Master Plan of the City of Vilnius on transport infrastructure development and traffic organization for 2025.

Development of the Base Scenario

A base scenario (2011) was calibrated according to the number of vehicles entering the main intersections during the morning peak determined during the conducted investigations. Model reliability was assessed using statistical methods the main of which include the number of observations N = 231 and the coefficient of

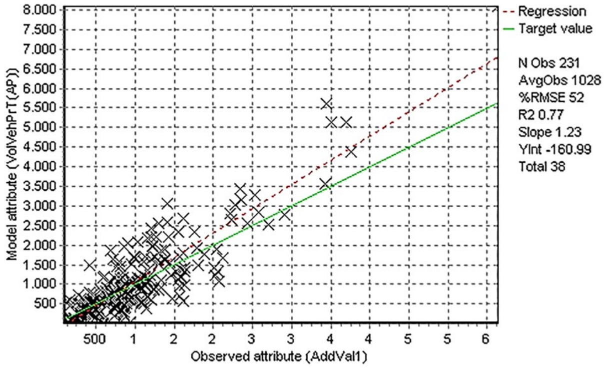

Fig. 6. Model verification

determination R^2 = 0.77 (Fig. 6) that is mathematically described by the formula:

$$R^2 = \frac{\sum_{i=1}^{n}\left(\hat{y}_i - \overline{y}\right)^2}{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2},$$

where: y_i – observed values; $\hat{y}_i$ – predicted values; $\overline{y}_i$ – the mean.

If R^2 = 1, it means that $\sum_{i=1}^{n}\left(y_i - \hat{y}\right)^2 = 0$ and the model is ideally suited. Lower R^2 than 1 indicates the larger difference of the predicted values from the observed values.

Model reliability can be assessed as 'good'. The results of modelling the base scenario, i.e. the cartogram of light private motorized transport flows, are given in Fig. 7.

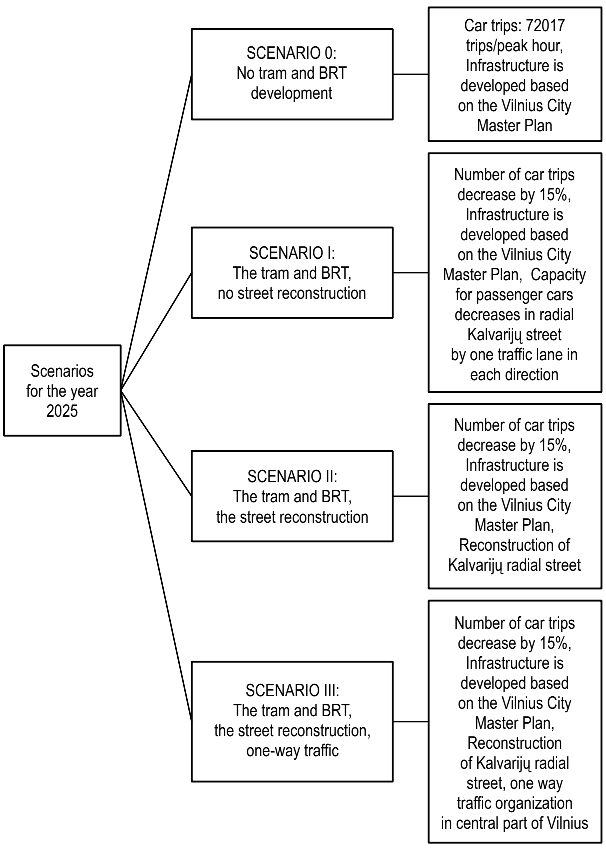

Fig. 5. The modelled scenarios

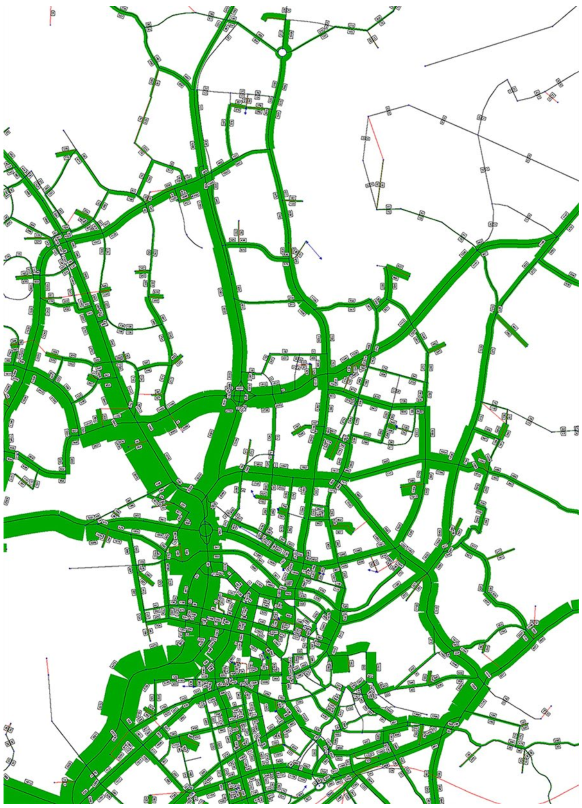

Fig. 7. A fragment of the traffic flow cartogram

Scenario 0: No tram and BRT development

The scenario modelled for 2025 describes the following situation during the morning peak:

- transport infrastructure is developed based on the Master Plan of the City of Vilnius;
- demand for passenger car travels increases to 72017 veh/h;
- distribution of inhabitants and working places for 2025 is predicted according to hypothetical housing intensity and land use.

Scenario I: The tram and BRT, no street reconstruction

The scenario modelled for 2025 describes the following situation during the morning peak:

- transport infrastructure is developed based on the Master Plan of the City of Vilnius; however, with the appearance of a new public transport mode in the corridor of the Santariškės–Stoties Square, no large-scale street reconstruction works are carried out (no street widening), and corridor capacity for passenger cars decreases by one traffic lane in each direction;
- demand for passenger car travels decreases to 61382 veh/h, since a part of passengers change cars to public transport;
- distribution of inhabitants and working places for 2025 is predicted according to hypothetical housing intensity and land use.

Scenario II: The tram and BRT, street reconstruction

The scenario modelled for 2025 describes the following situation during the morning peak:

- transport infrastructure is developed based on the Master Plan of the City of Vilnius; however, with the appearance of a new public transport mode in the corridor of the Santariškės–Stoties Square, street reconstruction works are carried out (the street is widened) and corridor capacity for passenger cars decreases minimally;
- demand for passenger car travels decreases to 61382 veh/h, since a part of passengers change cars to public transport;
- distribution of inhabitants and working places for 2025 is predicted according to hypothetical housing intensity and land use.

Scenario III: The tram and BRT, street reconstruction, one-way traffic

The scenario modelled for 2025 describes the following situation during the morning peak:

- transport infrastructure is developed based on the Master Plan of the City of Vilnius; however, with the appearance of a new public transport mode in the corridor of the Santariškės–Stoties Square, street reconstruction works are carried out (the street is widened), and corridor capacity for passenger cars decreases minimally;
- one-way traffic is organized in Vilnius City: the city centre is reached by the corridor in Kernavės street, and the centre is left by the corridor in Rinktinės street;
- demand for passenger car travels decreases to 61382 veh/h, since a part of passengers change cars to public transport;
- distribution of inhabitants and working places for 2025 is predicted according to hypothetical housing intensity and land use.

4. Analysis of Modelling Urban Transport Flows

The main qualitative results of modelling urban transport flows are given in Table 2. One of the main indices describing the quality of transport in the city are travel time [h/peak hour] (Griškevičiūtė-Gečienė 2010). A comparison of the presented scenarios clearly shows that the shortest travel time is represented by Scenario II; from the point of view of the total run, Scenario II is also the most favourable.

Conclusions and Recommendations

The implemented macro modelling of transport flows in the territory of Vilnius City is the basis for further improvement in and modelling of car and public transport traffic organization in Vilnius City, for assessing an environmental impact and for the further joint modernization and development of urban transport infrastructure and the network of public transport routes.

The developed network of public transport route (BRT and Tram) creates real preconditions for the realization of the sustainable transport system by giv-

Table 2. Qualitative modelling results

Modelling results	Scenario 0	Scenario I	Scenario II	Scenario III
Hourly run during the morning peak [km]	872545	740735	738375	739563
Average speed of the flow [km/h]	35.24	37.82	38.16	38.03
Travel time [h/peak hour]	25274	19619	19342	19509
Average time of one travel [min]	21.06	19.18	18.91	19.07
Number of travels	72017	61382	61382	61382
Average length of the travel [km]	12.12	12.07	12.03	12.05
Difference in travel time (Scenario 0 – Scenario X_i)		5655	5932	5765

ing priority to the development of the new transport mode. The planned route of Santariškės–Stoties Square on Kalvarijų–Pylimo streets corresponds to the main objective of transport strategy for Vilnius City to seek for compact housing in public transport corridors. The planned route allows significantly reducing the necessity for the use of private motorized transport and influencing the total structure of travels thus making it possible for a large number of people to reach the required destination by public transport.

Modelling the light motorized transport system showed that, from the point of view of travel time and the total run, Scenario II was the most suitable for Vilnius City (tram, street reconstruction).

A new tramway line will enable to form new transport behaviour – to change passenger cars to the new public transport mode. It is predicted that after the introduction of the new public transport route and following the suitable reorganization of the existing route network, 15% of passenger car drivers and passengers will transfer to the new public transport mode (comparing Scenario II '2025, Doing a project' to Scenario 0 '2025, Doing nothing'). In this case, a large effect will be achieved, since during the morning peak hour, as much as 5932 light vehicle hours will be saved, and this would amount to 32 thousand of light vehicle hours per day.

To improve the qualitative parameters of the transport system in Vilnius City, it is necessary to plan and ensure the timely realization of solutions to the transport system concerning the Master Plan of the City of Vilnius, as well as recommendations regarding special and detail plan solutions for separate territories. The introduction of the new transport mode is related to transport infrastructure development measures anticipated in the Master Plan of the City of Vilnius.

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