Enhancing Moscow transport network capacity through streetcar intersection management

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Abstract. Moscow's surface transport is represented by modern low-floor trams of various capacities. In order to ensure comfortable and safe transport, the tram infrastructure is constantly being modernised: jointless tracks are built, rails, sleepers and switches are renewed, tracks are separated from the roadway, etc. In places where tram lines cross and merge, "bottlenecks" are created, slowing down tram movements due to traffic light phases that do not take into account the actual presence of vehicles in front of them. The paper develops a concept of tram traffic separation at different types of intersections. The main idea is to identify the main routes whose delays need to be reduced and for which a "dedicated" tramway is organised. The "bottlenecks" in the Moscow tram network are identified and fragments of traffic modernisation schemes according to the developed concept are given.

1 Introduction

At the current developmental stage of urban transport systems, the main global trend is the creation, restoration or modernization of streetcar systems [1, 2]. Streetcar is the only type of ground public transport, technologically capable of providing high volumes of transportation in dense urban areas [3, 4]. At the same time, different variants of such systems realization can be envisaged: high-speed, elevated, surface street, streetcar - railroad, intercity, etc.

In Russia, after the long-standing tendency to dismantle streetcar tracks, concepts for the restoration and development of existing streetcar systems are being actively discussed and implemented. For instance, in St. Petersburg, Taganrog, Verkhnyaya Pyshma and 20 other cities, concession agreements for the modernization of transport infrastructure, purchase and operation of rolling stock have been created and are being implemented to provide transport services to the population. In Moscow, the streetcar network is being developed by combining it with the metro into one rail system. This approach is justified by the possibility of using advanced technologies of the subway for the repair and maintenance of streetcar tracks [5]. Their length is about 400 km of single track, on which there are 855 stops [6].

In Moscow the streetcar is the most important element of the transportation system, as it transports about 600 thousand passengers daily [7]. The rolling stock consists of modern low-floor three- and one-section cars. For uninterrupted provision of traffic the tracks are isolated. At the moment about 70% of lines are isolated from road traffic [8]. In addition, work is

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underway to develop transport infrastructure that provides a comfortable and safe environment for waiting, boarding and disembarking passengers (safety islands, elevated platforms or roadbed), modern technologies are used to replace the tracks to reduce the negative impact on the environment (for instance, noise level), traffic patterns on specific streets are changed to ensure the priority of streetcar travel, etc.

One of the priority areas for the development of the street streetcar network in Moscow is the creation of diametral routes, making it possible to cross the city through the ground. For the first such trunk routes, existing tramways are connected in the city center in order to provide a direct transport link between the city center and major transport and interchange hubs and remote areas with a reduced load on the metro. The operation of such diameters requires high capacity sections of the street road network. Thus, the goal of the research is to create a concept to reduce the idle time when streetcars cross traffic flows.

For this purpose it is required to fulfill the objectives to determine qualitative and quantitative characteristics of the research object; to establish the processes influencing the change of characteristics of objects and related processes; to determine the "bottlenecks" of the tramway system, providing traffic delays; to develop the concept of increasing the capacity of the identified "bottlenecks".

The object of research is the streetcar system of Moscow city. The subject of the research is the process of streetcar crossing the traffic flows of the street road network.

Theoretical significance of the research lies in the formalization of objects and processes of the transport system of the city, providing the possibility of developing mathematical models and algorithms for optimizing its parameters, solving social and environmental problems. The practical significance of the research lies in the creation of a methodology that provides effective management of traffic flows for sustainable development.

2 Materials and Methods

For the accomplishment of the set objectives, a set of methods was used, which can be conditionally divided into two groups.

The first group of methods was aimed at obtaining a description of the research object. Such a description was obtained using the methods of observation, structural analysis and synthesis. The transportation system is a complex object, which is a system of established rules (for instance, direction and schedule of traffic) and their actual observance. Thus, the schedule of public transportation on a certain section of the street road network may not be observed due to the occurrence of random events: repair works of the street road network, reducing the number of lanes for traffic; weather conditions; time of day; accidents, etc. Accordingly, the observation method made it possible to establish the change of the system states in certain places depending on the actual circumstances and to determine the model of behavior of the subjects of the relevant processes. Methods of structural and statistical analysis were used to determine the model of behavior of objects and changes in their states in ideal conditions (compliance with traffic rules, favorable weather conditions, permissible load on the street road network and other infrastructural objects). In research related to the modeling of transport or pedestrian processes, such methods are used to determine the input parameters of the model and the rules of its operation [9-11].

The main objective of the second group of research methods is to formalize the obtained results. Such methods include graphical and modeling methods. With their help, objects and relations between them are visualized, making it possible to establish regularities of changes in the states of both the system as a whole and its specific parts. As noted in research related to the creation of models of complex systems, the use of graphical methods makes it possible to establish regularities that are difficult to quantitatively describe and difficult to detect using analytical procedures [12-14].

3 Results

There are 35 active routes in Moscow (not counting three temporarily closed routes due to major repair works). It should be noted that there are no self-contained routes, i.e. some intersect with each other and parts of the traffic routes coincide.

There are points where streetcar tracks intersect with automobile flows, forming regulated and unregulated intersections. In general, streetcar tracks are separated from automobile flows in a variety of ways that may vary in different parts of the route. In most places, streetcar tracks are located in a dedicated public transport lane in the center of the roadway (Figure 1).

Fig. 1. Separation of streetcar tracks by road markings (Google Maps image source: https://maps.app.goo.gl/p5LoLgJSUfY87h2K6)

There are sections (mostly one-way) where the streetcar lane is located to the left of the road traffic lane. The main trend over the last few years is the physical separation of such sections. Instead of a solid line, a curb is placed to prevent vehicles from driving onto the tracks.

Another type of physical separation of the tracks is raising them above the roadway level, as shown in Figure 2.

Fig. 2. Separation of streetcar tracks by their elevation above the carriageway (Google Maps image source: https://maps.app.goo.gl/VFQ34PhiJo2QwHZE6)

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In addition to the above options for separation, there are sections of routes where the tracks are set back from the roadway (Figure 3).

Fig. 3. Location of streetcar tracks away from the carriageway (Google Maps image source: https://maps.app.goo.gl/hboT7FKguRLMihR59)

However, all this does not exclude the reduction of streetcar speed in places where the track crosses with automobile or pedestrian traffic.

A specific problem is the crossing of streetcar routes. Analysis of the streetcar traffic pattern has shown that from one to five routes can run on different sections of the system. Sections with only one route are minimal, with an average of three streetcar routes per section in the city. Traffic intervals can vary from five to ten minutes depending on the time of day and days of the week. This means that in places where tracks intersect with automobile traffic or streetcar routes, clusters of cars may form, waiting either for a traffic light signal permitting passage or for the next car to pass ahead. It should be noted that Moscow is just beginning to implement an intelligent system that provides streetcar priority at an intersection when approaching the intersection.

Fig. 4 shows the main types of crossing or merging of streetcar routes. A reserve route is a shortened route from the main route when necessary (for instance, to reduce the waiting interval for a car in case of a traffic disruption, when traveling to or from the depot, etc.).

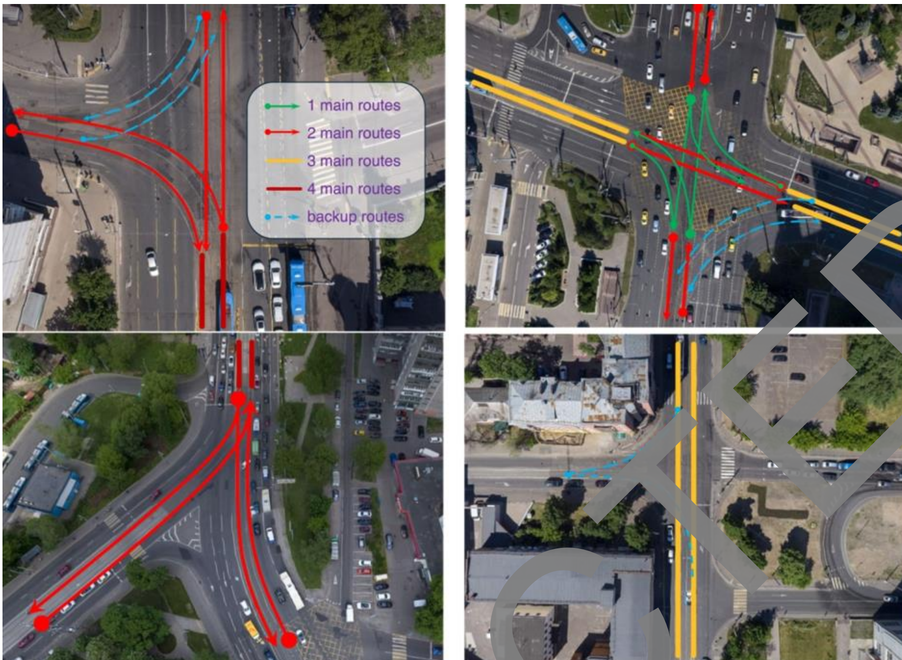

Fig. 4. Variants of streetcar intersections in Moscow (sources of Yandex Panorama background maps: https://yandex.ru/maps/-/CDWpUJZL, https://yandex.ru/maps/-/CDWpUWyy, https://yandex.ru/maps/-/CDWpUT~o, https://yandex.ru/maps/-/CDWpYLjZ)

When streetcars are heavily trafficked, tramcars can become congested in one direction before crossing traffic flows. This can cause a negative attitude of passengers expecting a smooth and fast movement to the destination point, and affect the traffic flows by blocking the passage of vehicles. Thus, the length of a three-section car is 27.5 meters, and the length of a single-section car is 16.7 meters. The safe distance between streetcars should be taken into account, which can be reduced to three meters according to the rules on a flat area.

The solution to the problem of such idle cars could be the addition of a third track at the intersection of streetcar flows. This would make it possible to separate streetcars waiting for a traffic light signal into one stream and streetcars that can move at this time into another stream. Fig. 5 shows the scheme of such traffic for a U-shaped intersection.

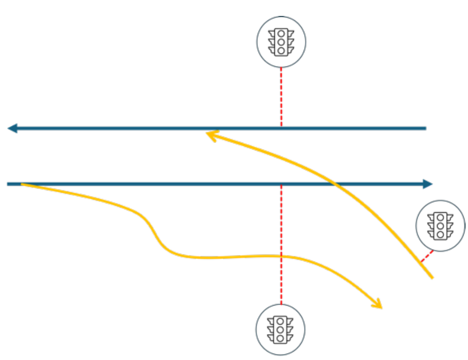

Fig. 5. Diagram of a dedicated streetcar flow making a right turn at a U-shaped intersection

Currently, the arrow is located directly at the location of the traffic light. Thus, in case of heavy streetcar traffic on such a section, there is a problem of idling of cars that should be moving straight ahead due to waiting for a permissive traffic light signal for cars turning right. Moving the arrow to the length of the car before the traffic light would make it possible to provide space for streetcars making a right turn maneuver. At the same time, there was no interference with streetcar traffic going straight ahead. The U-shaped intersection of Budennogo Avenue and Semyonovsky Proyezd (55.778776, 37.720556) is the section of the street road network where the relevant infrastructure could be upgraded to implement the presented traffic scheme.

To organize traffic at the T-junction and cross-junction it is important to determine which direction is a priority. As a priority direction can be chosen those on which there is a high traffic of streetcars, the route passes on the main road, etc. Fig. 6 shows the scheme of modernization of a T-junction.

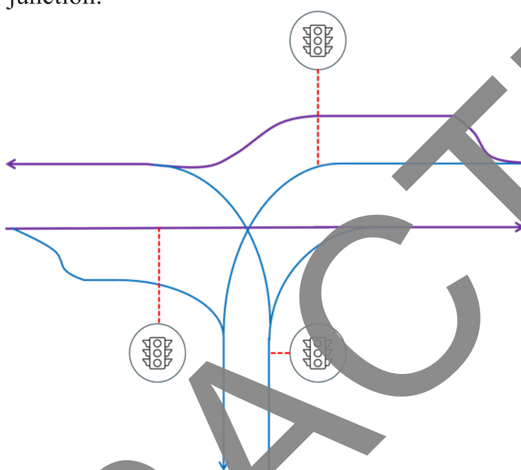

Fig. 6. Diagram of dedicated streetcar flows at a T-intersection

As an example of the section shown with the modernized streetcar traffic scheme in Fig. 6, the intersection of Verkhnaya Krasnoselskaya Street and Krasnoprudnaya Street (55.779486, 37.666166) can be used. The specified section has a high density of streetcar traffic, as there are four routes in each direction, two of which cross two other routes in each direction. Thus, at specific time intervals, up to four cars may accumulate in front of the intersection on the main road waiting to pass through the intersection. Although this section is located in the historic part of the city, but the streetcar tracks are laid in the center of the carriageway, on the side of which there are 2-3 lanes for motor transport (on the main road). Accordingly, moving the arrow from the traffic light can be done for a considerable distance, accommodating the consecutive stopping of two cars waiting to cross the intersection.

4 Discussion

The research analyzed states that transportation system modeling is necessary for engineering analysis, coordination and approval of the solution in terms of economic efficiency, transport safety, capacity and other factors defined by the project objectives [3, 15-17]. Creating a modeling plan involved conceptualizing the changes of the research object and setting its essential qualitative and quantitative characteristics. These are used as the basis for the input parameters and rules of the simulation model, which is a digital twin of the real research object. As noted in works related to simulation models of transportation systems, with the help of a digital twin it is possible to conduct experiments of any complexity in order to assess changes in the states of the object at a given time interval and to develop solutions for effective management of its states [10, 18, 19].

5 Conclusions

The analysis of transport systems makes it possible to solve a wide range of objectives on traffic management when changing the transport and operational indicators of its objects. The creation of digital models provides the possibility to use hardware and software to process a large amount of heterogeneous data, to constantly monitor changes in the qualitative and quantitative characteristics of the system, to forecast changes in the state of the system as a whole or its specific parts. The creation of a sustainable transportation system requires the development and implementation of smart city concepts, providing comfortable mobility of the population, reducing the negative impact on the environment.

The developed concept in its basis has a model of interacting subsystems, forming requirements and ways of implementation, corresponding to modern projects of the Moscow City Hall in the field of public transport. The implementation of the concept ensures the creation of through streetcar routes with minimal delays.

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