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ABOUT PASSENGER TRAVELS DEMAND MODELING IN URBAN TRANSPORTATION SYSTEMS

Summary. *In this paper, the basic concepts of modeling of urban transport systems are analyzed. The known variants of the definition of the concept of the transport system, its main components and the essence of the stages of identification of transport systems (TS) are presented. The example of the Lviv city TS shows the process of modeling the transport network, determining the time characteristics of the modeled transport system and forming a demand matrix for trips of a certain type in a certain segment of users (origin-destination matrix when moving students from their places of compact residence to the nodes of external transport for further implementation of intercity travel). The obtained indicators can be further applied in determining the demand for transportation in transport systems of large cities.*

Key words: *transport system, modeling transport, transport network, demand model, origin-destination matrix, time variation of transport system.*

1. INTRODUCTION

Transportation systems consist not only of the physical and organizational elements but also of the demand for travel from one place to another. This demand for travel, in turn, is the result of the interaction between different economic and social activities located in a particular area. Modeling is a necessary component of transportation planning. It includes forecasting future travel needs, identifying potential problems and offering common solutions to anticipated transportation problems. A practical approach to transportation studies is to solve transportation problems first by solving their models and then implementing the solutions in the real world [1]. The main challenge of modeling and analysis in the field of transportation is the ability to reproduce an authentic transportation environment within the laboratory, since real conditions are very complex to model and dependent on many factors [2].The urban transport system and city pattern have natural interdependency. Land-use pattern, population density, and socio-economic characteristics influence the choice of the transport system. At the same time, the availability of certain transport systems changes the accessibility of land areas and therefore land value, causing a change in land-use pattern and city form [3].

2. RESEARCH STATEMENT

Modeling urban transport systems requires up-to-date information about vehicles and user databases. The development of the concept of modeling of transport systems of the large Ukrainian cities should take into account the limits on the amount of data on users and the degree of relevance of the available information.

The collection, processing, and authentication of information for the formation and analysis of urban transport systems is a pressing problem. An analysis of the concept of modeling urban transport systems, taking into account and correlating the available information and information obtained during the research, will be able to identify key factors influencing the demand and supply on the functioning of urban transport systems.

To determine the accessibility of transport zones, it is necessary to determine the quantitative characteristics of the demand for travel. Demand includes accessibility functions, such as the cost of traveling between zones, the quantification of the attractiveness of transport zones and the number of potential users.

3. GENERAL PRINCIPLES OF URBAN TRANSPORT SYSTEM MODEL FORMATION ON THE EXAMPLE OF MODELING OF MOVEMENTS TO EXTERNAL TRANSPORT HUBS IN LVIV CITY

A transportation system is a set of elements and the interactions between them that produce both the demand for travelling within a designated area and the provision with transportation services to satisfy this demand [4].

In [5], the transportation system is defined as a system that serves to meet the needs of people in transportation and to meet the aspirations of transportation of the individual, family, community and business.

The transport system, its vulnerability and resilience, are critical to the welfare of modern societies. The research paper [6] analyzes two approaches to the analysis of transport vulnerability – topological (based on the analysis of transport networks) and based on the analysis of supply and demand. The resilience of a transport system is defined as its ability to maintain or quickly recover its function after a disruption or a disaster.

The author of the paper [7] considers the transport system as a set of six levels that interact: from the interplay of homogeneous material elements of the transport system to the interaction of the transport system and the economic sector.

In general, the transport system can be considered as an aggregation of such elements [8]:

– an infrastructure (e.g. a road network);
– a management system (for example, traffic rules);
– a set of transport modes and their operators.

In the research paper [9] a transport system can be introduced as the set of relationships between nodes, networks and the demand (Fig. 1).

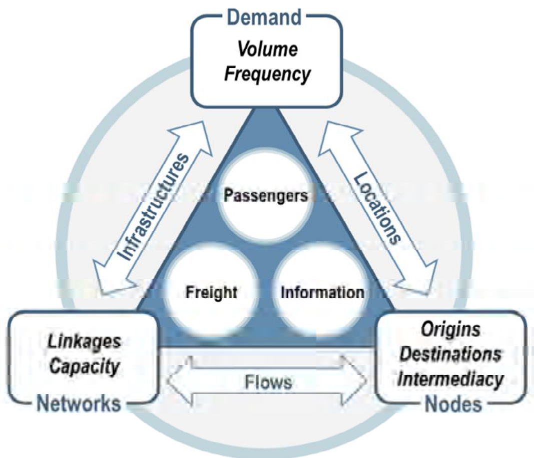

Fig. 1. Components of transport system [9]

For the identification of the transport systems definition the elements and relationships that form it have been determined. The identification process consists of three steps [10]:

– Identification of spatial dimensions;
– Identification of temporal dimensions;
– Definition of components of travel demand.

The process of determining spatial characteristics consists of three steps (Fig. 2):

– Definition of the study area;
– Traffic zoning;
– Identification of the basic network.

These three steps are the basis for the building of any model of the transportation system because they define the spatial extent of the system and its level of spatial aggregation [10].

Each network consists of access nodes, hubs and links connecting these nodes. When designing a network, the main task is to determine the required network density – increasing density improves access quality, but increases costs, and vice versa [1]. Fig. 3 shows the basic transport network of Lviv, made in PTV VISUM, with the classification of roads by the number of lanes and further analyzed access points – external transport hubs.

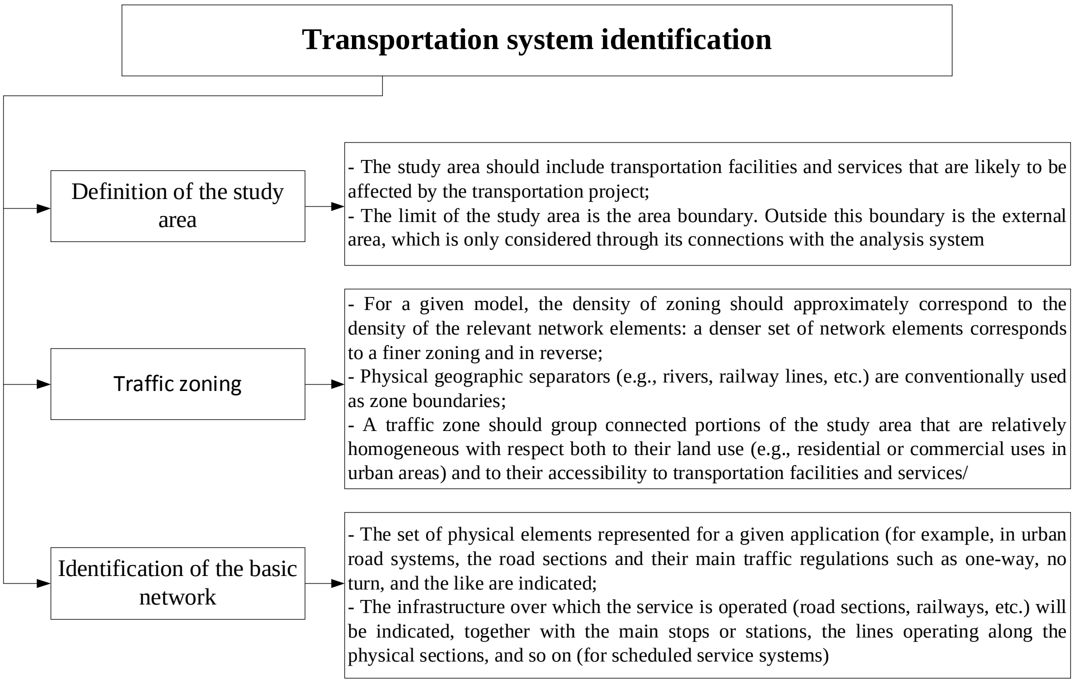

Fig. 2. Steps of transportation system identification

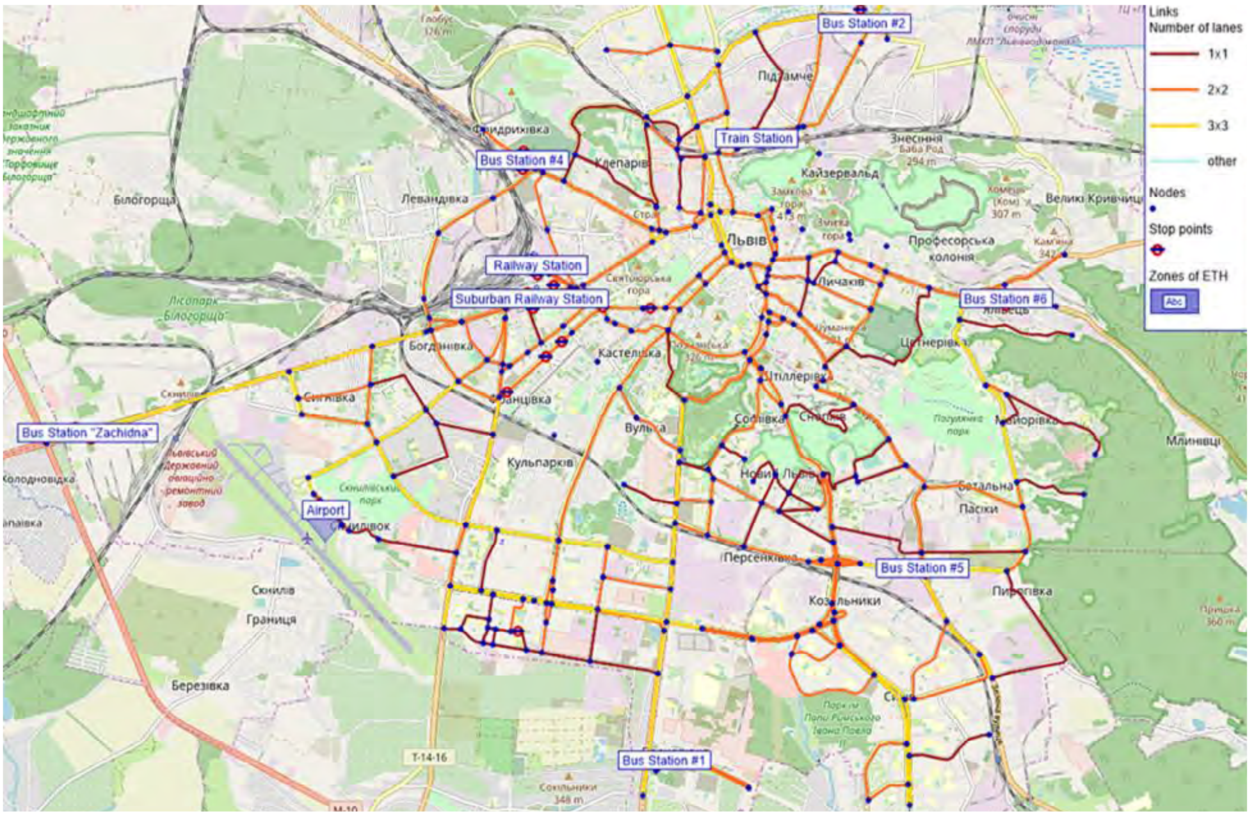

Fig. 3. Basic Lviv street network

A transportation system operates and evolves over time, with the characteristics of both travel demand and supply varying at different time range (by time of day, by day of the week or moon, and so on). There are three types of time variations of system characteristics [11]): There are three types of temporal changes in system characteristics

– Long-term variations or trends at the global level. Long-period variations are often the result of structural changes in the socio-economic indicators. For example, variations in the level of economic activity, household income, individual vehicle ownership, socio-demographic population characteristics, lifestyles, urban migration modified the level and structure of passenger transportation by bus and rail transport over the last 8 years (Fig. 4, according to the Main Statistical Office in Lviv region [12]);

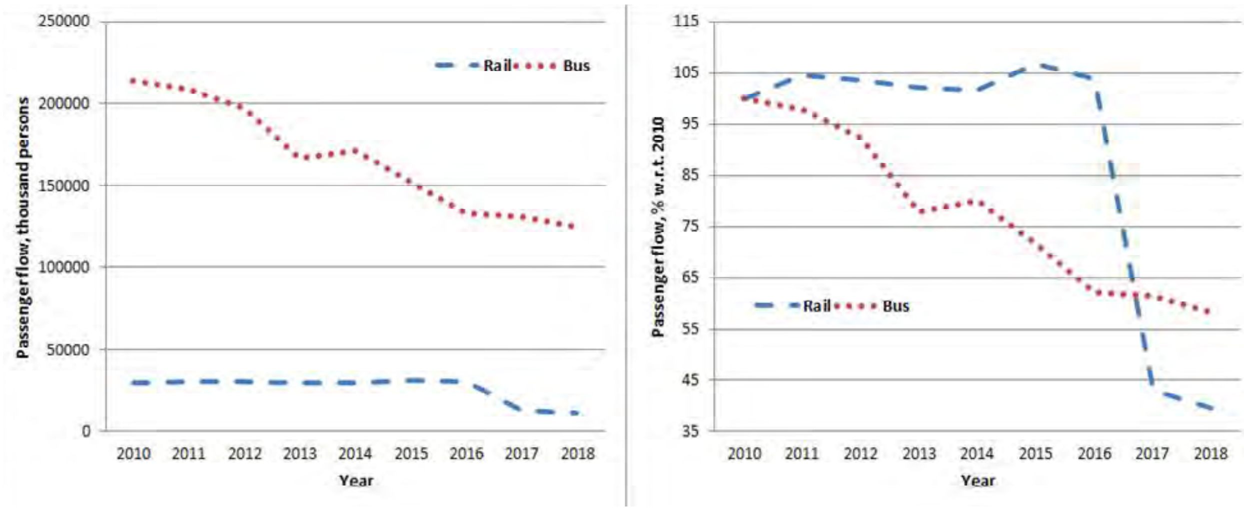

Fig. 4. Average long-term trends in Lviv region passenger transportation

– Cyclical (seasonal) variations occurring within the analysis period. These variations are repeated cyclically and can be observed by a comparative analysis of several cycles: cyclical repetition of the trend of fluctuations in the total number of passengers during the months of the year (Fig. 5, according to the Main Statistical Office in Lviv region [12]) or fluctuations of travel demand by time of day at the external transport hub during a typical working day (Fig. 6, according to the data field research conducted during the spring of 2019, Lviv Bus Station # 1);
– Between-period variations – random variations in demand and supply during stable reference periods caused by hard-to-predict factors (such as an accident or a citywide event).

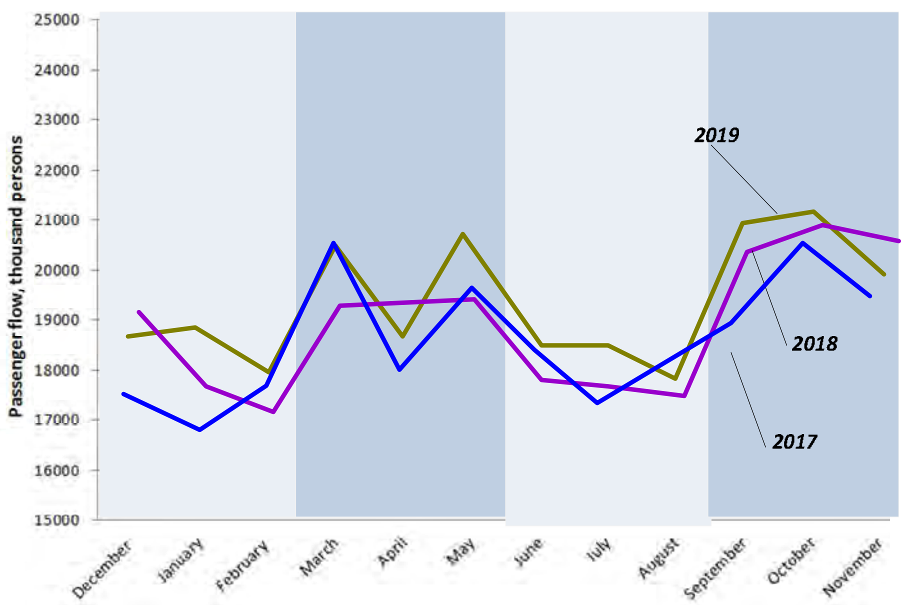

Fig. 5. Seasons reference periods in Lviv region passenger transportation

Definition of components of travel demand plays a central role in the analysis and modeling of transportation systems because most transportation projects attempt to satisfy this demand.

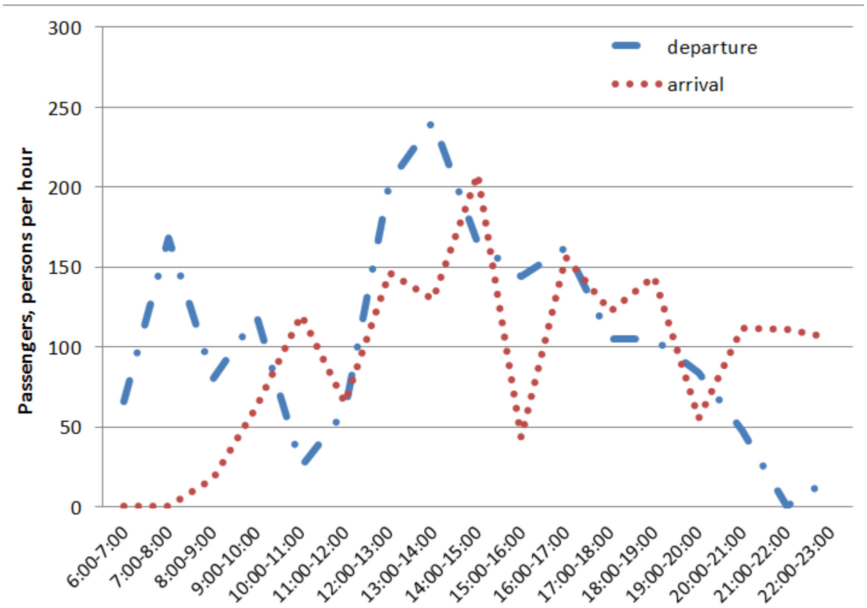

Fig. 6. The average number of passengers on a workday, persons per hour (Lviv bus station #1)

Usually, population travelling is not an end in itself, but ancillary activities related to work, study, shopping or leisure, etc. Accordingly, a trip is an act of moving from one place to another using one or more modes of transport to carry out one or more activities. Therefore, the demand flow can be defined as the number of users with certain characteristics who consume certain services offered by the transport system over some time [13].

In the general case, the relationship between supply and demand in the transport system can be represented in the form shown in Fig. 7 [14].

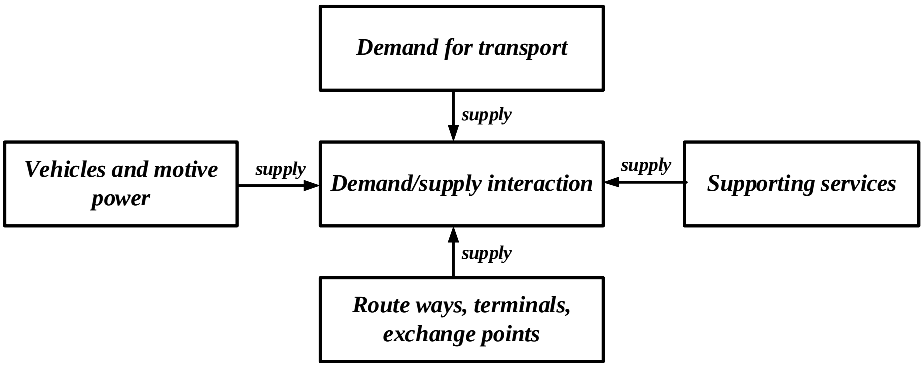

Fig. 7. Relationship between the demand and supply aspects of a transport system [14]

Users of the transportation system and the trips they perform can be characterized in various ways. The spatial characteristics of trips are carried out by grouping them by place of origin (origin zone) and destination (destination zone), and information on the magnitude of demand flow is often placed in tables called origin-destination matrices.

Another characteristic of demand classification may be the characteristics of users, such as their employment, income level, or driver's license. A group of users with the same socio-economic characteristics is called a market segment.

The trips are also classified by a purpose: work trips, educational trips, shopping trips, etc.

A travel-demand model is a mathematical relationship between travel-demand flows and their characteristic on the one hand and given activity and transportation supply systems and their characteristic on the other hand. Depending on the classification criterion, the following groups of these models are distinguished:

– for type of choice: mobility or context models and travel models;
– for sequence of choices: trip-based demand models, trip chaining models and activity-based models;
– for level of detail: disaggregate models and aggregate models.

In the paper [15] the authors propose a method of modeling transport systems in a "Bottom-up" way. That is, the plan of activity of an individual is first formed, and demand for travel is formed on the basis of linking consecutive activities in different places of travel. After the demand is generated, the travel properties are selected. This process is influenced by two types of factors: characteristics of choices (path length, the capacity of the place, etc.) and psychology and behavior of the individual (his or her travel requirements, personal preferences, etc).

The type of mathematical model used is determined depending on the initial data and the desired result. If we consider the model of demand for trips to external transport nodes, then the following alternatives of mathematical models are possible:

– by choice, travel model is more appropriate as it relates to the specific characteristics of the trip
– for a sequence of choices, the most appropriate model is the trip chaining model, which assumes that the choice during the trip affects other trips within the same trip. The choice of an external transport hub will be uniquely made considering a further destination when making an intercity trip;
– for the level of detail, using the aggregate model, because it does not take into account specific variables for each individual user, but uses the zonal level of aggregation.

The main result of the travel demand model is the origin-destination matrix.

The origin-destination matrix is calculated based on the methodology given in [16]. The starting dates for the calculation are the capacities of the transport zone of departure (H_i), the capacities of the transport zone of arrival (H_j) and the statistical coefficient taking into account the distances of movement.

Using this technique, the VISUM software environment calculates the matrices of the average daily number of movements (separately for weekends and working days) of students between zones of their compact residence (dormitory) and zones of external transport hubs. Capacities of transport zones for departure are determined by the number of residential places in dormitories, and capacities of transport zones for arrival – by the attractive capacity of external transport hubs, determined by the method described in [17] – Fig. 8. The results of the number of movements between traffic zones are given in Table 1 and in Fig. 9.

Table 1

Origin-destination matrix (holiday)

	External transport hub										
	Number	1	2	3	4	5	6	7	8	9	10
1	2	3	4	5	6	7	8	9	10	11	12
Places of compact residence of students	1	10	100	23	12	23	73	26	20	16	63
	2	9	90	21	10	21	66	24	18	14	56
	3	39	380	88	44	87	277	99	74	60	238
	4	33	318	74	37	73	232	83	62	51	199
	5	24	233	54	27	53	170	61	46	37	146
	6	85	830	192	96	190	604	216	162	132	518

Table continuation 1

1	2	3	4	5	6	7	8	9	10	11	12
	7	30	290	67	33	66	211	76	57	46	181
	8	16	156	36	18	36	114	41	30	25	97
	9	16	156	36	18	36	114	41	30	25	97
	10	23	227	52	26	52	165	59	44	36	141
	11	35	340	79	39	78	248	89	66	54	212
	12	12	113	26	13	26	82	30	22	18	71
	13	15	148	34	17	34	108	39	29	24	92
	14	41	396	92	46	91	289	103	77	63	248
	15	16	160	37	18	37	117	42	31	25	100
	16	38	374	87	43	86	273	98	73	59	234
	17	19	186	43	21	43	136	49	36	30	116
	18	8	78	18	9	18	57	20	15	12	49
	19	12	113	26	13	26	82	30	22	18	71
	20	19	184	43	21	42	134	48	36	29	115

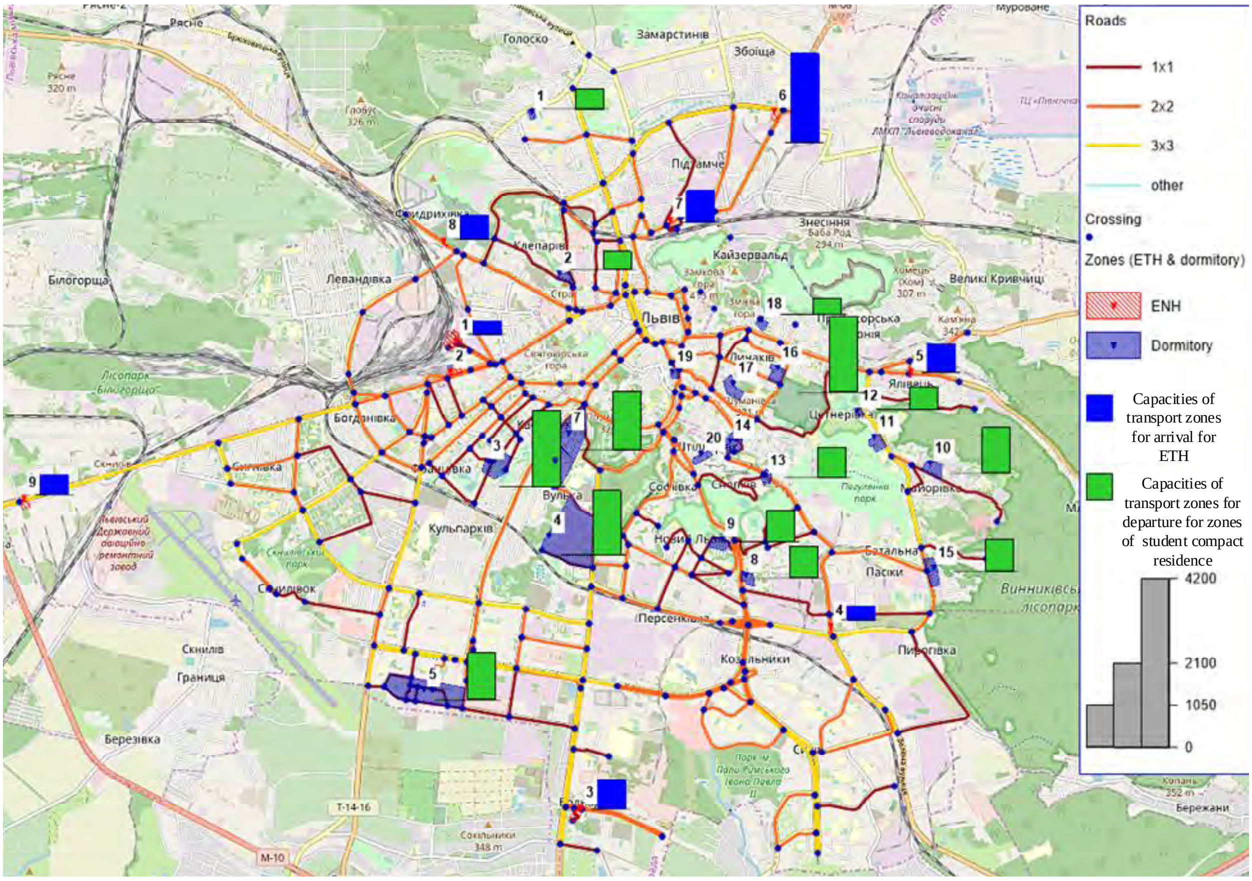

Fig. 8. Capacities of transport zones for modeling of movements between places of compact student residence and external transport hubs in Lviv

The data obtained can be the basis for further analysis: the choice of modes of movement, the optimal routes of movement, etc.

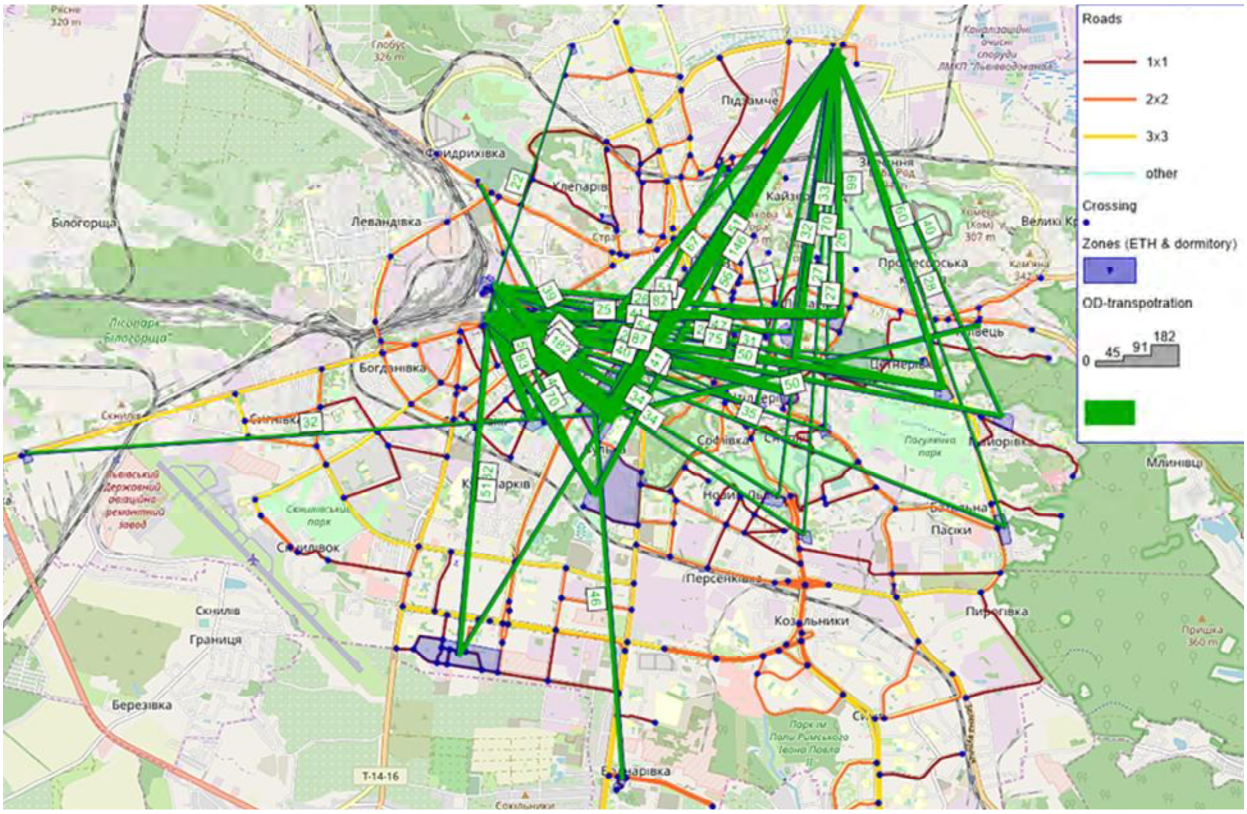

Fig. 9. Origin – destination pairs between places of compact residence of students and external transport hubs (workday)

4. CONCLUSIONS AND RESEARCH PERSPECTIVES

The methodological analysis of the transport system makes it possible to determine approaches to transport research. Such studies are needed for modeling, which plays a central role in the design and evaluation of transport systems since the values of some elements of existing transport systems can be derived from measurements, but this is usually a very expensive and time-consuming process.

As a result of the analysis of the Lviv transport system, it is determined that the number of students trips to the external transport hubs differs for weekdays and weekends. On Friday, Saturday and Sunday, these movements average 17.770 trips per diem, 67 % less than on weekdays. There is also an uneven increase in the volume of transportation to specific hubs. For the bus station # 6, bus station “Zakhidna” and Suburban Railway, the difference between weekdays and weekends is on average 54%, for the Main Railway Station – 78 %. The research outcomes can be used to model displacements and determine the directions of maintenance of external transport hubs.

The definition of transport system indicators and the formation of a methodological approach to their analysis will be further applied in determining the demand for travel in transportation systems of large cities.

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