Models of traffic and pedestrian flows for organization of smart traffic light traffic

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Abstract. The article defines the importance of organizing road traffic in urban transportation systems. The research targets are defined and all its key elements and characteristics are identified. The research target is a segment of the North-Western Chord of Moscow corresponding to Bolshaya Akademicheskaya Street in the Koptevo District and limited by Mikhalkovskaya Street and 3rd Nizhnelikhoborskiy Proyezd. The research resulted in a model of a transport system graph for the area under study delineating traffic and pedestrian flows. The model takes into account the points of conflicts in crossing and merging of flows. The research findings became the basis for a mathematical model of traffic in problematic spots of the area under study. Conclusions are made as to the suitability of the findings and their use in the smart city system.

1 Introduction

An increased number of vehicles and mobility of people puts transport systems in populated areas under test. This problem is relevant for both metropolis and small regional cities. Russian and foreign scientists note that developing mathematical models of interaction between all traffic participants and elements of transport infrastructure will give an answer to all questions of sustainable development [2, 3, 4].

Mathematic models describing such processes are easily adapted to high performance calculation tools that can create large models in real time [3]. This is especially relevant to improve efficiency of traffic flow management in big cities or metropolises at complicated crossings or junctions. Efficiency of such management (especially in real time) requires complex study of the formation mechanism of time delays of vehicles and pedestrian in each segment of the area under study depending on traffic intensity in all permitted directions and traffic light phases [1, 5, 6].

Developing and efficient system for transport system control and management is impossible without mathematic modeling and development predictions of the road transport situation depending on constantly varying factors [1]. Such factors include the number of flow crossings and merges, traffic light configurations, maximum speed, traffic density,

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number of exits or turns. In combination all these affect traffic safety and environmental condition [7].

In this manner, the research objective is efficient organization of road traffic at the given segment of the transport network.

This requires the following: defining relevant characteristics of all objects in the transport system of the area under study; formalizing the findings in the form suitable for use in mathematical or imitation modeling; developing a concept of traffic flow management depending on situations occurring in real time.

The theoretical significance of the research lies in formal description of the road network segment. The final form is suitable for various studies intended to evaluate the results of segment transformation or create instructions for prompt response to situations occurring in real time.

The practical significance is an ability to use the findings to implement the urban planning strategy in residential areas to ensure comfort and safety of traffic and environmental welfare.

2 Objects and Methods

The research target is the segment of Bolshaya Akademicheskaya Street 2 km long in the Koptevo District of the Northern Administrative District of Moscow. The segment under study is limited by Mikhalkovskaya Street and 3rd Nizhnelikhoborskiy Proyezd.

![Research target: a segment of Bolshaya Akademicheskaya Street in Moscow (Yandex Maps: https://yandex.ru/maps/-/CCU0ILXwHC)](image)

Developing models of the research target required a set of methods to be used. The authors have identified the primary aspects of the subject domain and their respective methods.

To describe the contents of the research target, the structuring method was used. This resulted in all objects and subjects of the subject domain as well as their qualitative and quantitative characteristics. The basis of any model is not only objects but also processes occurring in their interaction [6, 8].

Formulating a list of such processes became possible after using the analysis method. The analysis method gives not only internal processes within the research target but also external ones. As the researchers note, the analysis findings are used at the stage of designing or modeling systems of various complexity [9, 10].

Moreover, the combination of structuring and analysis findings helps form input parameters for simulation models of the area under study [11, 12]. To visualize the findings, the authors used the graphic method. This method resulted in an illustrative simplified representation of isolated parts of the area under study for further investigation.

3 Results
Studying the area showed that the segment of Bolshaya Akademicheskay Street is a part of the North-Western Chord. This chord is a trunk road connecting Moscow administrative districts between each other for unimpeded passage from west to north.

This segment is used for personal and public transport. Traffic is dense due to problematic spots: four intersections and three signal-controlled pedestrian crossings. Moreover, some parts of the trunk road have jammed traffic in the left lane in both directions due to no pockets for public transport stops. It should be noted that this segment is covered by 11 bus routes, one of which is express (e.g., reduced number of stops).

The segment was divided into four sectors during structuring and analysis. Sectoring was done based on bottlenecks. A bottleneck in this case is the segment with high probability of significant traffic delays for any mode of transport. Such spots include all intersections and one signal-controlled pedestrian crossing not combined with intersections.

Finding the phase duration requires identifying the proneness to conflict and density of traffic and pedestrian flows. The proneness of flows to conflict means their merging or crossing. Merging included those situations when flow participants simultaneously claim the same limited area. When crossing, participants collide in a conflict point close to 90°.

To build a model of conflict areas based on the findings of structuring, analysis and graphic methods, images were formed allowing to combine designations and real-world objects. Let us give one of the findings.

Let us present a designation for a formal model of the intersection between Bolshaya Akademicheskay Street and 4rd Novomikhailovsky Proyezd (Fig. 2).
Fig. 2. Designations of flows at the intersection between Bolshaya Akademicheskay Street and 4rd Novomikhailovsky Proyezd in Moscow

For convenience and structuring of designations, the formal model adopts the following rules:
● flows along Bolshaya Akademicheskay Street lanes have prefix A;
● flows along 4rd Novomikhailovsky Proyezd have prefix N;
● pedestrian flows along the crossing have prefix P.

The formal model of the crossing is given in Fig. 3.

Fig. 3. Graph model of traffic and pedestrian flows at the intersection between Bolshaya Akademicheskay Street and 4rd Novomikhailovsky Proyezd in Moscow

The shown model does not account for traffic light phases. Therefore, the authors created a parametric model describing transport and pedestrian flows accounting for traffic light signals. Let us designate the multitude of non-conflicting traffic and pedestrian flows $X_i$, where $i$ is the sequential number of the phase. The designations of all traffic flows correspond to nodes of the graph depicted in Fig. 3.

The resulting multitudes are grouped by two attributes:
1. Pedestrian flows are stopped:
   ● $X_1 = \{A1, A2, A3\}$;
\[ X_2 = \{N1, N2, A8\}; \]
\[ X_3 = \{A5, A6, A7, A8\}; \]
\[ X_4 = \{N1, N3, N4, A1, A2, A3\}. \]

2. Pedestrian flows are taken into account:
\[ X_5 = \{A1, A2, A3, A4, P1-2\}; \]
\[ X_6 = \{P1, A8, N2\}; \]
\[ X_7 = \{P2, P1\}; \]
\[ X_9 = \{P1-1, P2, A5, A6, A7\}; \]
\[ X_{10} = \{A5, A6, A7, A8, P1-1, N2\}; \]
\[ X_{11} = \{P2, A1, A2, A3, A5, A6, A7\}; \]
\[ X_{12} = \{P1-2, P2, A1, A2, A3\}. \]

It should be noted that pedestrian flow P1 can be divided into two flows depending on the traffic light configuration. The trunk road has a traffic island in the center where a pedestrian traffic light is mounted. Therefore, the pedestrian flow is designated as P1-1 through traffic flows A1–A4 and as P1-2 through traffic flows A5–A7.

4 Discussion

Creating a model of traffic and pedestrian flows of the street road network is an important and relevant task in organization of road traffic [3, 9, 10]. Modern researchers note that there are conflicts when flows cross each other or merge. To obtain such conflicts, the researchers study and structure the problematic domain to identify all quantitative and qualitative characteristics of the object [2, 8]. The research resulted in a detailed description of the area under study, which complies with the concept of modern scientific papers in this domain.

Structural objects and their characteristics are the basis for creating graphic and parametric models [3, 5, 6]. A parametric model enables identifying dependencies between object characteristics to predict changes in the model when various parameters are changed [13, 14]. Graphic models enable visualization of the research findings, improving the model understanding and displaying object characteristics, which could be hidden from researchers, in a clear and illustrative manner. This is a common procedure for developing the concept of flow operative management in a transport system in real time. The resulting model complies with the findings of related research works.

5 Conclusion

Signal-controlled and zebra pedestrian crossings are conflict zones where a high number of traffic and pedestrian flows are concentrated. Using dynamic traffic controls (such as smart traffic lights) improves the throughput capacity of a road network segment and enhances safety of road traffic and improves the regional environmental situation.

To configure smart traffic lights parameters, one must have an automatic system that would take a decision on traffic organization depending on the object parameters in real time. Such solutions require an adequate mathematical model describing the problematic domain. The models allow finding options for developing the transport systems under a certain criterion with defined limitations. Structuring and analysis of the subject domain helped developing criteria and limitations reflecting functional characteristics of the transport system and parameters of people’s needs, environmental condition, risks of
various accidents, etc. Using models to address all issues of transport planning, organization of road traffic and improvement of the passenger transport system.

The created models resolve the problem of prompt management of flows in the smart city system in real time. The findings of this research comply with all requirements of the subject domain and reflect all its qualitative and quantitative characteristics.

References