

Intersection capacity management: simulation model process diagrams

Vera Chernova¹, Yuliya Laamarti², and Alexey Kolodochkin^{1*}

¹Moscow Polytechnic University, 38 Bolshaya Semyonovskaya str., Moscow, 107023, Russia

²Financial University under the Government of the Russian Federation, 49 Leningradsky prospect, Moscow, 127282, Russia

Abstract. The article describes the features of creating formal transport and pedestrian flows models for the simulation model of the road network section formed by the intersection of Aviatsionnaya and Pekhotnaya Streets in the Pokrovskoe-Streshnevo district of the North-West of Moscow (RU). The aim of the study is to create a comfortable and safe environment by building a simulation model for the implementation of different scenarios of street section transformation. Application of the structural analysis method allowed us to identify all objects and subjects, and the relations between them in the implementation of transport and pedestrian processes.

1 Introduction

The growth of urban population is an objective trend in the development of any society, Sultanakhmedov (2011). In this regard, transport plays a major role to meet the needs of the population and ensure the activities of most sectors of the economy. As it is noted in various studies, the coexistence of ground passenger, truck, and personal transport on a single road network has aggravated, Sultanakhmedov (2011), Shepeta (2011). At the same time, the length of the road network does not change significantly, which increases the density of the traffic flow. Thus, the main problems are the prediction of changes and management of transport systems both at the city and local district levels.

The aim of the study is to manage pedestrian and traffic flows to increase the capacity of sections of the road network.

The main task for achieving this goal is to formalize the processes of the problem area for the subsequent building of a simulation model. Reliable and consistent process models display all qualitative and quantitative characteristics of the road network section.

The theoretical significance of the study is to build a universal model that reflects all aspects of the problem area. Such a model or its individual parts can be used in other studies to analyze the processes or objects that implement the scenarios of urban environment modernization.

The practical significance of the study lies in the creation of tools and methods for modeling the real conditions of the city transport system.

*Corresponding author: kolodochkin@icloud.com

2 Objects and methods








The object of the study: the intersection formed by Pekhotnaya and Aviatsionnaya Streets in the Pokrovskoe-Streshnevo district of the North-West of Moscow (Fig. 1).



Fig. 1. Satellite imagery of the study object (Source: Google Maps <https://goo.gl/maps/YGj9iFbF1Pakw3kV7>).

To create formal models of processes that correspond to the subject area and meet the requirements of simulation modeling, the method of structural analysis was used. As noted in various studies Timokhovets (2020), Logachev et al. (2022b), Logachev et al. (2022c), to achieve the accuracy of the results of such analysis, it is required to refine the characteristics step by step, dividing the complex parts of the objects into elementary ones. Thus, qualitative and quantitative characteristics of the object, required for real process model creation, are established. For visualization of the results, we used graphic notation, which allows to represent the model in a simple form. The graphic notation used is shown in Table 1.

Table 1. Graphic notations for formal research models.

No.	Notation	Brief description
1		A group of pedestrians performing the same actions
2		Movement of a group of pedestrians
3		Decision point, where the objects flow is separated according to a set rule
4		Process start / end event
5		Traffic flow
6		Group of motor vehicles performing the established maneuver. Load capacity is not taken into account
7		A group of trams going in one direction without route specification. Passenger capacity is not taken into account

The study uses the method of agent-based modeling, which makes it possible not to distinguish individual instances with specific behavior in a group of objects. However, as noted in the research, it is not necessary to change the process model for adding the specific behavior of individual instances of the group.

3 Results

The use of the stated research methods made it possible to build models of traffic and pedestrian flows that are typical for the object. Let's have a closer look at the obtained results.

At the first stage of building models, the team of authors defined the scheme of road traffic organization in the specified area. This traffic scheme overlaid on the satellite imagery of the study object is shown in Fig. 2.

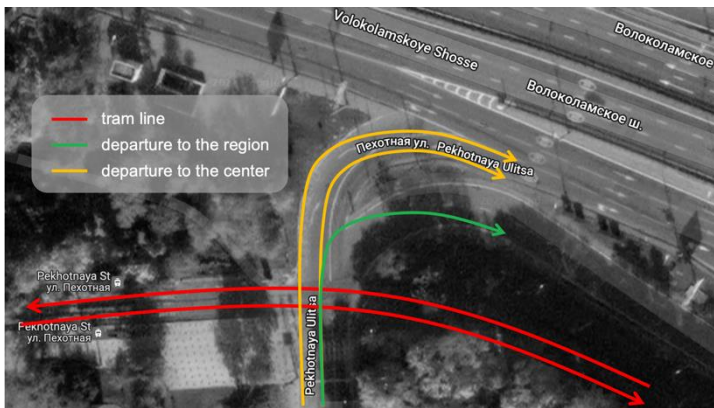


Fig. 2. The traffic flows organization scheme at the intersection of Pechotnaya and Aviatsionnaya Streets in the Pokrovskoe-Streshnevo district.

It should be noted that tram traffic is heavy in this section. This is due to the fact that there are five tram routes on Aviatsionnaya Street, which connect the bedroom suburbs of Moscow with metro stations of various radial lines, the Moscow Central Circle, and the Second Moscow Central Diameter (MCD-2). The frequency of trams during the peak hours is up to three minutes, and during the rest of the day and evening – about 5 to 10 minutes, at the start or the end of the movement – 15 minutes. On the other hand, Pechotnaya Street is exempt from public transportation in the study area. It is the street that connects the district with the city artery – Volokolamskoe Highway. Therefore, in Fig. 2 green indicates the exit to the U-turn under the highway in the direction toward the region, and yellow shows the direction toward the center.

At the second stage of the study, the traffic phases were defined, which is shown in Fig. 3.

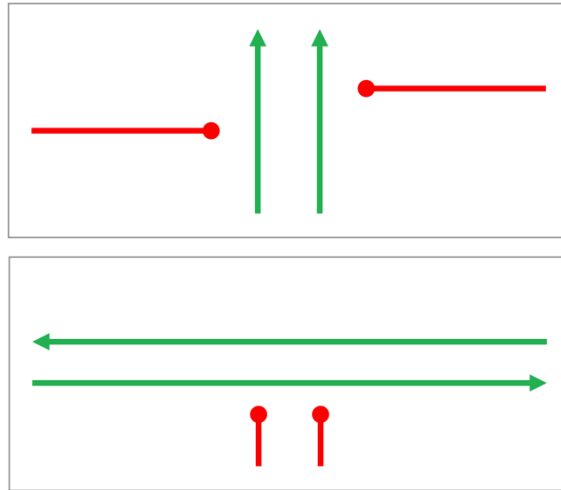


Fig. 3. Diagram of traffic phases at the Pekhotnaya and Aviatsionnaya Streets intersection in the Pokrovskoe-Streshnevo district (green indicates the moving traffic in the lane, red – the stopped).

The tramway traffic at the specified intersection has no priority (i.e., does not depend on the arrival of the tram).

The third stage of the study determines the directions of pedestrian traffic. The results are shown in Fig. 4.



Fig. 4. The scheme of pedestrian traffic at the Pekhotnaya and Aviatsionnaya Streets intersection in the Pokrovskoe-Streshnevo district.

It should be noted that pedestrian traffic in the study area is affected by the following factors:

- tramway stop platforms are located 40 meters away;
- an underground crosswalk under the Volokolamskoye Highway is located 70 meters away, providing access to the Streshnevo station of the Moscow Central Ring and the Second Moscow Central Diameter;
- ten daytime and one night bus stops are located near the underpass on the Volokolamskoye Highway;
- major medical centers and other significant social facilities are located within 200 m;
- a number of residential complexes.

The presence of such factors determines the high traffic of pedestrians during the operation of social facilities and public transport.

On the fourth stage, schemes of pedestrian and vehicle traffic at the intersection were created. The location of crosswalks is shown by blue arrows in Fig. 5.

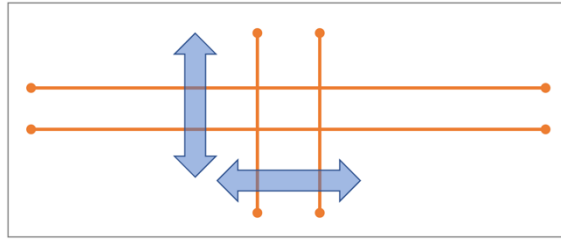


Fig. 5. The scheme of the crosswalk’s location in relation to traffic flows.

Fig. 6 shows the phases of pedestrian traffic at the studied intersection.

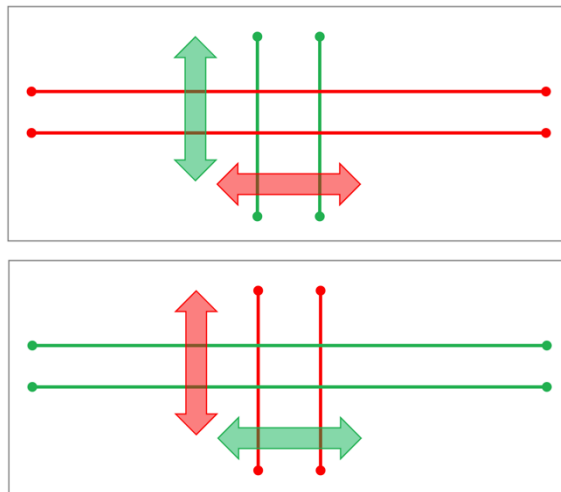


Fig. 6. The scheme of pedestrian movement in relation to traffic flows (Green color indicates permission to move, red – prohibition).

At the fifth stage, process diagrams have been created, which are the basis of the simulation model and correspond to the processes of the real object. The description of formal models of traffic processes at the intersection is presented in Table 2.

Table 2. Diagrams of traffic flows at the intersection.

No.	Process diagram	Brief description
1		<p>The movement of tramways. Does not depend on the direction. When moving from the left the beginning of the process is the departure from the stopping point, and the end of the process is the crossing of the intersection. For the opposite direction: the beginning is the appearance before the intersection, and the end is the arrival at the stopping point</p>

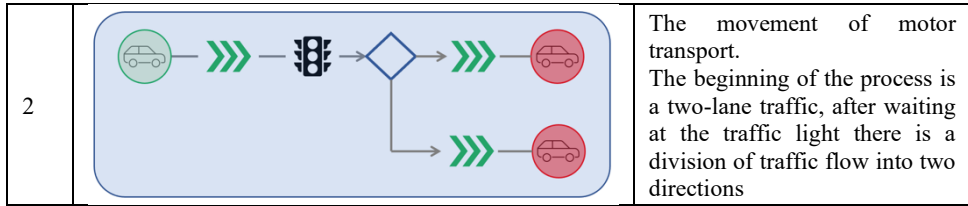


Fig. 7 shows one of the variants of the pedestrian traffic diagram in the studied area (based on the routes shown in Fig. 4).

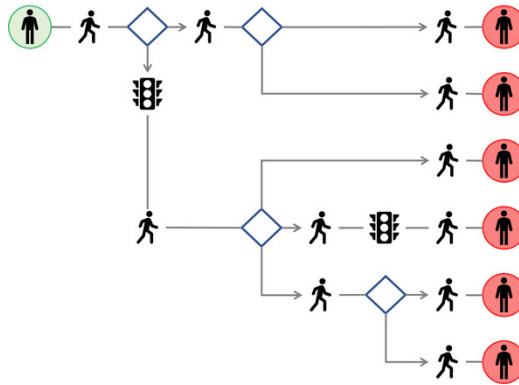


Fig. 7. Diagram of the movement of a pedestrian getting off a tram.

The process shown in Fig. 7 corresponds to a passenger arriving at a tram stop taking the right-to-left route. Therefore, the endpoints of such a passenger can be reaching a crosswalk, a park on the right across the road, a tram stop in the other direction, etc. When modeling certain scenarios, the option that the passenger has left the tram by mistake or is making a change to another route can be added. Thus, in such cases, the passenger will not have a route. As a part of the study, the diagrams of all other travel options (six) when the starting point of the route is changed have been developed.

4 Discussion

The results obtained during the study are reliable and consistent, as accepted scientific research methods were used correctly. It should be noted that the results correspond to the results obtained by other scientists in related studies on modeling and system design, Shepeta (2011), Chen et al. (2019). In addition, our team of authors paid special attention to the input parameters, which form qualitative relations between the objects of the problem domain. This approach corresponds to the studies of a number of scientists: Timokhovets (2020), Logachev et al. (2022a), Sreekumar and Mathew (2022).

5 Conclusion

The development of the road network or the organization of road traffic requires methods that increase the reliability of design decision data, and the accuracy of the development of transport systems based on traffic flows. Simulation modeling is such a tool.

When building a simulation model, all qualitative and quantitative features of the problem domain are taken into account to create formal processes. For traffic management in the urban environment, such processes include transport and pedestrian processes. In the study, all the

processes related to the problem area were analyzed and formal process models were built based on the obtained results. The usage of such models allows modeling different situations for various groups of road users: changing the number of lanes and traffic lights phases, increasing traffic speed, adding a lane for cyclists, etc. In addition, such process models allow creation of individual scenarios for certain instances from a group of road users (for example, creating emergency situations). All this allows us to efficiently manage road processes and to predict the results associated with long-term and fundamental changes in the road network section (e.g., construction of an alternate route or an interchange).

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