Assessment of time loss of buses in the route network

Dashamirov Fuad¹

¹ PhD, associate professor, Director of the Institute of Logistics and Transport; Azerbaijan Technical University; Republic of Azerbaijan

Abstract.
The article analyses the main time losses when buses move in the route network, and also considers the models used to evaluate each of them. The disadvantage of the used model for accounting for time lost by buses at controlled intersections when buses move along sections of routes is shown. Possible scenarios for buses passing through a given section of the route network with several intersections are described. A method for determining the probability of bus delays at intersections is considered.

Keywords:
bus
route network
route zone
time loss
Introduction

Bus transport is currently the most used and still effective form of public transport in cities. The main advantages of bus transport are its ability to cover a large section, accessibility for passengers, dynamism, and movement on the general traffic flow along the city's road network. It should be taken into account that the bus is a vehicle and has the property of door-to-door delivery. Bus routes serve all small, medium and large cities and take on a significant part of the passenger load in cities. Contrary to expectations, this type of transport, which is used both in the city and in the suburbs, has not given way to other types of transport with the development of technology. On the contrary, with the advent of environmentally friendly types (for example, electric buses), its use has become more effective. In addition, new prospects for bus transportation have opened up with the spread of metrobus systems, which represent an alternative form of high-speed urban transport moving along isolated lanes.

Except in special cases, bus transport does not require special infrastructure. The possibility of locating bus stops next to or in close proximity to stops of other types of urban public transport (trolleybus, tram) can be considered one of the main advantages of this type of transport. With a change in the location of centers of gravity in the city, with the introduction of new types of transport, etc. demand for bus routes may vary. Therefore, regular study and improvement of the bus route network is required.

The creation of a bus-route network model can provide conditions for ensuring a unified network approach in cities and operational management. Of particular importance is the study of the operation of buses traveling on certain sections of the route network. In addition, identifying and taking into account the factors causing loss of time on bus routes form the basis for optimizing the operation of the network.

Literature review

Many authors have proposed urban bus network models [1,2,3]. But these models do not touch on the concept of common (shared) sections of the route and it is assumed that in order to quickly get to the destination, the passenger
gets on the first bus that arrives at the stop in the direction in which he is traveling. Shimamoto et al. proposed a multicriteria optimization model consistent with existing approaches and proved that considering common sections of bus routes is more effective [4].

The work of Huang et al. shows that optimization of the route network of city buses is considered from different points of view, but this is a rather complex task and should be developed from the point of view of taking into account the influence of many factors [5]. The authors tried to create a framework for optimizing a bus route network using geographic information systems and a genetic algorithm, taking into account the use of space, population distribution, number of departures, and the attractiveness of stops using an accessibility model. To generate possible bus routes, a table of shortest distances was used, taking into account the distances between each pair of stops. An alternative route is accepted only if the criteria for that route match the previously accepted criteria. An experiment to optimize the model was carried out for four scenarios - a comparative analysis for a section of a normal road and a section of a loaded road for cases where the maximum route length is 20 and 25 km.

Ponachugin [6], who studied the reliability of urban public transport, characterized the internal and external impact of disruption of the process of urban passenger transportation by four situations:

- The transport process is disrupted under the influence of the internal environment: \( x_{\text{in}} = 0, x_{\text{ex}} \neq 0, X = x_{\text{ex}} \);
- The transport process is disrupted under the influence of the external environment: \( x_{\text{in}} \neq 0, x_{\text{ex}} = 0, X = x_{\text{in}} \);
- The transport process is disrupted by the combined influence of internal and external factors: \( x_{\text{in}} \neq 0, x_{\text{ex}} \neq 0, X = x_{\text{in}} + x_{\text{ex}} \);
- The transport process is in a state of dynamic equilibrium: \( x_{\text{in}} = 0, x_{\text{ex}} = 0, X = 0 \).

When modeling passenger transportation, various simulation programs are successfully used. However, the
influence of numerous parameters on the parameters of bus movement during bus passenger transportation does not allow the use of programs that create conditions for more rapid intervention. The models created must accurately describe the logic of the work of passenger dispatchers and other transport participants. [7]

Arrival time at a stop is considered the most important, even critical indicator when planning bus movements. Determining the delay at a signalized intersection is of particular importance when planning bus arrival times. In many cases, only the delay time of buses at traffic lights is studied. Zhang et al [8] examined the influence of traffic lights and flow on bus delays. Taking into account the remoteness of the signalized intersection and the dynamics of bus traffic, the authors separately studied the travel time of buses.

On bus routes, crowding of buses at a stop begins to occur when demand exceeds a critical threshold. To overcome this, the authors propose to synchronize the operation of the bus stop network [9].

Luo et al modeled roadside bus stops as a function of waiting time and found that this function followed a normal and logarithmic distribution [10].

The work of Al-Mudaffar et al. mentions that the proposed HCM 2000 formula for calculating bus stop capacity does not take into account the time spent turning and braking for a bus to enter the stop, the impact of pedestrian crossings and the disruption of the frequency of bus arrivals at the stop [11]. It was concluded that failure to take into account the distribution of bus arrivals at a stop led to an incorrect calculation of the stop’s capacity. Therefore, it was proposed to include a correction factor in the formula that takes into account the percentage risk of queuing before stopping, and an empirical factor based on experience in Swedish cities was also added to the formula.

1. Time loss model for the city bus route network

In general, the travel time of a bus along the route is influenced by various factors (longitudinal slope of the road, intensity of vehicle traffic on the street, operating mode of control devices on the streets, etc.) [12]. As noted above,
each city differs in the characteristics of its transport network, and in this regard, when developing the public transport network of each city, factors affecting its operation should be taken into account. Therefore, the number of modes of public transport used in cities, the density of vehicles, the terrain, the nature of passenger flows, the modes of public transport preferred by passengers, and the reasons for this preference should be studied in detail. The time lost by bus A on route M can be calculated as follows:

\[
L_{t_AM} = \sum_{i=1}^{n} t_{bsi} + \sum_{j=1}^{m} t_{dij} + \sum_{k=1}^{r} t_{nki}
\]

(1)

where \(t_{bsi}\) - time loss at the bus stop \(i\)
\(t_{dij}\) - bus delay time at a controlled intersection \(j\)
\(t_{nki}\) - time spent moving in the part \(k\)

The first term in formula (1) denotes the delay time at the beginning or end of the considered section of the route network. The other two terms are related to each other.

The bus stop (bus) time consists of the time of entry, stop and exit from the stop. The stop time mainly consists of the time of opening and closing of the bus doors, boarding time with a non-cash form of payment for the ride [13]:

\[
t_d = \max\left[P_a t_a; P_b t_b\right] + t_{oc}
\]

(2)

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

For various reasons, the time it takes to pass a bus stop can be increased, and this problem can be solved by eliminating queues before the stop [14].

The literature shows that the arrival of a large number of buses of different routes at stops obeys Poisson’s process [15]. However, coordinating the arrival times of buses of different routes at stops and increasing the accuracy of arrival can change the nature of bus operation at a stop [16].

2. Estimation of bus time loss at intersections with traffic lights.

The delay of buses at a specific traffic light is random and depends on the operating mode of the traffic light at a specific intersection. The probability of a bus being delayed at an intersection with a traffic light is determined as follows:

\[
P_{dbi} = \frac{t_{gi}}{T_{r ci}}
\]

(3)

where \( t_{gi} \) - duration of (green) traffic light \( i \), sec;

\( T_{r ci} \) - duration of one traffic light cycle \( i \), sec.

The average bus delay time at the intersection in question can be calculated as the product of the probability of a bus delay multiplied by half the duration of the green light in the direction of travel. However, this calculation method does not fully reflect the real situation.

In the Singapore model, it is proposed to take into account the operating mode of a traffic light facility located on a section of a road when calculating the time spent by a bus to cover a section of the route on a city street [16]:

\[
t_i = \frac{l}{V_i^{0.9}} + 0.9 \left[ \frac{C(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2N_c(1-x)} \right]
\]

(4)
where $C$ - traffic light cycle duration, $V^0$ - maximum flow speed in the section under consideration, $\lambda$ - green light efficiency share ($\lambda = \frac{g}{C}$), $x$ - intensity to capacity ratio ($0 \leq x \leq 1$), $N_i$ - traffic intensity in the section under consideration

It should be noted that formula (4) is effective for taking into account the operating mode of the traffic light at one intersection. As the number of controlled intersections increases, the formula should be adjusted to take into account the characteristics of city streets.

3. Description of the time required to travel a section of the route.

Experience shows that in many cases buses of different routes pass through the same section at different speeds, that is, at different times. The time spent by buses crossing a section of the route can have different values depending on the length of the section and the number of traffic light objects located on it, which is mainly due to the slowing down of the bus before the traffic light and the acceleration after passing the traffic light object. In real conditions, there are 2, 3, 4, and sometimes 5 intersections on some sections of city bus routes. Table 1 shows sections with 3 or more intersections on some Baku bus routes.

<table>
<thead>
<tr>
<th>Route</th>
<th>Starting and ending stops of the route section</th>
<th>Intersecting streets</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Pedagogical University - Rashid Behbudov Song Theater</td>
<td>Rashid Behbudov Ave. U. Hadzhibekov st.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rashid Behbudov Ave. Khagani st.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rashid Behbudov Ave. Nizami street</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28 May street. Azadlig Ave.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28 May street. Rashid Behbudov Ave.</td>
</tr>
</tbody>
</table>
Research shows that buses lose about 7% of the time spent crossing the route section at intersections [17]. The movement of a bus along a route can be divided into times of acceleration, movement at a constant speed and braking. When a bus stops at two consecutive traffic lights with a small distance between them or at a traffic light close to the stop, in many cases it does not move at a constant speed. On picture 1 shows several possible scenarios for a bus traveling along a route section with 4 traffic light objects.
The bus accelerates when leaving a stop on a section of the route, moves at a constant speed as far as traffic flow allows, and slows down before the next stop. If the bus is delayed at a traffic light, the number of accelerations and decelerations increases. If a green wave is used in the section between two stops, the bus loses time only in front of one of the traffic light objects.

If we denote by $A$ the event of a bus being delayed at a traffic light, then the probability of a bus being delayed in front of at least one of the traffic light objects located on the route section will be calculated as follows:

$$P(A) = 1 - \frac{t_{g1}}{T_{rc1}} - \frac{t_{g2}}{T_{rc2}} - \frac{t_{g3}}{T_{rc3}} - \ldots - \frac{t_{gn}}{T_{rcn}}$$

(5)

If a section of the route is located on one street and the green wave mode is applied on this street, then the probability of delay of buses at intersections will be equal to the probability of delay at the first traffic light on this section:

$$P(A) = 1 - \frac{t_{g1}}{T_{rc1}}$$

(6)

As can be seen from formula (5), the probability of a bus being delayed at a traffic light increases rapidly as the number of traffic light intersections increases. According to formula (6), we can say that the probability of a delay on a section of the route, on a street with a green wave, depends on the duration of the green light at the first traffic light.

**Conclusion**

In a route network, the time spent by buses on the road can be divided into time lost at stops, in traffic flow and at intersections. In bus routes, it is necessary to take into account the parameters that affect the movement of buses on the streets, especially the operating modes of traffic lights. The proposed method for calculating the time spent by traffic flows at street intersections is not fully effective for bus
routes. These methods mainly take into account the presence of one traffic light object in a route section.

In real conditions, on some sections of routes there are several intersections, and when calculating bus time losses, it is advisable to take into account their operating modes. Bus delays at traffic lights are random. If a green wave is used on the roads, bus delays on route sections are reduced.

References:
MANAGEMENT