The design of the length of the route transport stops' landing pad on streets of the city

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Abstract. An analysis of the condition and problems of stops of route transport functioning was carried out. The research used theoretical and empirical methods, mathematical modeling for creating a mathematical model of the bandwidth of stopping route transport and the final formalization of the scheme of its operation with and without maneuvering. Analyzing the places of congestion on the street network of the city of Kyiv, we came to the conclusion that one of the reasons for their formation had been insufficient organization of road transport and parking of passenger transport precisely at the locations of stops of route transport. Parameters of stops of route transport and intensity of traffic of public passenger transport have a significant influence on the capacity of city streets and roads. Increasing of the number of vehicles on the city streets, improving their specifications have required a new approach to determining the geometric dimensions of mass transit stops. On the basis of the conducted research, the sizes of the recommended calculated passenger vehicle for the design of elements of public transport stops have been proposed. It is established that when designing stops of route transport, it is necessary to consider the length and width of the calculated vehicle, which are important in determining the area of dynamic and static dimensions of vehicles in the area of the stop. An individual approach shall be taken during the designing of the bus stops on city streets that takes into account the dimensions of the passenger vehicle and allows optimizing the parameters of the boarding and boarding places and thereby reducing the time spent on the bus stop.

1. Introduction

Over the last fifteen years, in the big and large cities of Ukraine, with the rapid increase in the number of vehicles and traffic volumes, the problem of mismatching the street network with the needs of urban traffic has arisen. The solution to this problem is to make good use of the city streets' ability to pass vehicles and pedestrians. One of the main tasks of developing of the city's road network is to increase the capacity of its elements.

Every year, the technical, economic and dynamic parameters of vehicles moving along the streets and roads of our country are improving. Therefore, at the same time, requirements for improving the standards of designing highways, city streets and their elements that provide traffic for vehicles should be increased. It is of great importance to determine the optimum parameters of the elements of the road network to ensure the safety and proper conditions of vehicle traffic. The inconsistency of the road network of cities with traffic demand at high rates of motorization leads to the fact that the capacity of the street does not meet the needs of traffic, initially formed local, and subsequently network congestion. Unsatisfactory conditions of traffic of vehicles moving in the general intensive stream, lead not only to increase of financial expenses for transportation, but also to decrease of quality of service of the population of the city, and also are accompanied by increase of time of transportation, fatigue and deterioration of health, passenger health and drivers.

Nowadays, a great deal of scientific work of foreign and domestic specialists is devoted to the problems of increasing the capacity of the street-road network of settlements, which of cause determine and recommend possible methods of improving the appropriate situation in certain sections of city streets. These are measures for the organization and management of urban street traffic, design of the roadway and intersections, legislative, regulatory, urban and administrative measures. But, analyzing the places of congestion on the street network of Kyiv city, it should be noted that one of the reasons for their formation is insufficient organization of the road transport and parking of passenger transport precisely at the locations of bus' stops [1, 2].

It should be noted that the traffic capacity of city streets and roads is significantly influenced by the parameters of the shuttle bus stops and the traffic intensity of public passenger transport. The impact area of the shuttle bus stop is 400 m [3].

The question of placing bus stops and ensuring their capacity has recently been highlighted in the works of O S Kolia, O V Lipenko, M V Saruhaniana, G V Taubkina, Ey V Fominaand others. However, when analyzing well-known scientific works, it should be noted that precisely the determination of the geometric parameters of public transport stops have not paid much attention or insufficient attention.

Increasing of the number of vehicles on city streets, improving their technical characteristics, require a new approach to determining the geometric dimensions of mass transit stops.

2. The purpose of the work is to determine the patterns of interdependence of the size of ground public passenger transport, geometric parameters of platforms for boarding passengers, as well as places for stopping route vehicles.

3. The Main part

The territory of the bus stop includes a passenger boarding area and a stopover for route vehicles. It starts from the place of the relevant road sign and is placed in the opposite direction to the traffic. Stop boundaries (in the longitudinal direction) are determined by the length of the passenger seating areas.

According to the building code for the design of the road network, namely SBR.B.2.3.-5-2018 [4], the geometric parameters of the platforms for the placement of mass passenger transport stops are defined as follows: the length of the landing platform must be taken depending on the type of vehicles it serves (Table 1) and the total frequency of movement of single-stop itineraries; the width of the landing pad should be taken depending on the passenger traffic stop, the waiting time for passengers of the route vehicles, based on the estimated passenger density at the site 2 people / m^2, but not less than 1.5 m. The width of the "pocket" is taken equal to the width of the strip. There are two types of shuttle bus stops in the streets of Ukrainian cities: with specially equipped check-in, "pocket", and with a stop directly at the side stone on the far right lane. Therefore, when designing a section of a city street where a bus stop is located, it is necessary to select a site with the appropriate geometric dimensions so that it in no way affects its capacity and does not lead to congestion in this section of the street.

Table 1. Platform length for landing.

Types of route vehicles	Length of landing pad, m	
	single	double
Ordinary	20	35
Articulated	25	45
Duplicate	35	65
Triangular	50	-

The capacity of a section of the city street in the area of public transport stop is significantly dependent on the bandwidth of a bus stop and the intensity of passenger traffic.

The capacity of the line of the passenger transport route is limited by the capacity of the public transport stop, which in turn depends on the time during which the vehicle is at a stop [5].

$$N_{sp} = \frac{3600}{\mathrm{T}_{sp}}, \tag{1}$$

where N_{sp} – the capacity of the passenger stop, units / h;

T_{sp} – the total time during which the route vehicle is at a stop.

As is known [5], the total time during which a route vehicle is at a stop is determined by the formula:

$$\mathrm{T}_{sp} = t_1 + t_2 + t_3 + t_4, \tag{2}$$

where t_1 – time, that spends at approaching and stopping the vehicle at a stop, s;

t_2 – time, that spends on boarding and disembarking of passengers, s;

t_3 – time, that spends signaling the departure and closing of the door, s;

t_4 – time, that spends starting from the place and leaving the stop, s.

One of the problems of providing a certain capacity of a stop of a passenger transport is that in the middle zone of the big and largest cities through one stop passes from 20 to 30 routes at small intervals of time, some stops are the ends of a route. According to our data, it is established that there are 2.829 bus stops in Kyiv. According to the number of routes serving one stop, they can be divided as follows (Table 2).

The table shows that there may actually be more than one vehicle at the same time at the bus stop, but as a result, some service points may have additional downtime that are associated with obstacles created by the vehicles themselves.

Table 2. Number of routes serving one stop of the transport route in the Kiev city.

Number of stops, units	Fraction, %	Number of shuttle routes, units
1	0.04	more than 30
19	0.67	25-30
52	1.84	20-24
149	5.27	15-19
292	10.32	10-14
700	24.74	5-9
1616	57.12	1-4

Maneuvering buses results in additional time costs associated with the need to maneuver of the detour of a vehicle that has stopped for passengers to board and disembark. In the case of trolleybuses that are restricted in crawling maneuver, delays are associated with unnecessary downtime, resulting in inefficient use of the shuttle bus stop. In addition, a waiting vehicle for check-in creates obstacles to all other vehicles moving in the stream.

Staying at the stop of several passenger vehicles of different types and overall dimensions often exceeds the allotted length of the platform according to the SBR [4]. It is also very often observed that the stop is made outside the "pocket" or the vehicle is waiting for arrival in the second lane, and in some cases, even the passengers land in the second lane, which is prohibited by traffic rules (Figure 1).

Figure 1. Problems of maintenance of passenger transport at stops.

If the shuttle bus stop is designed for simultaneous maintenance of several routes, then its capacity is determined by the formula [5]:

$$N_{sp} = \frac{3600}{\mathrm{T}_{sp}} \times P_p \times k_i, \tag{3}$$

where P_p – number of places for simultaneous maintenance of route transport, pieces;
k_i – coefficient of inefficiency of service of several places at the stop of the public transport.

According to the research [5] it was found that the coefficient of service inefficiency is not constant and depends on a number of factors, namely the factor that takes into account the reduction of capacity due to temporary losses and conflicts between buses and the factor that takes into account the reduction of capacity. due to inefficient use of service facilities.

It should be noted that the inefficient use of service points shall be due to the geometric and technical diversity of the route, which significantly affects the bandwidth of the bus stop.

Looking to the influence of geometric and technical manifolds of the passenger transport (small, medium and large class buses, as well as large and especially large trolley buses) on approaches to the design of bus stops at city streets, it is necessary to consider the dimensions of vehicles.

As a result of the survey of bus stops in the city of Kiev, we made their distribution depending on the type of passenger transport serving the stop (Table 3).

Table 3. Number of bus stops in Kiev, depending on the type of passenger transport they serve.

Type of the passenger transport	Bus	Compatible (bus, trolleybus)	Itinerary taxis	Trolleybus
Number of bus stops, units	1383	556	555	335

It is clear that in the area of the bus stop, passenger transport is in the state of movement (check-in or check-out) and in the state of full stop (boarding and disembarkation of passengers).

According to the results of studies [6, 7], it is not recommended to have more than four seats at a city bus stop for simultaneous passenger service of vehicles. Data on reducing the efficiency of operation of stops of route transport at different number of places on it are shown in table 4 [5, 6, 7].

During the research, the efficiency of the seats was obtained by determining the dependence of the departure time of the bus with the intensity of the traffic on the extreme right lane, the nominal capacity and the coefficient taking into account the fact of maneuvering for the purpose of detouring the vehicle ahead.

Table4. Effective use of seats at shuttle bus stops.

Number of places at a stop, units	On the far right lane		In a special pocket		Average number of seats
	Efficiency, %	The total number of seats	Efficiency, %	The total number of seats	
1	100	1.00	100	1.00	1.00
2	85	1.85	85	1.85	1.85
3	60	2.45	75	2.60	2.52
4	20	2.65	65	3.25	3.09
5	5	2.7	50	3.75	3.22

Thus, we need to consider the cases of work of stops of route transport of different types of rolling stock, which will allow to determine patterns of change of time losses, as well as to take into account the factors of influence of the area of static and dynamic size of a passenger vehicle in the area of placement of the stop of route transport.

To determine the area of dynamic size we use the formula [8]:

$$\delta = b(l + t_p v + cv^2 + a), \tag{4}$$

where b – width required for passenger transport, m;

l – length of the passenger vehicle, m;

t_p – driver response time, s;

c – braking factor, which depends on the brake system, their condition and the friction of the tires with the road surface;

a – safety interval between two vehicles, m;

v – vehicle speed, m/s.

The area of a static dimension of a passenger vehicle shall be determined taking into account the dimensions of the vehicle and the distance required to ensure that the passenger vehicle itself is parked and that passengers are safely and conveniently landed and disembarked.

Therefore, in modern approaches to the design of bus stops on the streets of big and large cities, it is necessary to take into account not only the traffic intensity and the type of passenger transport serving the stop, but also the area of static dimensions of passenger transport (Figure 2).

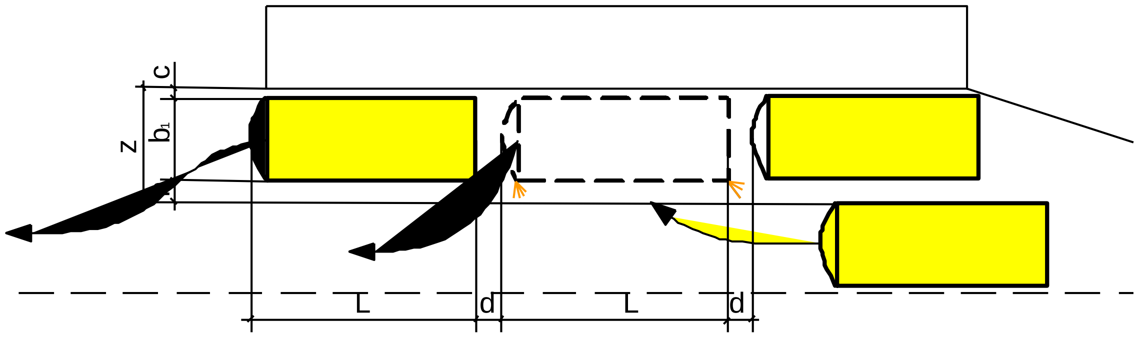

Figure 2. Scheme of placing vehicles at a stop.

The area of static size can be determined by the formula:

$$s_g = z(l + d), \qquad (5)$$

where z – width required for parking of passenger transport at the bus stop, m;
l – length of the passenger vehicle, m;
d – the interval between two vehicles, m.

As already mentioned, at the stop can be simultaneously passenger vehicles of different lengths, and the interval between the vehicles depends on the technical parameters for its maneuvering, taking into account the required safety gap.

The SBR B.2.3-218-550: 2010 [9] states that the design, stops, must take into account the class, type (make and capacity) of the largest transport route units.

Therefore, the question is how to determine the largest vehicle of the largest parameters, which will stop at the appropriate stop.

In view of the above, in order to improve the requirements for the design of bus stops at the streets of settlements, it is necessary to introduce the concept of "calculated passenger vehicle" (CPV) [10].

An estimated passenger vehicle is a vehicle whose dimensions and dynamic qualities are used in the design of shuttle stops.

All passenger street transport serving urban passengers, depending on the model of buses and trolleybuses (Table 5 and Table 6), has its length and width.

Table 5. Length and width of buses depending on their model.

Class of buses	Model of bus	Length, m	Width, m
middle and small class	Bogdan - A-092	7.4	2.39
	Bogdan – A221.12	8.21	2.3
	Bogdan - 144.5	9.6	2.5
large class	LAZ - 52527	11.4	2.5
	MAZ 103-060	12.0	2.5
	LAZ A-183D1	12.0	2.5
	MAZ 203-065	12.0	2.5
	LAZ A-191 F0	13.2	2.5
especially large class	Bogdan - A-231	14.6	2.5
	MAZ107467	15.0	2.5
	LAZ A-291	17.2	2.5
	MAZ 105	18.0	2.5
	LAZ A-292 D1	18.75	2.5

To substantiate the size of the "estimated passenger vehicle", observations were made and data collected on the operation of bus stops in the city of Kiev, and the survey selected stops serving more than fifteen routes.

Table 6. The length and width of the trolleybuses, depending on their model.

Trolleybus class	Model of trolleybus	Length, m	Width, m
large class	K12.04	11.5	2.5
	Skoda 14 TP	11.3	2.5
	LAZ E-183D1	12.0	2.5
	MAZ 103 T	12.0	2.5
	E-186	12.0	2.5
	T70110	12.0	2.5
	PMZ T2	12.1	2.5
especially large class	Trolleybus E-231	15.0	2.5
	Skoda 15 TP	17.7	2.5
	K 12.03	18.2	2.5
	LAZ E-301D1	18.75	2.5
	T90110	18.75	2.5

The obtained data were processed by the method of mathematical statistics, after which the accumulated frequency of distribution was determined (Table 7 and Table 8).

Table 7. The results of processing the study of the length of buses.

Grouped bus length, m	Periodicity	Frequency, %	Accumulated frequency, %
7.4-8.8	1104	56.6	56.6
8.9-10.3	336	17.2	73.8
10.4-11.7	48	2.5	76.2
11.8-13.1	160	8.2	84.4
13.2-14.5	64	3.3	87.7
14.6-16.0	112	5.7	93.4
16.1-17.4	48	2.5	95.9
17.5-18.8	80	4.1	100.0
Sum	1952	100.0	

According to Figure 3, the length of city buses at 95% provision has a length of 16.5 m. The width of almost all buses is the same and is 2.5 m.

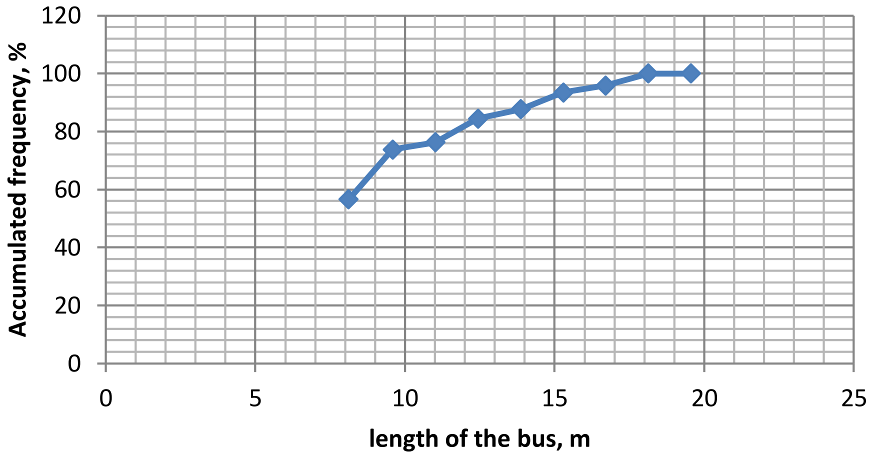

Figure 3. Cumulative length curve of city buses.

Table 8. Results of trolley length study processing.

Grouped length of trolleybuses, m	Periodicity	Frequency, %	Accumulated frequency, %
11.3-12.4	64	13.8	13.8
12.5-13.4	0	0	13.8
13.5-14.5	0	0	13.8
14.6-15.6	0	0	13.8
15.7-16.7	0	0	13.8
16.8-17.7	112	24.1	37.9
17.8-18.8	288	62.1	100
Sum	464	100	

According to Figure 4, the length of the trolleybus at 95% provision has a length of 18.1 m. The width of all trolleybuses is the same and is 2.5 m.

Figure 4. Cumulative trolley length curve.

A very important indicator in determining the area of static dimensions at the stops of route transport is the interval between the two vehicles standing at the stop. According to the results of the conducted observations, data were collected on the distance between two passenger transports, which are at the stop of the route transport and carrying out boarding and disembarkation of passengers. The obtained data were also processed by the method of mathematical statistics, after which the accumulated frequency of distribution was determined (Table 9) and a cumulative curve was constructed (Figure 5).

Table 9. The results of the study processing the distance between two passenger transports at a stop.

Grouped distance between passenger transport, m	Periodicity	Frequency, %	Accumulated frequency, %
1.0-1.1	24	12	12
1.2-1.3	26	13	25
1.4-1.5	50	25	50
1.6-1.7	52	26	76
1.8-1.9	28	14	90
2.0-2.1	20	10	100
Sum	200	100	

When determining the distance between two stopping passenger transports, the construction of a cumulative curve allows you to estimate the distance to be secured for transport and passengers, as well as to determine the optimum dimensions of the passenger landing area and the stopping place for route vehicles. The obtained value of 95% security of the distance between two passenger transports, which are at a stop (Figure 5), is the maximum accepted distance and is 1.65 m in our case.

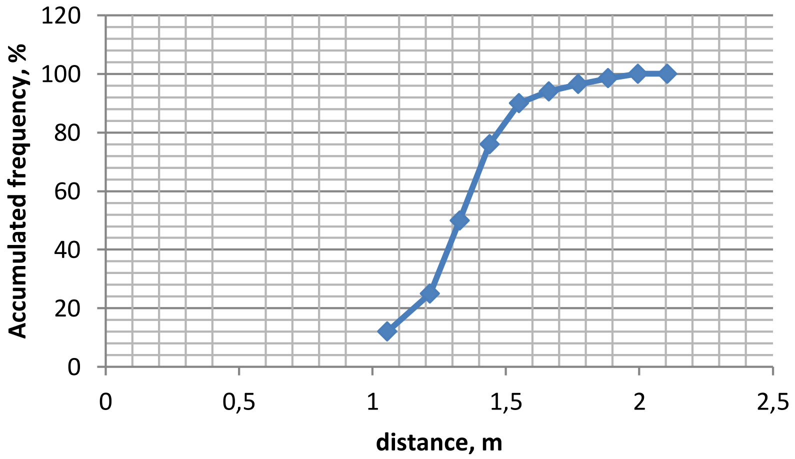

Figure 5. Cumulative distance distribution curve between two passengers bus stops.

4. Conclusion

On the basis of the conducted research, the sizes of the recommended calculated passenger vehicle for the design of elements of public transport stops are proposed. It is established that when designing stops of route transport it is necessary to consider the length and width of the calculated vehicle, which are important in determining the area of dynamic and static dimensions of vehicles in the area of the stop. This approach allows to take into account the peculiarities of placing vehicles at the stops of route transport, depending on the conditions of their operation. When designing bus stops on city streets, it is necessary to use an individual approach, taking into account the size of the passenger vehicle, which will optimize the parameters of the places of embarkation and landing of passengers and thus reduce the time spent during the shuttle vehicle at a stop.

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