Map data-driven assessment of urban areas accessibility

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Abstract. The study analyzes the existing approaches to assessment of the city territory transport accessibility. The method for the city territory sections connectedness assessment through the personal and public transport was developed. The assessment of transport accessibility is proposed based on an analysis of open cartographic data. The technology of calculation and visualization of urban areas interconnectedness with the use of a street network graph and public transport routes, data obtained from Internet map services have been developed. An example of territory accessibility assessments visualization on an online map is given.

1. Introduction
Making decisions related to the choice of places to live, work or spend free time is directly related to the conditions of mobility of the population. At the same time, the transport system of the city comes to the fore.

The transport system is a key spatial component of the urban area. The development of transport links often determines the quality of life itself in the city. The task of researching and evaluating the communications of territory sections through a street network and various transportation systems only increases its relevance for modern urbanized territories [1].

While ensuring the sustainable development of the city's system and meeting the needs of people's livelihoods, it is possible to follow the general principles of efficiency. However, it is always necessary to take into account the individual characteristics of the urban environment that have developed under the influence of historical, geographical and socio-economic circumstances [2].

In the framework of this study, it is planned to consider the existing solutions in the analysis of transport accessibility in urban areas. It is necessary to develop an approach to the analysis of internal relationships. Such approach should be invariant to the city under evaluation and be based on objective data related to the existing structure of a particular urban space.

2. Background
The main term used to determine the mobility of the population in the urban environment is transport accessibility. The authors of [3] define it as an indicator of the time spent on transport communications between different points within the system of group dispersal. At the same time,
transport accessibility is usually measured by the time required to travel from a given point of the city to the outer limits of the center.

Ranked values of transport accessibility can be considered justified criterion of zoning of the city territory. Accordingly, it is commonly believed that the value of the property is gradually decreasing as transport accessibility decreases and the time spent on trips to the city center increases.

According to existing studies in foreign practice, the term transport accessibility has two meanings [4]:

- full time expenditure on movement, committed for some purpose;
- the possibility of obtaining transport services by people with disabilities.

In this regard the term “Transport Affordability”, presented in [5], which is used in the USA and Canada, is more appropriate. Transport affordability means an economic assessment of transport availability.

The existing document in Russia, named SNiP 2.07.01-89* “Urban planning. Planning and development of urban and rural settlements” [6], normalizes the time spent in cities for movement from places of residence to places of work. In accordance with its requirements for 90% of workers, the time spent on traveling to a workplace should not exceed the established indicators for the size of cities. The availability of public transport stops should not exceed 5 minutes.

There are a variety of methods for analyzing and planning the urban environment, but most of them relate to manual calculation [7]. They are widely used in many research papers. For example, paper [8] presented work about calculating the weighted average time by using Microsoft Excel and work with the GIS system ArcGIS.

More modern methods can be considered such as the assessment of transport accessibility in the city by GIS-Lab [9]. The research uses the OpenStreetMap cartographic service data and the GIS system of GRASS GIS and QGIS.

Researchers from Urbica suggest using the isochron [10] method to solve the problems of assessing availability at specific points. They developed a web-based application with which one can instantly calculate the isochron of walking/driving by car for any place in the city. However, the list of cities, for which calculations can be made, is limited and includes 15 large cities. Similar studies on the analysis of pedestrian walk data can be seen in the works of Morphcode [11] according to data collected in Melbourne.

The analysis of the conducted studies showed their focus on the calculation of the centers of attraction when calculating the indicators of the availability of the territory. However, there is a noticeable tendency to single out one or several key centers of attraction, as well as work with local points of space. Such calculations do not reflect the full picture, because the livelihoods of the population in the city are dispersed throughout the territory. In this regard, the assessment of the availability of each given point in relation to all the other points is relevant at the moment.

3. Method for assessing territory connectedness

In this study, it was supposed to estimate the total internal territory connectedness of a settlement. Two problems arise:

1. selection of elements of the territory, the communication with which must be calculated;
2. determination of communication methods for selected areas.

Depending on the objectives of the study, functional areas, areas of compact residence, neighbourhoods or other administrative units can be identified as territorial segments of a settlement. Each way of splitting the territory into fragments is associated with some existing conditions and may reflect subjective relationships. In this case, in fact, the minimal universal unit of territory can be considered a point in space. Nevertheless, such segmentation will have a number of drawbacks:

- excessive computational complexity in the connectedness calculation of all points of space with all;
• the "narrowness" approach in assessing links of this point to others, taking into account that the path from it goes only through one communication channel.

This study is about the possibility of moving a person on a certain territory, rather than binding to a single point. Therefore, one can take into account the variability in the use of several communication paths near a single point. For this purpose, it was decided to use a free grid, superimposed on the map of the territory.

The grid cells are square with a side of 250 m. The choice of this dimension was due to the fact that the centers of all adjacent cells are within a pedestrian diameter (10-minute pedestrian isochrone).

The interconnection of the selected grid of cells determines their availability. This case implies the transport accessibility of the territory of the settlement as a whole. Therefore, it needs to be determined by assessing the links of parts of the city through road transport infrastructure. For this, the following ways of moving along an urbanized territory can be distinguished:

1) public transport - walking distance to/from the route lines, a trip along the route;
2) personal car and motorcycle transport - traffic on public roads;
3) walking course;
4) bicycle - traffic on public roads or specialized tracks.

Options 3 and 4, taking into account the city size and the average time of displacement [p6], can be included in paragraphs 1 and 2 respectively. Thus, transport accessibility was decided on the basis of public transport routes passing through the selected segments, including stop points, their groups, interchange stations and transport service quality indicators, density and non-straightforwardness of the transport network. In addition, the mutual communications were proposed to be calculated on the basis of an analysis of the availability of parts of the territory of the settlement by personal vehicles, taking into account the dynamics of the traffic situation and the static components of the structure of the transport network along the public street network.

As a result, to assess the transport accessibility of urban areas, a method was proposed that includes the following stages:

1. Determination of the boundaries of the territory of the settlement.
2. The marking of the selected area on the sector by a grid of the established step.
3. Obtaining data on the graph of network of streets (NoF) and public transportation routes in the selected territory.
4. Construction of an adjacency matrix of grid cells based on the data about movement possibility:
   a. by public transport.
   b. by personal transport.
5. Evaluation of the grid cells connectedness with each other on the basis of adjacency matrices.
6. Assigning the data to the corresponding grid cells with the formation of estimates.

4. Assessment of transport accessibility based on open map data

A technology for assessing transport accessibility was developed based on the proposed method. The technology includes the use of data from network mapping services. In this case, it was decided to focus on freely available open geodata. The sequence of actions includes a number of related solutions for data processing:

1. To determine the boundaries of the territory of a settlement, the coordinates provided by the Mapzen [12] service are used. This service uses OpenStreetMap data [13].
2. The allocated territory is divided into square sectors (cells). The cells are set by the grid of the set step. To generate a grid, the following actions are performed:
   2.1. The width and length of the settlement are calculated on the basis of the coordinates of the extreme points of its boundaries. The overall dimensions are necessary for specifying the limits of grid construction.
2.2. The number of cells in the grid horizontally and vertically is calculated from the data in § 2.1 and the specified step (cell size).
2.3. The point that will be the beginning of the grid (the upper-left corner) is calculated from the coordinates of the extreme north and west points of the settlement.
2.4. The cell coordinates are calculated in accordance with the algorithm shown in Figure 1.

3. The adjacency matrix of grid cells is constructed on the basis of data on the lengths of transport routes between cells:
   3.1. the matrix is built on the basis of the previously generated grid;
   3.2. for each cell is the distance from it to all the others.

4. The grid cell connectedness is evaluated on the basis of contiguity matrices. A relative 10-point scale is used for evaluation. Determination of the extreme values of the scale is performed on the minimum and maximum distances from the matrix. The evaluation is carried out for two cases:
   4.1. Evaluation of the relative connectedness of cells is performed by bypassing the adjacency matrix and calculating the root-mean-square value of the data in the row, with the determination of its position on the selected scale.
   4.2. Evaluation of the connectedness of each cell with all the rest is performed by line bypass of the adjacency matrix and calculation for each value in the line of its position along the selected scale.

5. The received data are assigned to the corresponding grid cells. The calculated data are stored in a "geojson" file format.

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**Input data:**
- $V_c$ -- number of cells vertically,
- $H_c$ -- number of cells horizontally,
- $S_c$ -- cell size.

**Output data:**
- $R$ -- result file.

**Algorithm for calculating coordinates of cells**

\[
\text{For } i := 0 \text{ to } V_c
\]
\[
\text{Calculate the first coordinate } I_c \text{ of the row of cells horizontally}
\]
\[
\text{For } j := 0 \text{ to } H_c
\]
\[
\bullet \text{ Calculate the left-upper coordinate of cell } L_{ij} \text{ using } I_c \text{ by shifting it to the right by } K \text{ elements, where } K = S_c \cdot j.
\]
\[
\bullet \text{ Calculate the upper-right coordinate of cell } R_{ij} \text{ by shifting to } S_c \text{ to the right of } L_{ij};
\]
\[
\bullet \text{ Calculate the lower-right coordinate of cell } R_{ij} \text{ by shifting downward to } S_c \text{ from } L_{ij};
\]
\[
\bullet \text{ Calculate the left-lower coordinate of cell } L_{ij} \text{ by shifting it to the left by } S_c \text{ from } R_{ij};
\]
\[
\text{Write } L_{ij}, R_{ij}, L_{ij}, R_{ij} \text{ in } R.
\]

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**Figure 1.** Algorithm for calculating coordinates of cells

The adjacency matrix of grid cells, which characterizes the possibilities of travelling by personal transport, is based on the lengths data of the "routes" for the travelling by personal transport. The matrix cells contain distances from center of one cell to center of the other. The distance data are calculated using the OSRM service [14].

The OpenStreetMap (OSM) service is used to obtain data about public transport routes. Data in OSM are represented in a "multilayered" XML format. To use them, one needs to perform some transformations:

1) extract public transport routes from the corresponding map layer;
2) in the same way, take the public transport stops;
3) correlate public transport routes with stops.

These conversions are necessary to correctly assess the availability of transplant between routes. As a result, it becomes possible to build a route between two points of the settlement with the use of public transport and find out the distance for a built route.

The construction of the adjacency matrix for public transport completely corresponds to the construction of an adjacency matrix for personal transport. The difference lies in the fact that the basis of such matrix is data on the distance between cells when using public transport.

5. Calculation and visualization of the territory sections connectedness
The proposed calculation technology was investigated on cells of different sizes. This was due to the necessity to analyse results of the obtained connectedness changes, as well as checking the cost-effectiveness of the calculations.

The developed algorithm tested on the grid with cell size of 10x10 kilometers for a city fits in a 50 kilometer square for a negligible time (fig. 2a). Processing for twice smaller grid cells (5x5 km) takes about 10 minutes (fig. 2b). Grid 2.5x2.5 km is processed in 2 hours.

A separate task was related to visualization of the results of the assessment. A good information visualization obtained as result of the research directly affects the quality of the perception of this information by the end user. That subsequently plays a significant role in the analysis of these data and the formation of adequate assumptions for the next stages of research.

Within the framework of this task, it was required to implement a representation of estimates related to certain zones (fig. 2). At the same time, for each zone it was necessary to visualize the results of the estimates, according to which it can be concluded that the site of the city is accessible, at any scale of map display. For this, it was decided to scale the gradation of colors, which represent a scale of estimates. And the bounds themselves remain tied to the coordinates with the desired cell size of 0.25x0.25 km.

![Figure 2. Visualization of accessibility estimation: a – cell size is 10x10 km; b – cell size is 5x5 km.](image)

6. Conclusion
Expert analysis of the results, visualization of the obtained assessments of the availability of the territory, based on the example of the city of Volgograd, showed the adequacy of calculations in comparison with the real situation. However, an important result of the study is to obtain numerical estimates for each selected area of the territory.
The obtained values of the territory availability indicators can be applied in the tasks of assessing qualitative differences of different sites for the resident population. Influence of transport conditions of the urban environment, expressed in quantitative form, in practice can be applied to analyse its contribution to the value of real estate. In a generalized analysis of the interdependence of accessibility indicators and cost estimates of infrastructure facilities, it will make it possible to contribute to the study of the prestige index of various sections of the territories within the city.

However, a number of problems requiring additional study were allocated to improve the research process. So, it is necessary to evaluate the possibility of solving the problem of finding the distance between points on the map using OSRM.

To solve the problems with the performance of the calculation algorithm, it is necessary to implement parallel version. It seems expedient to transfer the calculations to cluster equipment. At the same time, a task appears to find the optimal load balancing when displaying simulation results for visualizing data on the client's map. It is necessary to ensure minimum load on the client of the software system, but at the same time to exclude the influence of conversions on the perception of data by the user.

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