SELECTED PROBLEMS OF TRANSPORT NETWORK MODELLING OF UPPER-SILESIAN AGGLOMERATION (IN POLAND)

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Abstract. Some issues of modeling of public transport network on example of Upper-Silesian Agglomeration (in Poland) have been presented in this article. Methodology for projects of transport systems which are realized in Poland with UE financial resources were worked out in manuals called “The Blue Book” (editions: 2006÷2008). There is presented the methodology for cost-benefit analysis (CBA). CBA is based on results of traffic forecasting: traffic flows, average travel length and average travel times and also haulage work forecasting for a few defined investment variants and adopted comparative variant. In this case correctness of the standard-4-step model (trip generation, trip distribution: origin-destination (O-D) matrix, mode choice, distribution of traffic flow on transport network) de facto formed the basis of the correctly done CBA.

Keywords: mathematical modeling of transport network, standard-4-step model, trip generation, trip distribution: origin – destination (O-D) matrix, mode choice, distribution of traffic flow on transport network, cost-benefit analysis, The Blue Book, Upper-Silesian Agglomeration (Poland).

1. Introduction

Fundamental stage of a cost-benefit analysis for planned investment projects in transport is the analysis of traffic. All stages of the CBA of projects applying for means from European Union funds were presented in the Blue Book manual [2] which was created to standardize the assessment methodology of projects executed in Poland and applying for European Union funds. The Blue Book is an elaboration recommended by the Ministry of Regional Development and Polish Ministry of Infrastructure.

In the article there were presented selected construction stages of the model of transport network of 13 cities of Upper-Silesian Agglomeration1 (Poland) which has a road net and a public transportation network (tram, bus and railway) of a great density. To effectively conduct an analysis regarding an analytical complexity, the VISUM software was used by PTV Vision. It is worth to underline that this is one of the biggest models of transport networks in Poland – regarding size of modelled area and number of cities of which transport systems were represented.

2. Modelled area

2.1. Characteristics

The municipal transport network in the Silesia Province is the most developed in Poland (fig. 1), which is evidenced by, among others, over 20-percent share in the length of all the transport lines in Poland. Here, there are 363 km of the tram tracks (whereas in Łódzkie Province, there are 207 km and in Mazowieckie Province – 241). There are 2 of 4 corridors run through Poland (of 10 set Transeuropean Transport Network TEN-T): corridor III: Berlin–Wrocław–Katowice–Kraków–Lvov and corridor VI: Gdańsk–Katowice–Żylina. Within the area of the Silesia Province, there are the historically formed, important railway routes, heading north-south and east-west, of which the three main railway lines are a part of the international E and C-E (AGC and AGTC network)2:


1 The large Upper-Silesian Agglomeration consist of group of connected cities, which occupied place from Dąbrowa Górnicza to Głubice. Upper-Silesian Agglomeration have strong businesses concentration which covered 18 % area of Silesia province (1 200 km²). There are about 60 % inhabitants in Upper-Silesian Agglomeration. Average population density amounts above 1 900 persons/km². There is also a large junction for the sake of location as well as a haulage work. Upper-Silesian Agglomeration operated not only Silesia Province, but also is one of important element european transport network [17].

Modelling of transport network covered 13 cities of the Silesia Province within the area on which a tram service is present – it is an inner center of Upper-Silesian Agglomeration. Modelled area is inhabited by over 1.8 million residents what is approx. 38.3% of population of the Silesia Province. However, it should be underlined that the Silesia Province is simultaneously one of the biggest Provinces in Poland regarding population – 4.7 million people, that is 12.3% of population of Poland. Population density in the modelled area amounts to 1780 persons per 1 km² and is several times higher than in the Silesia Province – 379 persons per 1 km². With regard to the area size, the modelled area is 38.1% of area of the Silesia Province which is in turn 3.9% of area of Poland [17].

2.2. Zones

During the construction of transport models, analysed area is divided into a specified number of communication zones [1, 3, 5, 10]. Number of communication zones depends on the size of modelled area and a demographic and spatial structure (residential districts, schools and universities, hospitals, industrial companies, shopping centers, recreational areas and others) being a potential places generating and absorbing a traffic – hereafter traffic generators. The criterion of area division [5] constitutes an aspiration for assigning uniform zones and limits of these zones should run, within bounds of possibility, along limits of natural division, e.g. along rivers, ravines, railway lines, unbuilt areas. Division along arterial roads should be avoided because it is hard to assign a given artery to a particular zone.

However, within the areas with a dense road-street network it is hard to avoid such situation and sometimes a street network becomes a natural fence dividing a city area into zones and micro zones. The division of modelled area into communication zones was done in two stages. During the first stage, 13 macro zones were created and its limits constitutes administrative boundaries of cities belonging to a studied area. During the second stage, referring to the above mentioned criteria, further division of macro zones was conducted – to 185 micro zones (table 1 and fig. 2).

### Table 1. Division of analysed area cities to zones

<table>
<thead>
<tr>
<th>Number</th>
<th>City of modeled area</th>
<th>Number of zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Będzin</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Bytom</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Chorzów</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Czeladź</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Dąbrowa Górnicza</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>Gliwice</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Katowice</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Mysłowice</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Ruda Śląska</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Siemianowice Śląskie</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>Sosnowiec</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>Świętochłowice</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>Zabrze</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>External zones</td>
<td>14</td>
</tr>
</tbody>
</table>

| Total sum | 199         |

Source: Own formulation.

Dense road-street network imposed a division partly running along the A4 motorway and express roads (including division along Drogowa Trasa Średnicowa – an inner relief road) function of which in the network implies limited range of services to a direct environment and limited frequency of

See e.g.: [6] – division partly running along roads and streets, assumed after the division in the KBR-98 comprehensive traffic research - similarly, the traffic model for Warsaw.
connections with roads of lower class and category\textsuperscript{4}. So these are communication barriers for pedestrians trips and these done by a public transport. Comprehensive depiction of the process of modelling also indicates to the necessity of representation in the model a connection with an environment transport system. That is why 185 area zones (internal zones) were supplemented with external zones corresponding to entries and exits of the basic road system (zones on area border).

2.3. Zone’s centers of gravity

Location of zone’s centers of gravity in micro zones and their mutual spatial distance is significant because it influences a spatial traffic distribution (impact on a size and the directional structure of traffic) and further a traffic distribution on a modelled transport network. Zone’s centers of gravity are points in space which (in the model) gather inside them the potential of generated and absorbed traffic. To represent a traffic potential of micro zone (described by a function: number of residential district residents, number of work places in a service and industrial company, number of customers in a shopping center and other parameters) in one point – center of gravity – with a high/sufficient accuracy it is necessary to execute an individual land development analysis of each micro zone. It happens quite often that there is a few different traffic generators in one micro zone (e.g. a shopping center and neighbouring housing estate or a big factory) what influences the location accuracy of a center of gravity. Hence a division of the area is required to ensure an uniform land development within created zones – with one or several uniform traffic generators. It is obviously connected with increase of size and degree of model specification and ipso facto it increases a labour and time consumption (a cost) of construction and then its updating. A proper balance of proportion between model specification and accuracy of results is a fundamental problem of any model construction. Verification procedure (by comparison of results received from the model and research and measurement results conducted in an actual traffic) allows for a model calibration (selection of adequate descriptive parameters) but it should also include advices regarding possible changes in model specification (in both directions: increase and decrease). A possibility of using previous experiences during construction of similar models for similar areas and similar investments is also important.

Upper-Silesian Agglomeration is a big area with a various land development (many undeveloped post-industrial areas). Accordingly, some of communication micro regions included, for instance, housing estates with a dense development as well as undeveloped areas. That is why determination of zone’s centers of gravity was conducted through an individual detailed analysis of each micro zone. Number of appointed zones at the level of 185 was imposed by time frames, costs of model construction and limits of used software version (fig. 3).

3. Transport network modelling

Creation of the area network model is a highly time-consuming stage of the entire model construction, mostly because of the size of modelled area and number of represented roads, streets and communication lines. Works on the entire model were systematized by dividing the construction into stages (partial models).

3.1. Links and nodes

The basis of a model network constitute vector maps of roads and streets. It is a representation including, among others, such information as: geographic coordinates of road and street portions, its length, name, road class, traffic direction as well as a geometrical system of interchange roads and junctions. Network of road system model is very detailed. Both house estate streets (local and access ones) and motorways are represented (fig. 4). Thanks to the network representation in a proper scale, it is possible to determine the length of particular connections and distances between chosen, characteristic points of micro zones (e.g. between zone’s centers of gravity or stops of public transport).

\textsuperscript{4} Classes and categories of roads and range of servicing of adjacent area is regulated by [7].
High specification of vector maps was adjusted to the specification of representation of modelled network by removing roads which are meaningless within the scale of entire model (local and access streets, factory roads). The vector model of roads, in turn, did not include a separated tramway tracks and railway subgrades and in connection, there was the necessity of its addition.

### 3.2. Stops

Modelling of the public transport system (tram-network and bus-network), public transport stops were introduced. They were classified into three groups, divided with regard to the type of serviced mean of public transport: A – bus stop, AT – bus and tram stop, T – tram stop (table 2).

<table>
<thead>
<tr>
<th>Number</th>
<th>Category of stop</th>
<th>No of stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A – bus stop</td>
<td>1,331</td>
</tr>
<tr>
<td>2</td>
<td>AT – bus and tram stop</td>
<td>194</td>
</tr>
<tr>
<td>3</td>
<td>T – tram stop</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td><strong>Total sum</strong></td>
<td><strong>1,678</strong></td>
</tr>
</tbody>
</table>

Table 2. The number of tram-network and bus-network stops

Spatial structure of public transport stops of modelled area is presented on fig. 5.

### 3.3. Network

Another stage was a connection of models with each other: road, tram and railway network as well as public transport stops. As a result, new portions were created (by the division of the portion with a stop) for which stops became nodes. In case when stop was located within a junction environment, what allows for connection of two nodes of network: junction and stop into one node, then the overall number of nodes in the entire model may be smaller (fig. 6).

### 3.4. Model of a public transport line

Before starting the construction of communication lines model, on the basis of actual timetables, an average communication speed was calculated for particular means of public transport on portions of the network. Knowledge of speed and distance between nodes allow for a determination of time of ride. Intervals of variation of communication speed are as follows: a tram (14.4÷31.5) km/h, a bus (11.5÷44.0) km/h.

To distribute a traffic flow on a transport network, information about public transport lines is required. The most important regards representation of route courses, time of ride and a fill of public transport means. Fill on between stops portions is data necessary for the presentation of actual passenger flows and for verification of the model. It is worth to underline that the network of public transport in Upper-Silesia Agglomeration is the biggest public transport network in Poland. Municipal Transport Union of Upper Silesian Industrial District (it is: KZK GOP) manages 362\(^5\) bus and tram lines. Additionally, there are also other operators: PKM Tychy and PKM Jaworzno. For example, the Warsaw Agglomeration services in total 262\(^6\) bus and tram lines [16]. Modelled system of bus lines is presented on fig. 7.

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\(^5\) Data on December 9, 2008 on the basis of the KZK GOP web site [13].
\(^6\) Data on December 9, 2008 on the basis of the ZTM Warsaw web site [18].
direction; turn round only within tram terminuses) causes a directional diversification of routes of particular rides within day and night. In such cases, an additional division into sub-lines was introduced to the model of public transport network and they were adequate variants of a ride of each half-course in each direction. Total number of communication sub-lines (tram and bus ones) in modelled area amounted to 700. In view of technical limits (limited size of the model accepted by the Visum software), the aggregation of bus sub-lines was conducted in accordance with the criterion of mutual interaction and interaction with tram lines (substitution and complementarity in servicing the transport needs of area is represented by line courses). Modelled tram lines system is presented on fig. 8.

![Fig. 8. Diagram of tram network in the area of Upper-Silesian Agglomeration](image)

Procedures of the distribution of traffic flow for public transport usually use two basic characteristics of communication lines: a timetable or a service frequency. Service frequency [8, 11] is one of the fundamental transport postulates creating a service quality in public transport. From passenger’s point of view it is a measure of availability of public transport vehicle [11] felt as the adjustment of departures to the individual requirements of a passenger.

![Fig. 9. Information on the frequency implemented to the Visum software](image)

In discussed model there was assumed the criterion of traffic flow distribution based on a frequency which is determined on the basis of: time of the first and the last ride during day and night and an average interval between rides (fig. 9).

### 3.5. Passenger traffic flows in the network

Modelled network of public transport allows, at the very beginning of a traffic analyse, for the graphical presentation of actual passenger traffic flows. Twenty-four-hour passenger traffic flows within the entire tram network is presented on fig. 10 and flows in inner center of Katowice – a capital of the Silesian Province – on fig. 11.

![Fig. 10. Presentation of passenger traffic flows on a tram network](image)

![Fig. 11. Presentation of passenger traffic flows on a tram network in Katowice – a capital of the Silesian Province](image)

### Conclusions

In the elaboration, fundamental stages of construction of public transport network were presented. Attention was paid to these problems which have a significant impact on a model specification and simultaneously on cost and time of modelling. Beside the fact that rules of transport system modelling are known from at least the second half of the last century and modern tools in the form of computers and a specialist software are a very important support of this process, this is still a huge challenge, especially in case of big projects (dense transport networks).
References

7. Rozporządzenie Ministra Transportu i Gospodarki Morskiej z dnia 2 marca 1999 r. w sprawie warunków technicznych, jakim powinny odpowiadać drogi publiczne i ich usytuowanie.