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CALIBRATION OF VILNIUS PUBLIC TRANSPORT MODEL

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Abstract. The application of information technologies preconditions the optimisation of performance of transport systems: improvement of the performance quality, safety and efficiency of the overall system, increase in capacity, reduction of the trip duration without high financial investment into construction of the new technical infrastructure. The transport modelling is the only economical and sufficiently reliable way to carry out a forward assessment of the impact of the innovations to be applied on the overall system. The network of Vilnius public transport was built up on the data of 2002, and the year 2002 saw the last comprehensive surveys. Building up the PT network the data was taken from the VIDAS database, created in 2002 while drafting the special plan for Vilnius transport infrastructure (tram) development. The morning rush hour, when the passenger flows are maximum, was chosen for the modelling. Calibration of Vilnius PT network was carried out after selection of three possible methods: TSys-based, Headway-based and Timetable-based. In the timetable-based model Logit, Kirchhoff, BoxCox and Lochse distribution factors are inter-changed.
Analysis of all coefficients received when modelling allows a conclusion that further modelling of the development of Vilnius public transport network should be based on 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. This would facilitate adopting solutions to the development of the public transport systems and would increase their reliability. The calculated coefficients revealed that TSys-based methods were mostly removed from reality, and the average coefficient of failure to conform to the data of the 2002 survey is 0,24. This method did not give any data about the load on the stops, although the number of trips modelled with the help of this method was most proximate to the survey data, i.e. 0,69 %.

Keywords: Transport system, public transport, modelling, calibration of model.

1. Introduction

Growth of cities results in the expansion of their territory, widening gaps in welfare of individual zones and increasing distances from one zone to another. Increasing specialization of city districts and division of districts into residential, serving, trade, industrial and business areas result in the growing need for transport among individual zones and in greater load on the transport system, which requires greater importance attached to the solution of transport system problems [1]. The application of information technologies preconditions the optimization of performance of transport systems: improvement of the performance quality, safety and efficiency of the overall system, increase in capacity, reduction of the trip duration without high financial investment into construction of the new technical infrastructure.

Modelling of the transport system allows analysis of different phenomena related to the traffic organization without applying expensive practical experiments. Modelling is the only way to forecast the need for transport in future and the behavior of the system participants, as well as to plan actions for the implementation of the future scenarios. Thus, the knowledge about transport modelling and about the data used for modelling substantiates the application of the innovative solutions in dealing with the existing and perspective problems of the transport system. The transport modelling is the only economical and sufficiently reliable way to carry out a forward assessment of the impact of the innovations to be applied on the overall system [2].

Vilnius was deliberately chosen for production of a public transport model within the transport system. First of all, it is one of those few cities that are served by three modes of the public transport: buses, trolley-buses and mini-buses; second, it is the only city that has undergone comprehensive public transport surveys during the last five years.

Dynamic changes of the city should cause changes in the public transport that serves the inhabitants, as previously concluded plans of the public transport (PT) routes fail to meet the needs for mobility of the present-day population. This conditions the decrease in the flows of the public transport passengers. From 1992 to 2001, the passenger flows in the towns of Lithuania went down by 3.1 times, i.e. from 1103 million to 354 million. During this period the number of bus passengers went down by 3.36 times, which was a more rapid decrease than that on other public transport modes, as the number of trolley-bus passengers went down by 2 times [3, 4].

At present, the network of Vilnius public transport undergoes very chaotic changes: routes are being prolonged, shortened, established anew and then cancelled. Now Vilnius has 19 routes of trolley-buses and 67 routes of buses. Annually, on the average 17 routes get changed (see Fig 1), which accounts for 20 % of the total number of routes.

To make the planning of Vilnius public transport system more rational, it is necessary to create its model in order to:

- Streamline the network of the public transport routes that meets the new needs of population arising due to changes in their living and working places.
- Effectively serve the newly created objects of attraction, namely: trade and recreation centres, and cinemas.
- To establish the hierarchy of routes of different public transport modes, in order to decrease their overlapping, stop internal competition and cut the expenses for public transport services.
- To assess the outcome of the introduction of a new public transport mode on the distribution of passenger flows within the public transport network.

The paper is aimed at calibrating the model of Vilnius public transport that could further be used for

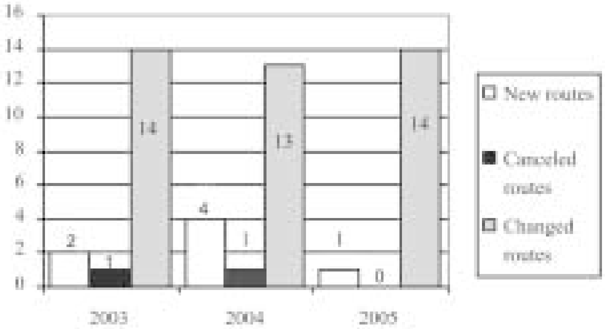

Fig 1. Public transport routes in 2003–2005

substantiation of solutions to the public transport system development.

2. Foreign experience in the public transport modelling with the help of software packages

In a real city, trips of people are more complex than those in models due to the fact that more than one public transport mode exists. Besides a route, people may choose a transport mode for their trips, possible transfer to other modes of the PT. In 1994, Fernandez et al. proposed development of the integrated trip system with combined modes of trips at three levels: integrated trip modes, points of change and choice of route [5, 6]. At present, the proposed modes are used almost in all the models being used (Scenes, Litres-2, Expedite, Logit, Lohse, Kirchhoff, etc.).

Today, a number of software packages used for the modelling of the public transport have been created in the world. Some of them are the following: VISION, EMME/2, TRIPS, TRANSYT usually used in European countries and America, and GETRAM and ASCII usually used in Asia. The programmes VISION and EMME/2 are most popular in the world. For flow modelling both of these programmes use a four stage integrated demand modelling, which covers traffic generation, distribution and choice of the mode of travel [7, 8].

3. Making a model of Vilnius Public Transport

The network of Vilnius public transport was built up on the data of 2002 and the year 2002 saw the last comprehensive surveys. Building up the PT network the data was taken from the VIDAS database, created in 2002 while drafting the special plan for Vilnius transport infrastructure (tram) development. According to the data available on this database, Vilnius urban and suburban zones served by the PT were divided into 230 transport districts.

Two-sided stops and, in certain places, a group of stops at the crossing zones were included into the PT model of Vilnius city, as specification of this field does not exert significant impact on the precision of the model. A 676.9 km long PT network with 506 groups of stops and about 700 additional points necessary for a more precise picturing of the route network was built up. Centres of transport districts are connected to stops by 3040 footpaths that indicate the shortest way not only to the nearest stops but also to the stops covered by other routes or even by the routes of another transport mode. To introduce the footpath that were only possible, the topographical data on the locations of water bodies and green areas were used. Taking account of the PT scheme of 2002, bus, trolley-bus and mini-bus routes were introduced.

Matrix O-D (origin-destination) for the PT modelling was taken from the survey of passengers carried out in 2002 while drafting the special plan for Vilnius transport infrastructure (tram) development. This matrix of trips was concluded after survey of 8895 passengers at 307 stops of Vilnius public transport. For most respondents (89 %) the trips were continual and took place at least 5 times per week. The obtained results were compared with the real values, thus they mostly reflect the real distribution of trips of Vilnius population among different transport districts at the morning rush hours.

4. Modelling with the help of software package VISUM

The morning rush hour, when the passenger flows are maximum, was chosen for the modelling. Periodical overcrowding is characteristic of the public transport and it is heaviest in the morning and afternoon rush hours (see Fig 2), while at the day-time the need for the PT is lower [9]. Thus, the need for the PT during the morning rush hours is most relevant and was chosen as the time interval of modelling.

Modelling with the help of the software package VISUM, the following main rule was observed: the lower the Impedances (IPD) of the travel being chosen the greater the number of trips is chosen. IPD is characterised as a combination of the time indicators defined by the user when choosing the travel among transport districts which may be the following: distance to a stop, time spent in a vehicle, the number of transfers, etc. Most foreign scientists agree that it is necessary to align not only the minima of the trip length and time but also that of the price in order to choose the most real travels chosen by passengers. Only the duration of waiting at the beginning and end of the trip maybe maximum as this time could be best controlled by a passenger, while the rest weight functions are minimal [5, 6, 10, 11, 12]. This indicator in the software package VISUM is being introduced during modelling, when the choice of different O-D travels is being compared.

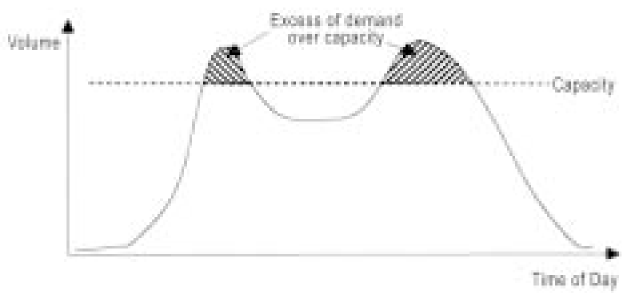

Fig 2. Need for the public transport during the day-time

The significance of IPD indicators in the modelling of Vilnius public transport network was defined on the grounds of population survey carried out in 2001–2002, which revealed that to 20 % of respondents a too long way to the stop (i.e. too much time spent while going from home to a stop) was the most important factor within the public transport system; to another 20 % of respondents the time spent while waiting for a public transport vehicle was the most important factor; to 9 % of respondents the time of the trip (i.e. the time spent in a vehicle, including the time needed for transfer) was the most important factor [13].

With the help of the software package VISUM, modelling may be carried out in three different ways:

1) Modelling based on the public transport system *(TSys based)*, where differentiation of trips is performed only considering whether the public transport is available on that connection, without taking account of individual public transport route lines. The shortest distance is looked for among the connections on which the public transport is available. In this case IPD of different travels, that consist of the information on the duration of the trip on the connections being crossed and time-losses suffered due to transfers, are being compared. The total demand of an OD relation is assigned to the route with the lowest impedance.

   The transport system-based procedure carries out exactly one best-route search for every OD pair.

2) Modelling based on the public transport route system and the time between consecutive public transport vehicles on the same route *(Headway based)*. This modelling procedure requires initial data on the public transport routes, the duration of the trip between the stops and the time between consecutive public transport vehicles on the same routes. Account is not taken of time of every individual trip, while the time loss related to a transfer is equal to a half of the headway. Modelling procedure is being carried out in three stages: calculation of the headway, search for and choice of a route and measuring the load of the route.

   The headway-based procedure differs from the timetable-based assignment in the combination of search and choice. In this second step, a search is made for possible paths between two traffic zones and a distribution is specified between them.

3) Modelling based on the public transport system

and the timetable *(Timetable based)*. Account is taken of a specific time of departure and arrival, and headway time at the stops. Passenger flows are directed to several routes on the basis of their IPD rather than to a single best route. The Timetable-based method calculates connections for each OD pair. It is assumed in the search that the passengers have timetable information available and choose their access time according to the departure on the first public transport line.

With regard to every route, on the basis of IPD values the number of passengers who will choose this route is being calculated as a percentage (P_i^a) of the total need for trips *i* during a selected headway *a*. Use of every connection U_i^a is calculated with the help of the function of trip distribution IPD_i^a .

$$U_i^a = f\left(IPD_i^a\right), \tag{1}$$

$$P_i^a = \frac{U_i^a}{\sum_{j=1}^{n} U_j^a}, \tag{2}$$

where *n* is the total number of connections.

The models reveal differences in the functional relation *f* of impedance and utility. When the impedance attribute is used, this is also included in the formula for calculating P_i^a .

From older versions of VISUM only **Kirchhoff** distribution law is used, which is defined as follows:

$$U_i^a = {IPD_i^a}^{-\beta}, \tag{3}$$

$$P_i^a = \frac{{IPD_i^a}^{-\beta}}{\sum_j {IPD_j^a}^{-\beta}}. \tag{4}$$

Coefficient β describes the sensitivity of passenger towards increased impedances. In this distribution law, IPD has a very low sensitivity.

The present versions have three more distribution laws introduced that have higher IPD sensitivity. One of them is the **Logit** distribution law in which IPD is defined as an indicator of function *e*:

$$U_i^a = e^{-\beta IPD_i^a}, \tag{5}$$

$$P_i^a = \frac{e^{-\beta \cdot IPD_i^a}}{\sum_j e^{-\beta \cdot IPD_j^a}}. \tag{6}$$

Another distribution law is **Box-Cox.** With $\tau \geq 0$ this distribution is calculated with the help of the following formula:

$$b^{(\tau)}(x) = \begin{cases} \dfrac{x^{\tau} - 1}{\tau} & if \;\; \tau \neq 0, \\ \log(x) & if \;\; \tau = 0. \end{cases} \tag{7}$$

When calculating efficiency, the Logit model consists of $b^{(\tau)}\left(IPD_i^a\right)$ instead of IPD_i^a , i.e. $U_i^a = e^{-\beta \cdot b^{(\tau)}\left(IPD_i^a\right)}$. P_i^a when the number of connections is *i* and the headway *a* is calculated with the help of the following formula:

$$P_i^a = \frac{e^{-\beta \cdot b^{(\tau)}\left(IPD_i^a\right)}}{\sum_j e^{-\beta \cdot b^{(\tau)}\left(IPD_j^a\right)}}. \tag{8}$$

It could be said that this model connects the above-defined models, as with $\tau = 0$ we get the Kirchhoff distribution, while with $\tau = 1$ we get Logit.

And the last distribution law in which IPDs are inter-related, which is substantially different from other laws, is **Lohse** distribution law:

$$P_i^a = \frac{e^{-\left[\beta\left(\frac{IPD_i^a}{IPD_*^a} - 1\right)\right]^2}}{\sum_j e^{-\left[\beta\left(\frac{IPD_j^a}{IPD_*^a} - 1\right)\right]^2}}, \tag{9}$$

where $IPD_*^a = \min_j IPD_j^a$ is the rarest IPD possibility in the model and β is the parameter that controls the IPD sensitivity.

In this case the dependences of connections are minimally related to IPD, i.e. differences in IPD connections are optimally precise. Taking the above-said into account, the Lohse model may be used as an alternative for Kirchhoff or Logit models but the Lohse distribution formula cannot be regarded as a special form of Box-Cox transformation.

5. Calibration of the received model

The received model reflects the distribution of the PT passenger flows during the morning rush hour (7.00 a.m. to 8.00 a.m.) and the points of transfer (except TSys-based method). The information was received on the origin and departure stops of the trips chosen by passengers (except TSys-based method), duration of their trips among transport districts, load of the PT routes, the number of transfers at stops and among transport modes, etc.

One of the key indicators in the model calibration was a total indicator of passenger transfers which was taken taking account of the public transport passenger flow surveys described in the paper *Performance analysis of Vilnius Public Transport and Proposals for Sustainable Development in 2002,* which revealed that 49 % of passengers travelled without transfers, 31 % made one transfer, 17 % made two transfers and 3 % made three transfers between different public transport lines.

The points that to the highest extent reflect the distribution of passengers within the network were selected: the groups of stops usually used for the transfer from one PT vehicle to another and the sections of streets with the heaviest loads during the morning rush hours.

Load on the groups of stops and the number of passengers crossing the sections by the PT, obtained in 2002 during the survey on Vilnius passenger flows, and was compared with the data obtained in the models.

Calibration of Vilnius PT network was carried out after selection of three possible methods: TSys-based, Headway-based and Timetable-based. In the timetable-based model all the above-described distribution models were used. Logit, Kirchhoff, BoxCox and Lochse were inter-changed.

The obtained results, i.e. the number of passengers at the stops and street sections in question, was turned into a coefficient revealing their correspondence to the basic data of the survey of 2002, which reveals the percentage of correspondence of the obtained numbers to the real survey data (Table). As it could be seen from Table, the results failed to meet even the number of trips, which had impact on the results; this happened because of the fact that during modelling some hardly believable trips were deleted as in reality they would be carried out only in case of necessity.

The calculated coefficients revealed that TSys-based methods were removed from reality, and, by the way, it did not give any data about the load on the stops, although the number of trips modelled with the help of this method was most proximate to the survey data.

Modelling by TSys-based method, the coefficient of the number of passenger transfers was very low (0,03) and, vice versa, it was high when modelling by applying Timetable-based method, while when modelling by applying Kirchhoff method, the data almost completely corresponded to reality.

The greatest stop group conformity coefficient (0,86) was received applying Timetable-based model with Logit and Lochse distribution laws. Using the Headway-based model, the coefficient of conformity of the group of stops was the lowest, i.e. 0,72. In this case the coefficient of Kirchhoff distribution law is slightly lower, i.e. 0,82. The lowest coefficients are those of conformity of the network sections, that distribute almost evenly, i.e. 0,65–0,7, within all methods used for calculations. To choose the way of modelling that is most appropriate for Vilnius, the average of the coefficients in question was found per each model individually.

Analysis of all coefficients received when modelling allows a conclusion that further modelling of the development of Vilnius public transport network should be based on 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. This would facilitate adopting solutions to the development of the public transport systems and would increase their reliability.

6. Conclusions

1. Modelling of the transport system allows analysis of different phenomena related to the traffic organization without applying expensive practical experiments. Modelling is the only way to forecast the need for transport in future and the behaviour of the system participants, as well as to plan actions for the implementation of the future scenarios.

2. Vilnius was chosen taking account of multiplicity of the public transport system: it is one of

Coefficients of Vilnius public transport network modelling by applying different methods

		Number of trips	Number of transfers	Transfer conformity coefficient	Stop conformity coefficient	Section conformity coefficient	Average
Survey data of 2002		71054	52580	1	1	1	1
TSys-based		68437	1364	0,03	n.d.	0,7	0,24
Headway-based		67572	28450	0,62	0,72	0,69	0,68
Timetable-based	Logit	68216	36893	0,80	0,86	0,67	0,78
	Kirchhoff	68216	45539	0,99	0,82	0,65	0,82
	BoxCox	68216	47624	0,96	0,79	0,67	0,81
	Lochse	68216	39084	0,85	0,86	0,67	0,79

those few cities that are served by three modes of the public transport: buses: buses, trolley-buses and mini-buses; second, it is the only city that has undergone comprehensive public transport surveys during the last five years.

3. Modelling of Vilnius public transport is necessary as the situation of the city has changed since 1990 due to changes in the dislocation of the working places of inhabitants, decay of industrial areas, occurrence of the new objects of attraction, movement of population to suburban areas. At present, the network of Vilnius public transport undergoes very chaotic changes; on the average only 20 % of routes undergo changes which does not satisfy the inhabitants.

4. The significance of IPD indicators in the modelling of Vilnius public transport network was defined on the grounds of population survey carried out in 2001–2002, which revealed that to 20 % of respondents a too long way to the stop (i.e. too much time spent while going from home to a stop) was the most important factor within the public transport system; to another 20 % of respondents the time spent while waiting for a public transport vehicle was the most important factor; to 9 % of respondents the time of the trip (i.e. the time spent in a vehicle, including the time needed for transfer) was the most important factor [13].

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6. The calculated coefficients revealed that TSys-based methods were mostly removed from reality, and the average coefficient of failure to conform to the data of the 2002 survey is 0,24. This method did not give any data about the load on the stops, although the number of trips modelled with the help of this method was most proximate to the survey data, i.e. 0,69 %.

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