VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Rasa UŠPALYTĖ - VITKŪNIENĖ

MODELLING AND DEVELOPMENT OF TOWN PUBLIC TRANSPORT NETWORK (ON EXAMPLE OF VILNIUS CITY)

Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Rasa UŠPALYTĖ - VITKŪNIENĖ

MIESTO VIEŠOJO TRANSPORTO MARŠRUTINIO TINKLO MODELIAVIMAS IR PLĖTRA (VILNIAUS MIESTO PAVYZDŽIU)

Daktaro disertacijos santrauka
Technologijos mokslai, statybos inžinerija (02T)

VGTU LEIDYKLA
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General Characteristic of the Dissertation

Topicality of the problem. During the last years of the 20th century, the United Nations adopted the concept of sustainable development that integrates economic, social and ecological development. In 1992 the Baltic States adopted AGENDA 21 that besides other conditions incorporates requirements concerning sustainable development of city transport systems, namely: support for land use management and development; development of sustainable energy and transport systems in urban areas; and the creation of a healthy environment in the city.

Rapidly growing mobility of people in Lithuania attaches greater importance to the sustainable development concept. According to forecasts of European scientists on passenger kilometres covered by cars, Lithuania, Slovakia and Poland are among the countries in which the number of passenger kilometres covered by cars in the period from 1995–2020 will rocket by more than 100%. That will have influence on the growth of traffic flows in cities. The available street networks will become too small for the increased traffic flow. The level of car ownership reached the level where 300–400 cars relate to 1,000 inhabitants, and the fact that 45–55 % of residents in large cities use the public transport for their daily trips. A comparison of modal distribution of European cities and Vilnius (capital of Lithuania), revealed that residents of Vilnius use public transport more than others (40 % in 2002) but Vilnius has less bicycle trips (<1 %). For example, trips by bicycles account for 17 % in Berlin and Oslo, and 9 % in Oxford. This situation is increasingly worsening in Lithuania's lager cities while the number of PT trips has decreased (1.3 % per years in Vilnius; 0.13 % in Kaunas). In the White Book it was recognized that public transport should take an important place in future transport systems when aiming at sustainable development of the transport system. Strategic plans for larger Lithuanian cities recognize PT as a top priority branch of transport. This attitude is grounded on the experience of the last 15 years when taking into account environmental issues, social and economic aspects. The key factor that predetermines environmental pollution, noise level generated by transport and passenger's idle time is the volume of the transport flow.

Approximately 70 % of traffic accidents occur in the territorial regions of Lithuania towns and only 10 % of these relate to PT. For example, in Vilnius 2003, of all the recorded traffic accidents (981) only 11,8 % (116) related to public transport, of which 1.5 % were linked to buses (15), 3 % to trolley-buses (29) and 7.3 % to mini-buses (72). At present the situation remains the same.

Pursuing the main aim – sustainable integration of PT into the urban development process by optimally satisfying the needs of Lithuania's people – it its necessary to consider aspects such as general planning of the development of residential and business areas: at the same time expand the priority system of the PT that will be environment-friendly and safe, integrate and inter-coordinate PT modes, and form a hierarchy and inter-coordination of PT modes.

Object of the research. The research's object is to analyze the public transport system and requirements imposed on it and the system's rationality, accessibility, hierarchy formation, and the system's priorities.

The specific object of the research is defined as the establishment and analysis of criteria that have impact on demands for public transport as well as apply these criteria for the development of a model of a rational and hierarchical form for public transport system (based on the pattern of Vilnius).

Aim and tasks of the work. The aim of this paper is to guarantee improved quality of life for inhabitants by modelling the network of public transport routes in Vilnius.

To achieve the aim of the paper, the following tasks were formulated:

- analysis of measures of modelling the public transport passenger flows, as well as analysis their function,
- establish the main criteria of the public transport's modelling in Vilnius,
- modelling of the public transport route networks in accordance with the established criteria,
- assessment of the influence of speedy trams on the distribution of passenger flows within the public transport of Vilnius,
- proposals on the possibilities of application of the public transport modelling criteria for other Lithuanian towns.

Methodology of research. In order to identify the main criteria that have impact on passenger flows and on the demands for PT, theoretical-analytical methods of statistic analysis were used. The used data included data from public transport research in Vilnius and theoretical research on public transport's accessibility and its economic indicators.

The empirical model of Vilnius PT was developed with the help of statistical analysis software Statgraphics. Statistical means were used to choose the most characteristic indicators that have impact on the demands for public transport and to formulate models of polynomial regression.

To create the model of the theoretical network of Vilnius city, VIPS and VISUM software were used. VIDAS database was used for modelling.

The main hypotheses. Analysis of foreign literature on carried out research in the transport field and on models applied for modelling of urban public transport resulted in the formulation of the following hypotheses:

- Hierarchy formation of public transport routes and implementation of a new transport mode will improve the quality of services provided by the PT.
- After certain changes are made, a criterion of the public transport modelling could be applied to other large Lithuanian cities.

Novelty of the dissertation. Novelty of the paper lies in the establishment of key criteria that have influence on public transport and of polynomial regression under market-economy conditions.

The network of public transport routes in Vilnius will have been first modelled under conditions of market economy for the time.

In Lithuania, a logical scheme for modelling the network of the public transport route, applicable to all Lithuanian towns, was also concluded for the first time.

Theoretical and practical results of the dissertation. The paper proves that modelling of the public transport route network in Lithuanian towns is very important. It is the new way for planning public transport services in Lithuania under market-conditions, in order to reach harmonious interaction between the public transport and the needs of citizens.

Two methods were applied in this paper. The first, an empirical statistical method was used for finding indicators that mostly have influence on public transport flows. The second, a theoretical method was applied to employ the indicators found with the help of an empirical statistical method for the development of the theoretical route scheme of public transport. Universal steps of optimization and verification of theoretical route scheme of public transport were also developed.

Attitudes and results from the public transport modelling were used when concluding special and strategic plans of public transport in larger Lithuanian cities.

Approval of dissertation's results and application of results. The main statements of the paper were presented and discussed at international and national conferences in Lithuania, Latvia, Slovakia and Russia. Content of the papers was published in 8 scientific publications and conference materials.

Research part of this paper was used when making feasibility studies of the public transport infrastructure development in Lithuania towns. The research' results were applied when developing the project of Kaunas public transport with Swedish experts and when concluding a strategy for the organization of Vilnius public transport until 2011.

The scope of the scientific work This paper consists of an introduction, 5 chapters, general conclusions and 127 reference entries. This dissertation contains 131 pages and its structure is presented in Figure 1.

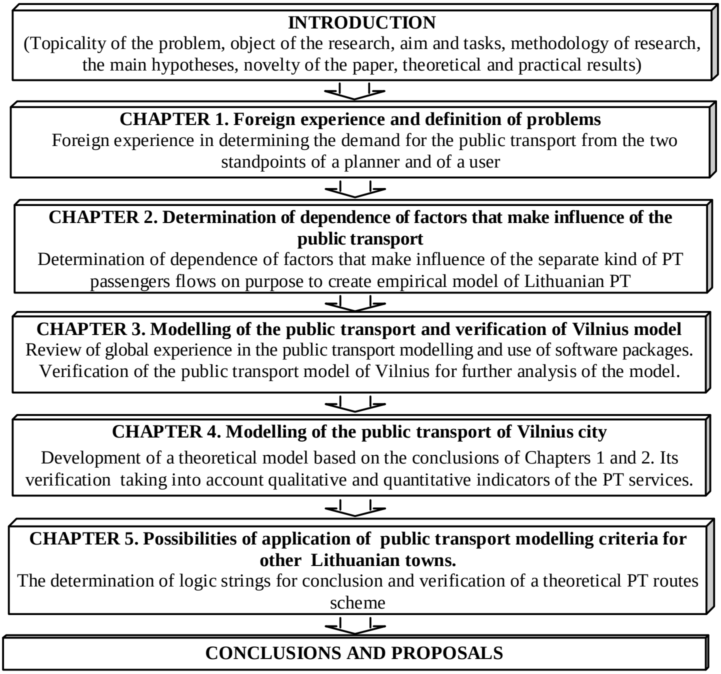

Fig 1. Structure of the dissertation

1. Foreign Experiences in Determining Demands for Public Transport and Definition of Problems

Two main attitudes of foreign and national scientists towards the demand for the PT (public transport) have been analyzed. Two standpoints are revealed: of a planner and of a user.

From the standpoint of a planner, five aspects that influence public transport planning were singled out: 1) planning of land use; size and dispersion of industrial areas; distribution of attraction objects intended for recreation and the demand for PT; 2) governmental policy that exerts influence on all transport solutions that in turn have influence on the level of public transport services, starting with land-use and ending with transport management; 3) size of economic sources; 4) installation of technologies that exert influence on comfort and speed of a transport mode; 5) social trends – mobility and people's chosen ways of travelling depend on social groups of people living in the town.

Looking through the results and criteria of the surveys carried out in Europe and USA that have influenced the use of PT, the demands of a passenger for the public transport system was determined, i.e. convenience, comfort, accessibility, safety, and environmental protection. Convenience was mentioned by most respondents as being a top priority, because it covers optimally chosen routes, sufficient frequency of routes, and good accessibility to PT routes. This aggregate of criteria should become vivid when planning the PT system in Lithuania towns. Comfort was also among the top criteria as indicated by inhabitants when speaking about the improvement of the PT system. Convenient and high-speed vehicles, well-installed stops – these criterions closely related to the volume of financial resources. Accessibility was the third important criterion mentioned by respondents. Information on the network of PT routes and its timetables should be prepared in detail and should be easily accessed; and set tariffs should make PT affordable even for low-income people. Safety was not very often mentioned among respondents, probably because it is in a good state at present. Environmental protection was a rarely mentioned criteria; it is more a social duty than a factor that raises passenger's concern. All the above can be implemented by a well-planned PT system with optimally chosen frequency of routes.

2. Determination of dependence of factors that influence public transport

Table 1. Description of researched indicators

Group	Indicator	Abbreviation
Group of urban structure indicators	Population density, inhab./ha	*Gyv_tankis*
	Work place density, inhab./ha	*Darbo_vt_tankis*
	Street density, km/km^2	*Gatviu_tankis*
	Car ownership level, cars/1,000 inhabitants	*Automobilizacija*
Group of indicators of transport mode use	Flows of bus passengers, passengers/h	*Kel_srautai_A*
	Flows of trolley-bus passengers, passengers/h	*Kel_srautai_T*
	Flows of passengers on private passenger transport, passengers/h	*Kel_srautai_Pr*
	Total flows of passengers, passengers/h	*Kel_srautai_B*
	Maximum flows of cars, cars/h	*Max_Automob_sr*
Group of indicators of public transport services	Accessibility of bus routes, %	*A_Marsrutu_pasiek*
	Accessibility of trolley-bus routes, %	*T_Marsrutu_pasiek*
	Accessibility of private passenger transport routes, %	*Pr_Marsrutu_pasiek*
	Total accessibility of routes, %	*B_Marsrutu_pasiek*
	Bus route density, km/km^2	*A_Marsrutu_tankis*
	Trolley-bus route density, km/km^2	*T_Marsrutu_tankis*
	Density of private passenger transport routes, km/km^2	*Pr_Marsrutu_tankis*
	Total route density, km/km^2	*B_Marsrutu_tankis*
	Frequency of buses, veh./h	*Marsrutu daznis A*
	Frequency of trolley-buses, veh./h	*Marsrutu daznis T*
	Frequency of private passenger transport, veh./h	*Marsrutu daznis Pr*
	Total frequency of transport, veh./h	*Marsrutu daznis B*
	Number of transport modes for travelling, pcs.	*Rusiu_sk*
Group of economic indicators	Passenger transportation price on buses, LT/passenger km	*Pervezimo kaina A*
	Passenger transportation price on trolley-buses, LT/passenger km	*Pervezimo kaina T*
	Passenger transportation price on private passenger tr., LT/passenger km	*Pervezimo kaina Pr*
	Total passenger transportation price on buses, LT/passenger km	*Pervezimo kaina B*

In order to conclude an empiric model for factors that have influence on the flows of the public transport passengers, the program Statgraphics was used, in which the precision of assessment of all dependence models was 95–99 %. These factors were analyzed in 50 Vilnius' transport districts and its suburbs on the grounds of the last comprehensive research on passenger flows of PT carried out in 2002 and on the theoretical research of public transport services and economic indicators. The analyzed indicators can be divided into 4 groups: urban structure, use of a transport mode, public transport services, and an economic group (Table 1). The importance of each indicator was established by using the following statistical values: Pearson correlation coefficient, ***t-criteria*** and ***p-value***, i.e. the observed level of significance.

Polynomial regression equation (r = 0.78, reliability level – 99 %) revealed the dependence of passenger flows on the density of bus routes, working places, frequency of bus routes and maximum flows of cars. The greatest dependence in this regression model was observed with the route density (r = 0.73) and driving density (r = 0.78). This reveals that the level of public transport services is the key influencing factor with regards to bus passenger flows. This corresponds to the results of passenger surveys described in Chapter 2, where respondent's statements showed that the choice of the public transport is predetermined frequency of the PT and by the possibility to reach to the destination point.

$$Kel\_srautai\_A = -29.25 + 30.193 \times A\_Marsrutu\_tankis - 2.252 \times Darbo\_vt\_tankis + 14.212 \times Marsrutu\ daznis\ A + 0.037 \times Max\_Automob\_sr\ .$$

A regression model of trolley-bus passengers (r = 0.57, reliability level – 95 %) revealed that passenger flows on trolley-buses depends on the price of passenger transportation (r = –0.51), route volume (r = 0.45) and maximum car flows (r = 0.46).

$$Kel\_srautai\_T = 399.619 - 2532.13 \times Perve\check{z}imo\ kaina\ T + 11.990 \times Marsrutu\ daznis\ T + 0.093 \times Max\_Automob\_sr\ .$$

Polynomial regression equation (r = 0.72, reliability level – 99 %) revealed that private passenger transport flows depend on the density of private passenger transport routes (r = 0.74), inhabitant density (r = 0.58), maximum car flows (r = 0.61) and are inversely proportional to the density of working places (r = 0.62). The possibility to directly reach the goal of the trip exerts influence on the choice of public passenger transport due to the negative attitude towards the time wasted during a transfer. Dependence on passenger density and maximum flows of cars revealed the correspondence of the private transport passenger flows of and general travel directions:

$$Kel\_srautai\_Pr = -4.468 - 1.405 \times Darbo\_vt\_tankis + 0.638 \times Gyv\_tankis$$
$$+0.029 \times Max\_Automob\_sr + 12.172 \times Pr\_Marsrutu\_tankis.$$

Dependence on total passenger flows of the PT is revealed by a polynomial regression equation ($r = 0.81$, reliability level – 99 %) in which passenger flows depend on the price of passenger transportation ($r = 0.73$), frequency of the public transport ($r = 0.82$), the number of transport modes chosen for the trip ($r = 0.73$) and maximum flows of cars ($r = 0.74$).

$$Kel\_srautai\_B = -274.168 + 1.537 \times Marsrutu\ daznis\ B + 0.044 \times Max\_Automob\_sr -$$
$$38.596 \times Pervezimo\ kaina\ B + 135.165 \times Rusiu\_sk.$$

The square of the correlation coefficient of all polynomial regression equations is ≥ 0.6, thus it can be stated that the factors exerting influence on passenger flows and included into the regression equations are the key factors.

For further modelling of the public transport system, the following indicators of regression models should be taken into consideration: frequency of served routes that have influence on all passenger flows except private passenger transport, the service frequency of which is sufficiently large not to have a negative impact on a passenger who wants to choose the route or travel means; route density that influences passenger flows on buses and private passenger transport, on which the existing public transport system is based, i.e. reaching a destination point without transferring.

3. Modelling of public transport and verification of the Vilnius model

The morning rush-hour (when are maximum passenger flows) was chosen for the modelling. At this time the main problems of public transport become vivid. Thus, the need for PT during rush-hours is most relevant and was chosen as the time interval for the modelling.

Modelling with the help of the software package VISUM, the following main rule was observed: the lower the Integrated Choice Index (IPD) of the travel means chosen, the greater the number of trips chosen. IPD is characterized as a combination of time indicators defined by the user when choosing the travel in different transport districts which may be the following: distance to a stop, time spent in a vehicle, number of transfers etc. This indicator in VISUM software package was taken into account during the modelling when the choice of different links was compared. Verification of Vilnius PT network was carried out after selection of three possible methods: TSys-based, Headway-based and Timetable-based methods. In the *Timetable-based* model the above-described distribution laws *Logit*, *Kirchhoff*, *BoxCox* and *Lochse* were inter-changed:

- Basing modelling on the public transport system (*TSys based*) where differentiation of trips was carried out, taking account of whether the public transport is available on the line in question.
- Basing modelling on the system of public transport routes and headways (*Headway based*).
- Basing modelling on the public transport system with the time-table (*Timetable based*), where account was taken of the specific time of arrival, departure and the intermediate time of every vehicle.

Table 2. Calculation formulas for different distribution lows

Distribution law	U_i^a calculation formula	IPD_i^a calculation formula
Kirchhoff	$U_i^a = IPD_i^{a^{-b}}$	$P_i^a = \dfrac{IPD_i^{a^{-b}}}{\sum_j IPD_j^{a^{-b}}}$
Logit	$U_i^a = e^{-b \cdot IPD_i^a}$	$P_i^a = \dfrac{e^{-b \cdot IPD_i^a}}{\sum_j e^{-b \cdot IPD_j^a}}$
Box-Cox	$U_i^a = e^{-b \cdot b^{(t)}\left(IPD_i^a\right)}$	$P_i^a = \dfrac{e^{-b \cdot b^{(t)}\left(IPD_i^a\right)}}{\sum_j e^{-b \cdot b^{(t)}\left(IPD_j^a\right)}}$
Lohse	$U_i^a = e^{-\left[b\left(\frac{IPD_i^a}{IPD_*^a}-1\right)\right]^2}$	$P_i^a = \dfrac{e^{-\left[b\left(\frac{IPD_i^a}{IPD_*^a}-1\right)\right]^2}}{\sum_j e^{-\left[b\left(\frac{IPD_j^a}{IPD_*^a}-1\right)\right]^2}}$

When modelling with regard to every road under IPD, the percentage of passengers that will choose this road (P_i^a) of the total demand for trips, *i*, on a chosen time interval, *a*, was calculated (Table 2). Employment of every link U_i^a was calculated in accordance with the trip's distribution function from IPD_i^a. Coefficient β was used to describe IPD sensitivity.

One of the key indicators for model calibration is a general indicator of passenger transfers, which was taken from research on public transport passenger flows. It is a very high indicator of transfers, which under moderate and inconsistent frequency of departures on routes has a negative impact on the choice of PT for travelling. To verify the model, points were chosen that gave the best illustration of passenger distribution on the network. These are groups of stops, usually used for transfer from one transport mode to another and the cross-section of the streets with the highest load during morning rush-hours.

Table 3. Coefficients of Vilnius PT network modelling applying different methods

Conformity coefficients		Transfer	Stops	Sections	Average
Survey data 2002		1	1	1	1
TSys-based		0.03	n/a	0.7	0.24
Headway-based		0.62	0.72	0.69	0.68
Time-table based	*Logit*	0.80	0.86	0.67	0.78
	Kirchhoff	0.99	0.82	0.65	0.82
	BoxCox	0.96	0.79	0.67	0.81
	Lochse	0.85	0.86	0.67	0.79

The obtained results, i.e. the number of passengers at the stops and street sections in question, were interpreted as a coefficient revealing their correspondence to the basic data. Modelling by the *TSys-based* method, the coefficient of the number of passenger transfers was very low (0.03) and, it was high when modelling by the *Timetable-based* method. However, when modelling by the *Kirchhoff* method (when $\beta = 4$), the data almost completely corresponded to the data estimated when investigating base passenger flows.

The greatest stop group conformity coefficient (0.86) was received by applying the *Timetable-based* model with *Logit* and *Lochse* distribution laws (Table 3). In this case the coefficient of *Kirchhoff* distribution law was slightly lower and equal to 0.82. We can conclude that the *Timetable-based* model with the distribution law *Kirchhoff* or *BoxCox*, where the average conformity of coefficients with the basic survey of 2002 and are equal to 0.82 and 0.81, and should be used for further development of Vilnius PT network.

4. Modelling of Vilnius public transport

Planning the new theoretically optimal route scheme and its services, the PT route network was optimized under the following criteria: 1) Simplification of the PT system to make it more understandable to a passenger; 2) Minimize passengers time spent on the trip; 3) To use the existing vehicle fleet in a more rational way. The proposed PT network consisted of 18 trolleybus (on existing contact network base), 24 bus and 22 minibus routes. The number of routes in Vilnius was reduced by half and to satisfy inhabitants' needs for travelling the frequency of routes was increased.

Three-level PT route network was modelled in the following way:

- Main routes consisted of trolleybus served routes and the main 10 bus routes. 7 bus routes serve the chords of urban street network and 3 routes are attributed to the highest service zones due to large flows of tourists. Frequency is 4–7 min.
- Service routes will consist of the routes served by buses. Frequency is 10–15 min.

- Feeder routes in Vilnius peripheral areas will be served by minibuses. Frequency is 15–20 min.

Results of the modelled basic scheme and a new scheme revealed that reduction in the number of routes by two times resulted only in 1,1 time (6 %) higher number of transfers during morning rush-hours, i.e. from 52 580 to 55 586. Comparing the number of transfers per trip, in the morning rush-hours it was found that the number of passengers travelling without transfer decreased by 17,5 %, and the number of trips with one transfer increased by 19.4 %. Transfers make the trip on the PT inconvenient and unattractive and force passengers to look for other ways of travelling. The time of transfers on morning rush-hours would decrease by 3 313 minutes, which would account for 3.8 % of time spent for transfers.

Taking into account changes in passengers' travel-time after changing the route scheme of the PT services, the travel time of passengers became shorter by 61.1 %. The travel-time of 36.7 % of passengers remained the same (±5 min.) After changing the basic route scheme, the travel-time became longer for only 2.2 % of passengers. This showed that the proposed PT routes connect the main arrival and departure points within the street network at a shorter distance.

The theoretical route scheme was verified in four steps. *The first step*: It covered verification of the theoretical route scheme in accordance with the run coefficient. After changing the routes and taking account the run coefficient, the trip became 0.5 % longer. Due to transfer of terminal route points to densely populated placed, the number of transfers decreased by 4.6 %, and the time spent for transfers decreased by 7.6 %.

The second step: Return of PT routes to the main street of Vilnius – Gediminas Avenue. This has a positive impact on general indicators of PT services during rush- hours. For passengers whose departure/arrival points are in the zone located nearest to the distance to the avenue, the travel duration to other districts decreased on the average by 0.7 min/1 passenger. Therefore, the scheme with routes on Gedimino Avenue was chosen for further modelling.

The third step: Covered verification of the theoretical route scheme in accordance with the vehicle capacity coefficient. Verification of PT routes on the grounds of run and capacity coefficients in every step improved the indicators of PT services, and when comparing the schemes before and after verification, it was obvious that the number of transfers decreased by 9.5 % and also the spent time decreased by 13 %. Therefore, it is proposed that verification of all the PT plans should be concluded with regard to the PT routes on the grounds of these two indicators.

The fourth step: The impact of the use of a new PT mode on the distribution of passenger flows: two independent routes were prepared to assess the launch of the tram. ***The first route*** was chosen by taking account of modern tram surveys carried out by a French company SYSTRA in 2002. The proposed route Santariškės – Kalvarijų g. – Žaliasis bridge – Pylimo g. – Station, was corrected by taking the changes on the network of streets until 2006 into consideration and was directed through Mindaugo bridge in order to avoid traffic jams. ***The second route*** was chosen on the grounds of conclusions made by the paper's author, Pilaitė – Konstitucijos pr. – Žirmūnų g. – Valakupių bridge – Saulėtekis.

The increase in the time spent for transfers was lowered by a half in the second route. The analysis revealed that at tram lines built at the same level as other PT routes would not be profitable and will not automatically overtake passengers travelling on that street by bus and trolleybus, unless a higher level of the quality of travel will be offered.

5. Possibilities of application of the public transport modelling criteria for other Lithuania towns

Taking foreign experiences into account: the PT route scheme should be planned for any form of ownership of routes. Low capacity vehicles should serve remote routes with lower passenger flows, and the town's centre should be left for electric public transport vehicles, as was planned for the development of a sustainable transport system in Norway or Malta. It is proposed in this paper that three levels of PT route network be modelled for Lithuanian, Norwegian or Malta's towns; and should consist of key routes, serving routes, and supplementary routes. To serve the key routes, priority is given to electric vehicles, trolleybuses, if it is maintained or planned to be maintained by the town in question. It is foreseen that key routes will serve the chords of urban street network. Creating chords routes at a higher service level two goals can be achieved: firstly, a higher level of PT services is guaranteed in the city and the time of trip becomes shorter. Secondly, passengers use buses in a more efficient way, as shorter trips will require lower run of a vehicle.

Outskirts of the town with low passenger flow are serviced by minibuses as use of larger capacity PT vehicles is not efficient in those areas.

The planned scheme of the PT was verified by this logical scheme. The first step of verification is verification of route run coefficients (1). In Lithuanian towns the PT run coefficient is equal to 0.97–0.99. To efficiently use vehicle run, the run coefficient should be at least 0.9.

$$b = \frac{\sum l_p}{\sum \left(l_p + l_t\right)}, \qquad (1)$$

l_p – run of a vehicle with passengers; l_t – idle run of a vehicle.

The second step is verification of the use of capacity coefficient (2):

$$\gamma_s = \frac{Q_f}{Q_n}, \qquad (2)$$

Q_f – the number of actually transported passengers; Q_n – passengers who could be transported by making full use of the capacity of a vehicle.

Capacity coefficient is different not only on different routes but also at different times of the day. Capacity coefficient in Lithuanian towns during rush-hours is 0.15–0.30 to 1.15–1.24. The author of this thesis assumed the condition of the capacity coefficient, by taking account of the maximum number of passengers on the route, that it should not be lower than 0,7 (for the operator to work without losses) and higher than 0.95 (for passengers to have a comfortable drive). A logical scheme of modelling public transport in Lithuanian towns is presented in Figure 2.

Modelling of the planned scheme of public transport routes is necessary for all towns of Lithuania (without taking their size into consideration) in order to avoid planning mistakes and to ground the solutions.

Conclusions and proposals

1. The main criteria on which to base the planning of the PT system in Lithuanian towns is set out on the grounds of surveys carried out in the USA and Europe that singled out the main criteria mentioned by respondents in this paper's research with regard to the use of the public transport. VT conveniences revealed by optimally chosen routes were; sufficient frequency of vehicles serving the public transport routes; good accessibility of the public transport routes. Maintenance of these criteria will allow optimization of public transport by the available material and financial resources and by satisfying inhabitants' needs and environmental requirements.
2. The resulting polynomial regression equation showed that the dependence of total passenger flows of the public transport is revealed by a polynomial regression equation (r = 0.81, reliability level 99 %) in which passenger flows depend on the price of passenger transportation, frequency of the public transport, number of transport modes chosen for the trip and maximum flows of private cars. Thus, further modelling of the public transport system, the following indicators of regression models should be taken into consideration: frequency of served routes that have influence on all passenger flows (r = 0.45–0.82); route density (r = 0.73–0.74) which have influence on passenger flows on buses and private passenger transport.
3. Analysis of all coefficients received when verifying the model allows a conclusion that further modelling of the development of Vilnius PT network

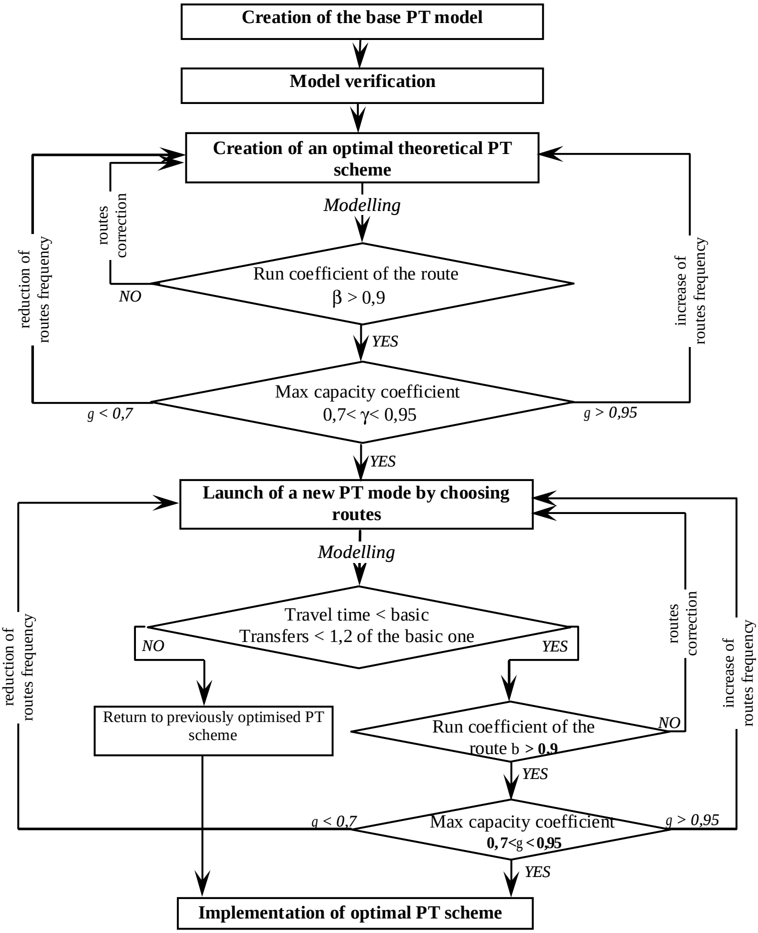

Fig 2. Logical scheme of public transport modelling in Lithuanian towns

should be based on the Timetable-based model choosing Kirchhoff or BocCox distribution laws, whereof conformity to the basic averages of coefficients of the 2002 survey is respectively 0.82 and 0.81.

4. Three-level public transport route network was formed for modelling, i.e. the network of key routes, serving routes and supplementary routes, the key routes of which will be served by trolleybuses and priority bus routes serving the tangents of urban streets. Routes serving the main flows of visitors and

tourists will also be attributed to the key routes. In order to maintain the attractiveness of the town, it is necessary to guarantee high-level services of the public transport for tourists and visitors.

5. For further modelling of the public transport should include Gediminas Avenue, because the launch of the public transport on this avenue has a positive impact on general indicators of public transport services during rush-hours. For passengers whose departure or arrival points are in the zone located to the nearest distance to the avenue, the travel duration to other districts decreased on average by 0.7 min/1 passenger.

6. Verification of public transport routes on the grounds of run and capacity coefficients at every step improved the indicators of PT services, and when comparing the schemes before and after verification, it is obvious that the number of transfers decreased by 9.5 % and the spent time decreased by 13 %. It is proposed to verify all plans of public transport routes to be concluded under the two main indicators as was determined by the paper's author.

7. Modelling results revealed that launching tram routes on the same level as the remaining carriage routes will overtake the passenger of only one route (tram line 1 – 1857 passengers, route of bus No 26 – 1925 passengers; tram line 2 – 1100 passengers, route of bus No 30 – 2077 passengers). Therefore, unless additional measures are implemented to improve the level and quality of services, the tram will not overtake all passengers going on analogical routes of buses and trolleybuses.

8. Modelling of the planned scheme of public transport routes is necessary for all towns of Lithuania, without taking their size into consideration. To plan the route's scheme, all Lithuanian towns could use the proposed theoretical logical route-scheme of the public transport by applying two or three route levels by taking the size of the town into consideration.

9. It is proposed that the routes of the theoretical public route scheme are verified when modelling to satisfy the following conditions:

- Route run coefficient should be at least 0.9;
- Vehicle capacity coefficient should be 0.7–0.95.

Published works on the topic of the dissertation

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About the author

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MIESTO VIEŠOJO TRANSPORTO MARŠRUTINIO TINKLO MODELIAVIMAS IR PLĖTRA (VILNIAUS MIESTO PAVYZDŽIU)

Darbo aktualumas. Paskutiniais XX a. metais Jungtinės Tautos paskelbė darnaus vystymosi koncepciją, kuri sieja ekonominę, socialinę ir ekologinę plėtrą. 1992 m. Baltijos šalys priėmė darbotvarkę „AGENDA 21“, kurioje, be kitų pagrindinių sąlygų, pateikti reikalavimai subalansuotai transporto sistemos plėtrai mieste: tai plėtros ir žemės naudojimo vadybos rėmimas, subalansuotų energijos ir transporto sistemų plėtros urbanizuotose teritorijose vystymas, sveikos aplinkos mieste kūrimas.

Sparčiai augantis gyventojų judrumas Lietuvoje subalansuotos plėtros koncepciją daro vis svarbesnę. Remiantis Europos mokslininkų pateikta automobiliais nuvažiuotų keleivių kilometrų skaičiaus prognoze, Lietuva su Slovakija ir Lenkija patenka į šalių grupę, kurioje automobiliais nuvažiuotų keleivių kilometrų skaičius nuo 1995 iki 2020 m. padidės daugiau nei 2 kartus. Tai darys įtaką sparčiam eismo srautų augimui miestuose. Tokiam išaugusiam srautui esamas gatvių tinklas bus per mažas. Automobilizacijos lygis pasiekė 300–400 automobilių 1000 gyventojų, o 45–55 % didžiųjų miestų gyventojų kasdieninėms kelionėms naudoja viešąjį transportą (toliau VT). Europos miestų modalinį pasiskirstymą palyginus su Lietuvos sostine Vilniumi, galima pastebėti, kad Vilniaus mieste gyventojai VT naudojasi daugiausiai (40 % – 2002 m.), bet čia yra gerokai mažiau kelionių dviračiais <1 %. Pvz., Vienoje kelionės dviračiais sudaro 17 %, Berlyne, Osle, Oksforde – 9 %. Ši situacija didžiuosiuose Lietuvos miestuose nuolatos blogėja, krintant kelionių VT skaičiui (Vilniuje 1,3 % per metus). Baltosios knygos politikos gairėse pripažįstama, kad VT turi užimti svarbią vietą ateities transporto sistemoje, siekiant stabilios susisiekimo sistemos plėtros. Didžiųjų Lietuvos miestų strateginiuose planuose viešasis transportas pripažintas prioritetine transporto šaka. Ši nuostata remiasi paskutinių 15 metų laikotarpio patirtimi, kai vertinami ne tik aplinkosaugos, bet ir socialiniai, ekonominiai aspektai. Lietuvos miesto teritorijose įvyksta apie 70 % visų eismo nelaimių, VT iš jų tenka tik 10 %. Pavyzdžiui, Vilniaus mieste 2003 m. iš visų įskaitinių avarijų (981) miesto viešajam transportui teko tik 11,8 % (116), iš jų 1,5 % – autobusams (15), 3 % – troleibusams (29) ir 7,3 % – mikroautobusams (72). Šiuo metu situacija išlieka ta pati.

Siekiant pagrindinio tikslo – visuomeninio transporto darnaus įsiliejimo į miesto plėtros procesą, optimaliai tenkinant Lietuvos miestų gyventojų judrumo poreikius, būtina atsižvelgti į tokius aspektus, kaip į bendrą gyvenamųjų ir verslo paskirties teritorijų plėtros planavimą, kartu plečiant prioritetinę viešojo transporto sistemą, kuri nekenks aplinkai ir sąlygiškai saugi; viešojo transporto rūšių integravimą ir koordinavimą tarpusavyje ir su kitomis transporto sistemos rūšimis; visuomeninio transporto priemonių rūšių hierarchizavimą ir koordinavimą tarpusavyje.

Tyrimų objektas. Tyrimų objektas – miesto viešojo transporto sistema ir jai keliami reikalavimai: sistemos racionalumas, pasiekiamumas, hierarchizavimas, prioritetiškumas.

Konkretus tyrimų objektas apibrėžiamas kaip kriterijų, darančių įtaką viešojo transporto poreikiui, nustatymas, analizė ir naudojimas racionaliam ir hierarchizuotam miesto viešojo transporto sistemos modeliui kurti (Vilniaus miesto esamos būklės pavyzdžiu).

Darbo tikslas ir uždaviniai. Darbo tikslas – užtikrinti geresnę gyventojų gyvenimo kokybę, modeliuojant viešojo transporto maršrutų tinklą mieste.

Darbo tikslui pasiekti buvo suformuluoti šie uždaviniai:

- Išanalizuoti viešojo transporto keleivių srautų modeliavimo priemones ir jų naudojimą.
- Nustatyti svarbiausius VT modeliavimo kriterijus Vilniaus miestui.
- Pagal nustatytus kriterijus sumodeliuoti viešojo transporto maršrutinį tinklą.
- Įvertinti greitojo tramvajaus paleidimo įtaką keleivių srautų pasiskirstymui Vilniaus miesto viešajame transporte.
- Pasiūlyti viešojo transporto modeliavimo kriterijų taikymo galimybes kitiems Lietuvos miestams.

Tyrimų metodika. Siekiant identifikuoti pagrindinius kriterijus, darančius poveikį keleivių srautams ir viešojo transporto poreikiui, buvo naudojami teoriniai analitiniai statistinės analizės metodai. Naudoti Vilniaus miesto viešojo transporto tyrimų duomenys ir autorės atlikti teoriniai viešojo transporto pasiekiamumo ir ekonominių rodiklių tyrimai.

Vilniaus viešojo transporto empirinis modelis buvo sukurtas naudojant statistinę programinę įrangą „Statgraphics“. Statistinėmis priemonėmis buvo atrinkti charakteringiausi viešojo transporto poreikį veikiantys rodikliai ir suformuluoti daugianarės regresijos modeliai.

Teorinio Vilniaus miesto viešojo transporto tinklo modeliui kurti naudota VIPS ir VISUM programinė įranga. Modeliuoti naudota VIDAS duomenų bazė.

Pagrindinės hipotezės. Atlikus užsienio literatūros analizę apie atliktus tyrimus šioje srityje ir modelius, taikytus miesto visuomeniniam transportui modeliuoti, buvo suformuluotos tokios hipotezės:

- Viešojo transporto maršrutų hierarchizavimas ir naujos viešojo transporto rūšies įdiegimas pagerins viešojo transporto aptarnavimo kokybę.
- Viešojo transporto modeliavimo kriterijus su tam tikrais pokyčiais galima taikyti kitiems didiesiems Lietuvos miestams.

Mokslinio darbo naujumas. Mokslinio darbo naujumą sudaro svarbiausių kriterijų darančių įtaką viešajam transportui, daugianarės regresijos modelių nustatymas rinkos ekonomikos sąlygomis.

Pirmą kartą buvo sumodeliuotas Vilniaus miesto viešojo transporto maršrutų tinklas rinkos ekonomikos sąlygomis.

Pirmą kartą Lietuvoje sudaryta miesto viešojo transporto maršrutinio tinklo modeliavimo loginė schema pritaikoma visiems Lietuvos miestams.

Teoriniai ir praktiniai darbo rezultatai. Disertacijoje įrodyta, kad viešojo transporto maršrutinio tinklo modeliavimas labai svarbus Lietuvos miestuose. Tai naujas Lietuvoje viešojo transporto susisiekimo planavimo būdas, rinkos ekonomikos sąlygomis siekiant darnios viešojo transporto sąveikos su miesto gyventojų poreikiais.

Disertacijoje buvo taikyti du metodai. Pirmasis empirinis statistinis metodas naudotas rodikliams daugiausia darantiems įtaką viešojo transporto srautams rasti. Antrasis teorinis metodas taikytas empiriniu statistiniu metodu rastų rodiklių panaudojimo teorinio viešojo transporto maršrutinei aptarnavimo schemai kurti. Sukurti universalūs teorinės maršrutinės viešojo transporto aptarnavimo schemos optimizavimo ir verifikavimo žingsniai.

Viešojo transporto modeliavimo nuostatos ir rezultatai buvo naudojami rengiant specialiuosius ir strateginius viešojo transporto susisiekimo planus didiesiems Lietuvos miestams.

Darbo aprobavimas ir rezultatų naudojimas. Pagrindiniai disertacijos teiginiai buvo pristatyti ir svarstyti tarptautinėse ir respublikinėse konferencijose Lietuvoje, Latvijoje, Slovakijoje, Rusijoje. Disertacijos medžiaga publikuota 8 moksliniuose leidiniuose ir konferencijų medžiagoje.

Disertacijos tyrimų dalis panaudota rengiant 2 galimybių studijas transporto infrastruktūros plėtros Lietuvos miestuose klausimais. Tyrimų rezultatai naudoti, su Švedų ekspertais kuriant Kauno viešojo transporto projektą ir rengiant Vilniaus miesto visuomeninio transporto organizavimo strategiją iki 2011 m.

Darbo apimtis ir struktūra. Disertaciją sudaro bendra darbo charakteristika, penki skyriai, bendrosios išvados, 127 literatūros šaltinių sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 131 puslapių, 57 iliustracijos, 16 lentelės ir 3 priedai.

Išvados ir pasiūlymai

1. Pagrindinis kriterijus, kuriuo galima remtis planuojant viešojo transporto sistemą Lietuvos miestuose, nustatytas pagal JAV ir Europos šalyse atliktų apklausų metu svarbiausius respondentų paminėtus viešojo transporto naudojimąsi veikiančius kriterijus. Tai – VT patogumas, kurį rodo optimaliai parinktos maršrutų trasos; pakankamas maršrutą aptarnaujančių transporto priemonių dažnis; geras viešojo transporto maršrutų pasiekiamumas. Šių kriterijų išlaikymas leis optimizuoti aptarnavimą viešuoju transportu turimais materialiais ir finansiniais ištekliais, tenkinant gyventojų poreikius ir aplinkosaugos reikalavimus.
2. Gauta daugianarės regresijos lygtis (r = 0,81, patikimumo lygis – 99 %) parodo bendrų viešojo transporto keleivių srautų priklausomybę nuo keleivių vežimo kainos, viešojo transporto maršrutų dažnio, transporto rūšių skaičiaus pasirinkimo kelionei atlikti ir maksimalių lengvųjų automobilių srautų. Todėl modeliuojant viešojo transporto sistemą, būtina įvertinti visus regresijos modeliuose atsispindinčius rodiklius: aptarnaujamų maršrutų dažnis, kuris daro įtaką visiems keleivių srautams (r= 0,45–0,82); ir maršrutų tankis (r = 0,73–0,74) darantis įtaką autobusų ir privataus keleivinio transporto srautams.
3. Išanalizavę visus verifikuojant modelį gautus koeficientus, darome išvadą, kad norint toliau modeliuoti Vilniaus miesto viešojo transporto tinklo plėtrą, geriausia taikyti Timetable-based modelį, pasirenkant Kirchhoff ($\beta = 4$) arba BoxCox ($\beta = 1$) pasiskirstymo dėsnius, kurių atitikimo su baziniais 2002 m. tyrimais koeficientų vidurkis atitinkamai lygus 0,82 ir 0,81.
4. Vilniaus miesto VT tinklui modeliuoti formuojamas trijų lygių: pagrindinio, aptarnaujančio ir pagalbinio lygio maršrutinis tinklas, kurio pagrindinius maršrutus sudarys troleibusų aptarnaujami maršrutai ir prioritetiniai autobusų maršrutai, kursuojantys miesto gatvių tinklo statmenomis stygomis. Prie pagrindinių miesto gatvių tinklo maršrutų priskiriami ir maršrutai, aptarnaujantys pagrindinius miesto svečių ir turistų srautus. Norint išsaugoti miesto patrauklumą, reikia garantuoti aukšto lygio viešojo transporto paslaugas atvykstantiems turistams ir svečiams.
5. Toliau VT modeliuoti Vilniuje parenkama maršrutų schema, įtraukianti Gedimino prospektą, nes viešojo transporto įvedimas šia gatve daro teigiamą įtaką ir bendriems viešojo transporto aptarnavimo rodikliams kamšos

valandomis visame VT tinkle. Keleiviams, kurių išvykimo arba atvykimo vietos yra arčiausiai prospekto esančios zonos, kelionės trukmė, darbo dienos kamšos valandą į kitus rajonus sumažėjo vidutiniškai 0,7 min/1 kelionei, o gyventojams, norintiems pasiekti šiuos rajonus, – 0,1 min/1 kelionei (tai per metus sudarys 2733,47 valandas).

6. Viešojo transporto maršrutų verifikavimas Vilniuje pagal ridos ir talpos panaudojimo koeficientus su kiekvienu žingsniu gerino viešojo transporto aptarnavimo rodiklius, o palyginus schemas prieš verifikavimą ir po jo, matyti, kad 9,5 % sumažėjo persėdimų skaičius ir 13 % – jiems sugaištamas laikas. Siūloma visus miestams ruošiamus viešojo transporto maršrutinių aptarnavimo schemų planus verifikuoti pagal šiuos du svarbiausius autorės nustatytus rodiklius: maršruto ridos ir transporto priemonės talpos panaudojimo.

7. Modeliavimo rezultatai parodė, kad nutiesus tramvajaus maršrutus viename lygyje su gatvių važiuojamąja dalimi, jie perima tik vieno maršruto keleivius (1 tramvajaus linija – 1857 keleiviai, 26 autobuso maršrutas – 1925 keleiviai; 2 tramvajaus linija – 1100 keleiviai, 30 autobuso maršrutas – 2077 keleiviai). Todėl be papildomų priemonių nebus pasiekta geresnio aptarnavimo lygio bei kokybės, o tramvajus savaime neperims visų analogiškais maršrutais važiavusių autobusų bei troleibusų maršrutų keleivių.

8. Modeliuoti planuojamą viešojo transporto maršrutų aptarnavimo schemą būtina visiems Lietuvos miestams, neatsižvelgiant į jų dydį. Maršrutinei schemai planuoti, visiems Lietuvos miestams galima naudoti pasiūlytą teorinę loginę viešojo transporto maršrutinę schemą, taikant du arba tris maršrutų lygius, atsižvelgiant į miesto dydį.

9. Modeliuojant siūlomos teorinės viešojo transporto maršrutinės schemos maršrutai verifikuojami, siekiant patenkinti šias sąlygas:

- kad maršruto ridos koeficientas būtų ne mažesnis kaip 0,9;
- kad maršruto transporto priemonės talpos koeficientas būtų 0,7–0,95.

Trumpos žinios apie autorę

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MODELLING AND DEVELOPMENT OF TOWN PUBLIC TRANSPORT NETWORK (ON EXAMPLE OF VILNIUS CITY)

Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)

Rasa Ušpalytė - Vitkūnienė

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Daktaro disertacijos santrauka
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