Concept and Imitation Modeling of Sustained Transport Model in Moscow Area

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Abstract. The article presents the concept of sustainable development of a street road network segment connecting the Koptevo district and the Timiryazevskiy district in the Northern Administrative District of Moscow. When designing the concept of changes, the authors used common scientific methods in their research in order to determine problems and related domain objects. It was found that the sustainable development of this area requires modernization of the district’s transport system. All traffic flows, their objects, relations and external characteristics affecting the nature of traffic were identified for this road segment. This resulted in a formal model of traffic flow. By analyzing the research findings, the authors developed a concept of road infrastructure changes to improve the time, environmental and safe efficiency of traffic flows. To substantiate the efficiency, a formal traffic model was developed along with its respective parametric model being a basis for the imitation model.

1 Introduction

The development of the transport network in Russian cities is greatly limited. This is historically related with the housing density not suitable for intensive traffic flows. Scientists note that an expanded vehicle fleet, an increased traffic intensity, and higher mobility all result in high burden on the existing transport system of the city in general [1].

This problem is especially prominent in crossings of trunk-roads and in places where traffic is held up (such as traffic lights, passing or expecting public transport). This increases the number of vehicles in the same place and negatively affects the environment. The researchers note that growing automobilization leads to dense traffic flows, increased complexity or traffic organization and a more negative consequences in this connection (such as a high noise level, increased cost of transportation, more accidents, etc.) [2, 3, 4].

To organize a traffic flow, reduce the environmental impact and increase the throughput capacity by reorganizing the existing area, various mathematical or simulation models are created. It is quite probable that such models can forecast various situations [5, 6].

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Therefore, the research is aimed at developing a concept of sustainable development of transport flows with lower negative environmental effects.

The research objectives include the analysis of the subject domain, identifying its key objects, qualitative and quantitative characteristics of such objects; graphically formalizing the links of domain objects between each other to form input parameters and rules of parametric models; designing a set of activities to reorganize the road network segment; creating a formal mode for reorganization of traffic flows complying with the developed concept;

The theoretical significance of the research is determining dependence and significance between the objects of the street road network and processes that take place between them.

The practical significance of the research is an ability to use its findings to model processes that can evaluate the quality of changes in the street road network for the purposes of sustainable development.

2 Objectives and Methods

The research target is the traffic flows on the road segment 0.5 km long connecting the districts of Koptevo and Timiryazevsky in the Northern Administrative District of Moscow. The road segment under study includes:

- Mikhailovskya Street (400 m) from the Moscow Polytechnic University to Bolshaya Akademicheskaya Street;
- Pryanishnikov Street (710 m) from Bolshaya Akademicheskaya Street to Timiryazevskaya street;
- Timiryazevskaya street (390 m) from Pryanishnikov Street to Petrovskay Square.

The map in Figure 1 shows the area under study.

Fig. 1. Research targets on the map of Moscow
(Yandex Maps: https://yandex.ru/maps/-/CCUWnOU~tC)

To create a concept of sustainable development of the district, the following methods were used:

1. *Divergence, transformation and convergence*: The authors used all the above methods in combination to determine relevant boundaries of the research target and its key objects, specify limitations related with characteristics of the problem domain and form details of research solutions meeting the query criteria [3, 4].

2. *Synthesis and analysis*. Simultaneously using these methods helped uncover relationships between structural objects of the subject domain, determine input parameters of the mode enabling to form a development prediction for the area during a defined interval [5, 7, 8].

3. *Parametric modeling method*. This method resulted in a mathematical model of traffic flow of the road segment under study. The findings are used to visualize
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3. Parametric modeling method. This method resulted in a mathematical model of traffic flow of the road segment under study. The findings are used to visualize scenarios of changes in the problem domain in time using simulation modeling methods [9, 10].

4. Graphical method. This method was used to create formal models of the research target that illustrate its key features in a simplified form [2, 11].

The research of Russian and foreign literature showed that the methods stated by the authors are up-to-date, reliable and sufficient to achieve the declared goals and objectives [6, 8, 10].

3 Results

These methods resulted in the following characteristics of the research target:

1. The entire segment is pierced by a double-track tram line not segregated from the roadway.

2. There is one lane 5m wide in each direction, expanding to two lanes for turning at the crossing with Bolshaya Akademicheskaya Street.

3. There are three public transport stops: for two tram routes and four bus routes. The stops for the same mode of transport in the same direction are not combined. It should be noted that the stops are not combined for each mode of transport driving in opposite directions. The layout of stops is given in Fig. 2.

Fig. 2. Layout of public transport stops

1. There are both signal-controlled and zebra pedestrian crossings.

2. It is possible to turn by changing the driving direction in other road network elements, and to exit the road to get to social infrastructure facilities. Fig. 3 represents the traffic layout.
In Figure 3, the key areas affecting transport flows are highlighted and numbered:

1. **Area 1.** Crossing of the segment with the North-Western Chord that goes under it and makes it possible to enter and exit it (Fig. 4). There are public transport stops under this crossing (Fig. 5).

2. **Area 2.** Exit to the driveway to the North-Western Chord and public transport stops before the Moscow Polytechnic University at Pryanishnikov Street (Fig. 6).

3. **Area 3.** Number of exits for accessing academic buildings of the Moscow Polytechnic University and the Russian Agrarian University (Fig. 7).
Fig. 3. Traffic layout at the road segment under study

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1. Area 1. Crossing of the segment with the North-Western Chord that goes under it and makes it possible to enter and exit it (Fig. 4). There are public transport stops under this crossing (Fig. 5).

Fig. 4. Panoramic image of entering the segment from the North-Western Chord (Yandex Panoramas https://yandex.ru/maps/-/CCUWnTqDdA)

Fig. 5. Public transport stop before the North-Western Chord at Mikhaylovskaya Street (Yandex Panoramas https://yandex.ru/maps/-/CCUWnTCxOB)

2. Area 2. Exit to the driveway to the North-Western Chord and public transport stops before the Moscow Polytechnic University at Pryanishnikov Street (Fig. 6).

Fig. 6. Panoramic image of the road segment near the Moscow Polytechnic University at Pryanishnikov Street (Yandex Panoramas https://yandex.ru/maps/-/CCUWnXQKoC)

3. Area 3. Number of exits for accessing academic buildings of the Moscow Polytechnic University and the Russian Agrarian University (Fig. 7).

Fig. 7. Panoramic image of the exits from the road segment to the academic buildings (Yandex Panoramas https://yandex.ru/maps/-/CCUWnXvjwA)

4. Area 4. Exit to Timiryazevskaya Street that continues the main road from Pryanishnikov Street (Fig. 8).

Fig. 8. Panoramic image of the road segment at the crossing of Pryanishnikov Street and Timiryazevskaya Street (Yandex Panoramas https://yandex.ru/maps/-/CCUWnXX92C)

5. Area 5. Public transport stops at Timiryazevskaya Street near the Petrovskaya Square (Fig. 9).

Fig. 9. Panoramic image of the road segment near the Petrovskaya Square (Yandex Panoramas https://yandex.ru/maps/-/CCUWn2e-xA)

By analyzing the structural elements within the research target, a concept for area development was developed according to the defined goals. Key points of this concept:

Point 1. Combined tram and bus traffic at the segment under study.

Point 2. In Area 1, narrow each lane for vehicles from 5.0 to 3.7 m to construct a landing platform directly abutting the public transport lane in the center of the driveway. Erect an inclined ramp from the platform that must be combined with the existing signal-controlled pedestrian crossing.

Point 3. In Area 2, remove all public transport stops and the signal-controlled pedestrian crossing. Move the stops to the beginning of Area 3 (after exit to the Moscow Polytechnic University when driving to Timiryazevskaya Street). Narrow the lane for motor vehicles and construct a landing platform directly abutting the public transport lane. Erect an inclined ramp for the platform at the access to the Moscow Polytechnic University and provide a signal-controlled pedestrian crossing.

Point 4. In Area 5, combine the public transport stops and place them behind the signal-controlled pedestrian crossing when driving to Pryanishnikov Street. Build a landing platform directly abutting the public transport lane and equip it with an inclined ramp to the signal-controlled pedestrian crossing.

Fig. 10 represents the traffic layout for the developed concept described above.
To evaluate the efficiency of changes in traffic flows, a simulation model reflecting all characteristics of the road segment under study was created using parametric modeling methods. Below are some parametric models on which the simulation model is based:

1. **Average density of traffic flow** \( \rho(x, t) \) in the Eulerian axes \( x \) along the road in the traffic flow direction over time \( t \):

\[
\rho = \frac{S_m}{S} = \frac{h n l}{h L} = \frac{n l}{L},
\]

where \( h \) is the traffic lane width;
\( L \) is the length of the research target;
\( I \) is the average length of vehicle with minimal distance between static vehicles;
\( n \) is the number of vehicles at the road segment under study \([9]\).

2. A continuous flow of vehicles is described by a continuity equation:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho v)}{\partial x} = 0
\]

3. Speed change complies with the following equations:

\[
\frac{d\rho}{dt} = a; \quad a = \max\{-a^-; \min\{a^+; a'\}\};
\]

\[
a = f_\rho \int a_\rho (t, y) dy + \frac{V(\rho) - v}{\tau},
\]

\[
a_\rho = -k^2 \frac{\partial \rho}{\partial x} + \frac{s}{\rho} \frac{\partial^2 v}{\partial x^2},
\]

where \( a \) is the traffic flow acceleration;
\( a^+ \) is the maximum possible acceleration when speeding up;
\( a^- \) is the acceleration when braking;
\( \Delta \) is the distance of decision-making;
\( f \) is the local situation characteristic as compared to the situation at some distance \((0 \leq f \leq 1)\);
\( \tau \) is the delay related with the finiteness of the time of driver’s response to a change of traffic conditions and vehicle performance characteristics.

**4 Discussion**
Russian and foreign scientists note an increased burden on the transport infrastructure and the street road network related with continuing urbanization and automobilization of the society [2, 4, 6]. The solution for transport and related environmental problems of cities is a consistent implementation of sustainable urban transport policy principles. Researchers believe that this requires development and functioning of urban transport systems in coordination with urban planning, environmental and health protection [4, 12]. They note that transport planning is an efficient basis for traffic organization [1, 10, 12]. Developing such plans and concepts will improve transport accessibility, provide fast and comfortable riding in public transport, enhance safety of traffic and reduce negative effects on the environment.

Creating a concept of sustainable development requires a detailed analysis of all its characteristics to find out key parameters [5, 7]. As scientists note, this is necessary to get input parameters of models [13, 14, 15]. Such models will help recreating the research target in virtual form using simulation modeling. The created model is a basis for various experiments and implementation of development scenarios for the area [2, 6]. This helps forecast the development of the road segment under study, evaluate its response to suggested changes since time, and take prompt decisions to manage various objects and their characteristics.

5 Conclusion

Sustainable transport is a reference point for development of urban infrastructure, public transport systems, logistics and delivery of goods, efficiency and transportation comfort, and for improvement of the environment and people’s health. Organization of traffic flows is important for sustainable development, namely to combat climate changes.

Traffic flows are complex objects comprising multiple parameters varying over time depending on behavior specifics of each agent and external effects. Any event (such as phase changing of traffic lights, prohibition to turn, repair of road pavement) can have an effect on the entire traffic flow. This may cause catastrophic consequences for individual flow agents and infrastructure facilities. Creating simulation models based on the developed concept of sustainable development is a powerful and useful tool to create various road situations for development of efficient scenarios to address issues and change certain points of the concept and rules of prompt management.

The findings of this research comply with all requirements of the subject domain and reflect all its qualitative and quantitative characteristics. All interaction rules of objects were identified, on which basis the concept was developed for changing the road’s throughput capacity, traffic speed of public transport, reducing the time of expecting other road users to complete their maneuvers, increasing the safety of passengers during embarkation and disembarkation. Efficiency, reliability and sufficiency of these findings is confirmed by using common scientific methods for addressing issuing related with transport flows.

The findings can be used in development of a city development plan or by experts engaged in modernization of the street road network.

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