A method of improving the pedestrian accessibility of the urban public transport stops based on a genetic algorithm

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Abstract. The article discusses the problem of pedestrian accessibility of public transport stops. Research considers and analyses of existing algorithms that allow solving the localization of public transport stops problem in metropolis. The study suggests a formal mathematical description model of the public passenger transport system with stops and routes. A new method based on functions and operators of a genetic algorithm for optimization of public transport stops dislocation was developed. The proposed method is implemented in Python programming language and has been tested on sample data of the city of Samara.

1. Introduction
Public transport system is an essential component of the urban infrastructure for metropolis. It plays an important role in the economic and social life of citizens. Passenger transport system is a subsystem of the urban infrastructure and the interactions between three systems: city, transport, population [1]. The main function of urban public transport is to ensure the transport mobility of the population. Consequently, there is a gap of the public passenger transport system development leads to the emergence of socio-economic urban problems.

Passenger traffic has a huge impact on the region transport accessibility, the level of the population mobility and the well-being of citizens. The purpose of passenger transportation system organization is provision the necessary communications for population. Every year the growing number of residents gives preference to personal vehicle in many Russian cities. There are two main reasons explaining the decline in demand for public transport services. Firstly, single routes of public transport for binding of different cities’ districts are absent. This circumstance contributes to transfer from one route to another in order to get the desired destination point. Secondly, there is a low pedestrian accessibility of public transport stops and residents spend a lot of time to reach them. Therefore, challenge of increasing the pedestrian accessibility of urban public transport stops is an actual direct.

In this paper, the problem of pedestrian accessibility is considered by the example of Samara city. Samara city ranks the first place in terms of the numbers of personal cars among million-plus Russian cities according to the results of the study by the analytical agency «AVTOSTAT». The car fleet has more than 390 thousand units and the population is about 1.2 million people, so there are 334 cars per thousand inhabitants in Samara city [2]. Samara city is divided into nine administrative districts, and at the moment there is a problem of transport accessibility of the city remote areas by public transport. The problem of low pedestrian availability of public transport stops is also relevant to the Samara city. In average residents spend 15 minutes in order to reach the public transport stop.
proposed for the Samara city, it is possible to make models of the transport infrastructure for other cities, thereby increasing the availability of public transport in them.

2. Review of existing approaches

Currently, there are quite a few methods that can be used to solve the task of optimizing transport routes. Since this problem is NP-complete, there is no effective formal solution method for it. However, heuristic and metaheuristic methods can be used to solve such tasks. To overcome the objective the principles of action for each algorithm should be analyzed and then select the appropriate.

The Clark-Wright algorithm, the Sweep algorithm and the optimization algorithm for a particular route are most often used among the heuristic methods. The Clarke-Wright algorithm is based on the process of merging smaller routes into larger. This process is carried out as long as the total cost of a detour is possible to reduce. In this algorithm, a number of additional factors that affect the final solution of the task take into account. The advantages of this method are its simplicity, reliability and flexibility, as well as a little error of decision, which is 5-10% [3].

The Osman algorithm, algorithms based on ant colonies, and genetic algorithms are also known as meta-heuristic methods, which are used for optimization tasks. The Osman algorithm is based on the use of the evaluation function, which contains the characteristics of the planned course and taking into account the value of the original function and the existing exceptions. At each step the algorithm selects solution in which the value of the evaluation function reaches maximum [4]. The ant colonies algorithm essence is to use the behavior of ants, which are looking for a path from the colony place to the food sources and leaving traces (pheromones) in this process for other ants. Thus, the optimal in terms of path length path is path, which is most often used by ants or where the most count of pheromones was remained [5]. The main feature of the genetic algorithm is the possibility of finding a global optimum in result of decision for NP-complete problems. The result of Genetic algorithms is a solution, which obtains from crossing promising cases, satisfies all the constraints and allows getting the optimal value of the fitness function [6, 7, 8].

We reviewed studies that enclosure accessibility of city areas. There are studies that propose to measure the influence of obstacles on pedestrian accessibility. Strohmeier argued that in order to improve the walkability of streets and urban spaces, and to design accessible mobility services, it is important that urban and traffic planners consider different kinds of barriers and understand their influence on mobility. The aim was to collect and examine all possible obstacles, their influence on mobility behaviour with further outlining of older pedestrians needs using surveys and personal interviews [9]. The objective of the study by Taleai and Amiri was to evaluate the walkability of streets, for which the authors used a novel two-step methodology based on the integration of geospatial information science, remote sensing and group multi-criteria analysis to assess the walkability of pathways in a city [10]. Adlakha et al. considered data on building environment and physical activity in low- and middle- income countries. This study compared building environment features, physical activity levels, and weight status among adults living in neighborhoods stratified by walkability and socio-economic status in the city of Chennai, India [11].

Despite a lot of number of studies in the transport optimization area, the task for optimizing public transport stops in urban environments is not fully addressed. The development of a comprehensive solution is necessary to build a public transport stops network that serves the population mobility. For achieving the intended impact mathematical models were suggested for formalizing of the notions in the subject area. In the constructed model the public transport stops availability criteria is calculated using the time-area method, which takes into account natural obstacles to pedestrians. [12]. The genetic algorithm was chosen as an optimization method. The special coding method that transforms the model into a binary form was developed. The developed approach will solve the problem of accessibility of public transport stops for citizens.
3. Models and methods

To solve the accessibility problem, a general model of the urban transport infrastructure was developed, which can be used to solve transport tasks later. The urban transport infrastructure model consists of the street-road network, transport city districts, public transport stops, and also includes descriptions of public transport routes. Thus, the mathematical expression of the urban transport infrastructure model is as follows:

\[ M = \{G, Z, S, R\}, \] (1)

where \( M \) is the urban transport infrastructure model, \( G \) is the street and road network, \( Z \) is set of transport city districts, \( S \) is set of public transport stops, \( R \) is set of public transport routes. Each component of the urban transport infrastructure has its own characteristics that must be considered in the process of solving the set task. Further, we will consider each component model in more details.

The road city network is a hierarchically constructed, interconnected system of streets and roads, intended for the movement of vehicles and pedestrians. Figure 1 shows the street-road city network in the oriented graph form, the main components of which are the edges and nodes. The edges (1-9) in the figure show the streets, the arrows indicate the direction of traffic on them, the nodes (1-4) denote the intersections of the streets.

![Figure 1. The oriented graph of the road city network.](image)

Therefore, the road city network can be represented as follows:

\[ G = \{E, V\}, \] (2)

where \( E \) is the set of edges, \( V \) is the set of nodes.

Subgraphs of transport districts were selected. It contains subsets of the vertices and edges of the road city network within the boundaries of certain transport regions. The district boundaries are defined based on the connectivity and population density of urban neighborhoods units. Mathematical equation of the \( i \)-th city district subgraphs is:

\[ Z_i = \{E_i, V_i\}, \] (3)

where \( Z_i \) is the \( i \)-th city district, \( E_i \) is the set of edges of road city network graph for \( i \)-th city district, \( V_i \) is the set of nodes of road city network graph for \( i \)-th city district. The based geometry property for describe the public transport stop \( S_i \) is:

\[ S_i = \{e_i, l_i^s\}, \] (4)

where \( e_i \) is the edge, which corresponds to \( i \)-th public transport stop, \( l_i^s \) is the destination between edge and location point of \( i \)-th public transport stop (figure 2).
Each public transport route is assigned an identification number \((N)\), a departure point \((P_o)\), a destination point \((P_x)\), and a list of vectors \((P)\) between intermediate stops \((P_i)\).

\[
R = \{N, P_0, P_x, P\},
\]

(5)

The vector \(P\) consists of intermediate stops \((P_i)\) has a length of \(N_i\) \((j \in [1, N_s])\).

The public transport stops availability is calculated based on time-area method – isochrones. Isochrone is defined as a line drawn on a map connecting points at which something occurs or arrives at the same time, for example duration of a trip [12]. The method of calculating isochrones shows where an individual can travel from a specified point within a certain time [13].

\[
D = \frac{s^m}{S} \times 100\% \rightarrow \text{max},
\]

(6)

where \(D\) is the public transport stops availability, \(s^m\) is the cumulative of the availability areas, \(S\) is the total area of the investigated territory.

**Figure 2.** Graphic image of the based geometry property of the public transport stop.

**Figure 3.** A model of the pedestrian accessibility.
The base distinctions in this task are planning regulations, which establish the maximum distance from residential buildings to the public transport stop points. To solve the problem of finding the optimal solution, a genetic algorithm is used. At the stage of inheritance in the genetic algorithm, individuals with maximum value of the fitness functions are chosen as the parent chromosomes. Besides these parent chromosomes must not violate the established restrictions [15].

Each chromosome consists of a set of elements, which are genes. Plurality of chromosomes make up the population. The gene encodes as a list of public transport stops and is represented using binary code. Previously, the existing public transport stops and the proposed location of new stops in places with low pedestrian accessibility were put on the map of the studied city area. Public transport routes are encoded with a list of public transport stops. In this case, the existing stops are indicated by the value “1”, and the expected stops are indicated by the values “0” (figure 4).

Figure 4. Graphic image of existing and proposed public transport stops.

At the first stages of the search of the optimal solution, the selection of the most adapted individuals is carried out, the fitness function of which has the greatest value. The selection process of individuals is carried out using the rank method, that is, a sorted list of individuals is created, ordered in the direction from the fittest to the least fit. Each individual is assigned a rank, which is a number determines its place in the list. Further, the process of crossing follows, the result of which is the appearance of new individuals forming a new population. After the appearance of a new generation, previous operations with individuals are repeated \( n \) times. The iterative start of the processes of the genetic algorithm is terminated when the transport availability assumes the maximum value. As a result, optimal locations of public transport stops were obtained, at which the transport infrastructure availability is maximum.

4. Results

The developed method is implemented in the “Apache Zeppelin” [16] interactive analytical environment in the “Python” programming language [17]. The genetic algorithm is implemented using the package “Deap”, a flexible tool for evolutionary modeling containing genetic operators [18]. The coding of objects of the model (1) for their use in the genetic algorithm was carried out using the “Numpy” package [19]. The fitness function is registered in the evolutionary model as a user function that calculates isochrones along the road network and finds value of the ratio (6).

Debugging of the developed solution was carried out at the city of Samara. Samara is a large Russian city in terms of population, the capital of the Samara region, a transport hub on the Volga River. There are almost all kinds of urban public transport [20, 21]. Samara region occupied the fourth place based on the volume of public transport passenger traffic in Russia. Source data with Samara city map are downloaded from the open source “OpenStreetMap” [22] using the “OSMnx” package [23]. The public transport routes data are loaded using the “Pandas” package [24]. The data obtained during debugging showed the convergence of the developed solution, but there is a need for additional research.

Figure 5a depicts dislocation of the public transport stops on the map of the city of Samara. We built pedestrian accessibility zones of 8-minute distance from each bus stop for pedestrians with average velocity 3.7 km/h. Figure 5b shows coverage of pedestrian accessibility of public transport stops in the city of Samara.
Figure 6. Areas with low pedestrian accessibility.

The next stage of this study is to determine the optimal location for the placement of new bus stops. After getting the results of simulation, we made the analysis of geo-data and identified three problem areas with low pedestrian accessibility (figure 6). In general, the region is characterized by the predominance of areas with high pedestrian accessibility. First area belongs to parks and do not need any improvements. Second and third areas require increasing of the pedestrian accessibility.

Figure 7. Value of fitness function by iterations.

To find out the optimal place of new bus stops we proposed 16 new places for each problem area. Having these new places, we construct genetic algorithm according described in section 3 methodology. We generated initial population with 100 individuals. Each individual represented bus stops maximum in four possible locations. After 45 iterations the genetic algorithm provided the reasonable pedestrian accessibility (figure 7). It found out the one bus stop for location #2 and two bus stops for location #3.

5. Conclusions
This article addresses the problem of the public transport stops availability to pedestrians.Existing methods for solving similar accessibility problems associated with optimizing of public transport stops location and public transport routes are considered. A general mathematical model of the city with stops and public transport routes has been developed. A general mathematical model of the urban transport infrastructure with stops and public transport routes has been developed.
A genetic algorithm was used to optimize walking distance. Using that method, such the optimal location of stops can be found, that it is corresponded to the urban planning regulations, and the value of fitness function for pedestrian accessibility to these stops is maximum. The particular case of Samara city accessibility problem is considered. However, the created mathematical model of the urban transport infrastructure and the developed algorithm of the solution are universal for any city. Further research involves conducting more experiments with various hyperparameters of the genetic algorithm and with models of cities of different scale.

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