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CONSTRUCTION OF FREIGHT TRANSPORT MODEL FOR TRANSPORT PLANNING IN URBAN AGGLOMERATIONS

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Abstract

The article presents the principles of freight transport model for transport planning in urban agglomerations construction. We presented one of the concept for its preparation and necessary assumptions, which should be adopted on conceptual stage. We show the example of freight model for Warsaw agglomeration, which was prepared under the Warsaw Travel Household Survey 2015. We presented formal record of the model with its implementation in the environment PTV VISUM. We characterized the network model and demand model and presented the issues of the model calibration. Developed model is a fully featured tool for modelling of travels of heavy goods vehicles in the area of Warsaw agglomeration. In addition, in accordance to the cooperation with the model of passenger traffic in the individual and public transport, as well as the model of bicycle traffic, it is an integral part of a comprehensive tool for modelling, analysis and evaluation of mobility behaviour of Warsaw agglomeration inhabitants, as well as business entities located in this area.

Calibrated model of freight traffic for the existing situation is the basis for the implementation of traffic forecasts, which are analyses the state of the transport system in the future.

Keywords: *model of freight traffic, urban agglomeration, Warsaw Travel Household Survey 2015, trip modelling*

1. Introduction

Traffic model is a mathematical description of the interaction between needs on the movement (transport demand) and transport network – the transport supply. In general it is a mathematical tool allowing for carry out transport analyses in the modelled area, the assessment of the effects of changes in the transport network and spatial development of the city (i.e. building of a new road). In the traffic model are always included [4, 6, 10, 12]:

- trips in individual transport,
- public transport,
- freight transport
- bicycle trips.

In traffic models, which are prepared for urban agglomerations we can analyse different kinds of trips. One of the concept of traffic analysis is presented below. Under this concept were developed:

- trip model of the dominant urban centre residents, which includes trips of dominant urban centre residents within the agglomeration performed on foot, by means of public transport and by car,
- trip model of inhabitants of agglomeration communes outside dominant urban centre, which includes their trips within the agglomeration performed on foot, by means of public transport and by car,
- external model, which includes trips to targeted area of the model (both in dominant urban

centre and to the rest of the agglomeration) and a source trips to the outside of the model (from the agglomeration). These trips are carried out by means of public transport and by car,
- model of freight traffic, which includes road freight transport within the model area with external travels, i.e. source, destination and transit in relation to the agglomeration. These trips are realized by light commercial vehicles (LCV) and large goods vehicles (LGV) with gross vehicle weight (GVM) exceeding 3.5 t,
- model of bicycle traffic, which includes trips carried out by bike.

In the model are mapped real displacement within the area of research based on the data from [9] the households' surveys as well as measurements of intensity of traffic and passenger flows, and also data from secondary sources i.e. statistical data, research results and traffic measurements carried out by other entities. Additional data for modelling can be obtain from secondary sources on the basis of another models prepared before this one.

2. Assumptions for the model of freight traffic in urban agglomeration

2.1. General assumptions

Model of freight traffic are always prepared taking into account the classical four-stage transport model [1, 3-6, 8, 11, 12, 14, 15, 17]. It is necessary to determine:
- trip generation for different communication areas,
- spatial distribution of traffic between these regions,
- transportation modal split between analysed modes of transport,
- distribution of traffic on the transport network.

Due to the described in the first paragraph concept and the scope of the modelling the third stage in freight traffic model was not implemented.

In developing the model of freight traffic it is necessary to adopt many assumptions. They concern:
- data, which are basis for the building of the model,
- territorial range of model,
- modelled type of freight vehicles,
- modelled type of traffic,
- principles of generation and absorption of the trip, their spatial distribution and distribution of traffic flow on transport network,
- modelled type of trip motivation,
- type of the day, for which model is constructing,
- hourly distribution of traffic flow,
- structure of communication areas,
- type of model in terms of continuous, passage of time and network status,
- time horizons for forecasting analyses.

2.2. Assumptions for freight traffic model in the area of WBR 2015

Presented in this article model of freight traffic is a part of project „Warsaw Travel Household Survey together with the development of traffic model" (WBR 2015) prepared by consortium consisted of: PBS Sp. z o. o., Cracow University of Technology and Warsaw University of Technology [10]. Data, which are basis for the building of the model, comes from primary and secondary sources [9, 10]. Territorial range of model is the area of Warsaw agglomeration. We included in it the movement of goods vehicles divided into the light commercial vehicles (GVM up to 3.5 tonnes) and large goods vehicles (GVM exceeding 3.5 tonnes). In the model we included internal traffic, source and destination traffic and transit traffic and also independent principles of generation and absorption of the trip, their spatial distribution separately for internal and source, destination and transit traffic and distribution of traffic flow on transport network. It maps movement for a typical working day and includes freight traffic for the whole day, for the morning peak hour (07:00 – 08:00) and for the afternoon peak hour (16:00 – 17:00). Developed model is a macroscopic, static and deterministic. It allows for forecasting analyses in time horizons 2016, 2020, 2030 and 2050.

Primary sources of data, which are basis for the building of the model come from research of freight traffic in the agglomeration. Conducted analyses showed that the average number of internal trips made by the one vehicle with GVM up to 3.5 t was approx. 5.25 and 4.26 for the heavier vehicles. In research of freight traffic we specified 64 different motivation trip. For further research motivations have been aggregated to 16 (see Tab. 1). For these motivations we estimated share of journeys of light commercial vehicles and large goods vehicles inside the agglomeration (Tab. 1).

Tab. 1. Estimation for individual motivation of journeys of goods vehicles by their GVM inside the agglomeration (movements/day)

Motivation[1]	Light commercial vehicles		Large goods vehicles	
	Trip per day	%	Trip per day	%
HANDEL_USŁUGI – HANDEL_USŁUGI	50 441	41.19%	1 988	3.46%
HANDEL_USŁUGI – WOH	3 469	2.83%	127	0.22%
HANDEL_USŁUGI – MAGAZYNY_PRZEMYSŁ	1 239	1.01%	127	0.22%
HANDEL_USŁUGI – POZOSTAŁE	11 564	9.44%	1 015	1.77%
WOH – HANDEL_USŁUGI	2 919	2.38%	254	0.44%
WOH – WOH	1 322	1.08%	42	0.07%
WOH – MAGAZYNY_PRZEMYSŁ	193	0.16%	0	0.00%
WOH – POZOSTAŁE	2 340	1.91%	169	0.29%
MAGAZYNY_PRZEMYSŁ – HANDEL_USŁUGI	854	0.70%	211	0.37%
MAGAZYNY_PRZEMYSŁ – WOH	633	0.52%	169	0.29%
MAGAZYNY_PRZEMYSŁ – MAGAZYNY_PRZEMYSŁ	2 698	2.20%	592	1.03%
MAGAZYNY_PRZEMYSŁ – POZOSTAŁE	3 745	3.06%	12 053	21.00%
POZOSTAŁE – HANDEL_USŁUGI	9 334	7.62%	1 015	1.77%
POZOSTAŁE – WOH	1 156	0.94%	0	0.00%
POZOSTAŁE – MAGAZYNY_PRZEMYSŁ	4 295	3.51%	12 137	21.15%
POZOSTAŁE – POZOSTAŁE	26 267	21.45%	27 488	47.90%
RAZEM	**122 469**	**100%**	**57 387**	**100%**

For lighter vehicles the most common source and destination of the journey was a place of trade and services outside major shopping centres. The source and destination of nearly half trips of vehicles with GVM exceeding 3.5 tonnes was construction site, place of permanent parking or other object (aggregated as others). Heavier vehicles more often than lighter vehicles perform trips which destination is industrial plant, warehouse, storage facility or wholesale. In research also includes the distances travelled by vehicles supporting the Warsaw agglomeration. The average trip length for all tested vehicles was approx. 26 km, while the average length of trips realized by vehicles with GVM up to 3.5 t amounted to 16.1 km, while heavier vehicles 52.6 kilometres. Conducted research indicates that the most freight trips begin at 07:00 – 08:00. In the following hours from 09:00 to 17:00 in the case of vehicles with GVM exceeding 3.5 tonnes the number of commenced trips remains at 8-10%. The situation is different for vehicles for which the greater part of the journeys takes place in the mornings, and then with time the percentage of those trips consistently declining.

[1] HANDEL_USŁUGI – place of trade and services outside large area commercial buildings, WOH – large area commercial buildings, MAGAZYNY_PRZEMYSŁ – logistics centre, warehouse, storage facility, wholesale, industrial plant, POZOSTAŁE – building, permanent place of parking, other.

3. The example of freight traffic model construction for Warsaw agglomeration

3.1. Network model

The model of freight traffic, prepared within the framework of the Warsaw Travel Household Survey 2015, has been developed for the area of Warsaw agglomeration, so for the dominant urban centre Warsaw and the following communes: Łomianki, Izabelin, Stare Babice, Ożarów Mazowiecki, Pruszków, Piastów, Michałowice, Raszyn, Lesznowola, Piaseczno, Konstancin-Jeziorna, Józefów, Otwock, Karczew (city part), Wiązowna, Sulejówek, Halinów, Ząbki, Zielonka, Kobyłka, Wołomin, Marki, Nieporęt, Legionowo and Jabłonna. During the work under the network model, in the field of freight traffic, we mapped all roads on which it is possible to move by goods vehicles. For each links and nodes we assigned a number of characteristics, including among others capacity, speed in free traffic or supported transport systems. Using the specialized database we mapped the rules of traffic organization, which also related to freight traffic. In addition in the model we mapped tonnage restrictions by dividing the links of the road network on:

- links, on which it is not possible to move by light commercial vehicles and large goods vehicles,
- links, on which it is not possible to move by large goods vehicles,
- other links.

In addition, we introduced a special parameters for different links on the area of Warsaw concerning zones with reduced goods vehicle traffic in the city according to [18]:

- I zone of tonnage restrictions where movement of large goods vehicles with GVM over 16 tonnes from 07:00 – 10:00 and 16:00 – 22:00 is prohibited,
- II zone where is a prohibition on entry of vehicles with GVM over 10 tons,
- III zone where is a prohibition on entry of vehicles with GVM exceeding 5 tonnes.

We mapped also additional restrictions for large goods vehicles which reduce the attractiveness of selected roads, due to the existing in agglomeration tonnage restrictions. Imposition of additional restrictions causes longer journey time, which results in a decrease in the number of large goods vehicles on the appropriate connections. On the turns on input links for each zone of tonnage restrictions we mapped the resistance to reduce the number of transit trips by light commercial vehicles and large goods vehicles through these zones.

3.2. Demand model

According to adopted assumptions, during the preparation of the demand model for freight transport which characterized the volume of reported demand for transport, we mapped:

- freight traffic inside the agglomeration,
- source and destination freight traffic,
- transit freight traffic.

Model of source, destination and transit freight traffic has been developed based on the results of traffic research from the outside cordon prepared under the WBR 2015 project [9] and the results obtained from the national traffic model, traffic model for Mazowieckie province [16] and Warsaw Travel Household Survey 2005. Due to this fact, the external model takes into account division of goods vehicles onto: light commercial vehicles (GVM $\leq$ 3.5 t), large goods vehicles without trailers (GVM > 3.5 t) and large goods vehicles with trailers and tractor units with semitrailers (GVM > 3.5 t). Trips motivations for these transport operations were not distinguished. For internal freight traffic we adopted trip motivation presented in point 2.2 in this article. Separately for each of the trips motivation we developed models of trip generation and models of the spatial distribution of traffic [7, 12, 13].

The next step in the construction of the demand model for freight traffic was to build trip generation model. To obtain the number of trips commenced and released in different areas we used the following explanatory variables for generation and absorption of the traffic flow:

- for large goods vehicles with GVM > 3.5 t for source and destination type:
  - HANDEL_USŁUGI – total area of commercial and service buildings,
  - WOH – total area of large area commercial buildings (for Warsaw) and area of large area commercial buildings (for vicinity of Warsaw),
  - MAGAZYNY_PRZEMYSŁ – total area of production buildings, warehouses, etc.,
  - POZOSTAŁE – weighed area of residential, transport services and maintenance buildings,
- for light commercial vehicles (with GVM ≤ 3.5 t) for source and destination type:
  - HANDEL_USŁUGI – number of workplaces in the trade, services and other activities (for Warsaw) and number of employees in the trade, services and other activities in 2015 (for vicinity of Warsaw),
  - WOH – total area of large area commercial buildings (for Warsaw) and area of large area commercial buildings (for vicinity of Warsaw),
  - MAGAZYNY_PRZEMYSŁ – number of workplaces in the category of activity: agriculture, industry and construction (for Warsaw) and number of employees in industry and construction in 2015 (for vicinity of Warsaw),
  - POZOSTAŁE – data on the total population at the end of 2015, according to the “modified data for Warsaw” (for Warsaw) and the number of residents based on data from the Local Data Bank prepared by Central Statistical Office adjusted according to study of prof. Śleszyński (for vicinity of Warsaw).

As explanatory variables for generation and absorption of source and destination traffic in relation to the sources or destinations located in the agglomeration for light commercial vehicles (with GVM ≤ 3.5 t) adopted: number of workplaces in the trade, services and other activities (for Warsaw) and number of employees in the trade, services and other activities in 2015 (for vicinity of Warsaw). For large goods vehicles with GVM > 3.5 t use total areas of different kinds of objects and buildings.

The values of the explanatory variables for different communication areas for trip motivation HANDEL_USŁUGI for large goods vehicles with GVM > 3.5 t shown in Fig. 1, and for the light commercial vehicles in Fig. 2.

As follows from shown in Fig. 1 and 2 maps for large goods vehicles with GVM > 3.5 t the highest values of the explanatory variables are obtained for the area Warsaw city centre i.e. for places where there are many places of trade and services which are not large area commercial buildings. For other districts of Warsaw, the explanatory variables are low, which means that the number of trips run and terminated in these areas is low. For light commercial vehicles situation is similar – the explanatory variables causing that a little trip is generated in the vicinity of Warsaw, and a lot in Warsaw, especially in the central area. For both kinds of freight vehicles the value of explanatory variables for vicinity of Warsaw are not high. It should be noted that the selection of the types explanatory variables, and hence their value, causes that obtained number of trips generated and absorbed in different areas correctly map the actual situation.

Formulas developed to determine the trip generation for internal and external areas in freight traffic shown in the study [10]. The spatial distribution for freight services was developed using a gravity model [12]. The of parameters area resistance function were determined using the module Kalibri in package PTV VISUM, taking into account surveys resulting from the spatial distribution of traffic. Their values are shown in study [10].

4.3. Distribution of traffic flow on the transport network and calibration of the model

Suitable parameterization of road network model and adapting it to service of light commercial vehicles and large goods vehicles, as well as development of demand matrices for different types of vehicles in division into trip motivations allowed to carry out experiments on the distribution of flow for the freight transport on the transport network.

The model assumes that light commercial vehicles and large goods vehicles looking for the optimal path for themselves to reach the targets, following another selection criterion. This criterion is the travel time calculated taking into account weight (another for light commercial vehicles and heavier) additional resistance specified on links and turns in the transport network. Of course, during searching the best route are taken into account constraints and parameters of the transport network concerning freight traffic presented in point 3.1.

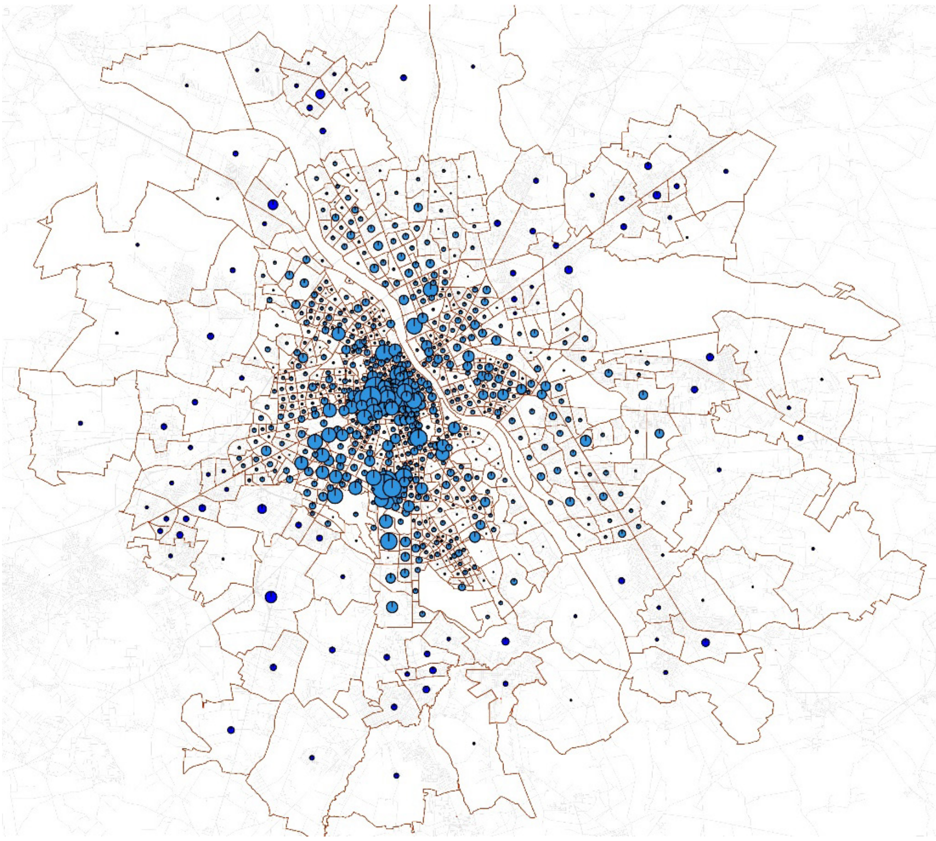

Fig. 1. The values of the explanatory variables for trip motivation HANDEL_USŁUGI for large goods vehicles with GVM > 3.5 t (source: own work using WBR 2015 Model in PTV VISUM)

The results of the traffic flow distribution of freight vehicles give the possibility to start the process of model calibration. In calibration procedure we used two sets of data. The first concerned the survey among drivers based on which we verified compliance of the declared number of trips and their distribution of length with the number of trips and the length resulting from demand model. The second type of data are the results of measurements of traffic on links and junctions of transport network.

During the calibration of model we checked for compliance of the distribution of traffic flow (see Fig. 3) with measurements on individual links of the network (by index R^2), and also on included in the model cordons (Warsaw cordon, agglomeration cordon, Vistula screen, central are cordon, diametric railway screen). In addition, based on the graphic presentation of the traffic distribution, we analysed waveforms of selected by the vehicle tracks. These paths were assessed in an expert way for correctness.

In results of the model of freight traffic calibration and evaluation we achieved assumed correspondence between the modelled and the measured flow of vehicles, and thus was considered that model is correct (the highest equal to 71% was achieved for the movement of light commercial vehicles during the morning peak).

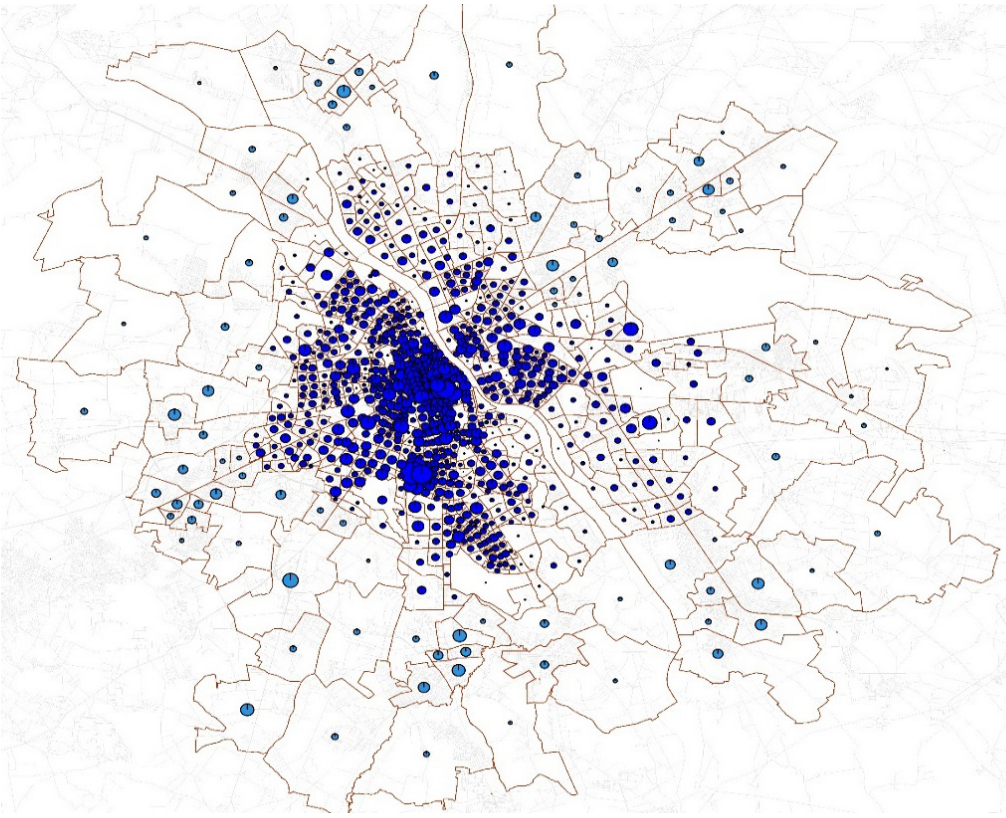

Fig. 2. The values of the explanatory variables for trip motivation HANDEL_USŁUGI for the light commercial vehicles (source: own work using WBR 2015 Model in PTV VISUM)

Fig. 3. Morning peak – light commercial vehicles and large goods

5. Summary and conclusions

Model of freight traffic developed within the project prepared on the order of capital city Warsaw "Warsaw Travel Household Survey" (WBR 2015) is a fully featured tool for modelling of traffic of light commercial vehicles and large goods vehicles in the area of Warsaw agglomeration.

In addition, in accordance to the cooperation with the model of passenger traffic in the individual and public transport, as well as the model of bicycle traffic is an integral part of a comprehensive tool for modelling, analysis and evaluation of mobility behaviour of Warsaw agglomeration inhabitants, as well as business entities located in this area.

Calibrated model of freight traffic for the existing situation is the basis for the implementation of traffic forecasts, which are analyses the state of the transport system in the future. It allows for answers on the questions about the impact of changes in the urban transport network and the demand for transport on traffic distribution of light commercial vehicles and large goods vehicles for 2016, 2025, 2035 and 2050. In traffic model we included planned road investments, changes in employment of residents in certain sectors of the economy and the allocation of new investment areas (e.g. Industrial, commercial, and residential). Analysis of prognostic alternatives can rationally plan the development of the transport system of the city and evaluate trends in the spatial development.

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