Simulation testing of traffic flow delays in bus stop zone

Fuad Dashdamirov[1*], *Umidulla* Abdurrazzokov[2], *Kamoliddin* Ziyaev[2], *Turan* Verdiyev[1], and *Ulvi* Javadli[1]

[1]Azerbaijan Technical University, Baku, Azerbaijan
[2]Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. Traffic flows are subject to certain delays due to the maneuvering of buses entering and leaving the stop. The study of how these delays change depending on the frequency of arrival of buses to a stop and, the change of lanes on the road, the intensity of the traffic flow on the road is important in organizing traffic and planning the movement of buses along the route. The article uses simulation models built in the PTV VISSIM program to estimate the delay time of the traffic flow on 2, 3, and 4 lane roads for 4 different values of the intensity of the traffic flow and 5 different values of the bus arrival frequency at the stop. The results obtained are analyzed. The changing nature of traffic flow delays in various scenarios has been studied.

1 Introduction

Bus transportation in cities is of particular importance for the implementation of the movement of the population. Bus routes have an advantage over other types of public transport due to the ability to travel along most sections of city streets. One of the main issues of eliminating city traffic congestion is encouraging the population to use public transport [1]. However, there are cases when some incidents in public transport cause serious traffic problems [2]. In addition, bus transport, like street public transport, has a certain impact on the nature of the traffic flow. Maneuvering buses at curbside bus stops or bus bays creates certain delays in traffic flows. A bus leaving a bus stop has a maneuverability advantage over vehicles moving in the traffic flow, so it obstructs the movement of vehicles. Evaluating these delays can help to make the right traffic management decisions. From this point of view, the issue under consideration is relevant.

As a result of a large number of vehicles on the route, passing through some stops in large cities, there are queues of vehicles trying to enter the stop before the stop, which increases the time loss of vehicles moving in the general flow.

Bus lanes increase the speed and reliability of buses on the route [3]. Introducing special lanes for bus routes should be introduced, considering the traffic flow, passenger traffic, and time losses [4]. However, applying such lanes along the entire route is not always possible. Therefore, it is important to study the change in traffic times depending on the

*Corresponding author: fuad.dashdamirov@aztu.edu.az

operations of buses at stops on streets where special lanes are not organized. The results of these measurements can be used to determine the optimal traffic mode on the considered street.

The maneuvering of buses at the bus bay located in transport pockets creates a serious obstacle to the movement of vehicles moving along the first lane. Traffic delays occur when the bus leaves the bus stop. A large number of studies have been devoted to the study of this issue. However, the impact of such stops on the traffic flow in the first lane has not been studied in detail. The authors studied the relationship between the time of braking, accelerating, and stopping the bus at the entrance to and exit from the stop, including the concepts of occupancy and the influence time of the bus [5].

Yao et al., who quantitatively and qualitatively assessed the intersection's capacity, considered 3 forms of bus lane placement [6]. It has been determined that the distance from the bus stop to the stop line depends on the frequency of arrival of buses at the stop, and the distance between the bus stop and the stop line should be sufficient to leave a place in the lane for buses to leave the stop when the red traffic light is on. For a more accurate assessment of the throughput capacity of a regulated intersection, the authors propose to improve the method for calculating the coefficient of corrective blocking of the bus.

Xiaobao et al. considered conflicts between buses and bicycles when entering a bus stop and with cars when turning into traffic [7]. The authors found that even if the bus stop capacity exceeds 200 bus/h, the bus stop is not considered favorable due to long delays of cars. Therefore, it is advisable to allocate a bus lane.

Public transport travel time affects service reliability, operating costs, and network efficiency. As a disadvantage of the routeing system in many large cities, unplanned stops in public transport are noted. Elhabiby studied the impact of such stops on the quality of service in the city of Cairo and developed a comprehensive plan to ensure the use of GPS data loggers and bus tracking [8]. The location of scheduled and unscheduled stops, speed, and travel time were taken as primary indicators. The initial data was used in modelling the travel time along the route. As a result of the study, it turned out that passengers prefer to get off at unscheduled stops.

The arrival time at the stop is considered the most important, even critical indicator in planning the movement of buses. Determining the delay at a regulated intersection is particularly important when planning the arrival time of buses. In many cases, only the delay time of buses at traffic lights is studied. Zhang et al. considered the effect of traffic lights and traffic on bus delays [9]. Taking into account the remoteness of the regulated intersection and the dynamics of bus traffic, the authors separately studied the travel time of the bus.

To develop public transport in some cities, using traffic lights that prioritize buses and trams is considered appropriate. The authors propose several modifications to the models of movement of public vehicles, combining traffic light regulation with the distribution of traffic flows [10]. Appropriate queue models are created, and optimal solutions for random scenarios are analyzed.

A report by Tang et al. on the effect of bus stop movement on the overall traffic flow shows that initial density and number of stops have the biggest impact on traffic flow stability [11]. The authors analyzed the change in the stability of the traffic flow for a different number of bus stops with a change in the traffic density of buses.

Yang et al. used images from surveillance cameras located around the bus stop to determine the effect of mixed traffic around the bus stop on the travel time of cars [12]. The paper also analyzes the impact of violation of the rules for stopping buses on the movement time.

Nguyen-Phuoca et al. note that bus transportation is one way to eliminate congestion and traffic jams [13]. A three-stage study investigated the impact of increased bus traffic on traffic congestion in Melbourne. With the help of micro-models created in VISSIM, the negative impact of bus stops on the traffic flow was analyzed. It was found that the bus route network reduces the number of traffic jams, delays, and heavily loaded intersections. When developing a macro model of traffic flows, a mathematical model of the change in travel time under the influence of operations performed at a stop is proposed. The delay of the traffic flow at the entrance and exit from the stop was calculated as a percentage of the time of movement in a free flow.

Johari et al. examined the impact of the performance of an urban public transport system on the performance of an urban transport network [14] macroscopically. The authors analyzed the impact of the bus route network on the speed of the traffic flow in 3 locations (near, far, middle), taking into account the intersections of bus stops in different scenarios. The authors found that stops further away from intersections slowed vehicles down less. The work also studied the impact of overlapping stops located far from and near the intersection on network performance.

Transport infrastructure, in particular bus stops, in addition to influencing the quality of public transport, also affects the formation of the driving mode of the vehicle and energy costs [15, 16].

Tu et al. identified the disadvantages of creating bus lanes on busy roads in Nagaoka City based on simulation tests based on traffic conditions and input parameters using the ParaMICS software [17]. In general, many studies have been devoted to studying bus routes by modelling operations at the bus stop [18,19,20,21,22, 23]. However, computer simulations of the impact of bus stop maneuvers on traffic flow are almost non-existent.

Gasser et al. [24] developed a microscopic model of bus passage from traffic bottlenecks and quantified the flow of both cars and buses.

Dakic et al. analyzed the impact of bus route network operation on traffic flow [25]. The authors have developed a model for creating an optimal route network of buses in conditions of free and saturated traffic flow, considering loading during peak hours, mixed traffic flow, and various traffic modes. However, the simultaneous consideration of many random variables using an analytical model during the optimization of the transport network may not be appropriate.

2 Objects and methods of research

The object of the study is traffic flow delays in the area of a curbside bus stop and the area of a bus bay. In the transport network, it is possible to carry out analytical measurements to consider the impact of bus operation at a stop on the movement of cars along road sections. The formula proposed by the US Bureau of Public Roads (BPR) to calculate the travel time between two vertices of the transport network takes into account traffic intensity and road capacity [26]:

$$t_{ij} = t_{ij}^{0}\left[1+\alpha\left(\frac{N_{ij}}{C_{ij}}\right)^{\beta}\right] \tag{1}$$

Here; t_{ij}^{0} is the travel time between the peaks i and j in a free traffic flow; N_{ij} is the intensity of the traffic flow between the peaks i and j; C_{ij} is the actual capacity of the road between the peaks i and j; α and β are correction factors. The US Bureau of Public Roads recommends values $\alpha = 0.15, \beta = 4$.

The formula proposed by Davidson suggests finding the travel time in terms of the delay time parameter [27]:

$$t_{ij} = t_{ij}^{0}\left[1 + J\left(\frac{N_{ij}}{C_{ij} - N_{ij}}\right)\right] \tag{2}$$

Here; J is delay parameter.

Methods are also proposed for considering the influence of traffic lights along the road to calculate the time spent on the passage of the considered section of the road [28,29,30].

The applied methods make it possible to consider road delays using certain coefficients. The values of these coefficients take on different values in different conditions. Using these methods, it is difficult to determine the nature of the impact of the operation of stopping points and to assess the extent of this impact. A simulation test using software tools can be used to estimate the traffic flow loss time due to block traffic maneuvers at the bus stop.

The PTV VISSIM software tool is currently widely used when planning an urban transport system. In the PTV VISSIM environment, we will measure the time loss at a different traffic flow intensities and different bus arrival frequencies on a 2600 m street section with the bus stop zone.

Simulation models of a road section were built in the PTV VISSIM program to evaluate and compare delays in traffic flows in the bus stop zone (Fig. 1.). We create various scenarios to take into account the impact of the entry and exit of buses from the bus stop on the average travel time of traffic flow. To do this, we assign different values of the intensity of the traffic flow on a 2, 3, and 4-lane road and the frequency of arrival of buses at a bus bay and a curbside bus stop. The measurements are repeated for cases where the speed limit in traffic is 50 km/h.

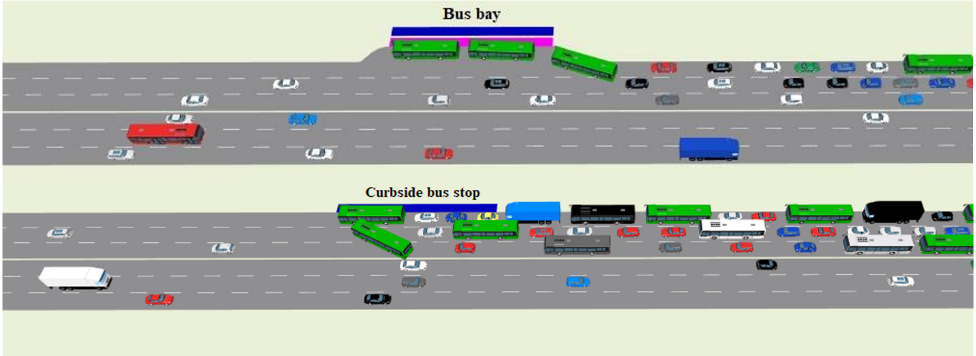

Fig. 1. Simulation of bus maneuvers at a bus bay and a curbside bus stop in the PTV VISSIM environment

The traffic flow time loss is estimated, averaged, and compared for various scenarios. With an increase in both the intensity of the traffic flow and the frequency of arrival of buses, the time it takes the traffic flow to pass the territory under consideration is estimated. Based on the measurement values obtained using the models installed in the PTV VISSIM software, the influence of bus maneuvers at the stop and queues in front of the bus stop on the traffic flow parameters is analyzed.

3 Results and Discussion

The average time taken to pass the considered distance by vehicles through the stop zone on a 2, 3, and 4-lane road was measured at a frequency of bus arrivals at the stop of 80, 100, 120, 140, 160, and 180 bus/h and at the traffic intensity of 800, 1000, 1200 and 1400 veh/h for both the bus bay and the curbside bus stop.

The change in the average travel time of the considered distance in different scenarios depending on the frequency of bus arrivals at the stop and the number of lanes for the methods of organizing the stop is shown in Fig. 1-6.

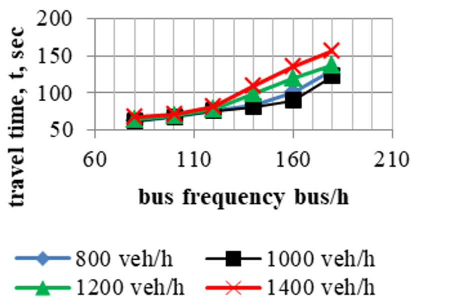

Fig. 1. Impact of bus arrival frequency on average travel time when placing a curbside bus stop on a 2-lane road

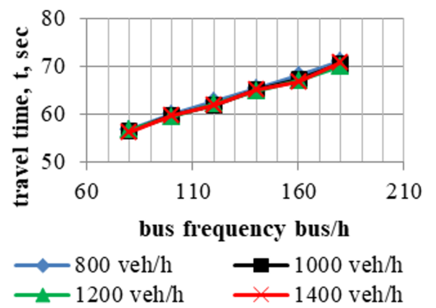

Fig. 2. Impact of bus arrival frequency on average travel time when organizing a bus bay on a 2-lane road

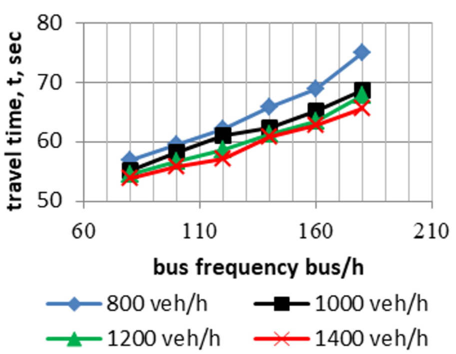

Fig. 3. Impact of bus arrival frequency on average travel time when placing a curbside bus stop on a 3-lane road

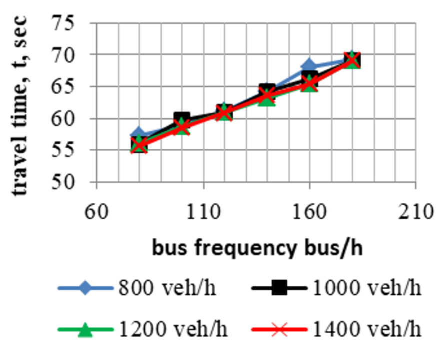

Fig. 4. Impact of bus arrival frequency on average travel time when organizing a bus bay on a 3-lane road

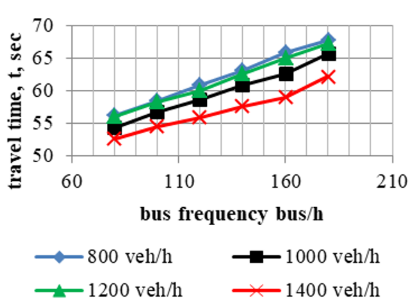

Fig. 5. Impact of bus arrival frequency on average travel time when placing a curbside bus stop on a 4-lane road

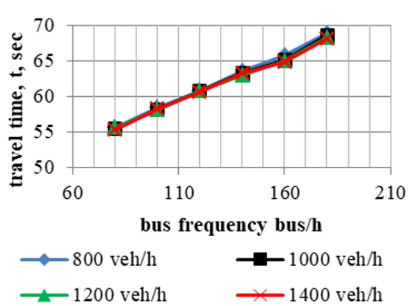

Fig. 6. Impact of bus arrival frequency on average travel time when organizing a bus bay on a 4-lane road

As can be seen from the figures, the average travel time for all values of the intensity of the traffic flow increases with the increase in the frequency of bus arrivals at the stop.

For curbside bus stops, delays in the traffic flow entail large values. This delay is more noticeable when the number of lanes is low. The organization of a curbside bus stop slows down the traffic flow more at high (1400 a/h) values of traffic intensity on a 2-lane road (Fig. 1). Although the delay time increases with increasing traffic on a 3- and 4-lane road, the shortest travel times correspond to the largest traffic volumes (Fig. 3, Fig. 5).

As can be seen, the frequency of bus arrivals at a bus bay increases traffic flow delays. However, an increase in traffic intensity does not significantly impact this growth.

Table 1 shows the values of the average travel time depending on the increase in the number of traffic lanes in the bus stop zone, organized both on the curbside and on the bus bay at various values of the intensity of the traffic flow.

As can be seen from the table, at a constant value of the frequency of arrival of buses at a stop, with an increase in the intensity of the traffic flow from 800 veh/h to 1400 veh/h, the average travel time under consideration distance does not change significantly. But at fixed values of the intensity of the traffic flow, with an increase in the frequency of bus arrivals at a stop from 80 bus/ h to 180 bus/ h, the travel time changes significantly.

Table 1. Average travel time of vehicles through the section with bus stop zone organized both on the curbside and on the bus bay at various values of the intensity of the traffic flow

Frequency of bus arrivals at the stop, bus/h	The intensity of the traffic flow passing through the bus stop zone, veh/h					
	800			1000		
Average travel time of vehicles on the section with a bus bay, sec						
80	56.74	57.21	55.61	56.51	55.93	55.4
100	60	58.95	58.41	59.64	59.79	58.14
120	62.57	61.19	60.81	61.99	60.86	60.84
140	65.53	64.15	63.65	65.09	64.1	63.27
160	68	68	65.76	67.37	66.23	65.22
180	71.16	69.28	68.94	70.55	69.02	68.64
Average travel time of vehicles on the section with a curbside bus stop, sec						
80	62.26	56.95	56.21	61.98	55.12	54.35
100	67.57	59.52	58.47	68.07	58.16	56.73
120	75.53	62.18	60.81	75.74	61.07	58.61
140	83.78	65.83	63.11	80.56	62.34	60.92
160	101.2	68.8	65.87	89.98	65.13	62.54
180	130.56	75.08	67.83	122.77	68.76	65.62

Continuation of table No. 1.

Frequency of bus arrivals at the stop, bus/h	The intensity of the traffic flow passing through the bus stop zone, veh/h					
	1200		1400			
Average travel time of vehicles on the section with a bus bay, sec						
80	56.67	56.03	55.58	56.24	55.54	55.29
100	59.55	58.62	58.12	59.75	58.45	58.25
120	62.06	60.94	60.76	61.78	60.83	60.7
140	64.92	63.21	62.9	65.25	63.62	63.27
160	66.95	65.44	65.07	66.69	65.46	64.77
180	70.12	69.06	68.26	70.78	69	68.12
Average travel time of vehicles on the section with a curbside bus stop, sec						
80	63.93	54.48	55.94	66.9	53.76	52.55
100	69.42	56.64	58.19	71.45	55.86	54.55
120	78.07	58.54	59.98	80.57	57.13	55.82
140	98.19	61.17	62.56	109.94	60.76	57.53
160	119.53	63.34	64.96	134.77	62.75	59.03
180	136.39	67.74	67.26	156.48	65.69	62.15

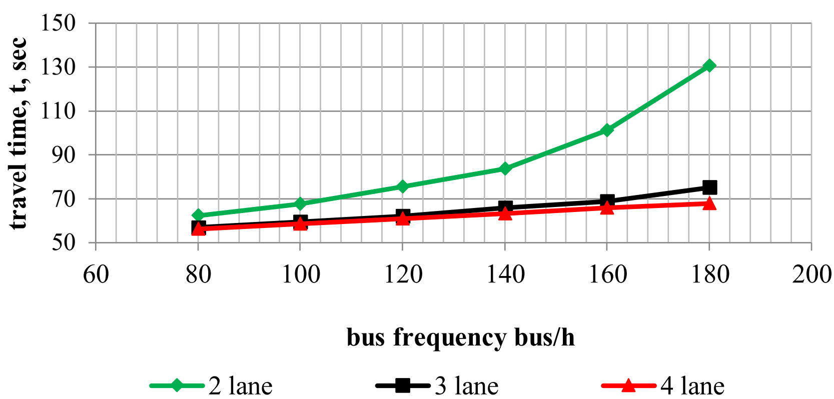

Fig. 7. Influence of the frequency of bus arrivals at a curbside bus stop on the average travel time of vehicles on the road at a traffic flow rate of 800 veh/h

As can be seen from the figure, an increase in the number of traffic lanes passing through the curbside bus stop area significantly impacts average travel time. Traffic delays on a 2-lane road increase dramatically as the frequency of bus arrivals at a stop increases. For example, with a traffic flow on a two-lane road of 800 veh/h and a bus arrival frequency of 80 bus/h, the average travel time for the section under consideration is 62.2 seconds, and at a bus arrival frequency of 180 bus/h, it is 130.6 seconds. The average travel times for a 3-lane road are 56.9 sec for 80 bus/h arrivals and 75.1 sec for 180 bus/h arrivals, respectively. On a 4-lane road, average travel times through the curbside bus stop zone are 56.2 and 67.8 sec, respectively.

Fig. 8 shows the influence of the frequency of arrival of buses at a bus bay on the vehicles' average travel time on the section.

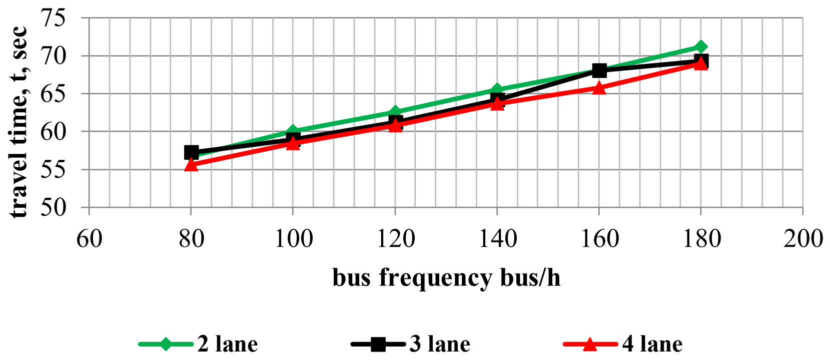

Fig. 8. Influence of bus arrival frequency at a bus bay on the average travel time of vehicles on the road at a traffic flow intensity of 800 veh/h

As can be seen from the figure, at the different intensities of the traffic flow, for vehicles passing through the bus bay zone, an increase in the number of lanes does not significantly affect the average travel time of the considered distance.

At high traffic flow intensity values (1000, 1200, and 1400 veh/h), the nature of the change in the travel times for the section with both the curbside bus stop and bus bay zone is the same, depending on the increase in the number of road lanes. As can be seen from Table 1, an increase in the intensity of the traffic flow on a 2-lane road significantly increases the average travel time of the traffic flow passing through the curbside bus stop zone. For example, on a two-lane road, with a bus arrival rate at a stop of 180 bus/h, the average travel time at a traffic intensity of 800 veh/h on the road is 130.56 seconds, at 1000 veh/h is 122.77 seconds at, at 1200 veh/h is 136.39 seconds, at 1400 veh/h is 156.48 seconds.

If a bus lane is used, the number of lanes used by vehicles is reduced, and traffic delays occur. However, this effect is minimal as the number of traffic lanes increases. Table 2 shows the average travel time values for the traffic flow passing through the bus stop zone when using bus lanes.

Table 2. Average travel time values for the traffic flow through bus stop zone when using special lanes for buses

Traffic flow intensity, veh/h											
On a 2 lane road				On a 3 lane road				On a 4 lane road			
800	1000	1200	1400	800	1000	1200	1400	800	1000	1200	1400
Average travel time trough under consideration distance, sec											
56.40	57.01	57.71	59.52	55.35	55.59	55.78	55.95	55.02	55.16	55.27	55.32

As can be seen from the table, in the case of using a special lane for buses, the for vehicles average travel time for a given distance does not differ significantly with a change in the number of lanes and traffic intensity.

4 Conclusion

The study of the influence of various factors on traffic delays on city streets is important from the point of view of improving traffic management. Like street public transport, bus transport interacts with traffic flows in various conditions. Analytical models are available to study this effect. However, the effects of different stop locations, changes in bus arrival times, different traffic volumes, and different numbers of lanes can be more effectively analyzed using simulation models.

The results obtained using the simulation model created in PTV VISSIM show that if there is a bus stop in the considered dis of the road, increasing the frequency of arrivals of buses to this stop significantly increases the time for vehicles to pass the considered section. This effect is more pronounced in curbside bus stop zones than bus bay zones.

The results obtained can be used in organizing the work of buses on the route and ensuring the optimal mode of traffic flow in the bus stop zones.

References

1. Aftabuzzaman M., Currie G., and Sarvi M. Evaluating the congestion relief impacts of public transport in monetary terms. Journal of Public Transportation, Vol. 13(1), pp.1-24. (2010).
2. Nguyen-Phuoc D. Q., Currie, G., De Gruyter, C., and Young, W. Exploring the impact of public transport strikes on travel behavior and traffic congestion. International journal of sustainable transportation, Vol. 12(8), pp. 613-623. (2018).
3. Cesme B., Roisman R., Burns R., List K., Koudounas A., Cuellar J., and Miller D. Strategies and barriers in effective bus lane implementation and management: best practices for use in the greater Washington, DC region. Transportation Research Record, Vol. 2672(8), pp. 29-40. (2018).
4. Szarata M. Bus lane implementation strategy. Transport problems, Vol. 17(3), (2022) DOI: 10.20858/tp.2022.17.3.08
5. Kwami A. V., Kuan Y. X., and Zhi X. Effect of bus bays on capacity of curb lanes. Journal of American Science, Vol. 5(2), pp. 107-118. (2009).
6. Yao J., Xu J., and Zhao J. Effect of near-side on-line bus stop on signalized intersection capacity. International Journal of Control and Automation, Vol. 8(12), pp. 393-402. (2015).
7. Yang X. B., Huan M., and Gao Z. Y. Car delay model near bus stops with mixed traffic flow. Journal of Applied Mathematics, pp.483-488. (2013).
8. Elhabiby M. M., Fikry A. O., Mahdy H. A., and Kandil K. A. Influence of unscheduled random public bus stops on transit travel time. Journal of Traffic and Logistics Engineering, Vol.1(1), pp. 20-21. (2013).
9. Zhang H., Liang S., Han Y., Ma M., and Leng R. A prediction model for bus arrival time at bus stop considering signal control and surrounding traffic flow. IEEE Access, 8, pp. 127672-127681. (2020).
10. Rech E., and Timpf, S. Simulating changing traffic flow caused by new bus route in Augsburg. (2021).
11. Tang T. Q., Li Y., and Huang H. J. The effects of bus stop on traffic flow. International Journal of Modern Physics, Vol. 20(06), 941-952. (2009).
12. Yang X., Gao Z., Guo H., and Huan M. Survival analysis of car travel time near a bus stop in developing countries. Science China Technological Sciences, Vol. 55, pp. 2355-2361. (2012).
13. Nguyen-Phuoca D.Q., Curriea G., De Gruyter C., Kim I., Young W. Modelling the net traffic congestion impact of bus operations in Melbourne. Transportation Research Part A, 117, pp. 1-12 (2018).

14. Johari M., Keyvan-Ekbatani M., and Ngoduy D. Impacts of bus stop location and berth number on urban network traffic performance. IET Intelligent Transport Systems, 14(12), 1546-1554. (2020).
15. Mukhitdinov A., Ziyaev K., Omarov J., and Ismoilova S. Methodology of constructing driving cycles by the synthesis. In E3S Web of Conferences, Vol. 264, p. 01033. (2021).
16. Abdurazzokov U., Sattivaldiev B., Khikmatov R., and Ziyaeva S. Method for assessing the energy efficiency of a vehicle taking into account the load under operating conditions. In E3S Web of Conferences, Vol. 264, p. 05033. (2021).
17. Tu T. V., Sano K., and Tan D. T. Comparative analysis of bus lane operations in urban roads using microscopic traffic simulation. Asian Transport Studies, Vol. 2(3), pp.269-283. (2013).
18. Larin O., Mavrin V., and Almetova Z. Simulation modeling for the evaluation of conflicts at stops of the urban route network. Transportation research procedia, Vol. 36, pp. 411-417. (2018).
19. Hawas Y. E. Simulation-based regression models to estimate bus routes and network travel times. Journal of Public Transportation, Vol. 16(4), 107-130. (2013).
20. Bąk R. Simulation model of the bus stop. Archives of Transport, Vol. 22(1), pp. 5-25. (2010).
21. Fernández R. Modelling public transport stops by microscopic simulation. Transportation Research Part C: Emerging Technologies, Vol. 18(6), pp. 856-868. (2010).
22. Dashdamirov F. Modeling of buses operation at stops with intensive use. Scientific Collection «InterConf+», Vol. 27 (133), pp. 342-352. (2022).
23. Kutlimuratov K., and Mukhitdinov A. Impact of stops for bus delays on routes. In IOP Conference Series: Earth and Environmental Science, Vol. 614, p. 012084. (2020).
24. Dakic I., Leclercq L., and Menendez M. On the optimization of the bus network design: An analytical approach based on the three-dimensional macroscopic fundamental diagram. Transportation Research Part B: Methodological, Vol. 149, pp.393-417. (2021).
25. Gasser I., Lattanzio C., Maurizi A. Vehicular Traffic Flow Dynamics on a Bus Route. SIAM Journal on Multiscale Modeling and Simulation, Vol. 11(3). (2013).
26. Zhang J., Liu M., and Zhou B. Analytical model for travel time-based BPR function with demand fluctuation and capacity degradation. Mathematical Problems in Engineering, pp. 1-13. (2019).
27. Manual H. C. Highway capacity manual. Washington, DC, 2(1). (2000).
28. Akçelik R. Travel time functions for transport planning purposes: Davidson's function, its time dependent form and alternative travel time function. Australian Road Research, Vol. 21(3). (1991).
29. Xie C., Cheu R. L., and Lee D. H. Calibration-free arterial link speed estimation model using loop data. Journal of Transportation Engineering, Vol. 127(6), pp. 507-514. (2001).
30. Skabardonis A., and Dowling R. Improved speed-flow relationships for planning applications. Transportation research record, Vol. 1572(1), pp. 18-23. (1997).