Conference Paper

Hexagonal Zones in Transport Demand Models

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Abstract

Planning the development of transport systems, as well as assessing the effects of investment activities in the field of spatial development requires the use of appropriate IT tools enabling an objective assessment of investment intentions. In the field of transport analysis, one such tool is a transport demand model. Reproduction of transport-related processes is the main role of such transport demand model. This applies to both the transport of people and goods, and includes both residential travel and visitors travelling to and within the study area. The description of the process of creation and implementation of transport demands is usually based on the assumptions in the field of places of generation and absorption of travel - i.e. sources and destinations of travel. The generalization of the mathematical description of this phenomenon introduced the concept of transport zones, which are separated homogeneous areas of the study area, as sources and destinations of trips. Practice in the construction and use of transport models indicates that the problem of defining transport zones requires further investigation. Increasingly extensive transport infrastructure data collected in open databases (such as OpenStreets) are encouraging a change in the approach to the problems of constructing transport zones. The current solutions are characterized by a high level of generalization of sources and destinations rather than detailed transport analysis. This article presents the author's method of dividing the study areas into transport zones based on a uniform hexagonal system, explaining the basic assumptions and evaluating the pros and cons of this proposed system.

Keywords: Transport, Demand models, Algorithms

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Received: 26 November 2019
Accepted: 13 May 2020
Published: 2 June 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICEUBI2019 Conference Committee.

1. Introduction

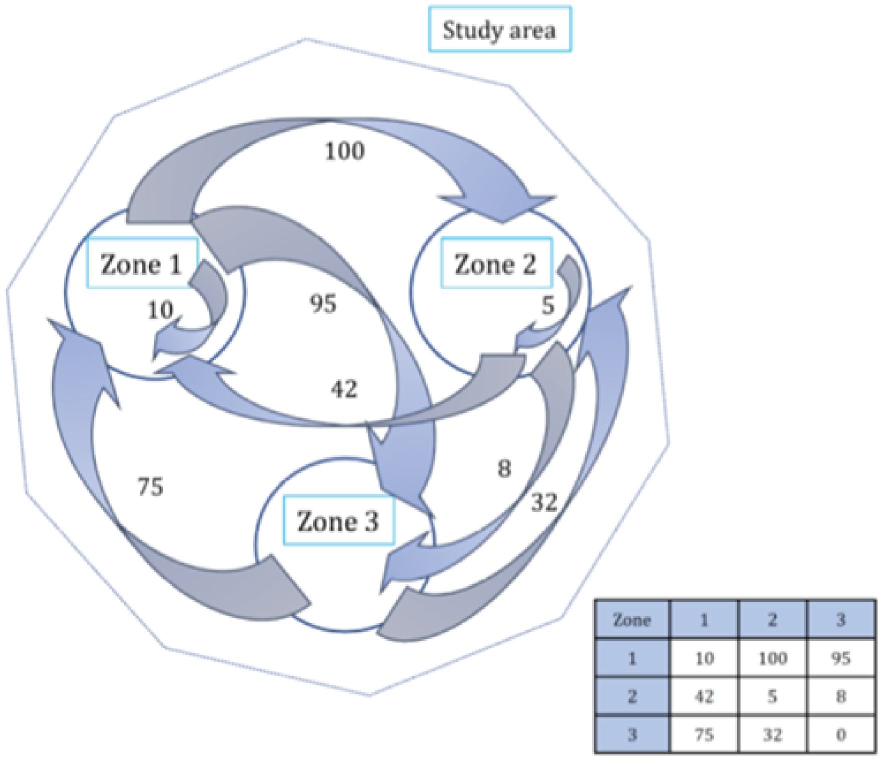
Planning the development of transport systems, as well as assessing the effects of investment activities in the field of spatial development requires the use of appropriate IT tools enabling an objective assessment of investment intentions. In the field of transport analyses, one of such tools is the transport demand model. The main goal of the transport demand model is to reproduce create transport-related processes in mathematical procedures. This applies to both the transport of people and goods, as well as the travel of residents but also visitors to the study area. The description of the process of creation and implementation of transport demands is usually based on the assumptions in the field of places of trips production and absorption - i.e. trips sources and destinations. Each transport demand is made between a pair of places in the space of the analysis area, constituting the source and destination of trips located in the study area or outside this area, a transport corridor (road, rail, water, air) connecting these places.

The location of these places within the study area depends primarily on the spatial development of the area under analysis, including primarily the location of the place of residence of travellers and the location of motivation (goals) of trips - like work place, education, shopping, private activity or leisure [1]. Therefore, this applies to specific objects (buildings), with assigned addresses, located in the study area (shops, banks, schools, shopping malls, etc.). Almost every existing facility is a source and/or destination of residents' daily trips, and the number of these trips depends on the so-called attractiveness of this facility. In the case of urban areas, there are usually many such facilities in the study area - for example in Warsaw, the capital of Poland, there are nearly 115,000, while in Cracow, the second largest city in Poland - Kraków, 61,000 [2]. Thus, the analysis of individual objects is in most cases impossible. Therefore, in practice, the study area is divided into larger than the surface of individual facilities settlement fragments, the socalled transport zones with defined centres of gravity (centroids). Between them, the transport demands of groups of people in a given time slot are determined (e.g. during the day, at morning and afternoon rush hour), made by various means of transport. Such zones may be poviats areas, as it is used in National Transport Demand Models, communes - in regional transport demand models, districts, housing estates or even smaller area - in local ones [3]. Regardless of the internal transport zones, in each case the so-called external transport zones must be defined [4], representing inlets and outlets to/from the study area, located on the transport corridors connecting the given study area with the external areas surrounding this area.

In relation to transport zones in transport demand models, trips are divided into [5]:

- local and intra-zones trips (all of which do not leave the given zone of the transport demand model);
- internal inter-zones trips, made within the study area (with crossing the border of the given transport zone);
- external trips with crossing the border of the study area.

To enable the mathematical description of these trips between transport zones, matrix entries of transport demands are used, using a square matrix whose size corresponds to the number of transport zones of the study area (including external zones), and the main diagonal describes the so-called intra-regional trips - that is, local [6]. Fig. 1 illustrates this system of displacements in relation to trips among three transport zones within a given study area, bypassing the external areas. It should be emphasized that as a rule, trips within the zone, i.e. from zone *n* to zone *n* are not analyzed – they are not assignment into transport networks.



Zone	1	2	3
1	10	100	95
2	42	5	8
3	75	32	0

Figure 1: The idea of matrix recording of trips between transport zones

This means, therefore, that in the case of the transport demand model, in which the transport zones are defined as municipalities (e.g. regional transport demand models), trip within a given commune is ignored. Consequently, the local road transport network (or public transport network) is not loaded with road traffic (or passengers flow) resulting from journeys between the source and destination located within this transport area.

2. A Classic Approach to Zoning in Transport Demand Model

In the classic approach, the scope of division into transport zones (so called zoning) results both from the size of the study area and the possibility of obtaining reliable data on spatial development [7]. Moreover, the computational capabilities of numerical devices (computers, computing servers or nodes, etc.) - including the speed of calculations and software limitations of the software, is taken into account. Currently the most popular software in Europe dedicated to the construction and operation of transport demand models, build and developed by the German company PTV Group Karlsruhe [8], a leader in the field of IT solutions for planning and traffic simulation, makes the cost of purchasing and using licenses (including the cost of technical support and maintenance) primarily depends on the maximum number of transport zones to be allowed by a given kind of license. Thus, while in terms of transport supply description, limiting analyses to the basic transport network is a classic example of simplifying reality, so in the case of demand, this simplification is the generalization of sources and destinations. This is because in practice, trips does not take place between transport areas (zones), but between individual buildings or objects. However, the local transport network, including access roads, is a component commonly used in most trips of residents of the study area.

Currently, there is a lack of guidelines, standards and description requirements in European Union and in the world, both of the demand and supply parts of transport demand models, which means that most of the solutions used in existing and operated transport demand models are based on the author's own experience and practice.

The state-of-art and world experiences in the division of the study area into transport zones (so called TAZs – Traffic analysis zones), often called the transport model zoning system [7], indicate the key role it plays in the aspect of correct transport solutions in transport demand models. This zoning is one of the basic problem, that should be solved at the stage of transport demand model construction. Analyzing the considerations contained in the literature on the subject, it can be pointed out that transport zones in the transport demand models should have the following features:

a) they should be uniform in the field of spatial development (e.g. high-rise residential areas, single-family housing areas, commercial areas, industrial areas, parking lots) [9], [10];

b) they should be uniform in the number of trips generated per inhabitant or household [11], [10];

c) they should keep boundary topologies, which means that boundaries should not overlap and boundary vertices should be interrelated [11];

d) they should not have holes or islands [11];

e) they should be separated by natural transport borders and obstacles such as railways, rivers, significant land elevations, mountains etc. [12];

f) they should have a minimum number of pedestrian trips within individual zones [13];

g) they should maintain the continuity of zone boundaries in studies from previous years (to enable analyses of changes and trends in different time horizons of transport behaviour of people and transport processes) [14];

h) they should comply with the boundaries of census and statistical regions, which facilitates obtaining data to describe their transport attractiveness [10];

i) they should have reasonably uniform access to modelled transport systems [10];

j) zones with stronger urbanization, high residents density should be smaller than those with a much smaller level of spatial development - zones in the city centre are usually much smaller in area than peripheral zones [10];

k) special zones with travel generation and absorption characteristics different from typical transport ones (such as train stations, airports) should be separate transport zones [10], [15].

At the same time, the literature on the subject emphasizes that the number of transport zones translates into the accuracy of a transport demand model construction [7], [15]. Therefore, one should be aware that an incorrect division into transport zones or an incorrect definition of the boundaries of these zones usually significantly translates into a reduction in the quality of the results of transport analyses prepared using such transport demand model. As it is underlined in [10], dividing the study area into less than 1000 transport zones usually gives a logical ratio of analysis time to the quality of the results, but may not work with a large area of this area. American experience in construction of state transport demand models (regional ones) shows that in regional transport demand models the number of people in one transport zone should not exceed 10,000 inhabitants, and in justified cases for large study areas, up to 15,000 inhabitants are allowed. At the same time, homogeneity of these zones is emphasized as extremely important. However, in [14] it is emphasized that the zoning of the study area is often associated with the research on the transport behaviour of residents, the results of which are directly attributed to separate transport zones. According to the authors, this is not good practice. It leads to enormous difficulties in changing the number and boundaries of zones in the study area of analysis. Therefore, it is recommended when conducting transport behaviour surveys among residents of the study area, to geocode survey data, rather than assigning them to specific zones. This gives the possibility of introducing new divisions into transport zones in the future created in such a way as to ensure better and better quality and precision of transport demand model construction [16]. The problem of optimizing the division of the study area into transport regions was already described in 1977 in the paper [15], in which the hierarchical heuristic procedure for automatic zoning by optimizing the objective function is presented - the effectiveness of the division of the study area in terms of transport demand model and its predefined modelling efficiency. Subsequent analyses in this research area [7], [17] concerned the cluster and cell division of statistical regions and census areas into traffic analysis zones within solutions based on GIS techniques. Further analyses presented in [17] in turn, focus on the definition of transport zones based on the analysis of the objective function, assuming the minimization of residents' internal trips (travel within the same transport zone). Considering the fact that skipping internal trips in transport models can lead to a significant distortion of reality, especially in large areas of those transport demand model zones, in the analysis phase determining the optimal number and shape of the borders of transport demand model zones should be aimed at eliminating pedestrian internal trips as much as possible. This creates the possibility of obtaining a more accurate representation of pedestrian trips in the study area. The issue of the number and definition of transport demand model zone borders requires further work and is undoubtedly one of the basic problems and dilemmas of building transport demand models. This is also indicated by many panel discussions among the authors of transport demand models, consulting offices, or researches and authors of selected publications [18], [12], [15].

3. Address Method of Zoning in Transport Demand Models

The residents' trips are usually associated with specific objects located in a given area. Apart from a few cases (forests, fields, lakes), these facilities are characterized by a specific address described by postal code, city, street and property number. In the scope of databases, in many cases they obtain specific geodetic or geographical coordinates represented in open access map portals (Google Maps, OpenStreets, Bing). This means that the sources and destinations of transport infrastructure users can easily be assigned to specific places in space defined by coordinates. What's more, these places are strict and clearly linked to transport systems - roads, pavements, bicycle paths or parking lots located in the immediate vicinity of these facilities, enabling travel. There is therefore a theoretical possibility to precisely identify all sources and destinations of resident's trips, and thus to very precisely describe the phenomena occurring in transport networks. The transport demand model built in this way can be called the address transport demand model. An example of the description of transport zones of such a model is presented in Fig. 2. While the idea theoretically seems to be the most correct and rational, it is the source of many problems and doubts in interpretation. They result, among others from the following facts:

1) difficulties in the detailed description of transport behaviour of residents of individual address facilities, because of problems with the generalization of the description of these characteristics;

2) high labour intensity when obtaining data on the transport attractiveness of each of the objects being the transport zone;

3) labour intensity when connecting a large number of transport zones with transport networks;

4) the need for precise knowledge of the location of new planned facilities - in the case of future scenarios of transport demand models.

It should be emphasized, however, that the address transport demand model has some significant advantages that are revealed at the stage of detailed traffic analysis and the concept of changes in traffic organization, or detailed transport solutions. Among others the following advantages of such solution may be mentioned:

1. high accuracy of reconstruction of trips and traffic on all transport networks, even of local ones;
2. high accuracy of mapping of real volumes and traffic structure in transport network nodes – turn relations at junctions and interchanges;
3. high accuracy of mapping parameters for estimating the functioning of transport systems: vehicle kilometres and vehicle hours;
4. the possibility of implementing detailed optimization solutions in the field of road infrastructure, such as the introduction of one-way roads, the closing of selected turn relations, parking restrictions etc.

4. Hexagon Transport Zones in Transport Demand Models

Considering the weaknesses of the abovementioned described address method of transport demand models' zones as an alternative solution to divide the study area into transport zones, the so-called hexagonal method of such division was developed, an example of which is shown in Fig. 3. The purpose of the research for an alternative solution was to introduce such a division of the study area into internal transport zones in order to best map the residents' trips while maintaining a uniform surface of each zone. This algorithm adopts the following assumptions in the zoning procedure:

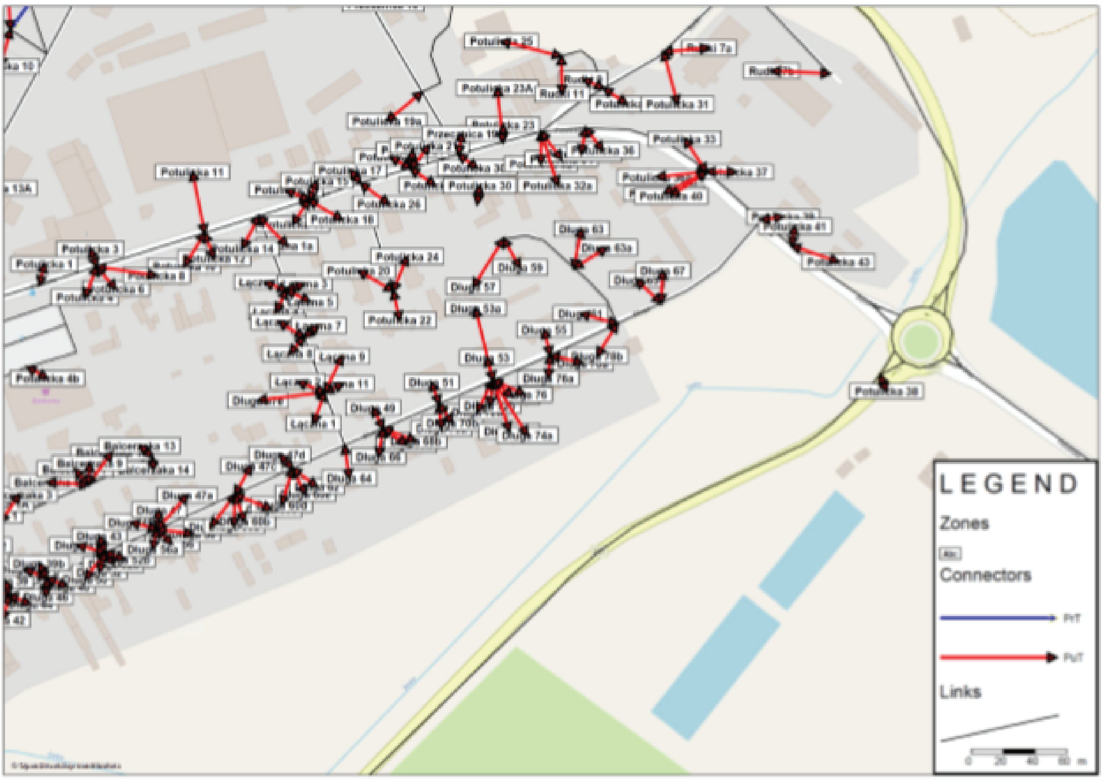


Figure 2: The map of transport demand model within the study area divided into addresses zones

1. The entire study area is divided into equal elements constituting the original arrangement of hexagon-shaped transport areas, the so-called hexagons - see fig. 3. Hexagons should have the same shape and surface. Thanks to this division, the adjoining neighbouring zones contacts are preserved. The number of these zones and the radius describing this hexagon are determined considering the size of the study area and the computational capabilities of the computer software used in the construction of the transport demand model. An optimal radius describing 125m was obtained from test calculations carried out for three cities of different sizes: 1.750 million, 0.50 and 0.35 million inhabitants.

2. The ones with zero transport attractiveness are eliminated from the initially adopted hexagons, which creates the possibility of reducing the hexagon radius for the remaining transport zones of the analysis area in the subsequent stages of analysis.

3. For each accepted non-zero hexagon, address points are assigned inside each of them and a distance matrix between these address points is created. The distance between region i and i, corresponding to the main diagonal of the distance matrix between transport zones, is assumed as infinitely long.

4. The final division of the study area into transport zones (hexagons) is considered to be correct if, for at least 95% of the transport zones, the maximum distance between the address points does not exceed the assumed minimum distance of trip - usually it is 100 m [14]. It is also allowed that the hexagon dimension will be larger on a region of the study area, e.g. in non-urbanized regions, but with nonzero transport attractiveness, e.g. a park, cemetery, etc.

5. All address points are assigned a transport zone number in which they are located.

6. For each internal transport zone, its centre of gravity is described by the weighted average coordinates of the objects generating and/or absorbing trips (buildings and other facilities), according to the transport attractiveness of these objects, calculated by the formulas:

$$X_i = \frac{\sum_{n=1}^{nni}((A_n + P_n) * X_n)}{\sum_{n=1}^{nni}(A_n + P_n)}$$

$$Y_i = \frac{\sum_{n=1}^{nni}((A_n + P_n) * Y_n)}{\sum_{n=1}^{nni}(A_n + P_n)}$$

where: X_i – X coordinate of the centre of gravity of the transport zone i;

Y_i – Y coordinate of the centre of gravity of the transport zone i;

nn_i – number of address facilities in the zone i;

A_n – attractiveness of facility n for trip absorption;

P_n – attractiveness of facility n for trip production n;

X_n – X coordinate of the address facilities n;

Y_n – Y coordinate of the address facilities n.

7. For each transport demand model zone one connector [19] of the given zone to the road network and one to the public transport network is defined; thus, a minimum of one and a maximum of two connectors can be defined for one zone.

8. One transport network node may be once connected to the transport zone of the road network and once to the public transport network (see Fig. 4).

9. The distance between transport zones i and j for transport system c is defined as $D_{c(i,j),}$ according to the formula:

$$D_{c(i,j)} = L_{c(i,N_i)} + D_{c(N_i,N_j)} + L_{c(N_j,j)}, \ [m]$$

where:

N_i – node of transport zone i connection with the given transport network of system the transport c;

N_j – node of transport zone j connection with the given transport network of the transport system c;

$L_{c(i,Ni)}$ – distance calculated in the air line between the centre of gravity of the transport zone i and, and the N_i node of the transport network of the transport system c [m];

$L_{c(Nj,j)}$ – distance calculated in the air line between the centre of gravity of the transport zone j and, and the N_j node of the transport network of the transport system c [m];

$D_{c(Ni,Nj)}$ – the smallest accepted distance between nodes N_i and N_j with the given transport network of the transport system c.

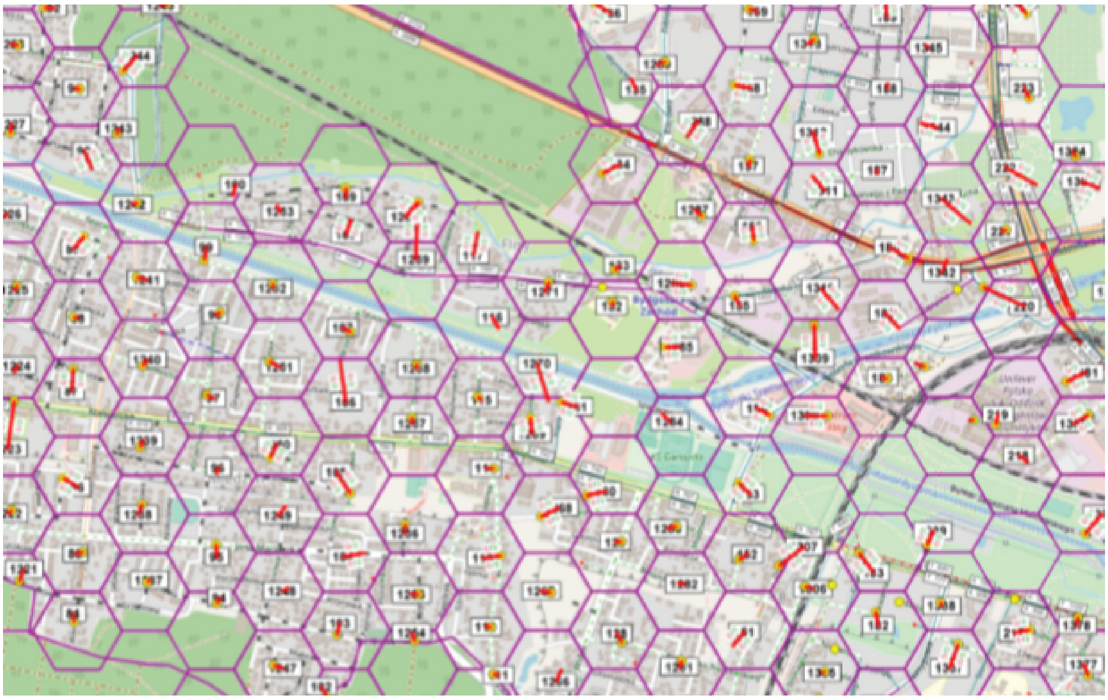


Figure 3: The map of transport demand model within the study area divided into hexagonal zones

As a result of test calculations carried out on selected transport demand models mentioned above, the following conclusions were formulated in the scope of the discussed method of dividing the study area into hexagonal transport zones:

a) the presented method, like the address method, is characterized by a much greater accuracy of mapping reality in relation to classical methods, primarily due to the correct indication of trip source and destination, as one specific node for each transport zone in road network and one in public transport network;

DOI 10.18502/keg.v5i6.7025

Figure 4: Example of connectors in the hexagonal transport demand model

b) internal trips within one transport zone are significantly minimized, which is one of the biggest problems of classic transport models;

c) the use of appropriate software scripts or macros enables fast zoning of the study area of any surface - transport areas are built automatically according to the standardized algorithm;

d) a verified database of address building and facilities makes it much easier to determine the attractiveness of individual hexagonal transport zones;

e) due to the aggregation of a small number of trips generators within one transport zones, the change in zoning does not significantly affect the results of transport demand model calculations - zones can be freely shaped, added and removed, which is a significant advantage over classic methods of zoning in transport models;

f) the number of transport zones depends on the size of the study area - with high population density of the analysis area and the area not exceeding 100 km2, an acceptable ratio of the zones number to the calculation time is obtained;

g) the large size study areas translate into an unacceptable number of transport zones - for such areas there is a need to introduce hexagons as transport zones with the hexagon radius gradation: from 125 m in areas with high urbanization to 250 m in areas with less urbanization;

h) due to the same size, hexagonal zones are easily compared with each other in terms of transport attractiveness;

i) the use of a hexagonal division of the study area into transport demand model zones does not allow for assigning zones boundaries to statistical and census unit boundaries, which makes it difficult to verify the correctness of the transport attractiveness definition of individual transport zones.

5. Conclusions

Planning the development of transport infrastructure requires the use of appropriate computational techniques. These techniques are designed to obtain reliable answers in the scope of the legitimacy of the implementation of transport projects, their economic and transport rationality (like it is done in feasibility studies), as well as their impact on the functioning of a given study area. The complexity of transport processes, interrelationships between them, as well as changes in the transport behaviour of residents require the use of increasingly accurate calculation techniques. Increasingly richer and more reliable databases in the field of both transport infrastructure and spatial development are forcing a new approach in the field of modelling transport demands. The accuracy of the mapping of transport networks based on GIS data requires changes in the area of division of study areas into so-called transport zones. Thanks to this, following the more detail description of transport systems, it is possible to map well the transport phenomena.

The methods of the new approach to zoning the study area into transport zones presented in this paper constitute a new look at the issue of the correctness of determining trip sources and destinations. The paper presents both basic assumptions regarding the method of innovative zoning procedure of the study area into places of trips sources and destinations, basic assumptions as well as potential difficulties in its implementation. The method implementation with the use of program scripts, which can be easily applied to any area of analysis, was pointed out. The use of spatial analysis operations using the spatial query language of the SQL Spatial Database in an excellent way enable rapid update of data on spatial development, and thus attractiveness to the generation and absorption of the inhabitants of the study area trips, as well as the study area visitors and commuters. At the same time, the application of the above method allows to undertake further work on the abovementioned method for zoning in transport demand models.

Acknowledgments

This paper has been supported by the Polish National Agency for Academic Exchange under Grant No. PPI/APM/2019/1/00003.

References

[1] Cascetta, E. (2009). *Transportation Systems Analysis: Models and Applications*. (New York: Springer)

[2] Central Office of Geography and Cartography (2019), General Geographic Objects Database (BDOO). [Online]. Available: https://www.geoportal.gov.pl/dane/baza-danych-ogolnogeograficznych-bdo

[3] Kulpa T., Kucharski R., and A. Szarata. (2016). Budowa regionalnych modeli transportowych – założenia i dylematy. *Transp. 21st Century*, vol. 111, pp. 347–356.

[4] Khattak A. J., Rasmussen D. Ph., and Rasmussen B. K. (2005). Traditional Neighborhood Development Trip Generation Study. North Carolina Dept. of Transportation, Research and Analysis Group.

[5] Transportation Research Board (2016), National Cooperative Highway Research Program (NCHRP) Report 716: Travel Demand Forecasting: Parameters and Techniques.

[6] Karlaftis M. G. (2002). Handbook of Transport Modelling. *Journal of Transport Engineering*, vol. 127, issue 6, pp. 546–546.

[7] Transport and Infrastructure Council, T1 - Travel Demand Modelling, National Guidelines for Transport System Management in Australia, 2016.

[8] PTV Visum 18 - New features at a glance © PTV AG, Kalsruhe, 2018.

[9] Ortúzar J. de D. and Willumsen L. G. (2011). *Modeling Transport*. (New Jersey: Wiley)

[10] J. A. Sokolowski and C. M. Banks, Handbook of Real-World Applications in Modeling and Simulation. 2012.

[11] Ding C. (1998). The GIS-based human-interactive TAZ design algorithm: examining the impacts of data aggregation on transportation-planning analysis. E*nvironment and Planning B Planning and Design,* vol. 25, issue 4, pp. 601-616

[12] O'Neill W. (1991). Developing Optimal Transportation Analysis Zones Using GIS. *ITE Journal*, vol. 33, pp.33-36.

[13] Crevo C. C. (1991). Impacts of zonal reconfigurations on travel demand forecasts. *Transport Research Record,* vol. 1305, pp.72-80.

[14] Kaczkowski M. and Krych A. (2010). Słownictwo kompleksowych badań i modelowania potoków ruchu. *Zesz. Nauk. Stowarzyszenia Inżynierów i Tech. Komun. w Krakowie. Ser. Mater. Konf.*, vol. 94, issue 153, pp. 357–396.

[15] Openshaw S. (1977). Optimal Zoning Systems for Spatial Interaction Models. *Environment and Planning A*, vol. 9, issue 2, pp.169-184.

[16] Trepanier M. and Chapleau R. (2001). Object-oriented and totally disaggregate analysis of origin-destination household survey data. *Canadian Journal of Civil Engineering*, vol 28, issue 1, pp.48-58.

[17] Martínez L. M., Viegas J. M., and Silva E. A. (2009). A traffic analysis zone definition: A new methodology and algorithm. *Transportation (Amst).*, vol. 36, issue 5, pp. 581–599.

[18] Martínez L. M., Viegas J. M., and Silva E. A. (1994/2007). Zoning Decisions in Transport Planning and Their Impact on the Precision of Results. *Transportation Research Record Journal of the Transportation Research Board*, vol. 1994, issue 1, pp. 58-65.

[19] Friedrich M. and Galster M. (2010). Methods for Generating Connectors in Transport Planning Models *Transportation Research Record Journal of the Transportation Research Board*, vol. 2132, pp. 133–142.