The existing influence of means of individual mobility on the speed indicators of urban traffic flow

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Abstract. This article presents the results of assessing the impact of means of individual mobility on the indicators of traffic flow by finding the dependencies of the speed of traffic flow on the number of SIM on the road network (UDS) in the morning rush hour, evening rush hour and inter-peak [1]. The purpose of the study is to obtain real values of the speed of the traffic flow for further analysis and comparison, which in the future will allow us to understand how the number of means of individual mobility [2] affects this value (study of the speed indicators of the traffic flow as a result of changes in its composition, taking into account the appearance of SIM). It is proposed to use a method for finding intermediate values, namely the interpolation method of the Lagrange polynomial. With its help, it is possible to find the values of the speed of the traffic flow.

1 Introduction

Road safety is an annual and one of the highest priorities of each subject of our country [3]. The Road Safety Strategy in Russia for 2018-2024 states that the main national goal of measures to improve road safety is "striving for zero deaths in road accidents by 2030", which corresponds to global priorities. Modern society is developing rapidly. New types of vehicles on public roads can be seen more and more every day. Devices used for human movement by means of an electric motor (electric scooter, electric skateboard, segway, gyro scooter) or muscular force (scooter, roller skates, skateboard), namely means of individual mobility are no exception [4].

The amendments to the traffic Regulations that entered into force on 01.03.2023 allow the movement of persons over the age of 14 who use means of individual mobility for movement on bicycle, bicycle paths, the roadway of bicycle infrastructure or a lane for cyclists.

The infrastructure for SIM movement on the road network is considered in detail:
- in the pedestrian zone - if the weight of the SIM does not exceed 35 kg;
- on the sidewalk, pedestrian path - if the weight of the SIM does not exceed 35 kg, and subject to one of the following factors:
  1. It is not possible to move along a bicycle or cycle path due to its congestion or absence;
2. Accompanying a child under the age of 14 using a SIM by a person who also uses a SIM for movement;
   - on the side of the road – it is not possible to move along a bicycle and bicycle path, a lane for cyclists, a sidewalk, a pedestrian path due to their congestion or absence;
   - on the right edge of the carriageway while simultaneously observing several factors at once;

1. it is not possible to move along a bicycle and bicycle path, a lane for cyclists, a sidewalk, a pedestrian path due to their congestion or absence;
2. the movement of vehicles with a speed of no more than 60 km/h, as well as the movement of bicycles, is allowed on the road;
3. The SIM is equipped with a brake system, a sound signal, white-colored retroreflectors in front, orange or red on the sides, red in the rear, a white-colored headlight (lantern) in front.

Different models of individual mobility vehicles have different speed potential, their speed can vary from 25 to 85 km/h.

Table 1. Speed characteristics of popular models of electric scooters.

<table>
<thead>
<tr>
<th>Model</th>
<th>Max. speed, km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mi Electric Scooter</td>
<td>25</td>
</tr>
<tr>
<td>Hiper VX800</td>
<td>35</td>
</tr>
<tr>
<td>Dualton Thunder 5400W</td>
<td>85</td>
</tr>
<tr>
<td>Ultron T128 6000W</td>
<td>75</td>
</tr>
<tr>
<td>Kugoo G-booster</td>
<td>65</td>
</tr>
</tbody>
</table>

A large number of road accidents occur due to the conflict between pedestrians and means of individual mobility, and vehicles, and means of individual mobility. Thus, according to official data provided by the Scientific Research Center for Road Safety (SIC BDD), 112 road accidents were registered with the participation of SIM only in 2021 (01.21-05.21). Compared to the same period last year, the increase in this type of accident was 195%. For 5 months, 2 people were killed and 119 injured in these accidents.

There are 5 types of accidents involving means of individual mobility (Fig. 1): hitting a pedestrian, collision, rollover, hitting a person who is not a road user, carrying out production work and another type [5-7].

2 Methodology

Simulation modeling is a convenient tool for analysis, it is visual, easy to use and often solves complex issues related to planning [13]. The Aimsun simulation program is used in the field of traffic management and is quite popular today. The main focus of the program is the design of autonomous traffic. The use of "Aimsun" is aimed at solving problems related to short- and medium-term planning and operation, for which models are well suited (Fig. 1).

Additional information is required to build the model:
- start time and duration of the control plan (cycle), with;
- cycle start time, from;
- duration of the yellow signal of the traffic light, with;
- turns associated with each signal group;
- time related to each group of signals, with;
- offset relative to other management plans.

With the help of this program, it is possible to add such types of transport as: passenger and cargo vehicles, public transport, cyclists, as well as means of individual mobility.

After modeling the UDS section, it is
possible to obtain such values as: stopping time, travel time, speed, number of stops, maximum length and density of the flow, delays of the traffic flow.

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**Fig 1.** Building models using the Aimsun simulation program.

As a simulated object, a regulated intersection located in the city of Belgorod is defined (Fig. 2), near which the central square of the city is located and rental scooter stations are located, which explains the increased number of SIM near this site [8].

**Fig 2.** Traffic model of Popova Street – Civil Avenue, simulating the movement of SIM with the allocation of specialized infrastructure, the "Aimsun" program.

### 3 Results

After analyzing the Belgorod road network, the section of the road network with the greatest attraction of individual mobility equipment to it was selected, which is to be modeled – Civil
Due to heavy traffic, the section of Popova – Grazhdansky Ave. is the most suitable option for modeling and making certain changes to the organization of traffic [9].

To date, the number of specially equipped SIM parking stations has increased significantly. The map of the city of Belgorod (Fig. 3) shows the places of accumulation of individual mobility equipment stations in 2022. The site under study was selected based on the concentration of SIM parking stations.

Captions should be typed in 9-point Times. They should be centred above the tables and flush left beneath the figures.

Fig. 3. A map of the city of Belgorod with the designations of the places of concentration of SIM stations in 2022.

There are various ways to find intermediate values. One of them is called interpolation. This method already works according to the existing discrete set of known functions and is used when it is necessary to find the functions y(x) with the value of the argument.

\[
P_n(x) = \sum_{i=0}^{n} y_i \cdot L_n(x),
\]

where \( L_n(x) \) – lagrange multiplier

\[
L_n(x) = \frac{(x - x_0) \ldots (x - x_{i-1})(x - x_{i+1}) \ldots (x - x_n)}{(x - x_0) \ldots (x_i - x_{i-1})(x_i - x_{i+1}) \ldots (x_i - x_n)} = \prod_{k=0}^{n} \frac{(x - x_k)}{(x_i - x_k)}.
\]

Therefore,

\[
P_n(x) = \sum_{i=0}^{n} y_i \left( \prod_{k=0}^{n} \frac{x - x_k}{x_i - x_k} \right).
\]

The Lagrange interpolation polynomial (1) is usually used in theoretical research (when proving theorems, analytical problem solving, etc.)

Substituting into this formula instead of the value (x) of the number of means of individual mobility (from 10 to 1000) (Table. 2), it is possible to find intermediate values of the speed of the traffic flow.
Table 2. Indicators of the speed of traffic flow depending on the number of SIM.

<table>
<thead>
<tr>
<th>( N_{\text{SIM}} ), units</th>
<th>( V_{\text{tp}} ) Morning, km/h</th>
<th>( V_{\text{tp}} ) Inter-peak, km/h</th>
<th>( V_{\text{tp}} ) Evening, km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>42.12</td>
<td>36.39</td>
<td>39.91</td>
</tr>
<tr>
<td>20</td>
<td>45.78</td>
<td>40.55</td>
<td>41.20</td>
</tr>
<tr>
<td>30</td>
<td>44.26</td>
<td>41.24</td>
<td>39.83</td>
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<tr>
<td>50</td>
<td>42.13</td>
<td>43.40</td>
<td>42.92</td>
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<tr>
<td>60</td>
<td>44.56</td>
<td>38.50</td>
<td>40.10</td>
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<tr>
<td>70</td>
<td>41.57</td>
<td>35.91</td>
<td>37.41</td>
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<tr>
<td>80</td>
<td>45.58</td>
<td>39.38</td>
<td>41.02</td>
</tr>
<tr>
<td>90</td>
<td>40.24</td>
<td>41.76</td>
<td>36.22</td>
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<td>...</td>
</tr>
<tr>
<td>950</td>
<td>24.89</td>
<td>21.50</td>
<td>22.40</td>
</tr>
<tr>
<td>960</td>
<td>24.88</td>
<td>21.49</td>
<td>22.39</td>
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<td>970</td>
<td>25.93</td>
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<tr>
<td>990</td>
<td>23.71</td>
<td>20.48</td>
<td>21.34</td>
</tr>
<tr>
<td>1000</td>
<td>23.89</td>
<td>23.64</td>
<td>21.50</td>
</tr>
</tbody>
</table>

Based on the data obtained, we will plot the dependence of the speed of traffic flow on the number of SIM on the road network in the morning rush hour, evening rush hour and inter-peak.

\[
V = -5.411\ln(N_{\text{SIM}}) + 64.703, \quad R^2 = 0.8726
\]

\[
V = -4.675\ln(N_{\text{SIM}}) + 55.9, \quad R^2 = 0.8726
\]
The development of equations of the relationship of the speed of the traffic flow from the number of means of individual mobility, allows you to determine the speed of the traffic flow with any number of means of individual mobility.

In order to create safe road traffic, as well as favorable conditions for comfortable interaction of vehicles and means of individual mobility, it is necessary to determine a comfortable number of SIM on the road network in order to avoid conflicts, as well as to provide vehicles with optimal driving speed [10].

In the course of plotting, an equation was obtained for the dependence of the number of SIM on the speed of the traffic flow, which allows determining the speed of the traffic flow when introducing any number of SIM into the general traffic flow.

Knowing the number of SIM cards, it is possible to simulate with great accuracy the maximum speed of the traffic flow allowed for the safe movement of other road users.

References