



Transport and Telecommunication, 2023, volume 24, no. 3, 309–319
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/tjt-2023-0025

IMPROVING OF INTERACTION OF ROUTES AT HIGH DENSITY STOPS BY ADJUSTING BUS ARRIVAL TIME

Fuad Dashdamirov

Azerbaijan Technical University
Baku, Azerbaijan, H.Javid 25
fuad.dashdamirov@aztu.edu.az

A significant part of the movement of the population in large cities is carried out by bus transport. Higher accessibility and connection to the network of other types of public transport are the main features of bus transport. The need for mass passenger transportation in Baku mainly is met by the metro and bus transport. A small number of metro stations and insufficient coverage of the city territory by metro network have significantly increased the load on the bus service. With the increase in passenger traffic, the frequency of bus routes has increased, and the intervals have decreased. As a result, bus traffic on some streets has become more intense. This led to an increase in the number of buses arriving at the stops at the same time and the formation of queues in front of the stops. To solve the problem, the article proposes a method for coordinating bus schedules of different routes and adjusting the time of arrival at a stop without changing the intervals. As a result of applying the proposed methodology, by modelling the sequence of bus arrivals in the Anylogic program, a reduction in queues and loss of time in front of the bus stop is justified. Simulation testing was carried out for the scenario of bus movement both in the general flow and along the bus lane.

Keywords: Bus route, stop, coordination, queue, simulation

1. Introduction

One of the main types of public transport in large cities is bus transport. Bus transport operates in parallel with other types of public transport or as a mode of transport bringing passengers to their lines. In most major cities in the world, many types of public transport serve the population in parallel. The sequence of use of public transport modes in many cities was formed by natural conditions, the historical development of cities and the emergence of public transport modes. Recently, in some large cities, the majority of the population prefers personal transport. To maintain the competitiveness of public transport, it is possible due to the high quality of service and the creation of an integrated transport system (Poliak *et al.*, 2017).

In Baku city, passengers are served by the metro (26 stations on 3 lines), bus transport (172 routes), as well as suburban high-speed trains (on 2 lines). The fact that the subway service network does not cover the entire city area has led to an excessive increase in the number of bus routes. This increase in the number of routes leads to an increase in the number of buses passing through the same stop on some streets and queues in front of the stops. At the same time, there are violations of the bus operation mode, an increase in the delay time at the bus stop and, as a result, a decrease in the quality of passenger service.

The accumulation of a large number of vehicles of different routes at a stop leads to the formation of queues before stopping, which can also cause a delay in the movement of the general traffic flow.

The work of the bus route network should be based on the real demand of passengers and be consistent with the work of other modes of transport. When organizing traffic on city bus routes, such main factors as the properties of city streets and roads (road slope, number of traffic lights and mode of operation), the intensity and pattern of passenger arrival at the bus stop, as well as the capacity of bus stops are taken into account (Dashdamirov, 2011).

If stops are used by a large number of vehicles on different routes, it is necessary to coordinate the work between these routes. This issue is more relevant for bus routes, as at bus stops operations take longer time than other forms of public transport.

2. Literature review

Numerous research works have been carried out and results have been obtained in the direction of establishing a bus schedule. This includes research on the coordination of the operation of different routes, the development of simulation models for the operation of the route network. Hafezi and others (2011)

reviewed these studies in detail and commented on the proposed models for improving bus routes in different countries.

In works devoted to the study of regularity and punctuality, characterizing the operation of buses on the line, there are different approaches to solving this problem. Kho *et al.* (2005) evaluate the punctuality of bus approach to a stop using the punctuality index and characterize the traffic punctuality index. The attractive side of public transport for passengers lies in its regular service. Therefore, an assessment of the regularity of public transport routes can lead to the correct organization of its work and, as a result, to an increase in its users. Melakhsou and Bhourri (2019) used the Gini Significance Index based on the Lorenz Curve to estimate intervals and traffic regularity in Dehli. The indicators that create the highest correlation with this indicator are determined.

Reijsbergen and Gilmore (2014) use stop arrival time, passenger delays, etc. to evaluate the punctuality of buses during the simulation. The authors show that the punctuality of bus traffic is affected by traffic intensity, road factors, the number of stops and length of the path, traffic control strategies, the diversity of driver skills, the distribution of passenger demand, etc.

The stop time is a scheduling indicator, but may vary depending on the influence of some factors. Sun *et al.* suggest considering the delay time at a stop as the sum of delays in arriving and leaving a stop. An analysis performed using a model that estimates the occupancy of places at stops using the theory of queuing makes it possible to determine the delay time at a stop (Sun *et al.*, 2015). In analytical modelling of bus stops, one can model the arrival at the stop, determine the capacity of the stop, and use queuing theory. Lindberg (2019) proposes a discrete event simulation of the process in and around a bus stop using the Sim Event software.

Recently, computer modelling has been widely and effectively used in the study of bus routes, their sections and the operation of bus stops. Ghariani *et al.* (2014) compared the capabilities of AIMSUN, VISSIM, PARAMICS, CORSIM, SUMO, TRANSIMS, ARCHISIM programs for modelling public transport. The researchers determined that among the considered programs, VISSIM has more opportunities to take into account the characteristic parameters of transport infrastructure, vehicles, drivers and passengers. However, these programs, including VISSIM, cannot take into account the changing characteristics of vehicles. In VISSIM and AIMSUN, this can be done in an external programming environment only with the help of special modules.

There are various techniques for creating microscopic simulation models of bus stops. Rodrigo Fernandez (2010) proposed to consider the operation of a bus stop as part of the traffic flow mechanism and to use the algorithm for modelling the stop of buses and light rail transport (PASSION), based on the formulas of the Highway Capacity Manual. Kumararaja and Karuppanan (2016) analyzed the impact of optimal bus stop placement, interaction between passengers, buses and traffic flow at stop delay time and developed a Microscopic Bus Stop Simulation Model (VISSIM).

Bak (2010) analyzed the bus stop as a system consisting of a bus stream. At the same time, the author, who proposed a methodology for estimating losses associated with queues of buses approaching a stop, also indicated the factors that must be taken into account when determining the number of boarding and alighting zones depending on the intensity. The author established a theoretical regularity in the distribution of time lost at a stop, analyzed the effect of time lost at a traffic light before a stop on the interval of arrival of buses. The author chose the types of buses (8, 12, 18 meters in length), the number of places at stops (hourly bus traffic is 10-90 units/hour), the width of the shoulder (20-60 meters), the time of boarding and alighting passengers as input parameters, compared the loss of time obtained as a result of measurements and simulation using a program in the C language.

Al-Mudaffar *et al.* (2016) noted that the HCM 2000 formula proposed for calculating the throughput of a stop does not take into account the time spent on turning and braking the bus before entering the stop, pedestrian crossings, as well as the impact of the violations of the frequency of arrival of buses at the stop. It is concluded that the failure to take into account the distribution of bus arrivals at the stop led to an incorrect calculation of the stop's throughput. Therefore, it was proposed to include a correction factor in the formula, taking into account the percentage risk of getting into the queue before stopping, and an empirical factor was added to the formula, based on experience in Swedish cities.

In another work based on the theory of queuing, a simulation model of a bus stop was developed by simulating the boarding and alighting of passengers, and the bus queue intensity factor was calculated (I Casas *et al.*, 2014). Elsayed and Torstensson (2020) comparatively designed a bus stop in two versions with respect to bike lanes and analyzed the results by developing a simulation model using PTV VISSIM.

Nikolaev *et al.* (2017) separated the agents as park, passenger, stop, and transport to simulate public transport in the Anylogic software. In the article, a logic diagram was built to simulate the process at stops, the movement of buses was simulated, which completed their work at the stop and returned to the park, and

continued their work on the line after boarding and alighting passengers. Graphs of changes in the waiting time of passengers and the occupancy of seats on the bus are given.

Azemsha (2021) showed that schedule deviations were significantly reduced as a result of the proposed technique with the construction of a discrete-event simulation model in GPSS WORD for bus routes with coinciding sections. When building a model for the proposed scenario, it was proposed to determine the interval of movement of buses operating on 6 coinciding sections of bus routes in the city of Gomel, based on the number of all buses operating on the routes. Building micro-simulation models of bus routes makes it possible to better understand the dynamics of work on the route. Many models are devoted to simulating the interaction of buses with other buses and passengers. The model proposed by Kieu *et al.* (2019) provides a numerical analysis of scheduling performance and comparison with existing models. It is also noted in the paper that the parameters of the movement of buses are actually stochastic, and therefore the model of the pursuit of the schedule is more accurate than the model of the pursuit of buses on the route. A study in Australia designed to improve schedule compliance involves calibrating the model by determining the location of buses on the Brisbane route. It is noted that the developed model can be successfully applied in other cities.

The work of Moosavi *et al.* (2020) notes the insufficiency of theoretical methods for the organization of bus traffic and shows the importance of simulation modelling. As the main elements of each transport network, the behaviour of passengers, the dynamics of traffic and the parameters of the movement of buses on the routes are noted. Route U32 was chosen for the simulation, passing through the busiest streets of Kuala Lumpur. A model of passenger demand, a model of travel time, a model of staying at a stop were developed, the proposed strategies were integrated, and the index of the regularity of development of various strategies was compared.

Fernández and Valenzuela (2003) used modern traffic management theory to determine the optimal distance between stops to develop a micromodel of a public transport corridor. The authors found that with the optimal choice of the distance between stops. It is possible to increase the speed of movement by 8-20%.

Agent-based modelling provides developers with certain advantages. Boev (2011) notes the advantages of agent-based modelling over discrete-event modelling in the GPSS WORD environment. Van der Spek (2017) proposed an agent-based model using the Anylogic software for a bus route passing from busy streets. In the simulation model, an agent-based simulation model is proposed that takes into account the modes of movement of the bus route and the regularity of the arrival of passengers at the stop, a statistical analysis is carried out for existing bus routes. Gkiotsalitis (2020) has developed a regularity-based optimization option for high-density bus routes. In this paper, the results of the solution using the heuristic search method were presented, the process was modeled using SUMO and calibrated using COBYLA.

3. Methodology

It is known that the number of vehicles operating on bus routes is determined by passenger traffic. The interval of movement between vehicles on the line is determined by the number of buses and the turnaround time on the line. This means that in order to meet the needs of passengers, the intervals between buses should be maintained. Therefore, it is proposed to shift the arrival times of buses of different routes while maintaining the intervals of movement along the route.

First, the busiest bus stops in the city are determined and the modes of operation of the routes passing through these stops are analyzed. The traffic parameters of bus routes passing through one of the most intensively used bus stops are analyzed.

At the selected stop serving a large number of buses of different routes, the process of arrival of buses to the stop is investigated and a comparison is made in terms of time losses under different scenarios. In order to correct and optimize the operating modes of routes at the stop in question, a model of the order of arrival of buses of different routes to this stop is proposed. The shift in the arrival time of buses to a specific stop does not affect the operation of buses on routes. The reduction of time losses as a result of the reduction of queues before stops according to the proposed scheme is justified by testing different scenarios in the simulation model developed in Anylogic.

4. Analysis of bus stops with high bus arrival frequency

The bus stops with the highest congestion and queues of buses in Baku are the bus stops located near the 8th km Bazaar, Neftchilar metro station, Gara Garayev metro station and stop at the Moscow

Avenue. The number of routes passing through these stops, the route numbers and the location type of stops are shown in Table 1.

Table 1. Indicators of heavily used bus stops

Stop	Routes numbers passing through the stop	Number of routes passing through the stop	Location type of the stop on the road
8th km Bazaar	11,12,15,22,,35,36,40,44,49,50,51,54,57,60,62,64,70,7a,81,	19	pocket
Moscow Avenue (Shamakhinka)	2,13,14,18,29,37,65,67,7a,83,92,119,135,156,170,193,199,525	18	pocket
Neftchilar metro station	11,12,15,22,35,36,40,44,49,50,51,54,57,60,62,64,70,7a,81	19	pocket
January 20 metro Station	2,13,14,18,29,37,65,7a,83,102,119,159,193,199,114a,114b	16	pocket

The queues of a large number of buses at the stops shown in Table 1 cause serious problems in the organization of traffic, causing delays in traffic and pedestrian flows. A bus entering and leaving a stop interferes with the general traffic flow. Among these stops, the most difficult is the 8th km bazaar stop, as it is also located in front of the intersection. As can be seen from the schematic view of the bus stop “8th km Bazaar” according to the satellite image (Figure 1), there is a traffic jam at the bus stop and queues of buses entering to the bus stop.

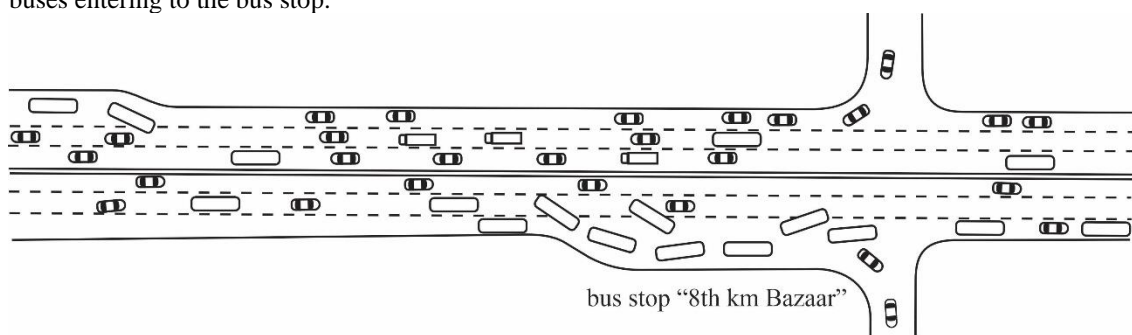


Figure 1. Schematic view of the bus stop “8th km Bazaar” according to the satellite image (from Google Earth)

From the stop near the 8th km Bazaar in the city of Baku, 19 bus routes run. The indicators of routes passing through this stop are shown in Table 2.

Table 2. Indicators of bus routes passing through the stop " 8th km Bazaar "

Bus stop	Route	Start and end stop	Interval, min.	Route length, km		Start and end times
				Forward direction	Reverse direction	
Bazaar 8th km	11	Park "Nikola Tesla" → School №257	7	19,8	20,5	6:00-00:00
	12	Tuberculosis dispensary №4 → Sadygdzhana street	5	11,29	11,88	6:00-00:00
	15	Koroglu metro station → Market "Happy"	7	15,19	13,99	6:00-23:00
	22	Sabunchu circle → Market "Emin"	12	14,4	16,36	6:00-23:00
	35	Komsomolsky circle → Hypermarket "Bravo"	8	15,19	13,49	6:00-00:00
	36	Ulduz metro station → t/c "Gunashli"	9	19,08	17,81	6:00-23:00
	40	Sabunchi railway station → Supermarket "PremiumMart"	6	17,23	16,68	6:00-00:00
	44	Gara Garaeva metro station → School №317	8	15,72	13,89	6:00-00:00
	49	Garden "Samed Vurgun" → School №68	5	22,2	21,98	6:00-00:00
	50	Neftchilar metro station → t/c "Gunashli"	4	9,54	5,63	6:00-23:00
	51	Neftchilar metro station → School №221	5	12,46	15,1	6:00-00:00
	54	Bazaar 8th km. → Market "Rabil"	20	7,26	7,03	6:00-22:00
	57	Bakikhanov railway station → Winery	6	13,79	16,49	6:00-23:00
	60	Koroglu metro station → School №221	7	22,44	18,57	6:00-23:00
	62	School №48 → Sabunchi railway station	4	14,73	16,8	6:00-00:00
	64	Neftchilar metro station → Concrete plant "AS RA"	4	10,85	9,17	6:00-23:00
	70	School N155 → Hospital "Azersutikinti"	10	17,24	20,53	6:00-22:00
	7a	International bus station → Residential complex "Khatai Park"	7	23,78	23,07	6:00-22:00
	81	Brick factory → Yusif Eyvazov street	4	12,12	14,22	6:00-00:00

As can be seen from Table 2, the interval of movement between buses ranges from 4 to 20 minutes on bus routes passing through the "8th km Bazaar" stop.

When a large number of vehicles arrive at a stop at the same time, solutions such as separating stops along a city street or limiting the use of specific stops to certain routes can be proposed. However, in the first case, the quality of road use decreases, and in the second case, the quality of passenger service decreases.

Most of the bus routes described in Table 2 stop at Gara Garayev Avenue. It should be noted that Baku Metro stations are located along Gara Garayev Avenue. This indicates that the passenger flow of street transport in this direction will not decrease in the future. Therefore, it is important to develop a methodology for eliminating bus queues and loss of time at stops by improving the traffic modes of existing routes.

4.1. Analysis of dwell time at bus stops

The delay of the bus at the stop is divided into 3 main parts: the loss of time caused by the queue before the stop due to the fullness of the stop, the time of boarding and alighting passengers at the stop and the time for which they leave the stop (Huo *et al.*, 2018). Analyzes have shown that the time spent at bus stops situated before traffic lights longer than bus stops in residential areas (Arhin *et al.*, 2015). In addition, the time spent at a stop has different meanings depending on the time of day and the type of stop. Studies conducted using automatic vehicle location tools and automatic passenger counting tools revealed the effect of passenger activity, bus floor height and time of day on the duration of bus stay in the bus stop (Dueker *et al.*, 2004).

The stop time is determined as follows, depending on the number of alighting and boarding passengers and the time of their alighting and boarding, as well as the time of opening and closing the doors (Cortes *et al.*, 2010):

$$t_d = P_a t_a + P_b t_b + t_{oc}, \quad (1)$$

where t_d - dwell time (s), P_a - number of alighting passengers per bus through busiest door, t_a - passenger alighting time (s/passenger), P_b - number of boarding passengers per bus through busiest door, t_b - passenger boarding time (s/passenger), and t_{oc} - door opening and closing time (s).

Taking into account that boarding and alighting of passengers at a stop occurs simultaneously, it is proposed to calculate this time as follows (Gonzalez *et al.*, 2012):

$$t_d = \max[P_a t_a, P_b t_b] + t_{oc}. \quad (2)$$

Boarding of passengers can take place without additional loss of time. However, in some cases, due to ticket confirmation or lack of balance of the trip, the bus stay at the stop is extended. Observations show that boarding times at stops are generally longer than alighting times. This is due to the loss of time to confirm landing with a payment card.

As can be seen, the time of occupation of a bus stop depends on various factors. The dwell time is about 30 seconds, although it is influenced by many parameters (Arhin *et al.*, 2016).

The time spent by buses at the observed stop "8th km Bazaar" in most cases also does not exceed 30 seconds. Only in exceptional cases, buses remain at a stop for a longer time. In order to reduce the queues before the stop and reduce the delays caused by the occupation of the stop, we adjust the time of arrival at the stop, keeping the calculated values of the intervals on the routes.

5. Development of a model of arrival of buses to a stop

At a stop with a large number of bus routes, coordinating the arrival time of buses at the stop while maintaining the intervals of movement on the routes can help reduce the queues before stops and, therefore, the time of loss. If the bus movement punctuality on routes is at a sufficient level, the method of shifting the moment (times) of arrival at the stop can be used to coordinate the work of public transport vehicles using the stop. Since, in front of the stop, queues are formed as a result of the fact that more buses drive up to the bus stop than the stop can receive at the same time, and the efficient operation of the stop is violated.

Traffic regularity and punctuality are the main indicators of the level of compliance with the traffic schedule on bus routes. The regularity of movements is calculated to evaluate the performance of all scheduled bus trips. Punctuality means that the buses arrive at each stop at the scheduled time.

The bus punctuality index can be defined as follows:

$$P = \frac{S^2}{h_t^2}, \tag{3}$$

where: h_t - is the planned interval, S^2 - is calculated as follows:

$$S^2 = \frac{\sum_{i=1}^I (t_i - \tau_i)^2}{I}, \tag{4}$$

where: t_i - actual time of arrival of the i -th bus at the stop; τ_i - time of arrival of the i -th bus at the stop according to the schedule; I - number of arrivals. The value of P will be equal to 1 if all buses arrive at the stop exactly at the appointed time. But, of course, this is ideal. As the number of buses and routes increases, this value decreases. However, high bus traffic punctuality is of great importance when simulating the operation of buses at stops where buses of many routes pass.

We simulate the time of arrival of buses at the stop, according to the algorithm shown in Figure 2. At the same time, we shift the arrival time of buses to a stop in the bus schedules in accordance with the established bus intervals. The time of arrival at the considered stop is planned in order from the route with the smallest interval of movement to the route with the largest interval. r - shows the bus route, i - interval in the route, t - minutes of arrival of the bus at the stop during hours. When the value of A is 1, it means that the bus will arrive at the stop at the given minute, and when it is 0, it means that it will not arrive. For example, $A_{r1;t(1+ki_1)} = 1, (k = 0, 1, 2 \dots n)$ means that buses of route $r1$ arrive at the stop on the $1, 1 + i_1, 1 + 2i_1, \dots, 1 + ni_1$ minutes.

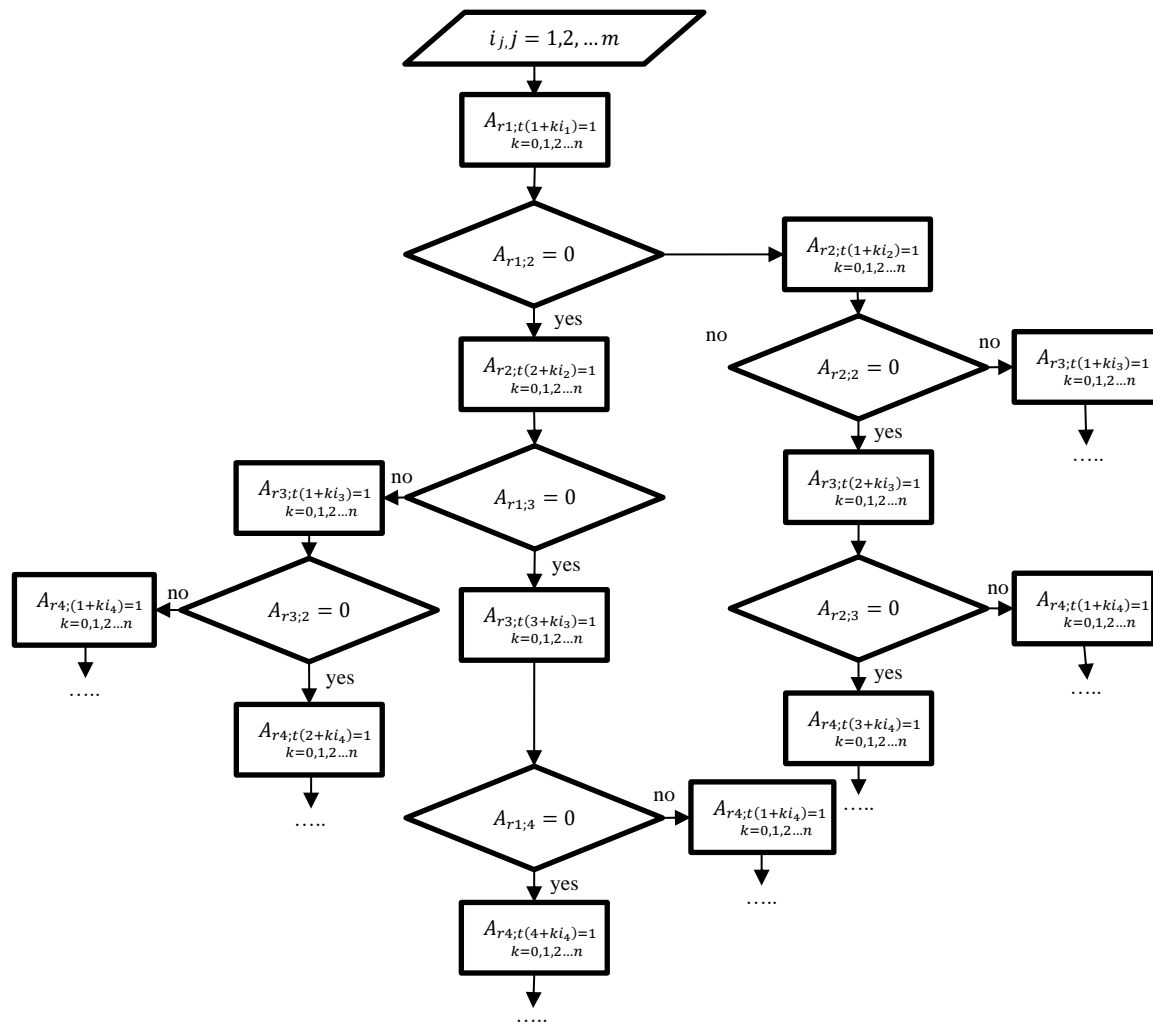


Figure 2. Model for determining the bus arrival time at the stop

The number of buses passing through stop j per hour on route i can be calculated as follows.

$$A_{ij} = \frac{60}{I_i}, \tag{5}$$

where: I_i – is the interval on bus route i , min.

If buses of routes passing through a stop arrive at the stop at regular intervals, then the number of buses arriving at stop j in one minute can be found as follows:

$$A_{j,1min} = \frac{\sum_{i=1}^n A_{ij}}{60} = \frac{\sum_{i=1}^n \frac{60}{I_i}}{60} = \sum_{i=1}^n \frac{1}{I_i}, \tag{6}$$

where: $i = 1 \dots n$ – is number of bus routes passing through the stop.

If we take into account the values given in Table 2 in the formula (6), then we will see that 3 buses will arrive at the stop in one minute if buses of different routes arrive at the stop at regular intervals. But it is impossible to apply uniform intervals in a certain period to coordinate the operation of all bus routes at such stops. Because the bus intervals depend on the number of buses, determined based on the passenger flow and the bus cycle time, and are determined separately for each route.

The capacity of the stop varies depending on the time the bus stays at the stop, the number of seats at the stop (Highway Capacity Manual, 2000). At the same time, the number of arriving buses should be limited to 250 buses per hour so as not to block the movement of the main traffic flow.

Based on the proposed in Figure 2 arrival model, the sequence of bus arrivals at a stop along the routes during the first half hour is shown in Table 3.

Table 3. Sequence of arrival of buses at a stop on routes according to the proposed model

Route number	Arrival minute																																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30									
50	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0								
62	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0							
64	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0						
81	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0					
12	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0						
51	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0					
49	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0				
40	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0				
57	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0			
11	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0			
15	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0		
60	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
7a	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0		
44	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
35	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
36	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
70	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
54	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
N_{bus}	4	4	4	3	3	3	3	3	2	4	5	2	3	3	3	5	4	3	1	1	4	4	5	2	3	3	2	3	4	3									

As can be seen from Table 3, the number of buses arriving at the stop (N_{bus}) will not exceed 5 in any of the considered minutes in the proposed sequence. We use the bus stop simulation model built in Anylogic to compare the existing situation in front of stops and the situation after applying the proposed bus arrival sequence.

First, we analyze the situation at the bus stop, introducing real interval according to the current traffic organization situation on bus routes. To do this, we use the *Interarrival time* parameter for *CarSource* in the *Road* library. We use the parameter *Schedule* to enter the arrival time for the bus stops according to the proposed arrival time sequence. The arrival time moments are entered into the table according to the bus interval. The *TimeMeasureStart* and *TimeMeasureEnd* parameters are used to calculate the time lost by buses from the moment they appear in the model to the moment they leave the stop. The time spent at the stop for all routes is 30 seconds.

Table 4 shows the time values fixed as a result of the simulation experiment, required to pass a stop on each bus route for the first 3 hours after entering all parameters of the stop and the bus route.

Table 4. Time indicators from the appearance of buses in the model to leaving the stop in three hours for a real version of the organization of work

Route number	interval	mean	deviation	minimum	maximum	Mean-confidence	Number of buses
Route N11	7	566.1	109.5	311.4	794.6	42.2	28
Route N12	5	564.8	113.8	193.9	787.3	39.6	34
Route N15	7	567.1	120.0	260.7	820.8	40.4	36
Route N22	12	572.2	79.8	426.9	709.5	38.2	19
Route N35	8	585.8	98.8	344.4	738.0	40.7	25
Route N36	9	586.6	119.2	350.0	810.8	50.1	24
Route N40	6	558.5	123.1	233.2	787.6	44.9	31
Route N44	8	570.6	101.0	366.8	746.0	41.6	25
Route N49	5	569.8	105.3	227.8	797.9	35.4	36
Route N50	4	554.0	118.5	128.1	813.7	35.9	44
Route N51	5	554.7	123.8	163.5	773.7	43.7	33
Route N54	20	401.1	57.48	327.2	513.7	36.1	12
Route N57	6	554.2	115.8	297.2	810.9	43.9	29
Route N60	7	570.5	105.7	269.1	813.5	41.5	27
Route N62	4	572.3	121.5	191.9	811.9	39.8	38
Route N64	4	538.9	113.7	160.2	769.7	36.8	39
Route N70	10	576.1	92.8	410.8	784.2	40.7	22
Route N7a	7	552.8	110.6	343.2	766.3	42.7	28
Route N81	4	566.7	128.5	126.2	789.3	41.6	39

As can be seen from the table, for the existing option, when buses move at regular intervals according to the schedule, the time for passing the bus stop in question varies over a wide range. For example, the minimum transit time from a stop on route 51 is 163.5 seconds and the maximum transit time is 773.7 seconds. Such figures are caused by the chaotic, inconsistent arrival of buses of different routes to this stop, because in some cases too many buses accumulate in front of bus stop.

Table 5 shows the simulation results of 3-hour bus operation on routes in the general traffic flow and on a dedicated bus lane. The given average times reflect the results of passing the bus stop under the existing option and after applying the proposed arrival sequence.

Table 5. The mean time from the appearance of the bus in the model to leaving the stop when buses move in general flow, and move through bus lanes

Route number	In general transport flow		After applying the bus lane	
	Only according to bus interval	According to bus interval, with coordinated arrival time	Only according to bus interval	According to bus interval, with coordinated arrival time
Route N11	566.1	437.5	476.7	330.7
Route N12	564.8	448.5	472.5	331.3
Route N15	567.1	433.2	469.2	333.2
Route N22	572.2	440.4	476.0	331.0
Route N35	585.8	445.1	475.4	334.7
Route N36	586.6	452.5	477.9	333.2
Route N40	558.5	440.9	470.9	333.6
Route N44	570.6	465.2	474.3	333.7
Route N49	569.8	436.9	468.5	331.7
Route N50	554.0	456.3	467.3	331.6
Route N51	554.7	443.3	468.1	330.2
Route N54	401.1	369.6	255.9	263.5
Route N57	554.2	454.6	466.1	335.4
Route N60	570.5	450.7	465.2	333.9
Route N62	572.3	446.2	470.2	333.2
Route N64	538.9	449.8	465.7	334.0
Route N70	576.1	435.6	481.7	332.7
Route N7a	552.8	459.2	472.9	334.7
Route N81	566.7	446.8	462.8	334.3

As can be seen from the table, as a result of coordinating the arrival of buses at a stop along the routes, as well as a result of the introduction of special lanes for buses, the average value of the time spent for buses to pass a bus stop is seriously reduced. For example, the application of the proposed bus arrival time model on route 81 reduces the time under study from 566.7 to 446.8 s; additionally, the use of a special bus lane reduces it to 334.3 s.

Table 6 shows the average time elapsed from the moment the buses appeared in the model until they passed the stop for all routes after the bus line was applied, for the first 1, 2 and 3 hours, respectively, for two options: when buses arrive only at a previously set interval and according to the developed sequence with observance of the established interval.

Table 6. The mean time from the appearance of the bus in the model to leaving the stop after applying the bus lane

Route number	Real bus interval, min.	During 1 hour		During 2 hours		During 3 hours	
		Only according to bus interval	According to bus interval, with coordinated arrival time	Only according to bus interval	According to bus interval, with coordinated arrival time	Only according to bus interval	According to bus interval, with coordinated arrival time
Route N11	7	380.1	321.56	430.6	328.5	476.7	330.7
Route N12	5	372.2	324.31	430.5	329.6	472.5	331.3
Route N15	7	369.1	326.49	426.7	331.2	469.2	333.2
Route N22	12	381.0	322.56	430.8	329.4	476.0	331.095
Route N35	8	384.6	334.78	431.8	334.2	475.4	334.7
Route N36	9	374.3	332.82	430.6	332.9	477.9	333.2
Route N40	6	370.7	333.48	424.3	333.3	470.9	333.6
Route N44	8	375.7	334.33	431.3	333.5	474.3	333.7
Route N49	5	368.3	332.61	422.0	331.5	468.5	331.7
Route N50	4	351.9	324.42	416.4	329.7	467.3	331.6
Route N51	5	364.8	327.04	419.4	329.1	468.1	330.2
Route N54	20	250.1	261.23	261.3	262.8	255.9	263.5
Route N57	6	366.9	337.53	424.2	335.6	466.1	335.4
Route N60	7	364.8	329.42	424.0	332.2	465.2	333.9
Route N62	4	366.2	330.16	425.5	332.3	470.2	333.2
Route N64	4	363.3	332.16	420.2	333.2	465.7	334.0
Route N70	10	385.5	320.09	435.7	329.8	481.7	332.7
Route N7a	7	368.6	334.66	426.1	334.5	472.9	334.7
Route N81	4	355.6	335.60	420.9	334.1	462.8	334.3

As can be seen from Table 6, even when using the bus lane, with an increase in the study period, the time for buses to arrive at a given stop in accordance with the interval provided for by the schedule for a stop increases with a large jump. For example, for route 44, the average value of passing a stop in the first hour was 375.7 seconds, in the first two hours 431.3 seconds, in the first 3 hours 474.3 seconds. However, under the same conditions, that is, with the same number of stops and the use of the bus lane, after applying the developed sequence of bus arrivals at the stop, the average value of the stop transit time for the route 44 was 334.3, 333.5 and 333.7 s for the first 1, 2 and 3 hours respectively. As can be seen from the results obtained, as the time period of the study increases when using the developed model, the loss of time for passing the bus stop for the first 1, 2 and 3 hours almost does not change.

If a sequence of arrival times for bus routes is provided for one stop, then buses will arrive at other stops along the same street in the same sequence according to the schedule.

6. Conclusion

As cities grow, the number of private vehicles increases and with this a number of issues, including increasing the attractiveness of public transport, the introduction of new types of public transport, the construction of bicycle paths, begin to become relevant. It should be noted that in order to increase mobility in cities, it is important to make full use of the available possibilities of existing transport systems, including public transport. One of the main steps in this direction is to optimize the operation of existing transport systems.

Bus transport in cities is the most historical and still efficient form of public transport. The main advantages of bus transport are its ability to cover a large area, accessibility, movement along the city's road network, and dynamism. However, a large number of bus routes sometimes cause delays in the general traffic flow, and in many cases queues form in front of bus stops.

Compliance with established schedules in terms of traffic volume and the punctuality of arriving at stops on a set schedule improves the quality of passenger service and simplifies the development of options for coordinating routes with a common stop.

At stops with a large number of served routes, adjusting the bus schedule to arrive at a given stop will help reduce delays and queues in front of bus stops. The proposed model of the sequence of bus arrivals at a particular stop significantly reduces the loss of time to pass the stop.

Improving the punctuality in bus routes by using the capabilities of existing monitoring and regulation tools, as well as using the proposed methodology for relatively few bus arrivals at a stop, can further improve the efficiency of the model.

Acknowledgements

The author is grateful to the ERASMUS + K2 CRENG (Crisis and risk engineering for transport services) project for software (Anylogic) support.

References

1. Al-Mudhaffar, A., Nissan, A., Bang, K-L. (2016) Bus stop and bus terminal capacity. *Transportation Research Procedia*, 14(2016), 1762-1771. doi: 10.1016/j.trpro.2016.05.142.
2. Arhin, S., Noel, E., Anderson, M., Williams, L., Ribbiso, A., and Stinson, R. (2015) Predicting Dwell Time by Bus Stop Type and Time of the Day. *Civil and Environment Engineering*, 05(05). DOI: 10.4172/2165-784X.1000189.
3. Arhin, S., Noel, E., Anderson, M., Williams, L., Ribbiso, A., and Stinson, R. (2016) Optimization of transit total bus stop time models. *Journal of Traffic and Transportation Engineering (English Edition)*, 3(2), 146-153. <https://doi.org/10.1016/j.jtte.2015.07.001>.
4. Azemsha, S., Kravchenya, I., Vovk, Y., Lyashuk, O., Vovk, I. (2021) Scheduling technique of route vehicles on duplicating stretches. *Scientific Journal of Silesian University of Technology. Series Transport*, 113, 5-16. ISSN: 0209-3324. DOI: <https://doi.org/10.20858/sjsutst.2021.113.1>.
5. Bąk, R. (2010) Simulation Model of the Bus Stop. *The archives of transport*, XXII(1). DOI:10.2478/v10174-010-0001-6.
6. Boev, V.D. (2011) *Study of the adequacy of GPSS World and AnyLogic in modelling discrete-event processes*: Monograph, St. Petersburg: VAS, 404 p.
7. Cortés, C.E., Burgos, V., Fernández, R. (2010) Modelling passengers, buses and stops in traffic microsimulation. Review and extensions. *Journal of advanced transportation*, 44, 72–88. DOI: 10.1002/atr.110.
8. Dashdamirov, F. (2011). Study of bus driving parameters on urban route. *Transport problems*, 6(4), 80-85. ISSN 1896-0596.
Available: transportproblems.polsl.pl/pl/Archiwum/2011/zeszyt4/2011t6z4_09.pdf.
9. Dueker, K., Kimpel, T., Strathman, J., Callas, T. (2004) Determinants of Bus Dwell Time. *Journal of Public Transportation*, 7(1). 2004. DOI: <http://doi.org/10.5038/2375-0901.7.1.2>.
10. Elsayed, M., and Torstensson, E. (2020) *Two different bus stop layout designs - A traffic simulation study in VISSIM*. Department of Science and Technology Linköping University, Sweden. Available: <https://www.diva-portal.org/smash/get/diva2:1484176/FULLTEXT01.pdf>
11. Fernández, R., Valenzuela, E. (2003) A model to predict bus commercial speed. *Traffic Engineering and Control*, 44 (2), 67–71.
12. Fernández, R. (2010) Modelling public transport stops by microscopic simulation. *Transportation Research Part C*, 18, 856–868. doi:10.1016/j.trc.2010.02.002.
13. Ghariani, N., Elkosantini, S., Darmoul, S., Ben Said, L. (2014) A survey of simulation platforms for the assessment of public transport control systems. *Conference: 3rd International Conference on Advanced Logistics and Transport - ICALT'2014*, Hammamet, Tunisia. DOI: 10.1109/ICAdLT.2014.6864088.
14. Gkiotsalitis, K. (2020) Improving service regularity for high-frequency bus services with rescheduling and bus holding. *Journal of Traffic and Transportation Engineering (English Edition)*, 8(5), 778-794. <https://doi.org/10.1016/j.jtte.2020.06.002>.
15. González, E.M., Romana, M.G., and Álvaro, O.M. (2012) Bus Dwell-Time Model of Main Urban Route Stops Case Study in Madrid, Spain. *Transportation Research Record Journal*, 126-134. DOI: 10.3141/2274-14.
16. Hafezi, M.H., Bin Ismail, A., Al-Mansob, R. (2011) Bus scheduling model: a literature review. *Regional Engineering Postgraduate Conference (EPC)*, January 2011, Bangi, Malaysia.
17. (2000) *Highway Capacity Manual*. Special Report 209, Transportation Research Board, Washington, DC.
18. Huo, Y., Li, W., Zhao, J., Zhu, Sh. (2018) Modelling bus delay at bus stop. *Transport*, 33(1), 12–21. doi:10.3846/16484142.2014.1003324.
19. I Casas, P.F., Sancho, E.C., Mercadé, L.M., Linares, M.P., Montañola-Sales, C. (2014) Formal and operational validation of a bus stop public transport network micro simulation. In: *Proceedings of the 2014 Winter Simulation Conference*. DOI: 10.1109/WSC.2014.7019925.

20. Kho, S-Y., Park, J-S., Kim, Y-H., Kim, E-H. (2005) A development of punctuality index for bus operation. *Journal of the Eastern Asia Society for Transportation Studies*, 6, 492-504. Available: www.jstage.jst.go.jp/article/easts/6/0/6_0_492/_pdf.
21. Kieu, L.M., Ngoduy, D., Malleson, N., Chung, E. (2019) A stochastic schedule-following simulation model of bus routes. *Transportmetrica B: Transport Dynamics*, 7(1), 1588-1610. ISSN 2168-0566 <https://doi.org/10.1080/21680566.2019.1670118>.
22. Kumararaja, P., and Karuppanan, G. (2016) Planning of Bus Stops for Safe and Efficient Passenger Boarding and Alighting. *International Journal of Engineering and Technical Research*, 5(06), 296-304.
23. Lindberg, T. (2019) *Discrete Event Simulation of Bus Terminals*. Department of Science and Linköping Studies in Science and Technology. Thesis No. 1841 Licentiate Thesis, Technology Linköping University, SE-601 74 Norrköping, Sweden. Available: www.diva-portal.org/smash/get/diva2:1313235/FULLTEXT01.pdf
24. Melakhsou, A., and Bhourri, N. (2019) Bus Regularity Evaluation using the Gini Index and the Lorenz Curve: A Case Study of New Delhi Bus Network. In *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2019)*, 569-577, ISBN: 978-989-758-374-2. DOI: 10.5220/0007795705690577.
25. Moosavi, S.M.H., Ismail, A., Yuen, C.W. (2020) Using simulation model as a tool for analyzing bus service reliability and implementing improvement strategies. *PLoS ONE*, (2020) 15(5): e0232799. <https://doi.org/10.1371/journal.pone.0232799>.
26. Nikolaev, A.B., Starikov, V.S., Yagudaev, G.G. (2017) Analytical and Simulation Planning Model of Urban Passenger Transport. *International Journal of Advanced Studies*, 7(1), 65-77. DOI: 10.12731/2227-930X-2017-1-65-77a.
27. Poliak, M., Poliaková, A., Mrnikova, M., Simurkova, P., Jaskiewicz, M., Jurecki, R.S. (2017) The Competitiveness of Public Transport. *Journal of Competitiveness*, September, 9(3), 81-97. DOI: 10.7441/joc.2017.03.06.
28. Reijsbergen, D., Gilmore, S. (2014) Formal punctuality analysis of frequent bus services using headway data. *Computer Performance Engineering: 11th European Workshop, EPEW*, September 11-12, 2014, Florence, Italy, Proceedings. vol. 8721, Springer International Publishing, 164-178. DOI: 10.1007/978-3-319-10885-8_12.
29. Sun, F., Sun, L., Sun, Sh-W., and Wang, D-H. (2015) Study on the Calculation Models of Bus Delay at Bays Using Queueing Theory and Markov Chain. *Computational Intelligence and Neuroscience*. <https://doi.org/10.1155/2015/750304>.
30. Van der Spek T. (2017) A multi-method simulation of a high-frequency bus line using AnyLogic. *Computer Science. Artificial Intelligence*. <https://doi.org/10.48550/arXiv.1704.05692>.