Modeling of buses operation at stops with intensive use

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Abstract.
City bus routes often use joint stops on certain streets. To reduce the delay time of buses at stops where several bus routes pass, it is important to coordinate the schedules of the routes. The article proposes the use of agent-based simulation to describe the operation of bus routes at the same stop. After determining the location of frequently used bus stops, a logical diagram of the movement of buses at one of these stops in the city of Baku is displayed using the Anylogic 8.7.7 software. Options for entering bus movement parameters in different ways are considered.

Keywords:
route
bus
stop
anylogic
simulation
Introduction

In big cities, residents prefer public transport for their daily commute. Many cities offer various types of public transport services. In different cities, depending on the density of the road network, population, terrain, etc. there are different modes of transport. It is impossible to imagine the life of modern cities without public transport, such as bus, tram, trolleybus, light rail, metrobus, metrotam, metro. The interaction of these modes of transport has a direct impact on the quality of everyday life of the population in cities. In some cities, under the influence of socio-economic conditions, the transition period and a number of other factors, there is a network of only some of these modes of transport. The city of Baku is also different in this respect. In the city of Baku, the population carries out daily transport trips by metro, buses, taxis and private cars. In the city of Baku, only commuter trains serve a certain direction, and its carrying capacity is not very high. It is no coincidence that the number of bus routes in the city is more than 170, and the number of buses in operation is more than 2000 [1]. On some streets of the city of Baku, vehicles of many routes pass through several stops in a row. Sometimes the number of such routes reaches 20, which causes queues before stops and transport delays.

The use of existing simulation programs, the creation of bus movement models along the route, the coordination of bus schedules operating on separate routes can improve traffic on routes with joint stops. At stops that serve a large number of routes, coordination may be the most effective approach initially.

Literature analysis

Quek et al. proposed a network model that is built using indicators related to the location and movement of buses based on information received from the GPS system along the route. Based on the developed model to prevent the accumulation of buses on the route, the speed of buses and the time of arrival of passengers at the bus stop were checked [2].

Polyviou proposed to create a microscopic simulation model to simulate various accident scenarios on bus routes.
It is noted that the model created in the study imitates the continuous movement of buses along the route [3].

The correct organization of the movement of buses affects the temporary loss of passengers at the bus stop. In the model proposed by So et al., it serves to minimize the waiting time for passengers on a route served by intelligent buses moving at the same and different speeds [4].

On bus routes, the accumulation of buses at a stop begins to be observed when demand exceeds a critical threshold. To overcome this, the authors propose to synchronize the operation of the bus stops network [5].

Nikolaev et al. interpreted the main agents of the model created for urban passenger transport in the Anylogic simulator and showed results proving its applicability in solving urban transport planning problems [6].

Luo et al. modeled the number of bus stops at a sidewalk stop as a function of waiting time and found that the function follows normal and logarithmic distributions [7].

Many authors have conducted studies to compare control systems and predict arrival times related to determining the number of passengers and the arrival time of buses [8, 9, 10].

Bauer proposed a stochastic model of the bus route, taking into account the changing characteristics of traffic conditions. The model is based on graph theory. The bus route is described as stops and sections between stops. The simulation model was created in the form of a dynamic system of vector equations [11].

**Research methodology**

The article proposes the creation of a simulation model of the most loaded joint stops of bus routes, taking into account the time of passenger service and traffic schedules, as well as a method for accounting for the main indicators of bus routes. Simulating a large number of shared bus stops in Anylogic using the Road library can make the model too complex and difficult to visualize. However, it can be effective to simulate buses operation and analyze the results using Anylogic at one or more stops serving a large number of bus routes. In the article, logic diagrams are built to study the operation of buses at a bus stop according to different
scenarios.

Based on the established schemes, the adequacy of the results obtained when entering the parameters of the movement of bus routes with different intervals is interpreted. The simulation model was tested for one of the busiest bus stops in Baku.

**Bus stop operation analysis**

The location of some bus stops serving a large number of bus routes in Baku is shown in Fig.1. The stops are mainly located on Gara Garayev street (4 bus stops) and Moskva avenue (one stop). Some of these stops serve 18 and some 20 bus routes. Bus arrival intervals vary from 3 to 20 minutes.

![Figure 1: Bus stops serving a large number of bus routes in Baku](map_image)

Depending on the time of the day and the bus schedule, the number of buses arriving at the stop in front of the market 8 km varies from 145 to 180 per hour, and the lines at this stop are observed from 7 am. until 8 pm. The intervals for passing bus routes through the stop and the period of operation are shown in Tab.1.
Table 1

<table>
<thead>
<tr>
<th>#</th>
<th>Route No</th>
<th>Interval on the route, min</th>
<th>Route length, km</th>
<th>Daily working period</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>7</td>
<td>19,8</td>
<td>20,3</td>
<td>6:00-00:00</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>11,29</td>
<td>11,88</td>
<td>6:00-00:00</td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>15,19</td>
<td>13,99</td>
<td>6:00-23:00</td>
</tr>
<tr>
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<td>12</td>
<td>14,4</td>
<td>16,38</td>
<td>6:00-23:00</td>
</tr>
<tr>
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<td>8</td>
<td>15,66</td>
<td>14,27</td>
<td>6:00-00:00</td>
</tr>
<tr>
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<td>8</td>
<td>15,19</td>
<td>13,49</td>
<td>6:00-00:00</td>
</tr>
<tr>
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<td>9</td>
<td>19,08</td>
<td>17,81</td>
<td>6:00-23:00</td>
</tr>
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</tr>
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<td>7,03</td>
<td>6:00-22:00</td>
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<td>6:00-23:00</td>
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<tr>
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</tr>
<tr>
<td>81</td>
<td>4</td>
<td>12,12</td>
<td>14,22</td>
<td>6:00-00:00</td>
</tr>
</tbody>
</table>

On Fig. 2 shows a photograph of a queue observed at a bus stop in front of the Km 8 market during most of the day.

Figure 2
Lines of buses at the bus stop in front of the market 8 km

Modelling of bus stop operation
To simulate the movement of buses in the parking lot, we create a logic diagram in the Anylogic 8.7.7 program using the tools of the Road library. To create a scheme, the tools

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Car Source, CarMoveto, CarDispose, Delay [12] are used. The entrance of buses to a stop for bus routes can be modeled in two ways within the capabilities of the program (Fig.3).

According to the logic diagram in Figure 3a, you can create a single agent for boarding passengers at stops. In this case, it is impossible to model which buses passengers will choose, and according to the model, passengers board the first bus that arrives at the stop. This is an acceptable option if buses stop at a stop for a certain period of time. Buses stop at a stop according to the time of boarding and disembarking passengers [13]. In addition, due to various reasons (compliance with the bus schedule, the level of passenger awareness, etc.), the nature of the arrival of passengers at a stop may be different for each route [14, 15].

In many cases, the arrival of passengers to the parking lot obeys the Poisson law [16]. According to the logic diagram in Figure 3b, you can create a separate agent for passengers at a specific stop of each bus route and enter its parameters. Parameters of 20 bus routes passing through the stop (bus speed in sections, acceleration and deceleration time, bus length) are entered using CarSource, stop parameters (landing area length, number of buses that can stop at the same time at the parking lot) using BusStop, parameters, related to passengers (number of passengers arriving per hour, passenger arrival frequency and patterns) using PedSource tools. On
fig. 4 and fig. 5 shows the result of 2D and 3D modeling of the working of bus stop for buses moving in mixed traffic after entering parking parameters in front of the market 8 km.

We analyze the situation at the stop, entering the arrival of buses by interval, by the number of arriving cars at a certain time, by the intensity entered from the schedule (directly or from the database (Process Modeling Schedule)) (Fig. 6). In these scenarios, the lines of buses in front of the bus stop take on a different character.
When entering the arrival of buses at the stop of route No. 35 by interval and by the number of arrivals per hour, the time spent by buses from the moment they appeared in the model until the moment they left the stop changed in large intervals (Fig. 7), and the distribution of this change had a different character (Fig. 8).
When using a lane for buses on the street, the delay time of buses at a stop does not decrease due to the formation of queues before stopping, and as a result, the efficiency of buses on the route decreases (Fig. 9).

Thus, the simulation model of the arrival of buses at a stop at an interval, a certain number per hour, intensity and compiled traffic schedules shows that when a certain number of bus routes are exceeded, the use of unrelated schedules between routes leads to the creation of queues in front of the bus stop.

Conclusion
At stops where there are a large number of bus routes, it is possible to describe the arrival of buses and queues before
a stop quite effectively using the Anylogic 8.7.7 software. The arrival of buses of different routes to the bus stop under different scenarios does not eliminate the queues in front of the bus stop. Therefore, the schedules of bus routes arriving at such a stop must be adjusted and shifted according to the time of arrival at this stop. The proposed bus route modeling model can be equally effectively applied to stops of other types of street public transport and mixed-use stops.

References:
MODELING AND NANOTECHNOLOGY

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