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MODELING OF POLYGONS OF MAXIMUM PASSENGER ROUTE TRANSPORT ACCESSIBILITY BY THE EXAMPLE OF THE TRANSPORT SYSTEM OF UKRAINE

Досліджена державна (регіональна) транспортна система на прикладі України. Розглянуто дорожню мережу залізничних і автомобільних доріг України. Одне з найпроблемніших місць інженерних і зокрема транспортних мереж є визначення їх максимальних потенційних експлуатаційних показників. Формалізація певних параметрів обумовлює планування технічних показників потоків в мережі.

Ключові слова: *транспортна система, дорожні мережі залізничних і автомобільних доріг, міжміські перевезення.*

1. Introduction

Ensuring the stable functioning of passenger transport systems can be considered a priority for organizers of transport and transport companies. In the case that passengers are provided with the opportunity to realize the need for moving in the most convenient way, it is the basis for maximum implementation of potential transport correspondence between the nodes of the transport network. The main factors that affect the actual indicators of passenger traffic between the nodes of the transport network include:

- potential correspondence;
- fare;
- haul cycle time;
- time of haul cycle day of riding;
- haul cycle comfort;
- regularity and frequency of the haul cycle;
- social and economic characteristics of population development in transport hubs. It can be noted that the actual indicators of passenger traffic volumes need to be adjusted to take into account the characteristic seasonal or daily fluctuations.

In turn, the intercity passenger route transportation system uses its monetary resources to ensure its activities. The planned arrival of a monetary resource to ensure the stable functioning and development of intercity passenger route transport systems is indisputably important. At the same time, no less important is the distribution of cash flows between the elements of the transport system in time and quantity. In conditions of a balanced flow of financial flows within the system, the quantitative sufficiency of this resource and its balanced use of system elements, it is possible to plan and develop the industry.

Proceeding from the foregoing, it can be argued that the study of the basis for the development of intercity passenger route transport systems, consisting in such correspondence of passengers of the receipt of a financial resource, from which there are qualitative characteristics, is relevant.

2. The object of research and its technological audit

The object of research is the state (regional) transport system based on the example of Ukraine. The paper considers a road network based on the example of Ukraine's railways, which consists of more than 30 thousand arcs and knots. The model of the investigated network is constructed using geoinformation technologies, thus providing a description of network elements with geographic accuracy.

One of the most problematic areas of analysis of engineering and in particular transport networks is the determination of their maximum potential performance indicators. Formalization of certain parameters determines the planning of technical indicators of flows in the network.

3. The aim and objectives of research

The aim of research is prediction of the transport functioning parameters in the existing road network, taking into account changes in the main characteristics of the transport process.

To achieve this aim, the following tasks are supposed to be solved:

1. To conduct modeling of polygons describing maximum passenger haul cycles for different types of transport.
2. To determine the effect of speed and network on changes in transport availability polygons.

4. Research of existing solution of the problem

At present, scientists are studying the issues of modeling of passenger route transport systems. As a result of their work, it is decided to separate tasks when considering not only state (regional), but also urban, interstate and intercontinental route passenger transportation systems.

Consideration of the issue of intellectual planning of urban passenger transport systems was dealt with by the authors of [1], who proposed an approach based on modeling the demand for dynamic intelligent planning and route optimization. The solution offered by the authors in the work allows the system operators to make a decision about the dynamic creation of new routes based on requests from passengers. The model is proposed for implementation in Smart City projects. Simulation of routes in the city was done by the authors of [2]. In this paper, scientists proposed modeling, designed to predict the route network scheme, taking into account the maximum interaction between bus and rail routes. The authors of [3] also dealt with the need to take into account the coordinated interaction between different modes of transport. They invented the decision to create a multimodal transport network, using the multi-criteria routing algorithm for modeling.

In [4], the authors considered the issue of the probability of choosing a route for traveling by passengers in the presence of a set of options. The model of the probabilistic process of bus communication is defined. The authors of [5] solved the problem of modeling the total travel time by the passenger in the route network, depending on the number of transport nodes and the location of stopping points. The decision of questions of efficiency improvement of functioning of passenger routes on railway transportation is reflected in work [6]. The authors of [6] simulate the state of the system when the technical parameters of the route are changed.

Complex authors took into account the effectiveness of the functioning of the route passenger transportation system [7]. The developed model is based on the consideration of various modes of transportation and a multimodal public transport system. The solution proposed by the authors of flexible scheduling optimization, based on modeling the flexible size of the car. The results of studies of the modeling of demand fluctuations during the transit operation of the bus route were suggested by the authors in [8]. The approach of modeling the demand for travel and its distribution in accordance with the volume restrictions at the zonal level, which are as compulsory as the limitation of the capacity of common references, are described by the authors in [9–11].

Modeling of passenger transport correspondence between the nodes of the transport network is done by the authors of [12]. This work is devoted to forecasting passenger correspondence using gravitational approach. In the model considered by the authors, correspondence is determined taking into account the overall economic activity and geographical features of cities:

$$H_{ij} = a\frac{\left(f_i f_j\right)^{F_j}}{L_r}, \quad (1)$$

where H_{ij} – the volume of passenger traffic between cities i and j ($i \neq j$); f_i, f_j – attractiveness factors for cities i and j; L_r – total length of the route between the starting and ending points of the route; a – empirical constant; F_j – parameter of attractiveness of factors for a trip.

$$H_{ij} = e^{\varepsilon} P_{ij}^{\pi} Z_{ij}^{\chi} F_Q^{\beta} VVP_{ij}^{\gamma} L_r^{\delta} T_{tr}^{\tau}, \quad (2)$$

where P_{ij} – the probability that the movement will start in region i and end in region j; Z_i – service area; F_Q – the purchasing power factor; VVP_{ij} – the gross domestic gross product of the city i and j; T_{tr} – time of movement of passengers in the vehicle; ε, π, χ, β, γ, δ, τ – empirical coefficients.

Both models use mainly geo-economic variables as independent factors.

The authors of the paper [13] considered the issue of the impact of passenger correspondence, as the main resource that influences the development of transport infrastructure. The influence and defensive processes are modeled.

The authors of the paper [14] determined the algorithm for establishing the area of distribution of bus routes, taking into account the geographical distribution of railway passenger networks. Relying on the proposed algorithm, a model for planning bus arrivals to bus stations has been developed. The authors [15] considered the problem of the impact of the size of population demand on the speed of movement. Consideration of changes in the indicators of the functioning of passenger transport systems was also undertaken by other authors in the works [16–18].

The author of the paper [19] determines that the main characteristic of the transport system is accessibility. The paper presents an approach to modeling regional accessibility. The authors [20] considered the issue of increasing mobility of the population. It is determined that the productivity of public transport is limited not only by its availability, but also by its capacity. The actual throughput of the transport line is determined by the operating frequency, as well as by the physical capabilities of each vehicle. The interrelationship between the loaded demand and capacity contributes to the establishment of comfort levels, including the quality of service in general. Modeling these phenomena in the destination model, describes the user of the route and the mode of choice, transportation of supplies must be subject to a number of limitations: vehicle power (sitting and standing seats), landing and disembarking movements, lines and network loads.

In work [21], the actual behavior of the passenger is modeled when choosing between variants of travel that combine a trip in public transport with a car or a bicycle. In work, the definition of a network is based on the formation of an implemented set of route options with the choice of their optimal combination. The method and indicators of the quality assessment of the route network are proposed.

The proposed approach in [21] is used to predict the passenger flow between different geographical points.

Unknown parameters are estimated using aggregated data, when information is provided only about the number of passengers of each city. The weighted sum of residual areas is used as an effective evaluation criterion.

$$H_{i,j} = \frac{(Hmi\,Hmj)}{(li,j)^{\tau}} \exp(a + (c_{(i)} + c_{(j)}) P_{tot}^{Hii} + g_{(i,j)}\gamma_c + V_{i,j}), \quad (3)$$

where $H_{ii,j}$ – the number of items in the transport area i in the j area for the calculation period; a, $P_{tot}^{Hii} = (P_{tot1}^{Hii} P_{tot2}^{Hii} \ldots P_{totm}^{Hii})^T$ and $\gamma_c^{Hii} = (\gamma_{c1}^{Hii} \gamma_{c2}^{Hii} \ldots \gamma_{cm}^{Hii})^T$ – unknown regression parameters; P_{tot} – general mobility of the population; γ_c – the coefficient of average use of the cabin capacity; $c_{(i)} = (c_{i,1} \ldots c_{i,m})$, $c_{(j)} = (c_{j,} \ldots c_{j,m})$ and $g_{(i,j)} = (c_{i,1} c_{j,1} \ldots c_{i,m} c_{j,m}) - m$ – data arrays; $V_{i,j}$ – independent and identically distributed random variables with mean zero and unknown variance σ^2; $l_{i,j}$ – distance between areas i and j; H_{mi}, H_{mj} – the number of inhabitants in districts i and j, respectively.

The influence of the region's economic development on the parameters of passenger correspondence was also established. For this purpose, the authors used the gravitational model of Newton [22] for this prediction. On the basis of this model, authors proposed the attraction between cities to present through an adapted model of gravity:

$$F_i = \frac{VVP_i \cdot H_{mi} \cdot VVP_j \cdot H_{mj}}{\left(L_m \cdot T_{avij}\right)^2}, \quad (4)$$

where F_i – the attractiveness factor of the i-th district for expressing the number of potential passengers, possibly came to city i from city j; VVP_i, VVP_j – the gross domestic product of cities i and j, respectively, in the pair x; H_{mi}, H_{mj} – number of inhabitants in city i and j respectively; T_{avij} – the average cost of air travel between the area i and j.

To calculate the number of passengers on the arcs of the route network – Qa_{ij} the quantitative approach (3) was adapted to:

$$Qa_{ij} = \sqrt{\begin{array}{l}\left(VVP_{ix} \cdot VVP_{my}\right)^2 + \left(VVP_{jx} \cdot VVP_{ny}\right)^2 + \\ + \left(H_{mix} \cdot H_{my}\right)^2 + \left(H_{mjx} \cdot H_{mny}\right)^2 + \left(T_{avx} \cdot T_{avy}\right)^2 + \\ + \left(l_{r\,ijx} \cdot l_{r\,ijy}\right)^2.\end{array}} \quad (5)$$

Similar approaches using gravitational modeling are presented in other scientific papers [23–26].

In the author's opinion [27], to determine the distribution of potential correspondence between passengers between modes of transport to the place of use of the following relationship:

$$P_k = \frac{e^{Uk}}{\sum_Z e^{Uk}}, \quad (6)$$

where p_k – the proportion of trips made in the k mode; U_k – utility of the k mode; Z – the index of efficiency of all modes; e – 2718281...

5. Methods of research

To establish scientific approaches to the calculation of passenger correspondence between cities, taking into account their geographical calculation, social and economic indicators methods of system analysis were used. Using the methods of computer modeling, the methods of polygons for maximum passenger route transport accessibility for various modes of transport were determined, which were used to determine the parameters of the technological process of passenger transportation.

6. Research results

For the modeling of polygons of maximum passenger route transport accessibility for various modes of transport, a geographical model of the transport network of Ukraine was used. In a certain model of the network, regional centers have been selected as transportation hubs, the roads of state and regional significance and railways have been selected as links (Fig. 1, 2).

From Fig. 1, 2, it can be determined that the road and rail transport networks are different. The number of links in the automotive network is greater. This leads to the possibility of constructing polygons that differ from each other. Selected transport network models satisfy the requirements of data reliability with an allowable geographical deviation. This ensures that the selected model can be used in further research. ArcGIS software (Network Analyst application) was used for the modeling of polygons for maximum passenger route transport accessibility for different modes of transport.

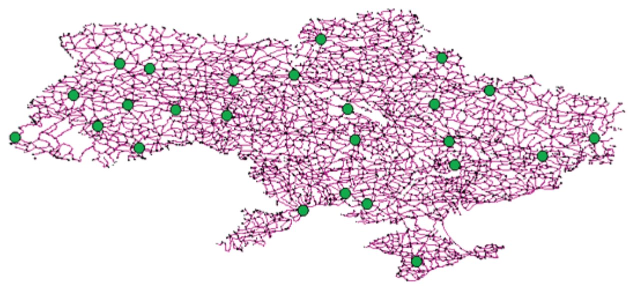

Fig. 1. Model of the automobile transport network in Ukraine

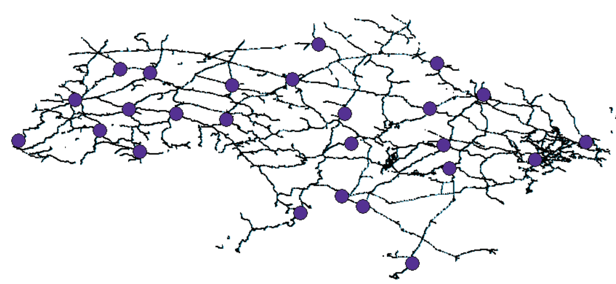

Fig. 2. Model of the railway network in Ukraine

For transport nodes, transport access polygons have been constructed, taking into account certain conditions for the functioning of the transportation process – the average time and the average speed. When simulating polygons for the maximum passenger route transport accessibility of the transport system for motor transport, the mean time of the trip is chosen to be 1.5; 3, 5 and 8 hours, and the average speed of the correspondence is 46 and 73 km/h. This corresponds to the existing rates of inter-regional bus communication in the experimental system. The models of the maximum passenger route transport accessibility for motor transport for the transport hubs, which correspond to such regional centers as Lugansk, Odesa, Dnipro, Kyiv, Simferopol are constructed. Fig. 3, 4 show the simulation results for the example of a polygon constructed with respect to the transport node, which corresponds to the Dnipro city.

Let's build similar models for railway transport, taking into account transport access limits of 1.5; 3, 5 and 8:00. The following speed limits were used in the simulation, namely: 31, 68 and 98 km/h. This corresponds to the existing rates of inter-regional railway communication in the experimental system. The results of the simulation are shown in Fig. 5–7 in the example of a polygon constructed with respect to the Dnipro city.

From Fig. 5 it is established that when simulating a route network for transporting passengers relative to the selected transport hub, it is possible to ensure the implementation of passenger route transport correspondences. Correspondence has been identified that can be realized between the center of the constructed polygon and three other nodes only in conditions of a haul cycle to 8:00.

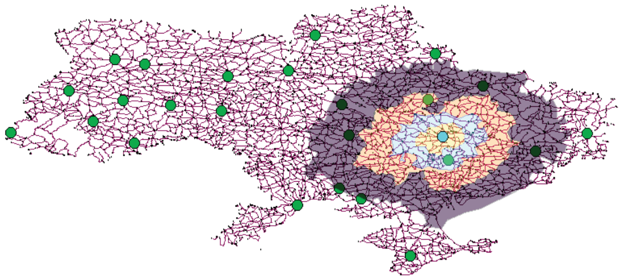

Fig. 3. Model of polygons for maximum passenger route transport accessibility in road transport at a speed of 46 km/h and a haul cycle of 1.5; 3, 5 and 8:00 respectively

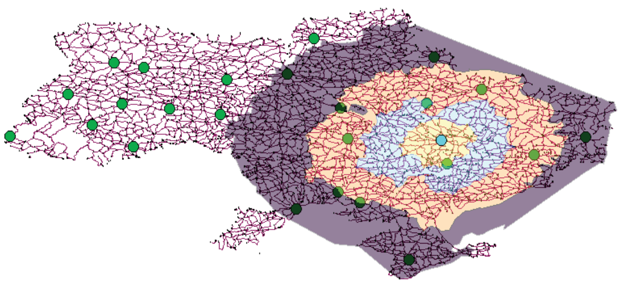

Fig. 4. Model of polygons for maximum passenger route transport accessibility in road transport at a speed of 73 km/h and a haul cycle of 1.5; 3, 5 and 8:00 respectively

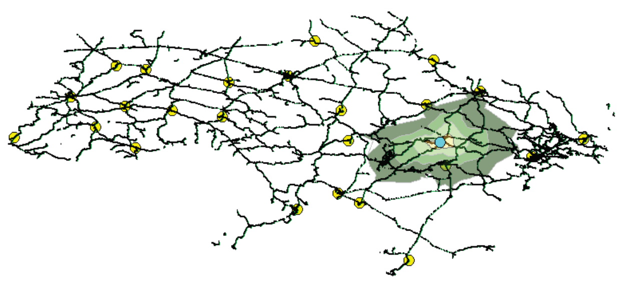

Fig. 5. Model of polygons of maximum passenger route transport accessibility in railway transport for certain parameters (31 km/h, 1.5, 3, 5, 8:00)

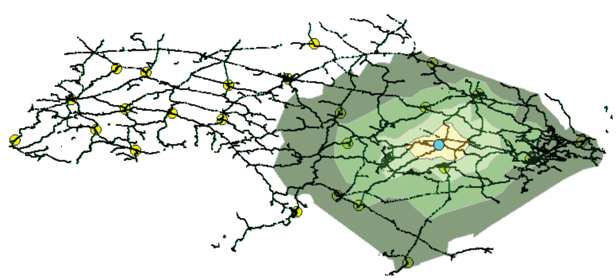

Fig. 6. Model of polygons of maximum passenger route transport accessibility on railway transport for certain parameters (68 km/h, 1.5, 3, 5, 8:00)

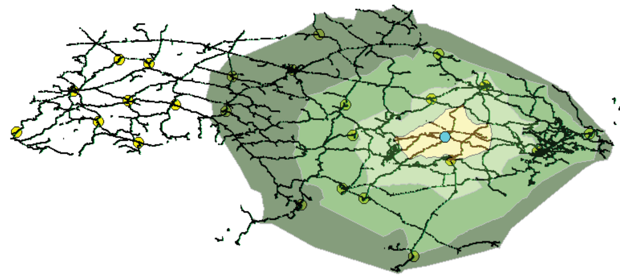

Fig. 7. Model of polygons of maximum passenger route transport accessibility on railway transport for certain parameters (98 km/h, 1.5, 3, 5, 8:00)

From Fig. 7 it is established that when simulating a route network for transporting passengers relative to the selected transport hub, it is possible to ensure the implementation of passenger route transport correspondence. If you save the established parameters for modeling the polygons for maximum route transport accessibility by passengers, it is determined that within 1.5 hours of driving the polygon contains only one node except the center of the polygon construction. When considering a landfill that meets transport accessibility with riders in the range of 1.5 to 3 hours, four transport nodes can be reached. In the case of the organization of route transport, with an average speed of 98 km/h and a journey time of 3 to 5 hours from the center of the constructed landfill, it is possible to reach seven nodes. Up to six nodes can be reached for a journey of 5 to 8 hours. Comparing Fig. 4 and Fig. 6 it can be argued that the polygon model is based on a network of highways, covering a greater number of transport nodes with an average connection speed greater by 5 km/h.

In Fig. 8 modeling of polygons using a model of the road network is implemented, in contrast to the previous one, is a combination of road and rail networks.

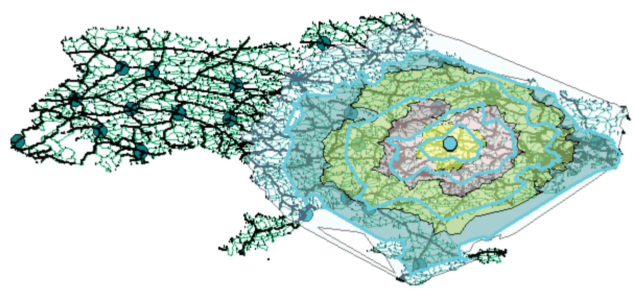

Fig. 8. Model of polygons for maximum passenger route transport accessibility in the integrated road network

Fig. 8 shows the results of modeling the parameters of route accessibility of traffic in both road networks simultaneously. It has been established that within 1.5 hours of driving, a railway track with a speed of 68 km/h doesn't reach any nodes (cities) in both networks, and an automotive polygon with the same speed contains one node (city). The polygon is built on the railway tracks with riders ranging from 1.5 to 3 hours contains equally a transport node, and the automobile in these conditions is two. When examining a landfill that meets the transport accessibility of railroads, within the range of 5 to 8 hours, there are eleven transport nodes, and the automotive in these

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conditions is thirteen. Comparing rail and road transport accessibility, it can be argued that road transport accessibility has a larger service area than rail.

7. SWOT analysis of research results

Strengths. The strengths of the research included modeling of the obtained polygons with geographical accuracy, obtaining the results of simultaneous operation of the railway and automobile networks. In contrast to the previously proposed approaches to solving the problems of planning the indicators of the transport process using network analysis, a comprehensive approach is proposed with the use of modern information technology tools.

Weaknesses. The weaknesses of the study include the failure to ensure that changes in the total time of the journey are taken into account when changing the networks by which the transportation is carried out. However, the proposed approach specifies that there may be certain conditions under which the maximum transport accessibility by networks will increase when using both networks of the same haul cycle. Failure to take into account the increase in the time of a ride when changing networks can result in a decrease in the average speed of the haul cycle. This is the basis for reducing the polygon defined in the work.

Opportunities. Further development of the proposed study can be obtained in solving the issues of planning the costs of temporary and energy resources used in the transportation process.

Threats. The threats to use the proposed means for planning parameters are not to ensure that the features of each of the arcs of the investigated network are taken into account. It is possible that in determining the polygons, the speed of movement was not realistic for use in certain sections of the railway and road routes. This causes the probability of obtaining design polygons with unrealistic characteristics.

8. Conclusions

1. For the modeling of polygons of maximum passenger route transport accessibility for different modes of transport, a geographical model of the transport network of Ukraine is used. In a certain model of the network, regional centers have been selected as transportation hubs, roadways of state and regional significance and railways have been selected as links. It is determined that the road and rail transport networks are different. The number of links in the automotive network is greater. This leads to the possibility of constructing polygons that differ from each other. Selected transport network models satisfy the requirements for the reliability of data with an allowable geographical deviation.

2. Based on the results of the modeling of polygons of maximum passenger route transport accessibility for various modes of transport, it is determined that the characteristics of the modeled set of plugins are affected by the selected network model and the connection speed. It is proved that at the same speed of movement polygons constructed in different networks differ. This is due to the individual features of the networks, in this case described by the figure and the number of links in the network.

It is established that within 1.5 hours of driving, a railway track with a speed of 68 km/h does not reach any nodes (cities) in both networks, and a car polygon with the same speed contains one node (city). The polygon is built on the railway tracks with riders ranging from 1.5 to 3 hours contains one transport hub, and the automobile in these conditions – two. When examining a landfill that meets the transport accessibility by rail, within the range of 5 to 8 hours, there are eleven transport nodes, and the automotive in these conditions is thirteen. Comparing rail and road transport accessibility, it can be argued that road transport accessibility has a larger service area than rail.

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МОДЕЛИРОВАНИЕ ПОЛИГОНОВ МАКСИМАЛЬНОЙ ПАССАЖИРСКОЙ МАРШРУТНОЙ ТРАНСПОРТНОЙ ДОСТУПНОСТИ НА ПРИМЕРЕ ТРАНСПОРТНОЙ СИСТЕМЫ УКРАИНЫ

Исследована государственная (региональная) транспортная система на примере Украины. Рассмотрена дорожная сеть железнодорожных и автомобильных дорог Украины. Одним из самых проблемных мест инженерных и, в частности, транспортных сетей является определение их максимальных потенциальных эксплуатационных показателей. Формализация определенных параметров обусловливает планирование технических показателей потоков в сети.

Ключевые слова: транспортная система, дорожные сети железнодорожных и автомобильных дорог, междугородние перевозки.

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