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ECONOMIC LOSSES AT BUS STOP AREA

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The paper deals with the method of calculation of economic losses at bus stop area. The aim of the method is to compare the losses on bus stops with different parameters. The losses shall be understood to mean value of those costs, which could have been avoided in absence of any restrictions (in this case – the bus stop with its parameters).

Keywords: Bus stop, public transport, economic losses, velocity losses, bus stop bay, bus stop length, road lane

1. Introduction

Under the loss in traffic we understand social economic cost of the optional, unforced costs, which appear during the movement. [1] In general, all of the losses are divided into economic, ecologic and accident. Economic losses consist of losses from delays and loss of vehicle stops. The less influence on the main traffic flow caused by bus stop, the fewer stops and delays occur. In order to minimize economic losses at bus stop areas, it is necessary to determine the method of calculating the losses, which takes into account not only the delay and stopping of main traffic flow, but also delays of public transport units. Thus, the organization of the bus bay contributes to a slight increase of time of PT unit leaving but significantly reduces the delay of the main traffic flow. This paper proposes a method of calculating of the economic losses at bus stop area at various parameters of a bus stop.

2. Description of the Research

The calculation of economic losses is carried out by the general method proposed in [1], [2]. Economic losses are determined by the equation:

$$L_{ecn} = 1{,}25 \cdot \frac{1}{I} \cdot (L_d + L_o)\text{, c.u./year,} \tag{1}$$

where I – total interval of arrival of public traffic (PT) to the bus stop, min;
L_d – economic lossescausedbytrafficdelays, c.u./year;
L_o – economic lossescausedbytraffic stoppings, c.u./year;

$$L_d = d \cdot Q \cdot K_{ec} \cdot F_y \cdot C_e \cdot K_{ec} \cdot K_{TF} \tag{2}$$

$$L_o = e_{o1} \cdot Q_1 \cdot K_{ek} \cdot F_y \cdot C_o \cdot K_{TF}\text{ ,} \tag{3}$$

where d – specific delay of total traffic flow, sec/veh.;
e_{01} – specific stopping, stop/veh.;
Q – traffic intencity (TI), physical, veh/h, ped./h;
K_e – economic reduction coefficient (Table 1). For pedestrians $K_e=1$;
F_y – annual fund time, h/year (Table 2);
C_e, C_o – price of costs (Table 3);

K_{ec}– economic reduction coefficient for dimentions, for calculation; traffic and pedestrian delays. K_{ec}=1/3600, for other costs K_{ec}=1;

K_{TF} – correction coefficient of annual fund time, which considers vehicles passing the object investigated in early morning and late evening (Table 2).

Table 1. Economic reduction coefficients for vehicles

Type of vehicle	Group	Kd	Ke
Motorcycles, scooters, mopeds motorcycles	Motorcycles	0,7	0,4
Cars, minibuses	Cars	1,0	1,0
Trucks, tractors,agricultural machinery	Trucks	1,4	1,7
Truck trailers, tractor trailers	Truck trailers	2,3	3,0
Public traffic (bus)	Buses	2,0	8,0
Public traffic (bus)articulated	Buses articulated	2,6	14
Public traffic (trolleybus)	Trolleybuses	2,0	8,0
Public traffic (trolleybus) articulated	Trolleybuses articulated	2,6	14

Table 2. Annual fund time

Load level	The total intensity of the conflicting traffic flows (at the ratio of main and secondary flow), veh/ h	Annual fund time for unregulated objects	Correction coefficient of annual fund time
		F_y, h/year	K_{TF}
Light	Less than 1000×500	3600	1,143
Average	More than 1000×500	4200	1,167
Strong	More than 2000×1000	4800	1,200

Table 3. Price of costs

Name		Designation	Dimension	Value
The cost of one hour of delay for reduced car		C_d	c.u./h	1,8
The cost of one hour of delay for pedestrian		C_{dn}	c.u./h	0,25
Prise of one stopping	for country roads	C_o	c.u./stop	0,06
	for the streets of settlements			0,04
	for residential areas and yards			0,01
The cost of one kilometer of over walk		C_{sn}	c.u./km	0,1
The cost of one kilometer of overruning		C_s	c.u./km	0,09
The cost of a liter of fuel		C_F	c.u./liter	0,4
Cost of one hour delay of public traffic		C_B	c.u./h	58,7

The bus stop impacts the following costs.

1. If there is no bus bay (or insufficient length or width of the bus bay) there are displacements from right lane in order to detour a bus stop. Specific delay of displacements is equal:

$$d_{\text{dis}} = \frac{e^{q_2 \cdot T} - q_2 \cdot T - 1}{q_2}, \tag{4}$$

where q_2 – TI on the second road lane, veh./sec;

T – acceptable interval in the main conflict traffic flow, sec.

$$T' = 3 \cdot \sqrt{K_{\text{d}}}\text{, sec,} \tag{5}$$

where K_{d} – dynamic reduction coefficient (Table 1).

2. Stoppings of vehicles, which were unable to make the maneuver of displacement:

$$e_{01} = \frac{7 \cdot v_{02}}{S_1 - 6 \cdot v_{02}} \cdot (1 - \frac{e^{-2,5 \cdot q_2} \cdot e^{-2 \cdot q \cdot T}}{1 - e^{-2,5 \cdot q_2} \cdot (1 - \cdot e^{-q \cdot T})}), \tag{6}$$

where S_1 – length of a span, free from the influence of the bus stop. During investigation of influence of the bus stop impact on traffic flow it has been found that PT starts deceleration before the bus stop at a distance of 75 m, wherein the part of vehicles slows down after the PT, a part makes a maneuver of displacement, thus, the length of a span, free from the influence of a bus stop is calculated as the distance to the nearest intersection before the bus stop or to the previous bus stop minus 75 m and plus the length of the acceleration section from the previous bus stop.

v_{02} – speed of movement on the first (right) road lane of the site S_1

$$S_1 = S - S_0, \tag{7}$$

where S_0 – area of bus stop influence. Distance of influence of a bus stop on the main traffic flow comprises distance of deceleration of PT. Distance of deceleration is equal 75 m before a bus stop. Length of a bus stop L_{bs} is calculated by the method described below. When PT leaves a bus stop, it gets the required speed not at once, therein the other members of traffic flow overtake it or make a maneuver of displacement. It is possible when the speed of overtaking vehicle is 10-20 km/h more, than overtaken. Thus overtaking (displacement) takes place while the speed of PT is less than 40 km/h (accounting the restriction of speed more than 60 km/h in settlements). The PT acceleration is 0,5 m/sec, speed of 40 km/h is achieved through 110 m. When the speed of traffic flow is low, this distance decreases.

$$S_0 = L_{dec} + L_{bs.} + L_{ac}, \text{ m.} \tag{8}$$

$$\mathrm{L}_{\mathrm{bs}} = \sum_{k=1}^{K_{МПТС}} l_k (P^{\mathrm{k}}_{\mathrm{art}}) + 2 \cdot l_{sc} + 2 \cdot l_{rb} + l_{\mathrm{rt}} \tag{9}$$

where l_{sc} – length of safety clearance(the distance between standing PT units), $l_{зб}$ =1m;

l_{rb} – length of road broadening. It is equal 20-30 m, in confined spaces – 10-20 m;

l_{rt} – length of route taxi (according to Table 3).

$$P_{ART} = \sum_{i=1}^{n} P_{i\mathrm{PTU}} \cdot \Delta_{\mathrm{ART}}, \tag{10}$$

where Δ_{ART} – share of articulated PT units on the route.

Quantity of the PT units on the i-th route, arriving during an hour:

$$N_{\mathrm{PTU}i} = \frac{60}{I_{\mathrm{PTU}i}}, \tag{11}$$

where $I_{\mathrm{PTU}i}$ – interval of PT arrival on i-th route, min.

Probability of arrival of PT unit of i-th route:

$$P_{i\mathrm{PTU}} = \frac{N_{\mathrm{PTU}i}}{\sum_{i=1}^{n} N_{\mathrm{PTU}i}}, \tag{12}$$

where n – number of routes.

Table 4. Length of place occupied on the bus stop by the route taxi

Length (accounting safety clearance), l_{rt} ,m	Share of route taxi, Δ_{rt}
6-8	$\geq 0{,}1$
0	$< 0{,}1$

Table 5. Number of PT units for bus stop length determination in dependence of the total arrival interval

Estimated number of PT unit on the bus stop, K_{PTU}	Total interval of movement I ,min
1	more than 2,2
2	[0,9 - 2,2]
3	[0,7 - 0,9]
4	less than 0,7

Table 6. Effective length of PT unit in dependence of probability of arrival of one articulated PT unit.

Effective length of PT unit, l_k ,m	Probability of arrival of one articulated PTU.
12 (if the bus stop serves just bus routes) 14,5	P_{art}^{k} <0,05
18,4	P_{art}^{k} ≥0,05

Table 7. Effective number of PT units for definition of bus stop length regarding to total interval of arrival

Effective nimber of PT units on the bus stop , K_{PTU}	Total interval of arrival, min
1	more than 2,2
2	[0,9 - 2,2]
3	[0,7 - 0,9]
4	less than 0,7

$$v_{02} = \frac{S_1 \cdot v_{01}}{S_1 + d_{\text{см}} \cdot v_{01}}, \tag{13}$$

$$v_{01} = 64 - 0{,}015 \cdot Q_2 \leq 60 \text{ km/h}, \tag{14}$$

where Q_2 – TI on the second road lane, veh./h

3. Delay during merging after stop:

$$d_{\text{mer}} = \frac{e^{q_2 \cdot T} - q_2 \cdot T'' - 1}{q_2}, \text{ sec/veh.,} \tag{15}$$

$$T'' = 4{,}5 \cdot \sqrt{K_{\text{пн}}}, \text{ sec.} \tag{16}$$

Velocity of stopped vehicles including deceleration and acceleration (both – 4 sec.), but excluding losses of standing time is equal:

$$v_{03} = \frac{S_1 \cdot v_{01}}{S_1 + 2 \cdot 4 \cdot v_{01}}, \text{ km/h,} \tag{17}$$

4. Velocity losses on the left lane caused by re-distribution of TI;
Traffic velocity on the second traffic lane in the area of bus stop influence:

$$v_{04} = 64 - 0{,}015 \cdot (Q_1 + Q_2), \text{ km/h,} \tag{18}$$

Thus, having distribution of TI, traffic velocity and time of road sections passing it is possible to define an average time of road section passing in presence of a bus stop:

$$t_0 = \frac{\sum Q_i \cdot t_i}{Q_i}, \text{ sec,} \tag{19}$$

where Q_i – TI on S_1 region, veh/h

Average time of passing of section in absence of parking is defined by the following equation:

$$t_1 = \frac{S}{v_1}, \text{ sec,} \tag{20}$$

where v_1 – velocity in absence of parking, km/h

$$v_1 = \frac{64 - 0{,}015 \cdot Q_1 \cdot 0{,}5}{3{,}6}, \text{ km/h,} \tag{21}$$

$$d = t_0 - t_1, \text{ sec/veh.} \tag{22}$$

If there is parking in front of the bus stops PT units have to go into the second lane because of the first occupied by parking and lose their priority of moving. It causes delays of PT, which are defined by the equation 15. PT unit operates in average 12 hours per day, makes 4 turns on the cycle and carries about 1600 passengers. Cost of 1 passenger carrying is 0,44 c.u., thus during a day cost of delays is 704 c.u. (58,7 c.u./h). In this case PT units accelerate and decelerate on the second traffic lane.

In the presence of a bus bay area of influence of a bus stop on the traffic flow is reduced to a distance of acceleration and deceleration of PT during coming and leaving a bus stop. In this case there are delays of PT units during coming to the bus stop (minor) and during leaving (2 sec.) accounting that drivers of vehicles of the main traffic flow give priority to PT, which leaves a bus stop.

The presence of traffic light causes consolidation of traffic flow in packs, and a dissipation of packs caused by the presence of unregulated pedestrian crossings, intersection, exits from the surrounding areas, presence of parking on the right traffic lane, presence of other bus stop. On the homogenous section of the road, dissipation of a pack is only possible because of different speeds of the vehicles, so the impact of the traffic light applies to the bus stop if the traffic flow moves in a pack at the bus stop area independently on the distance of traffic light location.

The degree of delays of the main traffic flow depends on the number of phases of traffic light. In the presence of the left (or the right) turn from the secondary direction in phase with green signal for pedestrians crossing the main traffic direction the saturation flow, there is no acceptable gap for PT units for leaving out the bay or overcoming the parking lot without making obstacles to main traffic flow. If the TI of vehicles is less than the traffic flow saturation or there is no turning vehicles in one phase with pedestrians, then 65% of the PT units leaves the bus bay without interfering with the main traffic flow.

In the presence of the intersection in front of the bus stop appear the displaces back to right lane in order to turn right (when there is no bus bay).

It must be noted that on the road, roadway of which has only one lane in each direction in the area of the bus stop the overchanges take place instead of displacements or the main traffic flow has to move on narrow area (because of presence of PT units on the bus stop).

For the calculation the following initial data are necessary: TI on road lanes, composition of traffic flow, PT intensity (trolleybuses, articulated trolleybuses, buses, articulated buses, route taxies); parameters of traffic light operation, passenger flowin order to calculate the waiting time and delays of passengers; main traffic flow velocity, distance to the nearest intersection or previous bus stop.

3. Conclusions

The method described in the article makes it possible to evaluate economic losses at the bus stop area that can be used for the analysis of the efficiency of bus stop operating and for making corrections in order to compare possible results.

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