Optimization of urban agglomeration transport flows

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Abstract. The article proposes methodological approaches to the study and optimization of traffic flows using simulation modeling by the example of one of the street intersections in the city of Novosibirsk. Possible stages of sequential implementation of analytical and practical measures for optimizing transport flows are given. It is proposed to use the AnyLogic environment as a modeling tool. When creating the simulation model, satellite images of the area were used, inserting an image of the analyzed section of the road network on top of the satellite image, setting objective indicators of traffic intensity, developing and optimizing a vehicle movement algorithm. The results of the study make it possible to assert that AnyLogic environment tools are an adequate way to optimize traffic flows. Optimization measures made it possible, based on adjusting the duration of traffic light control phases, to reduce the average time spent by cars at the intersection by 35% and, thereby, increase the throughput of the intersection by 10%. The use of the proposed approaches to the development of traffic simulation models is a promising direction for optimizing traffic control at urban intersections.

1 Introduction

Motorization is an inevitable result of scientific and technological progress and, as a result, not only has a positive impact on the social development and economic well-being of territories, but also has negative consequences in the form of environmental deterioration, traffic congestion and an increase in the number of road accidents. Road traffic accidents (RTAs) that result in death and injury cause significant damage not only to the victims and their families, but also to municipalities and countries. This damage can be estimated from an economic point of view by the cost of treatment and loss of productivity of the active part of the population due to death or injury. According to expert organizations, damage to most developed countries of the world from road traffic accidents can reach several percent of the gross national product. Moreover, more than 70% of all road accidents occur in megalopolises, large cities, and other populated areas. First, city intersections are the most dangerous. This problem is especially acute in modern cities with a population of one million, where the organization of traffic flows is often characterized by a certain irrationality. This situation tends to constantly worsen due to the increase in the number of cars. The problem of congestion and traffic jams in cities with a population of over a million will become more

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and more urgent every year if serious and large-scale measures are not taken to find ways to comprehensively solve the issues of optimizing traffic flows.

This situation is typical for most large cities of the Russian Federation, including the city of Novosibirsk. Novosibirsk is currently the largest transport hub in Siberia. The city stands at the intersection of six federal highways and is also a major railway junction and logistics center for river and air transport. There are plans to unite the city and nearby settlements into the Novosibirsk agglomeration. At the same time, almost the entire road infrastructure of Novosibirsk is based on the master plans of the period of the existence of the Soviet Union with the expectation of the corresponding number of cars and population. According to geopositioning data from the Dutch company TomTom, Novosibirsk ranks ninth in terms of traffic congestion, ahead of St. Petersburg, Tokyo, New York, and other world capitals.

Analysis of statistics of road accidents that occurred in the Novosibirsk region over the past five years shows that the number of fatalities is decreasing, but the total number of road accidents in the region is increasing. The decrease in the number of victims can be explained by an increase in the level of passive and active safety of the vehicle fleet in use, since the development of active safety systems is a very significant factor in ensuring road safety [1]. The reason for the simultaneous increase in the number of road accidents should be considered an increase in the number of transport units per capita and, at the same time, an insufficient level of traffic organization and development of transport infrastructure.

Protecting the public from the risk of road accidents and reducing the number of deaths and serious injuries are the main goals of road safety. Achieving these goals is impossible without conducting research in the field of traffic management and developing modern methods for analyzing the traffic situation. Traffic flow parameters, especially in busy intersection areas of large cities, must be assessed using new methods that provide measurement and quantification in each traffic zone. Roadway intersections are one of the main concentration areas of traffic accidents, having a significant impact on travel times and possible traffic delays. It also requires the use of special measures for the construction and maintenance of road infrastructure, ensuring traffic control, providing road users with information about potentially dangerous road transport situations before and during the trip, identifying and quantifying the impact of risk factors on traffic safety at intersections [2, 3]. Also relevant are the problems of dynamic control of railway crossings and vehicle traffic at the entrances to railway crossings [4]. The development of intelligent transport systems for real-time control of the optimal speed of traffic flows is also of no small importance [5].

The most promising method for managing traffic flows at urban intersections is computer modeling, which is important for analyzing the geometry of highways and urban street systems, as well as for determining the causes of the formation and ways to eliminate congestion on the roadway. Analysis of the safety effectiveness of the road network and regulation of traffic intersections allows us to identify the most vulnerable causes of car accidents. There is a significant number of similar studies conducted over a significant period of time, however, the constant development and change of the road situation in each specific locality requires continuous attention to this problem [6, 7]. The issues of solving problems of organizing traffic and controlling road signals at intersections seem especially relevant in connection with the prospects for using the road network, along with ordinary cars, as autonomous vehicles controlled using intelligent technologies [8].

The purpose of this research is to develop a methodology for studying and optimizing traffic flows using the example of one of the street intersections in the city of Novosibirsk based on simulation modeling. In this case, the study of traffic flows means identifying the presence and causes of congestion in directions for the purpose of their further optimization.
2 Methods

To achieve this goal, it is proposed to use analytical methods and simulation tools to find optimal solutions in the stated area of research. As such a tool, it is possible to use the AnyLogic environment, which combines methods of system dynamics and process modeling. There are examples of the successful use of AnyLogic for modeling transport processes [9, 10], but each specific logistics or other similar task requires an individual approach to the analysis and formulation of the tasks. The intersection of Georgiy Kolonda and Okruzhnaya streets in the city of Novosibirsk was chosen as the object of analysis of conditions and traffic organization [11].

The research methodology involves the sequential implementation of the following possible stages of analytical and practical activities.

1. General analysis of the condition of the selected section of the road network

The T-shaped intersection chosen as an example for analyzing conditions and organizing traffic is adjustable, and the traffic lights are working properly. Installed together with the “Main Road” sign, the “Main Road Direction” road sign indicates that turning left from Georgiy Kolonda Street to Okruzhnaya Street and turning right from Okruzhnaya Street to Georgiy Kolonda Street are the direction of the main road at the intersection. Before the intersection on Georgiy Kolonda Street there is a pedestrian crossing, marked with appropriate signs and duplicated by the marking “Pedestrian crossing”. The duration of the permitting signal for pedestrians to cross Georgiy Kolonda Street is 13 s. Pedestrians who start a maneuver and do not meet the specified time interval have the opportunity to stop on a traffic island. The traffic lanes at the intersection are separated by road markings. There are public transport stops on both sides of Georgiy Kolonda Street; the sidewalk from the roadway is protected by a fence.

2. Drawing up a traffic pattern on the analyzed section of the road network

When drawing up a diagram, roadways and directions of movement are indicated. Each roadway of the analyzed three-way T-intersection has two lanes for traffic. The diagram of the intersection with all possible permitted directions of vehicle movement indicated on it is presented in Figure 1.

3. Collection of objective information about the state of traffic flows

The intensity of traffic flows is considered using the method of field observations using video recording equipment. In relation to the intersection under study, the collection of objective information about the traffic of vehicles passing through the intersection under study was carried out during periods of morning (from 09:00 to 10:00) and evening (from 17:20 to 18:20) peak traffic values on weekdays in August 2023. At this time, traffic
congestion at the analyzed intersection reached eight points, and their length in direction N21 reached 570 m. An example of presenting the results of studying the composition and intensity of traffic flows in the form of a protocol in tabular form is presented in Table 1.

Table 1. Composition and intensity of traffic flows at the intersection analyzed during the period of peak traffic values.

<table>
<thead>
<tr>
<th>Direction #</th>
<th>Lane #</th>
<th>Car traffic intensity, 1/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Morning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cars</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>773</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>155</td>
</tr>
</tbody>
</table>

4. Calculation of the reduced intensity of traffic flows

Calculation of the traffic flow intensity reduced to the conditional number of passenger cars, estimated in the number of passing cars per hour, is recommended to be carried out for each possible direction of movement according to equation (1):

\[ Q = Q_p k_p + Q_t k_t + Q_b k_b + Q_{rt} k_{rt}, \]

where \( Q_p, Q_t, Q_b, Q_{rt} \) – the number of passing cars, trucks, buses and road trains respectively; \( k_p, k_t, k_b, k_{rt} \) – coefficients for reducing traffic flow to the conditional number of cars, equal for cars 1, for trucks and buses 2, for road trains 3.

The results of calculating the values of the reduced traffic intensities during peak hours are presented in the form of a conditional cartogram of the intensity of traffic flows, on which it is desirable to mark the conflict points of the intersection (Fig. 2, 3). There are three main types of vehicle maneuvers at intersections: crossing, merging, and branching. In the cartograms presented in Figures 2 and 3, black dots are symbols of branching flows, and transparent dots indicate intersections.

Fig. 2. Conditional cartogram of the intensity of traffic flows in the morning.
5. Presentation of calculation results in the form of large-scale diagrams of traffic intensity.

For a more convenient perception of the received information by potential users, the calculation results are presented in the form of scale diagrams (Fig. 4, 5).

6. Identification of shortcomings in the organization of traffic on the analyzed section of the road network.

Having analyzed the traffic situation at the intersection of Georgiy Kolonda and Okruzhnaya streets, the main shortcomings in the organization of traffic flows were identified. First of all, such disadvantages include forced violation of traffic rules by drivers. This is caused by turning left onto Okruzhnaya Street (in the direction N21) from the right lane when driving along Georgiy Kolonda Street, since the intensity of traffic in the left lane is much higher compared to the right lane. The right lane is predominantly unloaded and is used by drivers of route vehicles to turn right onto Okruzhnaya Street. As a result, emergency situations are created at conflicting points of the intersection and congestion occurs due to non-compliance with traffic lanes. In addition, the formation of congestion at the analyzed intersection, even outside peak traffic values, is caused by the inconsistent operation of traffic lights at adjacent nearby intersections.

7. Assessment of the potential danger of a section of the road network based on the number of conflict points.

To assess the potential danger of various sections of the road network, it is proposed to use a five-point system, using the number and type of conflict points as an assessment criterion. In this case, the conflict point of deviation is assigned one conditional point, the point of merging - three, the point of intersection - five points. The intersection complexity parameters can be calculated using the following equation (2):

$$m = n_0 + 3n_c + 5n_p,$$

where $n_0$, $n_c$, $n_p$ – the number of points of deviation, merger and intersection respectively.

At the analyzed intersection in the first phase of turning on the green traffic light on Georgiy Kolonda Street, there are no conflict points, provided that road users move in accordance with the lane directions specified by road signs. However, taking into account real traffic situations, in one of the phases of traffic light regulation there are points of deviation and merging, therefore, when calculating using equation (2), the complexity of crossing $m$ in the first phase is $m = 4$. In the second phase of traffic light regulation, when traffic is allowed on Okruzhnaya Street, there are points of deviation, merger and two points

Fig. 3. Conditional cartogram of traffic intensity of traffic flows in the evening hours.
of intersection and the complexity of the intersection is $m = 14$. In both cases, these situations should be classified as intersections of low complexity.

8. Creation of a model that simulates the real intensity of traffic on the studied section of the road network.

Fig. 4. Large-scale cartogram of traffic intensity in the morning.

Fig. 5. Large-scale cartogram of traffic intensity in the evening hours.

3 Results and discussion

To achieve the research goal, a new model was created in the AnyLogic environment using a graphical diagram editor of the Main agent type and the Simulation experiment block. Seconds were chosen as units of model time. The following scenario was used to create the simulation model:

- adding a satellite image of the analyzed road section to the environment of the selected simulation modeling tool;
- inserting an image of the analyzed area over the satellite image;
- setting vehicle traffic intensity using AnyLogic blocks;
– development of an algorithm for vehicle movement in all directions using the “Traffic Library” palette;
– checking the activity of all blocks of the model.

Figure 6 shows a fragment of block diagrams of the developed model, and Figure 7 shows an image of the original simulation model, working on the basis of existing traffic flow parameters.

![Fig. 6. Fragment of block diagrams of the developed simulation model.](image)

![Fig. 7. Initial simulation model.](image)
The resulting model clearly shows the congestion of the studied section of the road network. Based on the modeling results, it was established that after one hour of the model’s operating time, the average time the cars spent in the model was 88.179 s. During this time, 1280 cars passed through the intersection under study, and another 31 cars were in the model at the intersection of roadways. To increase the capacity of vehicles through the intersection under study and solve problems associated with traffic congestion in the area and difficult left turns from Georgiy Kolonda Street to Okruzhnaya Street, it is proposed to make changes to the organization of traffic light regulation. For this purpose, the ability to discretely change parameters in the built-in OptQuest optimizer in the AnyLogic environment was used. The creation of an optimization experiment made it possible, using sequential parameterization, to determine the recommended values for the duration of the phases of operation of traffic lights, at which the number of people passing the intersection under study will increase.

**Fig. 8.** Results of the optimization experiment.

**Fig. 9.** Optimized simulation model with modified traffic light phases.
As a result of creating the appropriate interface and launching an experiment to optimize
the phases of two traffic lights at the analyzed intersection, 462 iterations were created. Based
on the results of experiment number 194, the best iteration was recognized with the duration
of individual traffic light control phases obtained because of optimization (Table 2). The
results of the optimization experiment are presented in Figure 8. The average time spent by
cars in the system was 57.386 s, which is 30.793 s less than the original result. To assess the
dynamics of changes in the intersection's capacity, considering the optimization results, a
simulation model was again built (Fig. 9). As a result, we find that after one hour of operation
of the optimized simulation model, 1416 cars passed through the intersection, another 34 cars
remained in the model at the intersection of roadways.

<table>
<thead>
<tr>
<th>Phase #</th>
<th>Duration, s.</th>
<th>Initial data</th>
<th>Optimization results</th>
<th>Reduction in phase duration, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>55</td>
<td>44</td>
<td>–20</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>33</td>
<td>22</td>
<td>–33.33</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>67</td>
<td>66</td>
<td>–1.5</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>35</td>
<td>18</td>
<td>–48.57</td>
<td></td>
</tr>
<tr>
<td>Complete traffic light cycle 1-2</td>
<td>92</td>
<td>70</td>
<td>–23.91</td>
<td></td>
</tr>
<tr>
<td>Complete traffic light cycle 3-4</td>
<td>106</td>
<td>88</td>
<td>–16.98</td>
<td></td>
</tr>
</tbody>
</table>

4 Conclusion

This article describes a methodological approach to organizing research on traffic
management in order to identify problem areas that contribute to the occurrence of congestion
on the studied sections of the road network. The sequential implementation of possible stages
of analytical and practical measures for optimizing transport flows in the urban
agglomeration is proposed. It is shown that AnyLogic environment tools are an adequate way
to optimize traffic flows. As an example, the results of creating an optimization simulation
model of automobile traffic at the intersection of Georgiy Kolonda - Okruzhnaya streets in
the city of Novosibirsk are presented, repeating the existing traffic situation at the intersection
in reality. Optimization measures made it possible, based on adjusting the duration of traffic
light control phases, to reduce the average time spent by cars at the intersection by 35% and,
thereby, increase the throughput of the intersection by 10%. The use of the proposed
approaches to the development of simulation models of vehicle traffic is a promising
direction for optimizing traffic control at urban intersections, subject to obtaining objective
statistical data on travel time and capacity of the analyzed road sections of large settlements
and urban agglomerations

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