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Parametric modeling of traffic flows for predicting sustainable development of urban areas

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Abstract. The paper presents a description of the developed model of a section of the road network in the Nizhny Novgorod Region (Russia) near the regional center. There is a lot of traffic crossing the site. The key flow is the railroad, which carries passenger and freight traffic along the east-west transport corridor. The use of structural analysis, synthesis, and graphical methods allowed to establish all the objects and subjects of the area of concern. The data obtained were used in the parametric modeling method to obtain a formal model demonstrating the qualitative and quantitative characteristics of the study object. The developed model allowed to evaluate traffic and make decisions on modernizing road infrastructure to increase the capacity of highways and railroads and create conditions for the safety of all road users.

1 Introduction

The concept of increasing regional transport connectivity is the basis for solving economic and political problems. The basis of this concept is international transport corridors, which, given the continentality of the Eurasian regions, are the most important drivers of development and a way to effectively integrate into global economic relations and value chains [1]. As noted, the most important impetus for the construction and practical implementation of international transport corridors in Eurasia is the EAEU and China, which carry out the conjunction of Eurasian integration and the Silk Road Economic Belt [1].

The basis of international transport corridors is the railroad. The advantage of such transportation is the speed (compared with sea transportation) and cost (compared with air transportation), which provides an increase in the concentration of cargo flows on continental routes. All this ensures the need for the long-term development of such transport corridors and the infrastructure that supports them.

The main direction on the Eurasian continent for transit traffic is the route China-Europe-China (East-West latitudinal corridor). The East-West Eurasian route crosses Russia by land, providing access in the east to the rail network of North Korea, China, Mongolia, and Kazakhstan, and in the west to European countries via Russian ports and

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border crossings [2]. This corridor provides a single economic space of Russia, transport connectivity of the central part of the country with the regions of Siberia and the Far East.

The expansion of the transport corridor increases the load on the adjacent infrastructure. The problematic place of such a corridor is the intersection or overlap of flows. In the case of railway flows, such a place is a railway crossing [3]. With the increase in rail traffic, the idle time of road transport increases, ensuring the absolute priority of rail transport at the crossing. All this harms the sustainable development of urban areas, an increase in accidents, etc.

Thus, **the purpose of the study** is to identify the bottlenecks of the East-West transport corridor in central Russia.

The practical implications of the study are to obtain results for the development of the road network of cities and the organization of road traffic.

The theoretical implication of the study is to create a model of a section of the road network and the definition of its objects and subjects affecting the transport processes and processes related to the supporting infrastructure.

2 Materials and methods

The object of the study is a 5.4 km road section connecting the village of Novoye Doskino (Nizhny Novgorod Region) and Nizhny Novgorod. The scheme of the studied section is shown in red in Figure 1.

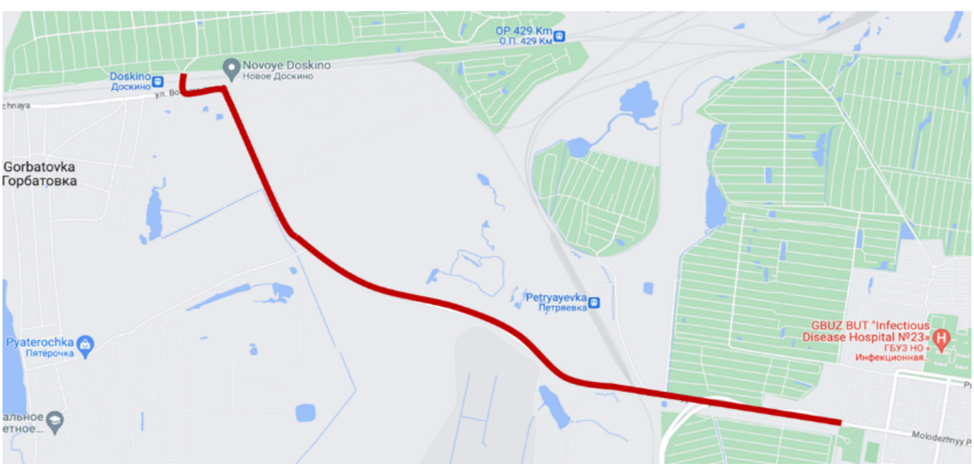


Fig. 1. Location of the research object (Source: Google Maps https://goo.gl/maps/8knqoE3JTHLTcdaG9)

The study area is limited by the beginning of the 13-th line street in Novoye Doskino and passes through the railway crossing further along Vostochnaya Street in the settlement of Gorbatovka (Dzerzhinsky District of Nizhny Novgorod Region) to the railway crossing near Molodezhny prospect in Nizhny Novgorod.

To develop a parametric model of traffic flows, the following methods were used:

1 **The structural analysis method,** which allowed us to identify all the significant elements of the research object. Different levels of abstraction have been used in setting up such elements, allowing a significant restriction of the context for each level [4, 5].

2 **Synthesis method** for setting rules of interaction between elements of each level of abstraction obtained as a result of structural analysis [6].

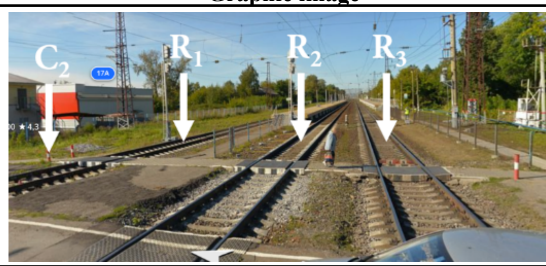
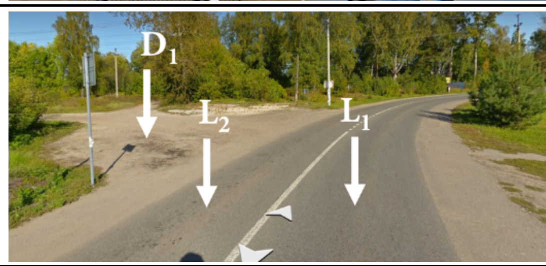
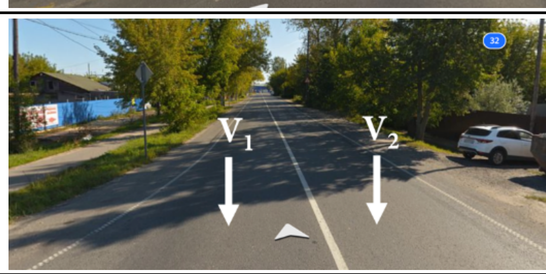
3 **Graphic method**, which resulted in diagrams showing the characteristics of the research object obtained as a result of applying the method of synthesis and structural analysis [7].

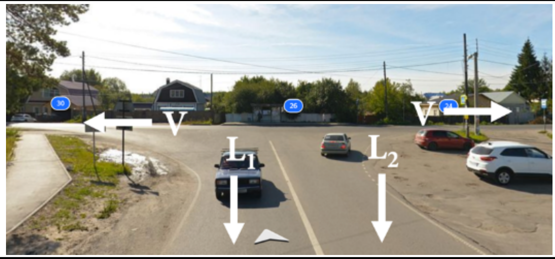
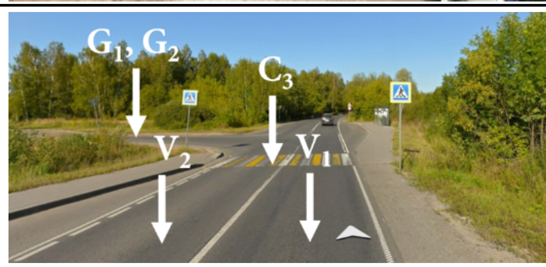
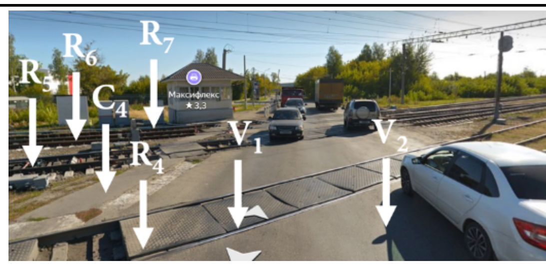
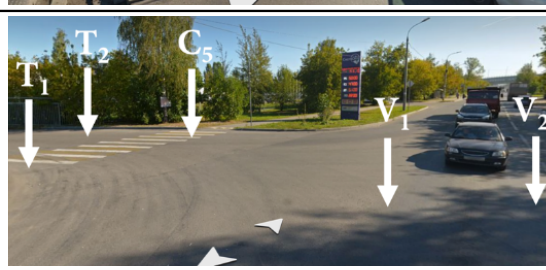
4 **The parametric modeling method** allowed to establish the exact characteristics and their relationship to each other to formalize the study object [8-10].

3 Results

All the key objects and actors involved in its corresponding processes were identified to create a parametric model of the studied site. For the parametric description of transport and pedestrian processes, we introduced the notation, the values and description of which are presented in Table 1.

Table 1. Designation of transport flows of the study object.

No.	Designation	Graphic image
1	$R_{1,..3}$ – railway tracks of the latitudinal direction of the Gorki railroad. C_2 – unregulated crosswalk over railroad tracks	
2	L_x – the main road that provides entry and exit for residents in Novoye Doskino D_1 – secondary road from the western part of Novoye Doskino	
3	V_x – Vostochnaya Street of the Gorbatovka village. H – bus stop located on the roadway. C_1 – unregulated crosswalk between bus stops of opposite directions	
4	V_x – Vostochnaya Street in the direction of Nizhny Novgorod	

5	General view of the T-junction near the railroad crossing from Novoye Doskino	
6	M_x – exits to unpaved roads on Lugovaya Street from Vostochnaya Street in Gorbatovka village	
7	General view of the T-junction at the intersection of Gorbatovka – Nizhny Novgorod and Doskino. G_x – the road in two directions to the village of Doskino. C_3 – unregulated crosswalk between bus stops of opposite directions near the corresponding intersection	
8	$R_{4, .., 7}$ – the tracks of the Gorki railway bypass of Nizhny Novgorod. C_4 – unregulated pedestrian crossing over railway tracks	
9	T-junction in Nizhny Novgorod behind the railway bypass. V_x crosses over to Molodezhny prospekt C_5 – unregulated crosswalk. T_x – road, providing access to Petryaevka station	

Note: image source of the study object Yandex-Panorama https://yandex.ru/maps/-/CCUk7TqR~D

The use of the designations stated in Table 1 allowed obtaining a parametric description of the processes of intersections and mergers of traffic and pedestrian flows. Table 2 shows the components of the corresponding parametric system.

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Table 2. The system of sets describing traffic and pedestrian flows of the research object

No.	Multiple flows	Set description
1	$P_1 = \{L_1, L_2, R_1, R_2, R_3\}$	Flows regulated by automatic signaling means at the railway crossing in the area of Novoye Doskino
2	$P_2 = \{C_2\}$	Pedestrian flows across the railroad tracks in the Novoye Doskino area
3	$P_3 = \{D_1, L_1, L_2\}$	Merging and separation of traffic flows near the railroad crossing in Novoye Doskino
4	$P_4 = \{V_1, V_2, L_1, L_2, C_1\}$	Merging and separation of traffic and pedestrian flows carried out in the area of the unregulated crosswalk in front of the railway crossing from the side of Nizhny Novgorod
5	$P_5 = \{V_1, V_2, L_1, L_2, C_1, H\}$	Similar to P_4, but carried out during the bus stop in the lane when picking up and dropping off passengers
6	$P_6 = \{V_1, V_2, M_1, M_2\}$	Traffic flows through the exits from East to Lugovaya Street
7	$P_7 = \{V_1, V_2, G_1, C_3\}$	Traffic and pedestrian flows at the T-junction towards Nizhny Novgorod from Doskino
8	$P_8 = \{V_1, V_2, G_1, G_2\}$	Traffic flows at the T-junction towards Doskino from Nizhny Novgorod
9	$P_9 = \{C_4, R_4, R_5, R_6, R_7\}$	Pedestrian traffic crossing the railroad tracks through the Gorki railway bypass
10	$P_{10} = \{V_1, V_2, R_4, R_5, R_6, R_7\}$	Intersection of automobile and railway flows at a railway crossing near Molodezhny prospekt in Nizhny Novgorod
11	$P_{11} = \{V_1, V_2, T_1, T_2, C_5\}$	T-junction with an unregulated crosswalk behind a railway crossing near Molodezhny prospekt in Nizhny Novgorod

A study of the results found that P_1, P_5, P_9, and P_{10} have a large number of conflicts. This means that there are a significant number of intersections or confluences of different types of flows at these locations.

Using these results and the graphical method, an analysis of the road section in "conflict" places was carried out. It has been established that there are railroad crossings in such places (Figure 2).

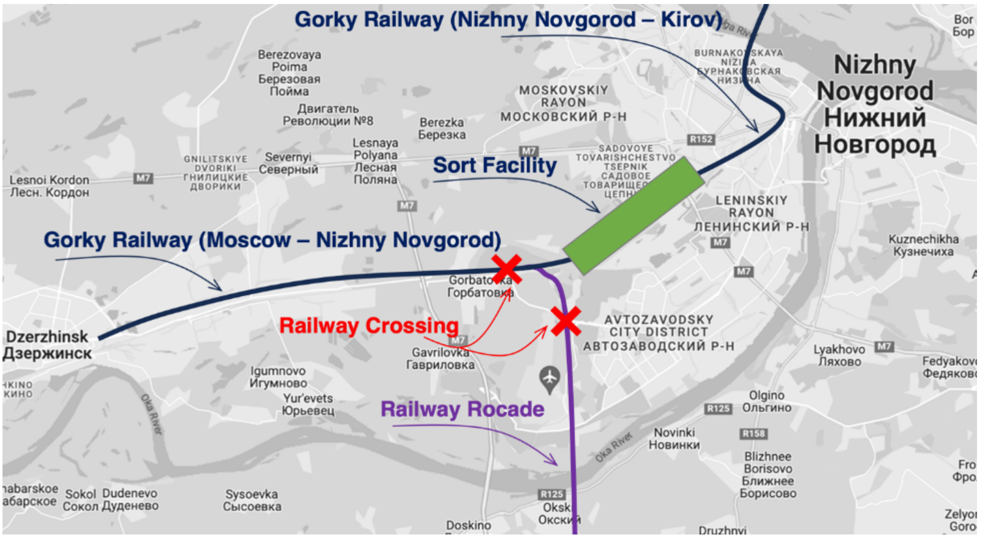


Fig. 2. Diagram of the main railroad lines of Nizhny Novgorod.

Such places are equipped with barriers, automatic barriers, and means of sound and light alarms (Table 3 shows their description).

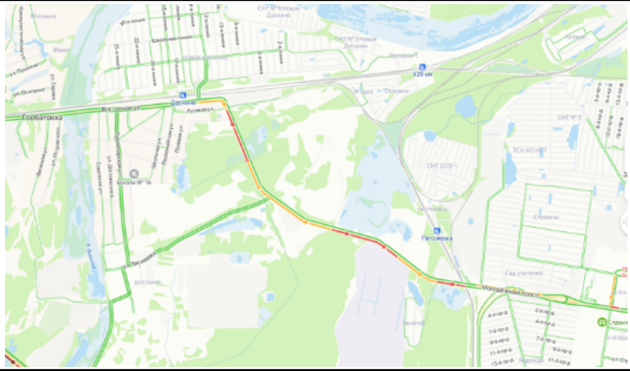
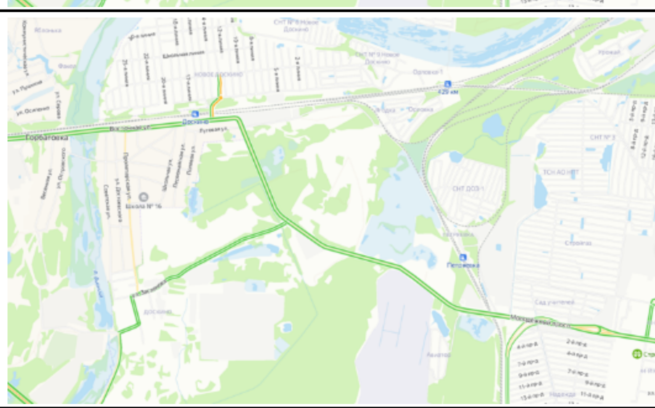
Table 3. Railway crossings of the study object.

No.	Coordinates	Characteristic
1	56.247079, 43.804041	 Yandex-Panorama image source: https://yandex.ru/maps/-/CCUk7PxDhD The intersection of the highway with the railway bypass, linking the latitudinal directions of the Gorky Railway (Moscow – Nizhny Novgorod and Moscow – Kazan – Yekaterinburg). The railway bypass provides a southwest bypass of Nizhny Novgorod for freight and passenger traffic
2	56.264712, 43.759794	 Yandex-Panorama image source: https://yandex.ru/maps/-/CCUk7TqR~D The intersection of the highway with the latitudinal direction of the Gorky Railway. Railroad tracks ensure freight and passenger train traffic between the Urals, Siberia, and the Volga region, connecting Moscow, Yekaterinburg, Kazan, Kirov, and Nizhny Novgorod

It was found that the railway traffic is heavy, which determines the multiple closures of traffic in a day for the unimpeded passage of railway trains. The study found the impact of such closures on vehicular traffic density. Table 4 shows the corresponding results.

Table 4. Traffic of motor transport in the study area

No.	Time interval	Graphic designation

1	Weekday, 08:00-10:00	
2	Weekday, 10:00-16:30	
3	Weekday, 16:30-21:00	
4	Weekends, mornings	

5	Weekends and weekdays, day, evening, and night	

Image source: Yandex.Traffic https://yandex.ru/maps/47/nizhny-novgorod/probki/

The images in Table 4 show that the capacity of the studied section decreases at the railway crossings. Among other things, it creates a threat to the safety of road users: pedestrians and motorists cross railroad tracks with heavy traffic. Thus, to ensure safety and increase the capacity of the road section a road bridge should be built.

4 Discussion

The model parameters obtained during the study show the organization of traffic and pedestrian flows of one of the sections of the transport corridor “west-east”. Such parameters are used to assess transport accessibility scenarios and identify traffic patterns and other sustainable development scenarios for residential areas. All this allows the creation of a simulation model that demonstrates the behavior of all participants of the flows. The use of the stated methods and the obtained results of the conducted study are confirmed in the scientific works of scientists Belov [4], Nguyen [11], Fomina [12], and Van [13].

The use of parametric and simulation modeling for the implementation of urban infrastructure modernization projects, streamlining traffic or pedestrian flows is a global practice [5, 8, 14, 15].

The created parametric model allows the creation of a concept for the area development taking into account the need to increase the capacity of the transport corridor “east-west” with the bypass of a large population center with a reduction of the negative impact of various factors on the inhabitants of the region.

5 Conclusion

Stable development of east-west transportation is possible with the strategic development of transport logistics on the Eurasian continent. Such logistics are possible when institutional and transactional barriers are reduced or absent when digital technologies are used to organize traffic flows, and when supporting infrastructure is modernized.

According to the strategy of railway transport development in the Russian Federation 2030, a set of measures for the construction and reconstruction of bridges and tunnels, modernization of railway infrastructure, and construction of marshaling and port stations should be implemented. All this is aimed at a serious transformation of railways, providing accelerated passage of both container and passenger trains.

The use of parametric modeling allowed for obtaining a formal model of the subject area, combining motor transport and railway traffic on a section of a major railway line connecting central Russia with the Urals, Siberia, the Volga region, and the Far East.

The results obtained in the study are adequate to the subject area, reflecting all of its qualitative and quantitative characteristics. This is confirmed by the use of general scientific methods. The developed parametric model is suitable for use in simulation modeling of the problem area to predict and visualize scenarios to assess the traffic congestion of the road section, traffic safety, the capacity of the railway or road junction, and justify the need to build a bridge over the railroad tracks.

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