International Journal of Ecosystems and Ecology Science (IJEES) **Vol. 14 (4):** 209-216 (2024)
https://doi.org/10.31407/ijees https://doi.org/10.31407/ijees14.4

ENHANCING URBAN AIR QUALITY AND TRAFFIC FLOW: MULTIMODAL SOLUTIONS FOR UNSIGNALIZED JUNCTION EFFICIENCY AND SUSTAINABLE CITY DEVELOPMENT

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Received October 2024; Accepted November 2024; Published December 2024;

DOI: https://doi.org/10.31407/ijees14.425

ABSTRACT

Ensuring clean air in the city is one of the tasks of ensuring the quality of life of the population and the principle of sustainable development of the city as an ecosystem. On the elements of the road network, a high concentration of pollutants occurs when their capacity decreases and time delays for drivers and pedestrians increase. The global trend of assessing the quality of service of elements of the road network includes a multimodal or integrated approach that takes into account the needs of all road users. The article presents the results of a study of the length of the queue of cars at unsignalized junctions at the same level, a formula for determining the minimum distance for placing a queue of cars in front of a pedestrian crossing is proposed, design solutions for the arrangement of measures to increase the capacity of traffic lanes and unsignalized junctions are proposed. The proposed method takes into account the influence of the coefficients of reduction to a passenger car on the length of the queue of cars and the choice of a design solution to increase the capacity of an unsignalized junction in conditions of high traffic congestion. The application of the proposed measures will increase the efficiency, taking into account the multimodal approach to taking into account the opinions of drivers and pedestrians.

Keywords: capacity, level of service, unsignalized junction, unsignalized intersection, urban network, pedestrian, traffic.

INTRODUCTION

The level of service is the quality of traffic on the elements of the road network or its transport services according to the assessment of users. The service level gradation is represented by six levels from A to F, where A is considered the best and F is considered the worst. The generally accepted LOS value is between levels C and D (Austroads, 2015; Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), 2015; National Academy of Sciences, 2016). A multimodal approach to assessing the quality of service includes the opinions of motorists, public transport passengers, freight carriers, pedestrians and cyclists who need mobility, safety, access, information and convenience (Hensher et al., 2021; Maas, 2022; Wong et al., 2020). A comprehensive assessment of the quality of service is necessary when designing elements of the road network in order to determine the appropriate level of service for all or one of the road users and make the optimal decision under given conditions (Guerrieri and Mauro R, 2021; Wu and Brilon, 2021). The use of the proposed system complements the need for detailed computer modeling to verify the impact of the proposed design solutions on the capacity of elements of the road network during the design process. Today, environmental safety issues are an integral part of ensuring high-quality and comfortable conditions for all types of human activities. The concentration level of pollutants formed in the lower layers of the atmosphere can be determined by factors such as traffic intensity, traffic flow composition, meteorological conditions, geometric characteristics of the road network, local relief, the presence of green spaces, the number of intersections (Bakulich et al., 2024). The strategy of socio-economic development of Russia with low greenhouse gas emissions until 2050 has It is aimed at reducing emissions of harmful substances. According to the United Nations Human Settlements Programme (UN Habitat) (United Nations, n.d.) cities account for up to 70 percent of global anthropogenic greenhouse gas emissions. In this regard, a number of cities are implementing their own climate strategies and plans, including, among other things, the desire to achieve "carbon neutrality". More than 100 cities have now announced their intention to achieve "carbon neutrality" by 2050, and individual cities plan to achieve "carbon neutrality" by 2025-2040 (Stockholm, Helsinki, Copenhagen and others). There are also climate initiatives in which Russian cities participate (for example, the cities of Moscow and Rostov-on-Don participate in the Global Pact of Mayors on Climate and Energy). Emissions of harmful substances are monitored in the cities of Russia. Statistics from open sources (Open Data Portal of Moscow Government, n.d.) have shown that over the past 5 years the volume of emissions of pollutants into the atmospheric air from motor transport in the city of Moscow has decreased from 781.90 thousand tons to 318.60 thousand tons as of 2023. The statistical data are shown in Figure 1.

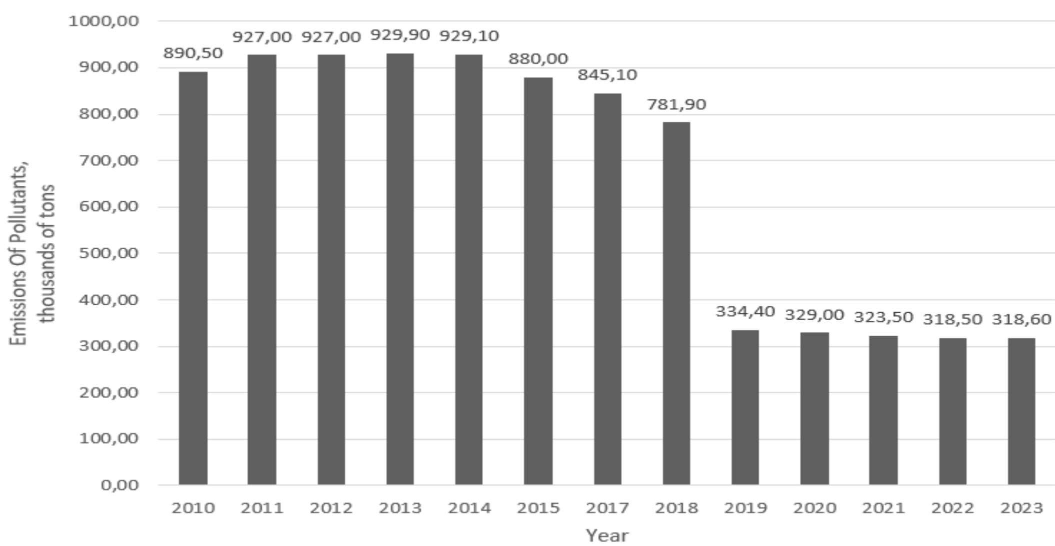

Figure 1. Dynamics of emissions of pollutants into the atmosphere from road transport in Moscow (Open Data Portal of Moscow Government, n.d.).

The current trend towards reducing pollutant emissions should be maintained to improve the quality of life of the population. Providing clean air in the city contributes to its sustainable development as an ecosystem. The most harmful components of exhaust gases from internal combustion engines are nitrogen oxides, sulfur oxides, carbon monoxide and unburned hydrocarbons. The largest number of emissions from an internal combustion engine is produced by a car when operating in neutral gear or when idle at an intersection or in a traffic jam. Exhaust gases have a negative impact on human health (Gaybullaev and Bazarov, 2023). Their impact is especially strong in places of concentration near transport facilities and at pedestrian crossings. In conditions of heavy traffic, vehicles are waiting in line, and pedestrians are waiting for the opportunity to cross the roadway. From the point of view of the principles of a multimodal approach to assessing the quality of service of elements of the road network and ensuring high quality clean air, one of the effective measures to reduce emissions of pollutants is to reduce the time delays of drivers when passing intersections and junctions. The study on the assessment of the average queue of cars and time delays of drivers will allow the development of design measures to improve the quality of service of elements of the road network and reduce emissions of pollutants.

MATERIAL AND METHODS

Methods

To apply the LOS concept in the context of designing elements of the urban street and road network, it is necessary to continue research on capacity (Komarova, 2022, 2023a, 2023b) and develop practical recommendations for increasing the capacity of unsignalized junctions at the same level.

According to formula (1), the analysis of the length of the queue of cars Q was carried out depending on the load level of lane z and the bandwidth of lane $C_{mx} = P$ (veh./hour). The results are shown in Figure 2.

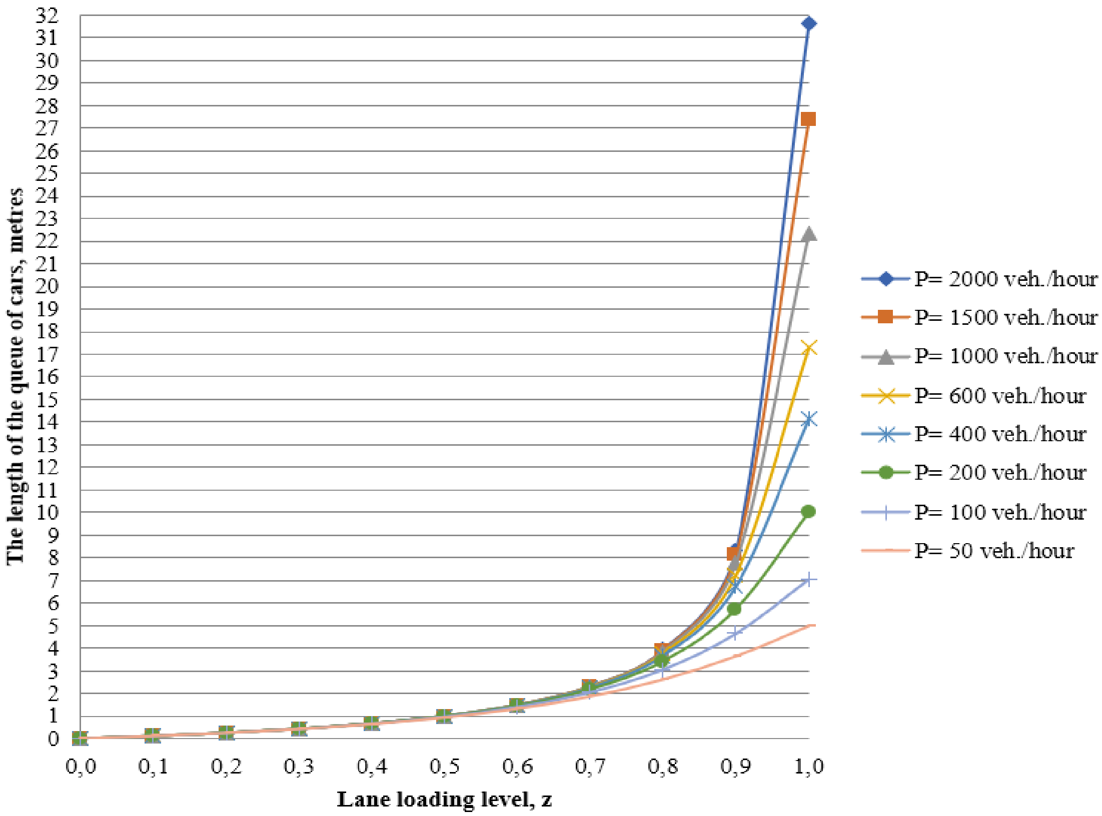

Figure 2. Dependence of the length of the queue of cars on the level of traffic lane load at different traffic lane capacity.

The queue length of 95% of Q_{95} security is determined by the formula (1) (Komarova, 2022; National Academy of Sciences, 2016):

$$Q_{95} = 900T \left[\left(\frac{V_x}{C_{mx}} - 1 \right) + \sqrt{\left(\frac{V_x}{C_{mx}} - 1 \right)^2 + \frac{\left(\frac{3600}{C_{mx}} \right) \left(\frac{V_x}{C_{mx}} \right)}{450T}} \right] \left(\frac{C_{mx}}{3600} \right), \quad (1)$$

where Q_{95} is the queue length of 95% security, m;
T is the duration of the analyzed period (fraction of an hour);
V_x is the intensity of movement of the minor stream, in veh./hour;
C_{mx} is the throughput of the minor stream, in veh./hour.

With the load level $z = 0.7$ accepted in Russia (Federal Agency for Technical Regulation and Metrology, 2019; Ministry of Construction of the Russian Federation, 2018), the queue length was no more than 3.0 m, which is less than the length of one average driven car.

A queue of cars with a length of more than 5.0 m occurs in the case of a maximum load of the junction at $z \geq 0.85$. When assessing the operability of the junction, the time delays of drivers and pedestrians should be taken into account.

An analysis of the time delays of drivers d was carried out depending on the level of traffic lane z and the bandwidth of the lane $C_{mx} = P$ (veh./hour) according to the formula (2):

$$d = \frac{C_{mx}}{3600} + 900T\left[\left(\frac{V_x}{C_{mx}} - 1\right) + \sqrt{\left(\frac{V_x}{C_{mx}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{mx}}\right)\left(\frac{V_x}{C_{mx}}\right)}{450T}}\right] + 5, \quad (2)$$

where d is the drivers' time delay, sec;
T is the duration of the analyzed period (fraction of an hour);
V_x is the intensity of movement of the minor stream, in veh./hour;
C_{mx} is the throughput of the minor stream, in veh./hour.

According to the results of the analysis in Figure 3, the formula (2) is applicable only at P≥400 veh./hour.

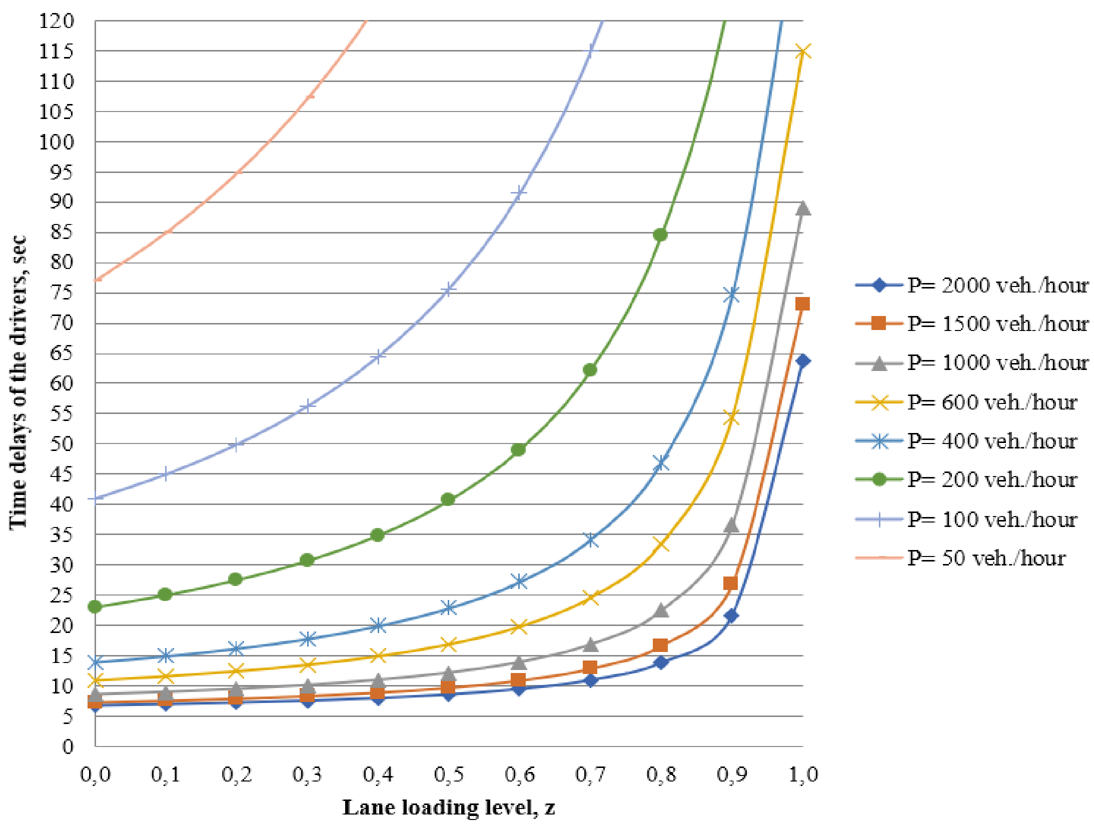

Figure 3. Changing the time delay values of drivers depending on the lane load level with different traffic lane capacity.

RESULTS

A scheme at Figure 4 for determining the minimum distance from the edge of the roadway to the pedestrian crossing l_{min} and formulas (3-5) are proposed:

$$l_{min} = x + R + y, \tag{3}$$

$$l_{min} = l_i^{major} = x_i + R_i + y_i \text{ at } i = 1, 3, \tag{4}$$

$$l_{min} = l_j^{minor} = x_j + R_j + y_j \text{ at } j = 2, \tag{5}$$

where l_{min} is the distance from the edge of the roadway to the pedestrian crossing, m;
x, y are the distances from the beginning/end of the interface radius to the pedestrian crossing or the length of an additional lane for a right turn, if available, m;
R is the radius of the junction, m;
i is the ordinal number of sections of the main road;
j is the ordinal number of the sections of the minor road.

The distances l_min, x and R depend on the composition of the traffic flow, the dimensions of the vehicles, the coefficients of conversion to passenger cars, the length of the queue of cars and the surrounding area.

The value of l_{min} depends on the number of cars in the queue and the average length of the given passenger car l_{av}. The analysis of the average length of the reduced passenger car l_{av} in urban traffic conditions was carried out based on the results of field studies of the composition of the traffic flow and the coefficients of reduction to passenger cars (Pospelov et al., 2021).

The results of the study of the maximum queue length at z = 1.0 and the number of cars in the queue are shown in Table 1.

Table 1. Results of the study of the maximum queue length.

P, veh./hour	Maximum queue length at $z = 1$	Number of vehicles in the queue ($l\_av = 4{,}45\ m$) (Pospelov et al., 2021)	Number of passenger cars in the queue ($l = 4{,}90\ m$) (Ministry of Construction of the Russian Federation, 2018)
2000	31,6	7	6
1500	27,4	6	6
1000	22,4	5	5
600	17,3	4	4
400	14,1	3	3
200	10,0	2	2
100	7,1	2	1
50	5,0	1	1

Design solutions have been developed to ensure the l_{min} distance in the presence of additional lanes for right turns of different lengths for the design schemes in Figure 4.

The design solutions could be presented as high length radius of the curve or added traffic lane in different variations depending on the situation.

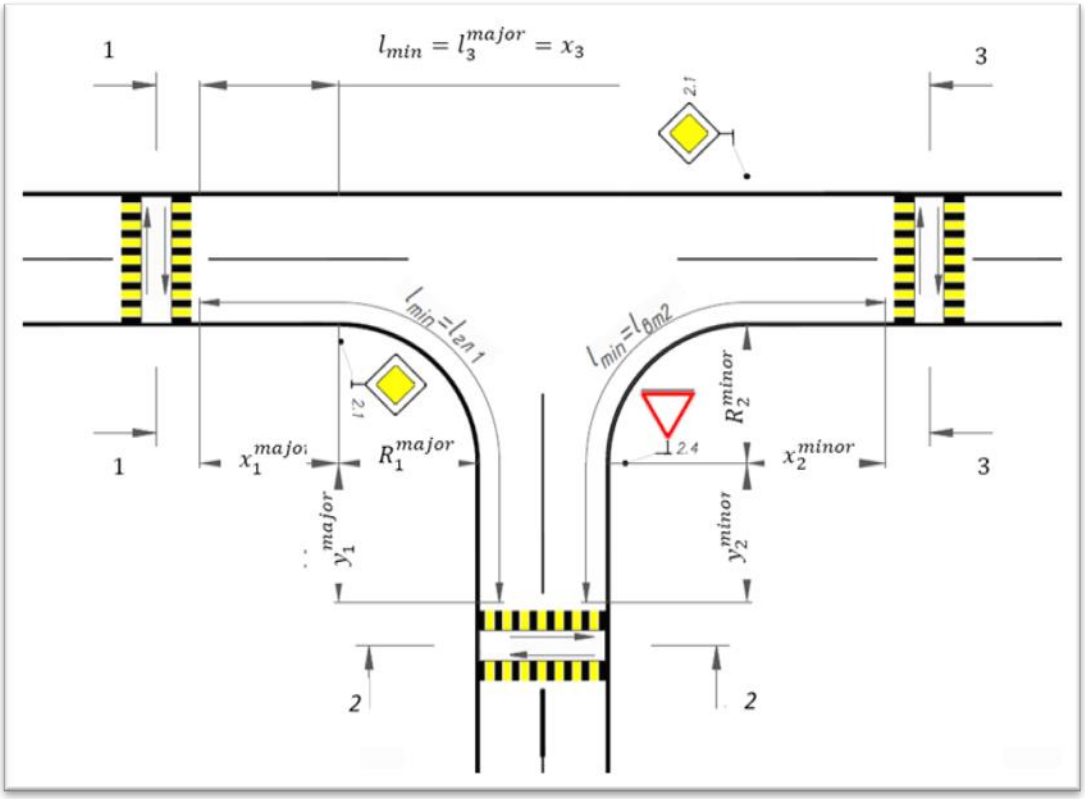

Figure 4. Design schemes of unsignalized junctions.

CONCLUSIONS

- The placement of a queue of cars is possible with the following measures: an increase in the radius of the junction, the installation of additional traffic lanes for right turns.
- Design solutions have been developed to ensure the l_{min} distance in the presence of additional lanes for right turns of various lengths.
- Practical recommendations for increasing the capacity of unsignalized junctions at the same level, given in the article, demonstrate the application of the LOS concept in the context of designing elements of the urban street and road network.
- In the future it is necessary to use a multimodal approach in assessing the quality of service of unsignalized intersections and junctions equipped with a pedestrian crossing as an element of the road network and assessing the impact of the proposed design solutions on the quality of service of the facility.
- International and national requirements for the volume of pollutant emissions require the development of modern technical and design solutions to improve the elements of the road network, increase their efficiency and reduce time delays for drivers.
- The proposed measures in areas near unregulated junctions in high-load conditions will allow you to place a queue of cars off the main road, which will reduce time delays for drivers of the main traffic directions.
- Reducing the time delays of drivers when passing the junction will reduce the volume of exhaust gases and air pollutants.
- Clean air is one of the signs of sustainable development of the urban ecosystem. The proposed measures are aimed at improving air quality, which has a positive effect on the urban environment, the quality of life of the population and the comfort of movement of all road users.

Acknowledgments. The article was prepared as part of the 1st stage of research work carried out at the expense of the federal budget (the source of funding is the Ministry of Education and Science of the Russian Federation) on the topic: "Innovative technical solutions and modifying technology to improve the performance and durability of highways. Development of a new scientifically based and experimentally confirmed method for calculating accumulated deformation and instantaneous loss of bearing capacity of reinforced earthwork and its base under multi-cyclic dynamic loads" (code of the scientific topic FSFM-2024-0025).

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