Increasing the environmental safety of the motor transport complex by optimizing traffic on emergency road sections

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Abstract. The article presents the results of using microscopic simulation modeling to optimize traffic on emergency sections of highways. It is shown that these areas are characterized not only by high rates of road traffic accidents, but also by large volumes of pollutant emissions from vehicle exhaust gases due to high traffic intensity, congestion, and imperfect road infrastructure. Based on the results of field studies, a simulation model of an emergency-hazardous section of the urban road network was developed, the adequacy of the model was proven, and virtual experiments were conducted. An option has been proposed to improve the environmental and traffic situation on the site by improving the technical means of organizing traffic. When implemented, because of an increase in throughput, there is a noticeable reduction in mass emissions of pollutants and an increase in the safety factor.

1 Introduction

The motor transport complex is one of the dominant sources of harmful effects on adjacent territories, including atmospheric air, soil, surface and ground water, which is most pronounced in megacities, large industrial and transport and logistics centers [1-2].

The most significant types of environmental pollution by road transport are emissions of harmful substances from exhaust gases [3-6], acoustic impact [7-8], and the formation and accumulation of waste from transport activities. Road traffic accidents have an extremely negative impact on the environment, which, in addition to injuries and deaths, destruction of vehicles and elements of road infrastructure, lead to traffic congestion, which leads to additional air pollution.

To reduce pollutant emissions from vehicle exhaust gases, solutions are used that include the development of transport infrastructure, improvement of vehicle design, transition to environmentally friendly fuels such as hydrogen, methane, oxygenates, development and implementation of chemical power sources, fuel cells instead of internal combustion engines.

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To develop management decisions for the purpose of optimizing road traffic, a simulation modeling method is used, which involves microscopic, mesoscopic and macroscopic levels [9-10]. At the micro level, the modeling unit is an individual vehicle, which makes it possible to highly accurately simulate the movement of cars on the limited section of the road network under consideration, taking into account their individual characteristics. The advantage of microscopic simulation modeling is also the ability to consider the operation of transport infrastructure elements in more detail than with macro modeling [11].

Examples of the successful use of microscopic simulation modeling to solve transport problems and increase the sustainability of the transport system are presented in the works of Makarova and co-workers [12-13].

It is assumed that the scale of the negative impact of the motor transport complex on the environment will increase in the coming decades, which is associated with the growing pace of motorization. In this regard, research into expanding the possibilities of using computer modeling to optimize road traffic and, as a result, improve environmental safety indicators of road transport is an urgent technical, environmental, and organizational task.

2 Materials and methods

The development of a simulation model was carried out for an emergency-hazardous section of the city road network. The selection of the modeling object was made on the basis of the accident rate map and data on the number of road accidents from the road safety inspectorate. Using the video recording method, extensive field studies were carried out in the selected area to obtain information about the intensity and speed of transport and pedestrian flows.

For a more detailed analysis of the area under consideration, the Anylogic simulation software package was used.

Emissions of harmful substances from vehicle exhaust gases were calculated in accordance with the requirements of the national standard of the Russian Federation GOST 56162-2019.

To assess the level of road traffic accidents of the analyzed section of the road during the simulation, the safety coefficient $K$ was determined, which was calculated as the ratio of the maximum speed of vehicles on the section of the road network under consideration to the maximum speed of entry of a vehicle into this section:

$$K = \frac{V_{\text{max}}}{V_{\text{initial}}_{\text{max}}}$$  \hspace{1cm} (1)

- $V_{\text{max}}$ – maximum speed of vehicles on the road section, km/h;
- $V_{\text{initial}}_{\text{max}}$ – initial speed of vehicles, km/h.

The results of full-scale and virtual experiments were subjected to correlation analysis using the Statistica software product.

3 Results and discussions

The problem of increasing environmental and road safety of the motor transport complex is relevant not only in large industrial centers, but also in small cities, where its solution is complicated by the lower availability of budget funds for improving transport infrastructure. For small cities, it seems appropriate to use the simulation modeling method, including the development of virtual twins of sections of the road network and conducting computer experiments on them.

A section of the road network in the city of Elabuga, located in the Republic of Tatarstan, was considered. Yelabuga, with a population of 74 thousand people, formally classified as a...
medium-sized city, is the center of the special economic zone of industrial type "Alabuga" with an area of 4000 hectares, on the territory of which there are more than 40 operating and under construction enterprises in the mechanical engineering, construction industry, chemical, woodworking, food industries, which creates significant transport problems.

After analyzing data on the number of road accidents, one of the most accident-prone areas in the city was selected - the intersection of Mira Street and Molodezhnaya Street. The choice of the site for modeling was determined by its location in the city center in a densely built-up area, resulting in a high concentration of vehicles and pedestrians, especially during peak hours. Field studies of the intensity and speed of transport and pedestrian flows were carried out and the information necessary to develop a simulation model of the intersection under study was collected.

An analysis of the structure of traffic flow in the area under consideration demonstrated a noticeable predominance of passenger cars, the average share of which is 90.2%.

A simulation model of the analyzed area is presented in Figure 1.

![Simulation model of the analyzed section of the road network.](image)

**Fig. 1.** Simulation model of the analyzed section of the road network.

The adequacy of the developed model was checked using the Cochran criterion and the Pearson correlation coefficient. The results are presented in Table 1 and Figure 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence probability P</td>
<td>0.95</td>
</tr>
<tr>
<td>Experimental value of Cochran's criterion $G_{exp}$</td>
<td>0.3779</td>
</tr>
<tr>
<td>Table value of Cochran's criterion $G_{table}$</td>
<td>0.3910</td>
</tr>
</tbody>
</table>

For the results of calculations based on the data of full-scale and virtual experiments, the following condition is satisfied: $G_{ex} \leq G_{theor}$. Therefore, the variances are homogeneous with a confidence level of 95%.
The value of the correlation coefficient between the values of traffic flow intensity obtained during field studies and when running the simulation model was: \( r = 0.92 \) at \( P = 0.95 \).

The values of the Cochran criterion and the correlation coefficient indicate the adequacy of the model and its suitability for conducting virtual experiments.

The main problem of the intersection under consideration is the different width of the dividing strip on Mira Street before and after the intersection with Molodezhnaya Street. It was this factor that influenced the increase in the number of road accidents in this area, the occurrence of traffic jams and, as a consequence, the increase in emissions of pollutants from vehicle exhaust gases. The problem is aggravated by the fact that road markings related to technical means of traffic management are erased at the intersection, so it becomes increasingly difficult to notice a change in lane direction, and in adverse weather conditions or limited visibility it is impossible to notice the curvature of the road. The most obvious way to solve this problem was to mark the intersection by applying horizontal markings with wear-resistant materials.

A histogram illustrating the results of virtual experiments on the model is presented in Fig. 3, the abscissa axis indicates the time of movement of the car along the section, the ordinate axis indicates the number of cars as a percentage of the total number of vehicles passing through the intersection. With markings, traffic intensity increased, the average time for vehicles to cross an emergency area decreased, and the likelihood of conflict situations decreased.

The safety coefficient, calculated in the model as the ratio of speeds according to formula (1), increased as a result of modeling to 0.64, which allows us to characterize the intersection as non-hazardous.
Calculations based on the constructed simulation models for the analyzed accident-prone area showed: as a result of increasing capacity, the average time of movement of vehicles in this area decreased by 33.3%, emissions of harmful substances decreased by 22%, and the safety factor increased by 42.2%.

Table 2. Results of simulation modeling of a section of the road network.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Model of the intersection as is (without markings)</th>
<th>Model as it could be (with markings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic intensity (in problem direction), cars/hour</td>
<td>741</td>
<td>855</td>
</tr>
<tr>
<td>Average travel time, min</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum travel time, min</td>
<td>5.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Pollutant emissions, g</td>
<td>499.5</td>
<td>384.3</td>
</tr>
<tr>
<td>Safety factor</td>
<td>0.45</td>
<td>0.64</td>
</tr>
</tbody>
</table>

4 Conclusions

Accident-hazardous sections of the city's road network, which have a high accident rate, are also characterized by low values of environmental safety parameters, in particular, large mass emissions of pollutants from vehicle exhaust gases. To solve environmental problems and simultaneously improve road safety in such areas, it is proposed to use microscopic
simulation modeling, including the development of virtual twins of such areas and conducting experiments on them.

An option has been proposed to improve the environmental and traffic situation on a section of the city's road network by improving the technical means of organizing traffic. During its implementation, because of increasing capacity, the average vehicle travel time was reduced by 33.3%, pollutant emissions decreased by 22%, and the safety factor increased by 42.2%.

Simulation modeling at the micro level is an effective method for solving problems of increasing environmental and road safety of accident-prone sections of the road network and the motor transport complex.

References

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