Analysis of city transport network based on geoinformation systems in transport zones of industrial city

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Abstract. The analysis of transport accessibility is a standard task requiring the search for the optimal solution, the solution of which is necessary for the harmonious development of the urban environment in general, and the effective organization of the transportation process in particular. The article discusses the indicators necessary for determining transport accessibility based on analysis of the urban transport system and calculation methods using geographical information systems. The main parameter is time-based accessibility from the central part of the city to other transport zones. To determine the rank of the transport zone, the following statistical characteristics are required: road network density in urban areas; a number of jobs, a number of equipped parking spaces; the number of objects of gravity in transport zones. A decision support system based on geographic information systems can be carried out by two methods: the choice of a relatively ideal solution and simple additive weighing. Analysis of transport zones can improve the quality of statistical data on urban transport medium. The article presents the models, the use which is necessary for efficient operation of urban transport, as well as indicators necessary for the stable functioning of the infrastructure. It can be integrated into planning systems and sustainable development of urban transport and planning.

1. Introduction

Assessing the performance of the transport system is one of the most important tasks of transport modeling. To solve this problem, it is necessary to select departure/destination points in which public transport could successfully compete with individual transport, and to analyze: the overall system performance, changes in the quality of transport services provided and the cost of transportation. Studies in this area show that transport is the most competitive in areas with dense population [1]. Such areas are areas with a high concentration of population and heavy traffic. The concept of transport accessibility can be applied to various tasks of spatial location: logistics centers, socially significant objects (hospitals, schools), objects of gravity. It is used to efficient traffic routing in an urban environment using geoinformation technologies. Due to such technologies, travel time and territorial distribution of areas can be obtained, taking into account network of streets and the GIS approach. The matrix of transport accessibility is implemented by reconstructing the departure/destination matrix used in the analysis of travel demand [2].

To obtain more accurate research results, it is proposed to use the methodology for determining centers based on the attractiveness of trips, taking into account disaggregated types of employment. This algorithm determines the areas in which a disproportionate number of trips are carried out. The proposed methodology has two positive characteristics. Firstly, the approach assesses the attractiveness of the trip from the point of view of the user of services, using standard socio-economic data available at the level of transport planning in the region. Secondly, employment is the main
indicator in determining the center of the city, and the approach to identifying subareas that exceed certain thresholds remains unchanged.

The basis for the analysis is transport accessibility. The following factors were also taken into account: population density, number of jobs, density of the network of streets, density of coverage of the territory by public transport, average daily number of trips in the analyzed area. As a result of a comparative analysis of indicators of network of streets and territorial distribution, it is possible to rank the transport zones.

Table 1. Indicators of the transport system of the city of Angarsk.

| Indicator                                                      | Value  |
|---------------------------------------------------------------|--------|
| **Density of public transport network of the street (km/km²):** |        |
| within the city limits                                       | 4.40   |
| main streets and roads in the built-up area                   | 2.24   |
| main streets and roads within the residential area            | 2.68   |
| **Peak average traffic (r/h):**                              |        |
| St. Alyoshina                                                 | 894    |
| St. Engels                                                   | 438    |
| Leningrad Avenue                                             | 1330   |
| St. Market                                                   | 644    |
| St. Orechchina                                               | 438    |
| St. 40 Years of Victory                                      | 108    |
| St. Decembrists                                              | 1050   |
| St. Comintern                                                | 909    |
| Angarsky Avenue                                              | 838    |
| St. Cosmonauts                                               | 834    |
| St. Tchaikovsky                                              | 1418   |
| St. Karl Marx                                                | 1614   |
| St. Gorky                                                    | 1288   |
| St. Lenin                                                    | 752    |
| St. Voroshilova                                              | 1036   |
| Moscow tract                                                 | 1048   |
| **Number of trucks in the average flow, %**                  | 11     |
| **Trucks at peak hours, %**                                  | 37     |
A sharp jump in the level of motorization causes problems regarding the stability of the transport system, which affects the economic, social and environmental aspects of life [3]. In 2013, 35.9 million passengers were transported in Angarsk by road, in 2014 – 31.1 million passengers; in 2015 – 26.3 million passengers. Thus, there is a tendency towards a decrease in the number of passengers carried, which is associated with a significant increase in the number of individual vehicles. The indicators of the Angarsk transport system in 2019 are presented in table 1.

2. Formulation of the problem
The city of Angarsk within the boundaries of the settlement includes the following functional areas: residential, public and business, industrial use, engineering and transport infrastructure, agricultural use, recreational zone, special purpose. It is an industrial compact city, which can conditionally be divided into 30 residential areas. When dividing into zones, the type of development is taken into account (areas with large-sized housing stock, areas with 2- or 3-storey buildings with wooden floors, one-story buildings).

Figure 1. Zoning on an example in the city of Angarsk (residential areas).

Transport accessibility when examining residential areas is measured by the time costs to travel from a specific point in the city to the outer borders of the central region. Accessibility allows creating a reasonable zoning of the city. As the level of transport accessibility decreases, there is an increase in travel costs.

The general research methodology for the agglomeration transport network consists of the following steps [4, 5]:
1. Three “levels” of separation of centers are determined: large urban (in megacities), secondary urban (in small cities) and suburban. Employment and density thresholds are set to identify areas with higher occupancy characteristics than adjacent ones.
2. Formation of activity clusters. Zones that do not meet employment thresholds can be grouped with neighboring ones, satisfying the criteria for the formation of enlarged zones. Adding zones is possible until the restriction exceeds the threshold value. This method is proposed to be used for suburban activity centers in order to avoid the case when one zone with ultrahigh density in the city center dominates and all neighboring zones will be included in the “superzone”. Separately added zones must meet the minimum occupancy density threshold. This requirement excludes the case when open space adjacent to a high-density employment center is considered a part of a suburban center. Two zones are considered adjacent if they have a common boundary of any length.
3. A hypothetical mining area attracts far fewer passengers than a retail area. There are models of transport developed for zones, the main area of which is occupied by shopping centers [4]. As a rule, retail trade generates more trips, and therefore has an impact on regional transportation patterns. Thus, to analyze the transportation process, it is necessary to use the method of determining the centers based not only on the density of employment, but rather on the attractiveness of trips, taking into account all types of employment present in each zone. To include in the model such an indicator as “the attractiveness of travel in a certain zone”, we can calculate the product of employment and the
attractiveness coefficient of a trip to work for each type of employment by category. Those areas that have exceeded the threshold for travel density per unit area are then considered as a part of the retail area. The approach under consideration is the definition of a hypothetical “average trip attractiveness”. Suppose that in each type of employment there is a zone with one option for applying labor. In this case, the total number of daily trips will be attracted to this zone, and it will be possible to calculate the average number of trips.

3. Materials and methods
The tourist attractiveness of the zone in large agglomeration is [6]:

\[ TA = 1.4Ag + 1.2Mi + 3.0Re + 2.4Se, \]

where \( TA \) – number of trips in zone; \( Ag \) – number of workers employed in agriculture; \( Mi \) – number of workers employed in mining industry; \( Re \) – number of jobs; \( Se \) – number of jobs associated with the services.

It is necessary to take into account the coefficient of attraction \( \alpha_k \) workers arriving at business trips for type of employment \( k \):

\[ \chi_k = \frac{\alpha_k n}{\sum_{i=1}^{n} \alpha_i}, \quad \text{for all } k, \]

where \( \chi_k \) – coefficient of each type of employment \( K \); \( n \) – total number of types of employment.

The analyzed territory is combined into a zone if:

\[ \sum_{k=1}^{n} E_k \chi_k \geq \xi, \]

\[ \sum_{k=1}^{n} \frac{E_k \chi_k}{A} \geq \varphi, \]

where \( E_k \) – actual employment of type \( k \); \( \xi \) – gross employment threshold; \( A \) – area of the transport zone; \( \varphi \) – threshold for employment density (number of jobs per area).

Thus, the analyzed zones that correspond to or exceed threshold values taking into account jobs are considered clusters. The creation of a cluster framework occurs by adding neighboring zones (with a density of employment of more than 3.0 jobs per 0.4 ha), so that the overall cluster remains above the threshold level.

4. Results and discussion
The highest concentration of jobs was noted in the production service area of the city (figure 2).

Figure 2. Centers of transport activity in the city of Angarsk.
The next step is to calculate the rating of zones with the assessment of traffic flows by taking into account various indicators. To obtain a rating, it is possible to use two methods for assessing the rank of zones – based on socio-economic data and / or based on information from geographic information systems.

The authors consider the methodology underlying the analysis. The initial data for the calculation are the criteria and their degree of influence. The matrix of criteria is normalized in accordance with these conditions:

If the criterion is maximized:

\[ X_{ij} = \frac{X_{ij}}{X_{ij}^{\text{max}}} \]  

If the criterion is minimized:

\[ X_{ij} = \frac{X_{ij}^{\text{min}}}{X_{ij}} \]

The normalized matrix for each criterion is multiplied by a coefficient expressing the degree of influence. Multiplied criteria are summarized for each row (zone). Highest value means the best traffic situation in a particular area.

Let us consider the method of comparing the obtained solutions with ideal ones. The comparison is carried out using data from geographic information systems.

The matrix of criteria is normalized by this formula:

\[ X_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \]

The matrix of criteria is multiplied by the matrix of importance of values [5]:

\[ P^* = [X] \times [q], \]

where \( q \) – matrix of importance of values.

The normalized matrix is used to calculate the ideal positive (\( f_j^+ \)) and negative (\( f_j^- \)) options. The calculation of the deviation from the ideal positive option is based on:

standardization of matrix criteria:

\[ L_i^+ = \sum_{j=1}^{n} (f_{ij} - f_j^+)^2 \]  

calculation the deviation from the negative option:

\[ L_i^- = \sum_{j=1}^{n} (f_{ij} - f_j^-)^2 \]  

calculation the proportional deviation from the ideal variant (\( K_{\text{BRT}} \)):

\[ K_{\text{BRT}} = \frac{L_i^-}{L_i^- + L_i^+}, \]
The best solution is the one with the highest $K_{BIT}$ value.

The influence of the studied indicators (%) is presented in table 2. The importance of each indicator was evaluated by conducting transport surveys.

Table 2. Transport system indicators of the Angarsk city.

| Indicator                                           | Function           | Influence of an indicator, % |
|-----------------------------------------------------|--------------------|------------------------------|
| Density of the road network (km / km$^2$)            | maximization       | 18                           |
| Density of public transport network (km / km$^2$)    | maximization       | 14                           |
| The length of the road network per 1000 inhabitants in each zone | maximization       | 17                           |
| Imbalance in population and work density             | maximization       | 26                           |
| Density of parking spaces (parking spaces / ha)      | maximization       | 9                            |
| Accessibility from each zone to the city center      | maximization       | 8                            |
| Average daily travel                                 | maximization       | 8                            |

5. Conclusion

The considered methodology is flexible and can be successfully applied for analysis and ranking in other cities. In the process, indicators were identified that are important for transport research. The quality of the data affects the levels of the survey, the details are determined based on the available sample size. Depending on socio-economic data, there is an increase in the opportunity to get a real assessment of work, while identifying tasks that need to be addressed: development of the transport network, increasing the attractiveness of urban passenger transport. The availability of tools to assess the performance of the transport network is one of the relevant areas of scientific research in the framework of transport modeling.

References

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