THE IMPACT OF BUS STOP LOCATION ON PEDESTRIAN SAFETY

Ljupko Šimunovića, Mario Ćosićb, Tomislav Vujčićc.
aFaculty of Transport and Traffic Sciences, Vukelićeva 4, Zagreb, Croatia, ljsimunovic@fpz.hr
bFaculty of Transport and Traffic Sciences, Vukelićeva 4, Zagreb, Croatia, mcosic@fpz.hr
cFaculty of Transport and Traffic Sciences, Vukelićeva 4, Zagreb, Croatia, tvujcic.fpz@gmail.com

Abstract: In terms of road safety, a bus stop is one of the most important parts of the bus transportation system. Within their coverage range, passengers conflict with other traffic participants, and they are in direct conflict with cyclists and motor vehicles. The paper will analyse the level of pedestrian safety at specific bus stop locations. Furthermore, the specific examples of existing bus stops in the City of Zagreb will be shown altogether with the examples of good and bad practices of bus stop locations included. A more clear insight is expected in terms of influence of bus stop location on the safety improvements for pedestrians and improvements in the transportation process within the coverage range of bus stops. The results will be based on basic bus stop implementation theory and examples from practice.

Keywords: pedestrian safety, bus stop, transportation planning

1. INTRODUCTION

Bus stops are one of the most important elements of the transportation network in terms of road safety, and by that, they require special attention. There are approximately 1.600 bus stops in the City of Zagreb. They are usually placed near the intersections, which are the places with high risk of road accidents by default. They are also places with higher pedestrian densities compared to the other parts of the network. Besides the usual pedestrian traffic present at the intersections, bus stops generate additional pedestrian traffic (as its attractors). The structure of the pedestrian flow is mostly heterogeneous, with high proportions of children, elderly and people with disabilities, which are the most frequent public transportation users and the most vulnerable traffic participants as well. Their paths are in direct conflict with cyclists and motor vehicles in the coverage range of a bus stop, resulting in higher risk of traffic accidents for pedestrians.

According to the statistics indicators, pedestrians make more than one third of the total number of injured traffic participants in urban areas. Compared to passengers, pedestrians are 1.3 times more vulnerable in terms of number of trips, 16 times more vulnerable in terms of distance crossed and 2 times more vulnerable in terms of time spent in traffic.

A great number of passengers is killed in the coverage range of bus stops. Therefore, the efficient positioning and design of bus stops can reduce risk of traffic accident and, consequently, contribute to safety improvements of the vulnerable road users.
2. BUS STOP LOCATION

The position of a bus stop is directly related not only to the safety, but the convenience of public transport for passengers in urban areas. The bus stop has to be positioned in areas with high pedestrian volume – such of those areas are residential places, shopping malls, educational institutions, recreational institutions, industrial areas, etc. In addition, the availability of the bus stop has to be considered in terms of walking time as well. The final decision about the location of a bus stop depends on the available space, traffic conditions and the possibility to make passenger transfers.

In the process of determining bus stop location, the distance between stops has to be taken into account. This distance is proportional to the number of passengers demanding transportation on a specific route, and disproportional to the driving speed. The distance also depends on the location within the urban area or the content and the use of the area. According to the available literature, the distance is between 300 and 400 meters in urban areas, which requires 5 minutes of walking with a speed of 80 meters per minute. In the peripheral and suburban areas, the distance can rise up to 1,500 meters. Unfortunately, there have not been detailed studies which research the relations between bus stop location and pedestrian safety conducted, although the legislation clearly points out the elements directly related to road safety.

According to the Regulations from the Croatian Ministry of Maritime Affairs, Transport and Infrastructure from 2007, the bus stop location relative to the intersection is in accordance with the need of public transportation, and the stop has to be positioned at least 20 meters behind the intersection, following the driving direction. The same Regulations state that the justification for placing a bus stop has to be supported by an analysis, elaborating:

- Passenger needs,
- Complete analysis of the public transit line with the present bus stop locations,
- Technical road elements,
- Average annual daily traffic and traffic volume in the peak period,
- State of road safety,
- Possible deviations from the existing traffic conditions on the observed road corridor if the new bus stop was included.

The international literature consists of many detailed recommendations and manuals for optimal bus stop location, but they have certain drawbacks as well. When making final decision about the final bus stop position, a series of questions related to pedestrian safety in the stop coverage range have to be answered – the questions consider the following:

- Bus stop surroundings (places with high activities among people or people attractors generating pedestrian flows),
- Traffic flow intensity and direction in the coverage range of the bus stop,
- Stop suitability (stop visibility on the corridor, pedestrian or passenger visibility in the coverage range of a bus stop),
- Lighting (stops and pedestrians),
- Physical characteristics (crosswalk positions, bus stop availability, pedestrian paths towards the stop and from the stop, etc.)
- Traffic control,
- Transfers to another stops.
After the initial consideration related to bus stop locations on the planned route, the next for consideration is the road network (composed of links and nodes) and traffic operations (turning, merging, interlacing, etc.). Based on the above mentioned, bus stops can be positioned:

- Near the intersections:
  - Prior to the intersection (near-side),
  - After the intersection (far-side),
- Between the intersections (mid-block).

Figure 1 shows a bus station directly behind the intersection (blue), between the intersections (yellow) and prior to the intersection (red) [1], [2].

![Figure 1. Bus station positioning in the road network](image)

The bus can stop:

- On the road:
  - On a traffic lane,
  - On a bus bay,
  - Next to a traffic island between two traffic lanes,
  - On a sidewalk extension towards the traffic lane,
- Excluded from the road (stations and terminals).

The paper considers only bus stops on the road.

3. PASSENGER SAFETY IN THE BUS STOP COVERAGE RANGE

In terms of road safety, the critical point in transit is made when pedestrians cross the road to make alighting and boarding in public transport. After alighting the vehicle, passengers become pedestrians who sometimes have to cross the road in order to get to the desired location. Those pedestrian crossings are sometimes made without the presence of a crosswalk, creating dangerous conflict points between pedestrians and oncoming vehicles, resulting in high-risk situations. When crossing the road, pedestrians expose themselves to risk whether they cross the road in front or behind the public transportation vehicle, or between two vehicles. The risk is even higher if the number of lanes is higher.
Poorly designed traffic environment usually encourages pedestrians to use places on the road without crossways to get to the opposite side. However, some patterns have been detected even in those unpredictable situations – the pedestrians tend to walk in as straight lines as possible in order to minimise the walking distance and walking time to reach their destinations. When designing a crosswalk, passenger behaviour and needs should be taken into consideration so that the crossing could be safe and attractive. It is unacceptable to place a crosswalk in front of a bus stop when the ongoing traffic moves in the same direction as the bus. The bus stop should be located behind the place of attraction (the bus passes that place and then stops to exchange passengers) if the ongoing traffic is moving in the opposite direction, the crosswalk should then be located in front of the bus stop, and the bus stop should be placed in front of the place of attraction.

The understanding of how pedestrians behave in the bus stop coverage range is essential to passenger safety. Pedestrian movements after alighting the bus are unpredictable, which can lead to unsafe crossings from one side of the road to another. According to a research [3], risky behaviour among pedestrians is more probable on roads with less traffic volume. The following is considered as an unsafe crossing:

- Road crossing without the presence of the crosswalk,
- Moving between parked vehicles in order to cross the road,
- Running in order to cross the road,
- Running in order to catch the public transportation vehicle,
- Traffic light contravention,
- Illegal road crossing with prolongations.

The risk of traffic accident is greater when pedestrians want to cross the intersection directly after alighting or before boarding without paying attention to traffic signs. Traffic accidents in the coverage range of bus stops can be divided into two categories:

- Vehicle-pedestrian accidents,
- Accidents involving pedestrians and other traffic participants.

### 3.1. Far-side bus stop

The stop is placed behind the intersection, meaning that the bus has to cross the entire intersection before making a stop to exchange passengers (Figure 2). Placing a stop directly behind the intersection is dangerous, because it can cause crashes involving the bus and the vehicles behind the bus. The bus inclusion into traffic after the passenger exchange is also difficult due to the oncoming vehicles passing the intersection. The far-side bus stop ensures greater capacity of right-turn vehicles in the intersection.

The far-side bus stop is safer for pedestrians crossing the road behind the bus. Drivers of the oncoming vehicles behind the bus can see pedestrians easily and adjust to the situation. In addition, pedestrians are less encouraged to violate traffic rules and they cross the road on the crosswalk. This makes a less number of unpredictable situations for drivers, resulting in better pedestrian safety.

Far-side bus stops are recommended:

- When the number of vehicles is greater before the intersection,
- When the intersection is characterised by a high proportion of left and right turns on the main road,
- When there is a possibility to establish public transit priority in the intersection.
At peak hours, the intersection could be congested in the case of a road with high bus capacity due to long dwelling times at stops for passenger exchange.

Figure 2. An example of a far-side stop [3]

3.2. Near-side stop

In this case, a bus stop is placed directly before the intersection, and the pedestrians are allowed to use the crosswalk in the intersection directly before the bus stop. This reduces the walking distance and walking time in order to cross the road. However, this kind of bus stop positioning has its drawbacks in terms of road safety. The most drawback is the risk of traffic accident involving vehicles and pedestrians trying to cross the crosswalk in the period when the bus dwells at the stop. In addition, the dwelling bus obstructs the view so that the drivers of the oncoming vehicles cannot see traffic signs on the right side of the road. Therefore, those drivers experience the lack of information and they have to pay extra attention in these cases by adjusting their speed to the current road conditions.

In the case of near-side stops, the minimum distance between the crosswalk and the dwelling bus is denoted as “x”. The illustration of the minimal distance is shown in Figure 3.

Figure 3. Minimum distance between a bus station and a pedestrian crosswalk

The minimum distance x between a bus stop and a crosswalk can be derived from the following relation:

\[(A + B):B = Lp:x\]  
\[x = \frac{\delta \times Lp}{(A - B)}\]
Table 1 shows the stopping distance in the case of sudden braking, which is then used to define the minimum distance between moving vehicle next to the dwelling bus in the moment when the pedestrian steps on the crosswalk.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopping distance (m)</td>
<td>3.4</td>
<td>7.8</td>
<td>13.4</td>
<td>20.1</td>
<td>27.9</td>
<td>36.9</td>
<td>47</td>
<td>58.2</td>
</tr>
</tbody>
</table>

For example, if the measurement is considering the same situation as in Figure 2, the vehicle speed of 40 km/h and the lane width of 3 m, the distance between the crosswalk and the bus stop is at least 10.05 meters.

If the stop is located on a traffic lane, the ongoing traffic cannot move even though the green traffic light is on, which reduces capacity, especially during peak hours.

The near-side stop is recommended:

- When there is enough visibility at the intersection,
- When the walking corridors are more accessible before the intersection for better convenience during alighting and boarding,
- When the most significant travel sources are positioned before the intersection,
- When the higher number of vehicles moves behind the intersection in the moving direction of the bus,
- When buses go straight or make right turns at the intersection.

![Figure 4. An example of a near-side stop [3]](image)

![Figure 5. An example of a mid-block stop [3]](image)

### 3.3. Mid-block stop

The mid-block bus stop is placed between two intersections on the location with the less traffic volume than in the vicinity of the intersection. The stops are usually placed behind the crosswalk to ensure safer crossing to the opposite side (Figure 5). This kind of bus stop positioning eliminates the visibility problem for both pedestrians and drivers, and encourages pedestrians to cross the road on the crosswalk.

However, if the bus stop is placed in front of the crosswalk in the direction of bus, the disadvantage is the fact that the risk of an accident can be increased due to reduced visibility for other drivers when the bus dwells at the stop. Bus stop positioning in front of the crosswalk should then be avoided.

As it was stated in Chapter 3, pedestrian behaviour is unpredictable, and by that, the usage of crosswalks highly depends on the destination location, the doors passengers use for alighting, etc.
Mid-block stops demand higher accelerating and stopping distances near the stop, and as well an additional space to discourage car parking.

If the bus stop is placed farther from the curb (between the road lanes), then a pedestrian island should be constructed so that the pedestrians could wait for the bus safely.

Mid-block stop is recommended:
- When there is a generator of a high pedestrian volume present in the vicinity,
- When such stop is compatible with the urban development plan of the area.

4. CASE STUDY – THE CITY OF ZAGREB

According to the statistics, there are approximately 8,000 pedestrian casualties in Europe, and every fourth pedestrian dies on a crosswalk. According to the data from the Ministry of the Interior [4], pedestrians make 20% of casualties and 10% of injured in road traffic. Every second pedestrian casualty is a person older than 65, and 70% of accidents with pedestrian casualties occur during the daytime. It is important to notice that data reports usually consider accidents involving pedestrians and motor vehicles. Traffic accidents in which pedestrians fall and injure themselves are almost not mentioned in reports.

The data about the exact number of road accidents near bus stops in the City of Zagreb does not exist. However, activities related to these problems are much greater more recently – for example, authors [5] suggest solutions based on the road accident analysis and data visualisation in geographic information systems for the City of Zagreb. Some of the results arising from the analysis are displayed as accident focal points involving casualties or injuries (Figure 6, Figure 7).

Figure 6 and Figure 7 show accident focal points with casualties and injuries in the City of Zagreb – it is obvious that the focal points are placed on the same spots as bus or tram stations. Also, the grouping of accidents involving pedestrians along the main streets has been noticed, especially in Savska Street and Ilica Street. This is because many business and residential areas in the vicinity of these streets are generating high passenger volume, and the streets are dominated by the public transport mixed with other traffic.

Figure 8, Figure 9, Figure 10 and Figure 11 show the most common disadvantages of public transport stops in the City of Zagreb. Figure 8 shows a bus stop prior to the intersection, at which there is only one crosswalk with traffic lights. Pedestrians usually run over the crosswalk to reach the bus approaching the stop. The passengers alighting the bus usually rush to their destinations, mostly located on the opposite side of the road. They are unaware that the intersection has many technical flaws. The drivers get the impression that the whole intersection is operated by traffic lights. This inconsistency often leads to driver-pedestrian impacts on the crosswalk without traffic lights.
Figure 9 shows an inappropriate bus stop position. The stop is located on a road lane without the waiting space for passengers or the crosswalk to get to the opposite side. This kind of a stop layout directly impacts passenger safety and is a disruption to regular traffic operations.

Figure 9. Pantovčak Street in Zagreb [6]

Figure 10. King Zvonimir Street in Zagreb [6]

Figure 11. Tram stop relocation[7]

Figure 10 shows a tram stop farther from the curb with a crosswalk placed after the stop included. The tram stop is not equipped with a safety fence, allowing the pedestrians to cross the road beyond the crosswalk. The pedestrians who cross the road on the crosswalk are also exposed to risk because the motor vehicle drivers moving in the same direction and public transport vehicles cannot notice them on time. Due to the high number of points of conflict between pedestrians and vehicles, a relocation of the stop is suggested to have the pedestrians alight directly on the sidewalk. (Figure 11). This intervention could significantly improve the safety for every traffic participant.

6. CONCLUSION

The decision about placing the bus stop is under the influence of not only the safety, but the other criteria related to efficiency and effectiveness of the transportation system. The criterion that should definitely be unavoidable is land use – the layout of attractors in the vicinity of the potential bus stop location, determining paths of the pedestrians. The additional criteria are related to traffic flow and road network (volume, structure, moving direction and traffic control). Poorly designed road network (narrow streets, lack of crosswalks, etc.) encourage pedestrians to cross at disallowed places. An additional unavoidable criterion, necessary for conducting efficient analysis is the understanding of passenger behaviour. The availability of surveillance cameras and simulation tool can help to conduct a high-detail analysis which could ensure better quality in terms of studying the impact of bus stop location on pedestrian safety.

Based from the criteria above, it is evident that the decision about the bus stop location on the road network (far-side, near-side, mid-block) is highly complex. The optimal solution can be obtained only by considering all the variables and performing proper evaluation of their influence on the pedestrian safety.
7. REFERENCES


