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Bus stop design and traffic safety: An explorative analysis

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ABSTRACT

One way to prioritize public transport over private vehicle mobility, is to implement curbside rather than layby bus stop designs. There is, however, uncertainty about the consequences of implementing curbside rather than layby stops for traffic collision risks. To begin investigating this issue, we describe an exploratory analysis in which national data describing bus stops, road properties, traffic collisions and built-up areas were merged based on geographical location. Analysis of the resulting data set suggests that the relative rates of traffic collisions resulting in personal injury within 60 m of the bus stop, is higher for curbside than for layby stops in built-up areas (0.32 vs. 0.22 collisions per ten million passing vehicles, respectively). Our analyses suggest that the higher risk of nearby collisions for curbside stops is not necessarily due to bus stop design, but rather because they tend to be located closer to junctions and side roads, where collisions are more likely. Our data are not consistent with hypotheses that curbside stops are associated with greater shares of head-on or rear-end collisions than layby stops, nor that layby stops are associated with greater shares of side-on collisions than curbside stops. The limitations of this exploratory analysis, and of the use of national-level data for studying the effects of bus stop design on collision risk, are related to lack of control of bus stop design features other than curbside vs. layby, statistical power, data registration and compromises made when coupling data based on geographical location. Future work should attempt to build on our approach, and supplement database analyses with analysis of in-depth reports of bus stop collisions, observations of road user conflicts near bus stops, and before-after studies following conversion from layby to curbside stops or from curbside to layby stops.

1. Introduction

Bus stops are associated with increased traffic risks (Cheung et al., 2008; Rhee et al., 2016; Phillips et al., 2019). One factor that can influence collision risk near bus stops is bus stop design. Many features can be varied when designing bus stops, but one feature thought to influence the risk of nearby traffic collisions in Norway is whether the stop is curbside or layby stop (Fearnley and Krogstad, 2017). Since curbside stops afford buses more mobility than layby stops, road administrators with sustainability goals want to know more about the relative effects of these bus stop types on rates of traffic collisions. This article explores whether merging of national data on bus stops, traffic collisions and associated road properties – based on common geographical location – can provide that helps give the empirical traffic safety knowledge needed to help administrators decide whether to implement curbside or layby stops. It adds to the existing literature by generating knowledge on the rates of crashes occurring with increasing proximity to the two different bus stop types.

1.1. Literature review

In Norway, most bus stop designs vary around two main types curbside or layby stops (Fig. 1).

When buses pick up or drop off passengers at curbside stops, they must stop in the road, often interrupting the flow of traffic behind. At layby stops, buses can stop in a designated area to the side of the road, enabling traffic to continue to flow (Fig. 1). Thus, while design features vary within each of these categories, grouping bus stops as curbside versus layby stops describes a major difference in design that is likely to affect passing traffic.

Curbside stops increase mobility for passengers, because the bus saves time by not having to turn into the layby or wait to re-enter the flow of traffic after collecting passengers (Fearnley and Krogstad, 2017). Compared with layby stops, curbside stops generally increase the space available for pavement users, have capacity for several buses at once, and can be less expensive to construct and maintain. A disadvantage of many curbside stops is the reduced mobility of road traffic behind the

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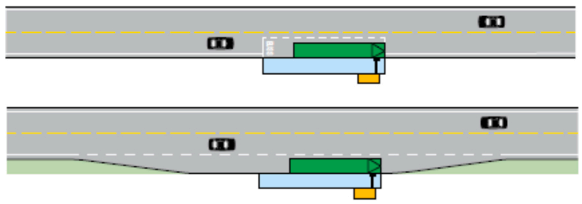

Fig. 1. Curbside (upper) and layby (lower) stops. Laybys may be open to or physically separated from passing traffic. © 2014 Norwegian Public Roads Administration.

bus, which either must wait for the bus to pull out or negotiate with oncoming traffic to pass the stopped bus.

1.1.1. Should administrators choose curbside or layby stops?

At higher speed limits (normally > 60 km/h) and traffic volumes (normally > 10,000 vehicles passing per day), road administrators in Norway implement mainly layby stops. At lower speed limits and traffic volumes either curbside or layby stops can be considered (National Public Roads Administration, 2019). Recently, a small number of layby stops in built up areas have been converted to curbside stops, partly to increase mobility for public transport. This has caused debate among authorities and citizens (e.g. Fearnley and Krogstad, 2017; Tidene, 2019), with opponents arguing that curbside stops increase the risk of collisions by causing drivers to undertake risky maneuvers to overtake stopped buses, or by forcing pedestrians to cross the road from behind the bus, potentially into the path of oncoming traffic (Høye, 2019). Supporters of curbside stops argue that there is no empirical evidence base for higher collision rates near curbside than layby stops, and that buses pulling out of layby stops also increase the risk of a collision with other road users (Fearnley and Krogstad, 2017; af Wåhlberg, 2002). This debate is often taken up by the media when pedestrians are injured in collisions at curbside stops.

Unfortunately, there is little to inform administrators about the effect bus stops have on nearby collision rates. While empirical studies generally agree that bus stops are associated with an increased *number* of nearby traffic collisions – involving motorists (Cheung et al., 2008; Goh et al., 2014; Rhee et al., 2016; Shahla et al., 2009), cyclists (Miranda-Moreno et al., 2011; Strauss et al., 2013; Wei and Lovegrove, 2013) and pedestrians (Kim et al., 2010; Pulugurtha and Sambhara, 2011; Chen and Zhou, 2016; Hedelin et al., 2002; Quistberg et al., 2015a; af Wåhlberg, 2002, 2004), many of these do not account for the amount of passing traffic or other important confounding variables, making conclusions about collision risk difficult.

1.1.2. Many factors influence collisions near bus stops

In addition to speed and traffic volume – factors influencing collision risk in most traffic situations – many variables have the potential to confound conclusions about the effect of bus stops on the number of nearby collisions. Examples are (Goh et al., 2014; Phillips et al., 2019):

- frequency of buses stopping;
- number of driving lanes;
- number of pedestrians, cyclists or passengers using or passing the bus stop;
- cycle lane or path and position relative to bus stop;
- pedestrian crossing nearby (with or without signals);
- number of bus stops along the stretch of road;
- pavements or pedestrian islands;
- lamp posts or surrounding lighting conditions;
- season, weather and driving conditions;
- location relative to junctions and side roads;
- road curvature and sighting possibilities; and
- the number of parked cars.

One of the most consistent findings from traffic safety studies of bus stops is that collisions are more likely at any bus stop placed near or within 75 m of a junction (Pessaro et al., 2017; Huang et al., 2017; Strauss et al., 2013; Chin and Quddus, 2003), possibly due to complex interactions between motor vehicles, cyclists and pedestrians. Studies also show that there are more collisions on roads with bus stops placed before (upstream of) than rather than after (downstream of) junctions (Cheung et al., 2008; Shahla et al., 2009; Quistberg et al., 2015b).

Given so many confounding variables and the current state of the accessible literature, it is difficult to know what it is about roads with bus stops that makes collisions on them more likely. One study finds that many of the bus collisions occurring on roads with bus stops do not actually occur while the bus is at the bus stop, but when the bus has stopped at a nearby junction or crossing (Brenac and Clabaux, 2005). Another study finds that the narrowing of driving lanes on approach to stops is the source of conflicts between cyclists and motor vehicles (Currie and Reynolds, 2010). To begin to understand more about the causes of collisions on roads with bus stops, and the role of bus stop location and design, it is therefore important to measure not only important confounding factors such as traffic or pedestrian volumes, but also the location of collisions in terms of distance from the bus stop, and location in relation to junctions and driving lanes.

1.1.3. Existing knowledge on the effects of curbside versus layby stops on traffic collision rates

In a recent literature review, we found few empirical studies comparing the risk of collisions in traffic near curbside versus layby bus stops, largely because road safety studies of bus stops often fail to describe the type of stops included (Phillips et al., 2019). The studies that we did find were hard to compare due to use of different dependent variables. An early study of Swedish stops suggested that there were 74 per cent fewer traffic collisions resulting in personal injury at layby stops than at curbside stops (Skölving, 1979), although it was not clear whether speed limit and traffic volume were controlled for or how far from the stops the included collisions were located. Moreover, the findings seemed to conflict with that of a German study based on 770 collisions, which suggested that (i) curbside stops are associated with 70 per cent lower collision costs than layby stops; and (ii) costs per collision are higher for all types of road user at layby stops, except for cyclists (Baier et al., 2007). A Chinese study supports the German study, concluding that collision risks are lower at curbside than layby stops. This study is notable in that it controls for traffic volume, and local variations in traffic lights, bus stop sign, type of road surface and light conditions (Ye et al., 2016). The number of stops included, however, was limited and conclusions about collision risks are extrapolated from the number of observed conflicts between motorists, cyclists and pedestrians.

1.1.4. How curbside and layby stops might influence traffic collision risk

Several authors have observed that curbside stops increase the number and risk of overtaking maneuvers performed by drivers attempting to pass stopped buses (Høye, 2019). From this, one might expect curbside stops to be associated with more head-on collisions than layby stops. Likewise, one might expect for curbside relative to layby stops, more collisions caused by pedestrians crossing the road from behind the stopped bus (unseen by traffic passing in the opposite direction). There is also evidence consistent with a large share of rear-end collisions at curbside stops, caused by buses stopping unexpectedly in the driving lane (af Wåhlberg, 2002, Baier et al., 2007). For layby stops, there is indirect support for a greater risk of side collisions caused by buses exiting layby stops into passing traffic (af Wåhlberg, 2002, Baier et al., 2007).

1.2. Study aim

There are several reasons why decision makers lack consistent empirical knowledge on the effect of curbside versus layby bus stop design on road user collision rates. First, many studies report the number of collisions on roads with bus stops, rather than collision *rates*, i.e. the number of collisions relative to an appropriate unit of exposure such as traffic volume. Second, it is difficult for studies to control for variables other than bus stop design that influence collision risk – these variables are many and they are difficult to measure. Third, data on bus stop design may be difficult to obtain, as indicated by the fact that few of the studies on bus stops collisions report data on bus stop design. Fourth, few studies consider *how* bus stops might affect collision rates, for example by looking at the sorts of accidents associated with each bus stop type and/or mapping the location of collisions relative to bus stops.

While in-depth accident investigations (e.g. Yannis et al., 2010) and conflict studies (e.g. Phillips et al., 2011) can help address the last of these issues, quantitative analysis of national data combined from geographical road and accident databases has the potential to address each of them. In this study, we therefore wanted to explore use of the Norwegian road database *Vegkart* to combine data on the geographical location of roads and bus stops with data on traffic collisions, such that we could identify and study road collisions occurring near urban bus stops registered as either curbside or layby stops.

Based on available data, inspection of urban layby and curbside stops in Oslo, and previous studies by Huang et al. (2017) suggesting collision rates could be elevated up to 76 m from bus stops, we decided to consider as "bus stop collisions" any collision occurring within 60 m of a bus stop's line or midpoint. We judged that this distance would include most accidents potentially caused by the bus leaving and entering the traffic flow, e.g. downstream collisions caused by overtaking maneuvers.

Using this approach, we attempted to answer the following questions:

1 In built-up areas, what are the relative rates of traffic collisions resulting in personal injury within 60 m of curbside versus layby bus stops?
2 Do types of collision occurring occurring within 60 m of curbside and layby stops in built-up areas differ in ways that might suggest bus stop design is responsible for collisions caused?

This is an explorative study in the sense that we wanted to assess the extent to which data from national databases is suitable for answering these questions.

Finally, collision rates are expressed as the number of collisions occurring within 60 m of the bus stop per million passing vehicles, and we account for speed limit and traffic volume as two main confounding variables on comparing curbside and layby stops:

2. Method

For the past few years, the Norwegian Public Roads Administration (NPRA) have published and continually updated the interactive road database *Vegkart* (vegkart.atlas.vegvesen.no). *Vegkart* is available for public use and enables an array of positionable road-related data to be selected and downloaded in Excel and other formats. Data were collected for collisions occurring within 60 m of bus stops in the limited period from 1st January 2014 to 31st December 2018 to try and exclude confounding effects of changes to the road situation over longer periods.

2.1. Data sourcing and process

Data processing in March and April 2019 resulted in a data file containing data describing bus stops in built-up areas across Norway and any traffic collisions occurring near those bus stops.

2.1.1. Bus stop database

Data for variables describing one of several "themes" were exported from *Vegkart*, with each theme including variables for geographical location. The themes were bus stop characteristics, traffic collisions, speed limit and traffic volume (average annual daily traffic, ADT). Data delimiting built-up areas were also exported from Statistics Norway's database (www.ssb.no) and integrated using the free and Open Source Geographic Information System, QGIS. Using the function "choose based on location", bus stops were assigned the value "1" on a new variable "built-up area" if they fell within zones described by Statistics Norway's 2018 data as built-up. Statistics Norway define built-up areas as a group of houses less than 50 m apart, and with 200 or more inhabitants (i.e. a collection of at least 60–70 houses).

In Vegkart bus stop location can be defined using midpoint or line data. We chose to use the more complete line data describing the length of the bus stop. To link bus stops to traffic collisions occurring up to 10 m away from them, we used the function «Multi-ring buffer» in QGIS to create a 10 m buffer around each bus stop "line". Each 10 m circle was assigned data describing bus stop characteristics, together with a column "distance" describing how far away the outer perimeter of the area is from the bus stop "line". In a similar way, we created variables describing buffers up to 20, 30, 40, 50 and 60 m away from each bus stop "line". Because we used line and not point data to describe the bus stops, the buffers vary somewhat in shape (Fig. 2).

The data set describing bus stops was connected to data describing traffic volume along road stretches exported from *Vegkart*. These data were collected in 2017 and describe a single ADT value for varying lengths of road. To link these data to bus stops, we assigned a 20 m buffer around each ADT road length; any bus stop falling within an ADT buffer (using the QGIS functions "intersect", "touch", "overlap", "area within" and "cross") was assigned the corresponding ADT value (Fig. 3). Traffic volume data was not available for all roads, especially minor roads. In some cases, ADT data was only available for certain lengths ("links") along a road. Bus stops falling outside of these links were not assigned an ADT value, and are excluded in our calculations of collision rates based on ADT (Fig. 3).

Using the same process, we also assigned to each bus stop data for speed limit along the stretch of adjacent road. The resulting database gave a new data file containing all bus stops exported from *Vegkart*, corresponding data on built-up area, traffic volume and speed limit.

2.1.2. Collision database

The QGIS function "choose based on location" was used to identify any traffic collisions with locations falling within the buffer rings created above. Data describing each "bus stop" collision identified was exported to a new collision database, and each collision assigned data

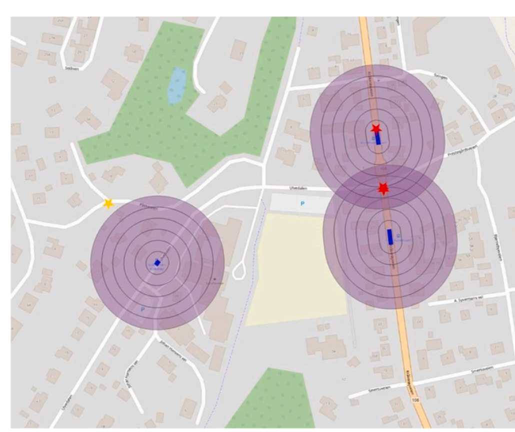

Fig. 2. Buffers around bus stops vary in shape and size due to the different lengths of bus stops (shown in blue). Buffers are calculated from line data delimiting each bus stop. Bus stops are marked as a blue line and traffic collisions within the buffer are marked red, those outside yellow. Map background generated from OpenStreetMap.

Fig. 3. Road lengths with (red line) and without (no red line) associated ADT values. The bus stops in yellow fall within a 20 m buffer (orange area) of ADT stretches, and have been assigned an ADT value. The blue bus stops fall outside of the ADT buffer and are not assigned ADT values.

for corresponding bus stop characteristics, built-up area, traffic volume and speed limit. If a collision occurred within 60 m of more than one bus stop, the collision was assigned data for the nearest bus stop.

The result was a database (.shp or. csv format) with information on the collision, the nearby bus stop, distance from the bus stop (within 10, 20, 30, 40, 50 or 60 m from the stop), speed limit, traffic volume, and whether the bus stop and collision were located within or outside a build-up area. Fig. 4 shows example of collisions falling within and outside the bus stop buffer rings, as well as bus stops falling inside and outside of built-up areas.

Fig. 5 shows collisions that have occurred within and outside buffer rings according to built-up area.

2.2. Data analysis and calculating collision rates

The. csv files were imported into Microsoft Excel, and then into IBM SPSS Statistics 24, and the data cleaned. We noticed that due to incomplete conversion of the. csv files from QGIS, 225 (3.8 per cent) of the collisions did not have an assigned value for "distance" from bus stop. These collisions were filtered out during subsequent analyses. We conducted descriptive analyses of the data sets, and tested whether differences in the distribution of frequencies between two bus stop types were due to chance using the non-parametric Chi-squared test with an alpha level of 5 per cent unless otherwise stated. Interesting pairwise differences in the proportions were tested for significance using a spreadsheet based on the method of Sverdrup (1961).

Bus stop collision rates were defined as the number of collisions

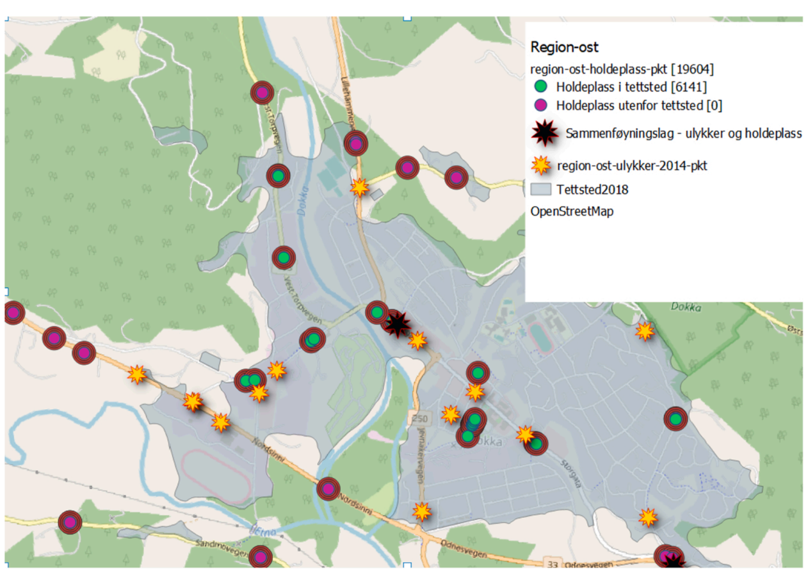

Fig. 4. Collisions falling within (black star) and outside (yellow star) bus stop buffer rings of a Norwegian town. Bus stops falling inside (green circle) and outside (pink circle) built-up areas are also indicated.

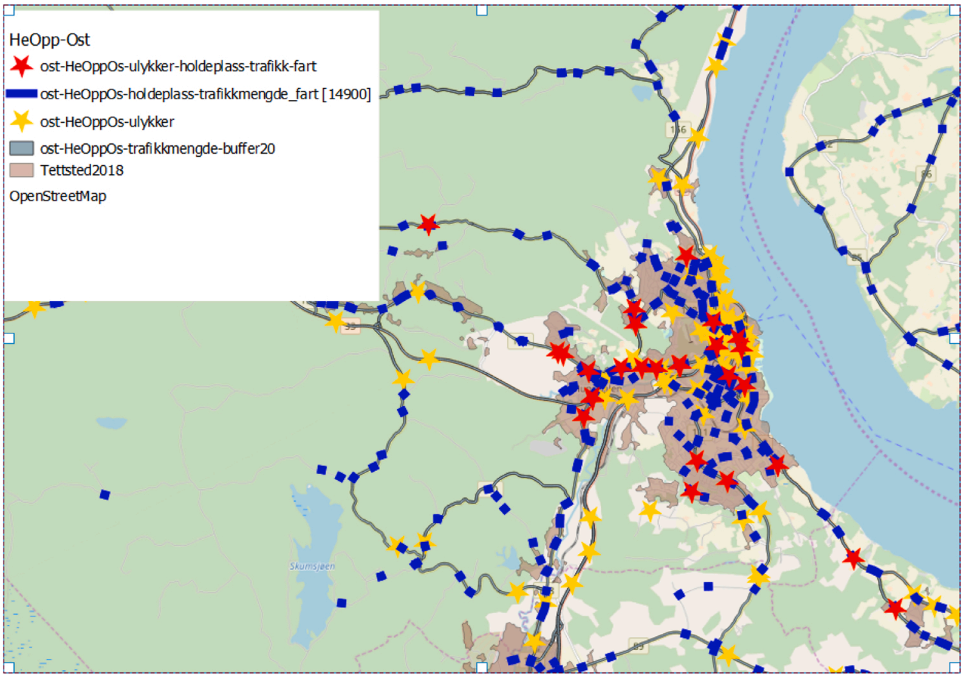

Fig. 5. Overview of collisions occurring within (red stars) and outside (yellow starts) buffer rings and within (brown shading) or outside built up areas of a Norwegian town.

occurring within 60 m of a bus stop per passing vehicle, and were calculated based on the number of accidents occurring over a five-year period from 2014 to 2018. To calculate the number of accidents per passing vehicle, we effectively divided the number of accidents per bus stop by the average number of vehicles passing over a five year-period (= ADT x 1,825 days). Thus:

$$\text{Bus stop collisions per passing vehicle} = \frac{\text{No. collisions registered up to 60 m from bus stops for 2014to 2018}}{[\text{Number of bus stops x Average ADT for bus stops x 1 825}]}$$

To obtain the number of collisions per 10 million passing vehicles, we then multiply by 10^7.

3. Results

3.1. Data set characteristics

3.1.1. All bus stops in Norway

Registrations in *Vegkart* indicated 63 729 of the 69 067 stops as bus stops. Twenty-five per cent of these bus stops (n = 16 061) were located in built-up areas (Table 1).

Bus stop type had not been registered in the case of 6 884 of the bus stops in a built-up area and a further 2 027 of them had a design other than curbside or layby-with-platform (e.g. layby-without-platform, signal stops, sign only). Our subsequent analyses are based on the remaining 7 150 bus stops in built-up areas, comprising 940 curbside and 6 210 layby-with-platform stops. In the rest of the paper we refer to

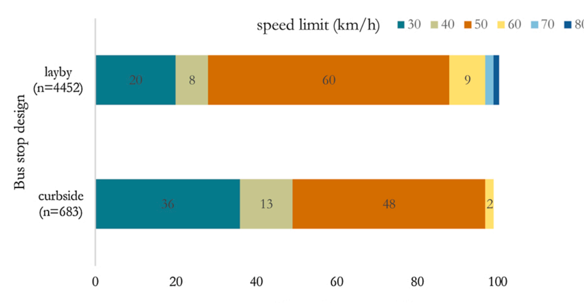

Fig. 6. Distribution of curbside and layby stops on roads with different speed limits in built-up areas in Norway, according to data registered in Vegkart.

Table 1
Number and share of different types of bus stop in and outside of built-up areas in Norway.

Location	Type									
	Curbside		Layby with platform		Other type		Type not registered		Total	
	n	%	n	%	n	%	n	%	n	%
In built-up area	940	54	6210	29	2027	18	6884	23	16061	25
Outside built-up area	811	46	14926	71	9138	82	22793	77	47668	75
Total	1751	100	21136	100	11165	100	29677	100	63729	100

Fig. 7. Distribution of curbside and layby stops on roads with different traffic volumes in built-up areas in Norway, according to data registered in Vegkart.

the latter simply as layby stops.

3.1.2. *Curbside and layby stops in built-up areas*

Speed limit for the stretch of adjacent road had been registered for 683 of the 940 curbside stops and 4 452 of the 6 210 layby stops in built-up areas. Traffic volume (ADT) had been registered for stretches of road adjacent to 660 of the 940 curbside stops and 4 588 of the 6 210 layby stops in built-up areas.

According to registrations, a greater share of the curbside than layby stops were located along roads with lower speed limits (Fig. 6).

The distribution of curbside and layby stops on roads with different traffic volumes were similar, with a slight tendency for curbside stops to be located on roads with lower traffic volumes (Fig. 7).

Many of the curbside and layby stops were located on roads with speed limit 50 km/h (Fig. 6), allowing for a separate analysis of these bus stops as a way to control for speed limit. Although curbside stops on 50 km/h roads are associated with somewhat higher traffic volumes than layby stops on 50 km/h roads, distributions were similar with most stops on 50 km/h having traffic volumes between 2001−10 000 ADT (Fig. 8).

3.2. *Collision rates near bus stops*

3.2.1. *For all types of bus stop in all areas of Norway*

According to the registered data, 5 625 traffic collisions occurred within 60 m of 63 729 bus stops (all types) in the period 2014–2018 in Norway, in and outside built up areas. This is equivalent to an average of 0.09 collisions per bus stop.

Traffic volume registrations were only available for stretches of road adjacent to 47 929 of the 63 729 bus stops (all types); 4 703 collisions had occurred within 60 m of these bus stops. The average ADT for these bus stops was 2 684.

Traffic collision rates for all types of bus stop across Norway was calculated as,

$$\frac{4\,703}{[47\,929 \text{ x } 2\,684 \text{ x } 1\,825]} = 2.0 \times 10\text{e-}8 = 0.20 \text{ collisions per 10 million}$$

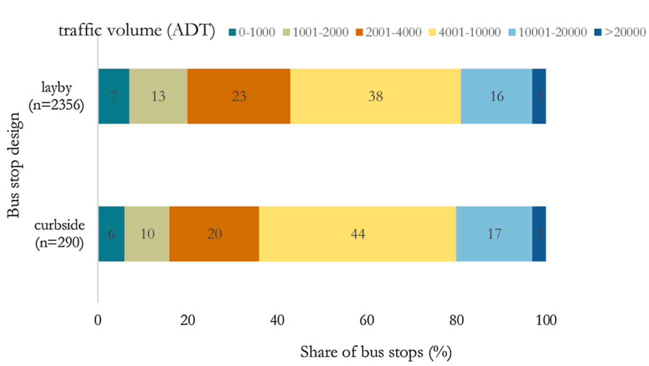

Fig. 8. Distribution of curbside and layby stops with traffic volume on 50 km/h roads in built-up areas in Norway. According to data registered in Vegkart.

Table 2
Rate calculations for traffic collisions within 60 m of bus stops in and outside of built-up areas, in the period 2014-2018.

Location	Collisions within 60 m from bus stop	No. bus stops*	No. collisions per bus stop	Traffic volume (ADT)	Collision rate
Built-up area	2896	10600	.27	5626	.26
Outside built-up area	1834	37329	.05	1849	.15
Total	4703	47929	.10	2684	.20

"ADT" = average ADT for all stops in each category. Only data for bus stops with corresponding data for ADT is given.

Table 3
Risk calculations for traffic collisions within 60 m of curbside and layby bus stops in built-up areas, in the period 2014-2018.

Location	Collisions within 60 m from bus stop	No. bus stops*	No. collisions per bus stop	Traffic volume (ADT)	Collision rate
Curbside	237	660	.36	6040	.32
Layby	1302	4588	.28	6894	.22
Other type / type not registered	1330	5352	.25	4266	.32
Total	2869	10600	.27	5626	.26

"ADT" = average ADT for all stops in each category. Only data for bus stops with corresponding data for ADT is given.

passing vehicles

3.2.2. *For all types of bus stop in and outside of built-up areas*

After accounting for traffic volume, crash rates near bus stops were higher inside than outside of built-up areas (Table 2).

3.2.3. *For curbside vs. layby stops in built-up areas*

In built-up areas, the rate of traffic collisions occurring within 60 m of curbside stop was greater than for layby stops (Table 3).

3.2.4. *For curbside vs. layby stops on roads with different speed limits in built-up areas*

Our analysis suggests that after controlling for traffic volume there is a greater risk of collision within 60 m of a curbside stop on roads with lower speed limits (30 km/h) than on roads with higher speed limits (Fig. 9). For either curbside or layby stops, the data did not support positive link between speed limit and collision rates, up to speed limits of 50 km/t for curbside stops and 60 km/t for layby stops. There were too few stops to allow for comparison on roads with speed limits lower or higher than those shown in Fig. 9.

3.2.5. *For curbside vs. layby stops on roads with different traffic volumes in built-up areas*

To examine the effect of the number of passing vehicles (traffic volume) on collision rates while controlling for speed limit, we looked at collisions within 60 m of bus stops on 50 km/h roads with varying traffic volumes. On roads with speed limit 50 km/h, rates of collisions within 60 m of either curbside or layby stops increases with traffic volume (Fig. 10). On 50 km/h roads with over 5 000 vehicles passing per day, rates of collisions are markedly greater within 60 m of curbside stops than for layby stops.

3.3. *Characteristics of collisions occurring near curbside vs. layby bus stops in built-up areas*

To control for the effect of speed limit and traffic volume while

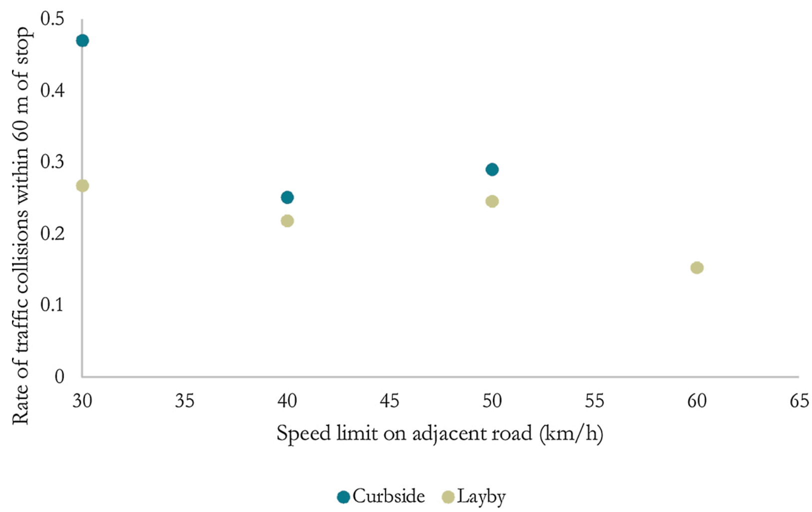

Fig. 9. Rates of traffic collisions within 60 m of a curbside or layby stops in built up areas, according to speed limit of adjacent road.

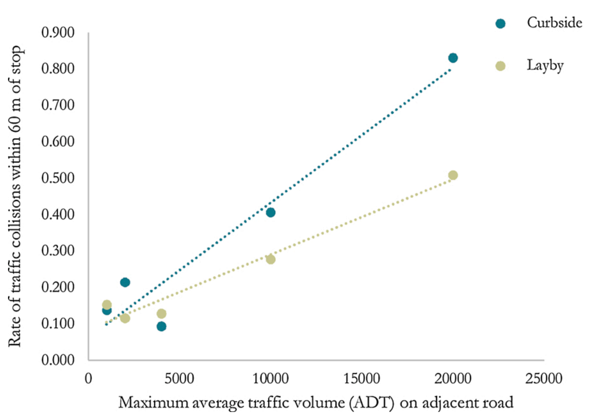

Fig. 10. Traffic collision rates within 60 m of a curbside or layby stops on roads in built up areas with speed limit 50 km/h, according to traffic volume.

providing sufficient statistical power for the analyses, where possible we analysed data for collisions occurring within 60 m of a curbside or layby bus stops in built-up areas on roads with a 50 km/h speed limit and a limited range of traffic volume.

3.3.1. *Injury outcome and type of road user involved*

We detected no large differences in collisions near curbside vs. layby stops in terms of either severity of resulting injuries or collision type as defined by type of road users involved (Table 4a and 4b).

Due to limited statistical power, however, there may be moderate differences (ca. 7.5 % or less) that we were not able to detect. A substantial share of collisions occurring near bus stops resulted in death or serious injury (Table 4a) and over half of collisions involve vulnerable road users (Table 4b).

Table 4a
Injury severity in traffic collisions within 60 m of curbside and layby bus stops in built-up areas on roads with 50 km/h speed limit and traffic volume 4 000 – 10 000 ADT.

Injury level	Curbside (n = 57)	Layby (n = 293)
Killed / seriously injured	7.0 %	11.9 %
Lightly injured / not injured	86.0 %	84.6 %
Not registered	7.0 %	3.4 %
Total	100.0 %	100.0 %

Table 4b
Collision types, as defined by involved road users, occurring within 60 m of curbside and layby bus stops in built-up areas on roads with 50 km/h speed limit and traffic volume 4 000 – 10 000 ADT.

Collision description	Curbside (n = 57)	Layby (n = 293)
Car collision	45.6 %	46.4 %
Pedestrian involved	15.8 %	18.8 %
Motorbike accident	17.5 %	17.7 %
Cycle accident	21.1 %	17.1 %
Total	100.0 %	100.0 %

3.3.2. *Collision type*

To test our hypothesis that there are more side-on collisions near layby than curbside stops, and more head-on collisions near curbside than layby stops we used the variable “Accident code” (*Uhellskode*) available in the *Vegkart* data. We collapsed 69 different codes denoting different accident types under “Accident code” into eight main collision codes, and looked for differences in distribution of these codes for curbside versus layby collisions (Table 5). To provide sufficient numbers, we did not control for speed limit or traffic volume.

We found little difference in the proportion of curbside and layby collisions coded as “Pulling out to the left in front of vehicle travelling in same or opposite direction”. From this we conclude that the data do not support a hypothesis that there are many more side-on collisions at

Table 5
Share of collisions of different types, according to systematic registrations, occurring within 60 m of curbside versus layby stops on roads with different speed limits and traffic volumes.

Collision type	Curbside (n = 280)	Layby (n = 1561)
Single vehicle	7.9 %*	13.3 %*
Pedestrian	21.1 %	16.7 %
Rear-end	23.9 %	24.4 %
Turning off left into path of oncoming traffic	4.3 %	5.1 %
Pulling out to the left in front of vehicle travelling in same or opposite direction	5.4 %	6.3 %
Crossing driving paths without turn-offs	9.6 %**	5.3 %**
Head-on	2.9 %	5.3 %
Other	25.0 %	23.5 %
Total	100.0 %	100.0 %

A Chi-squared test for independence at an alpha level of .05 indicated that the differences in distributions were statistically significant.
* Two-sided test for pairwise difference is significant at 5% level.
** Two-sided test for pairwise difference significant at 1% level.

laybys than at curbside stops due to buses pulling out into passing traffic. Further, the data suggest that a greater share of collisions occurring at *layby* stops are head-on collisions, and therefore do not support our hypothesis that head-on collisions are more likely to occur at curbside than layby stops due to risky overtaking maneuvers by drivers trying to get past stopped buses. We also detected no pairwise difference in the share of rear-end collisions occurring at curbside vs. layby stops, indicating that the data do not support a hypothesis of curbside stops increasing collision rates by making rear-end collisions more likely than layby stops do. A substantial share – around 25 per cent – of bus stop collisions are rear-end collisions, whether at curbside or layby stops.

Since our study is explorative, it is interesting to note other differences in collision types occurring at curbside vs. layby stops. First, significantly more of the collisions occurring near curbside than layby stops are classified as "crossing driving paths without turn-offs", a type of collision that is typical for crossroad accidents. Second, more of the layby than curbside collisions are classified as single vehicle collisions. Third, the data allow for the possibility that curbside stops are associated with a greater share of pedestrian collisions, although this difference is not statistically significant.

3.3.3. *Collision location relative to junctions*

To investigate whether there was a difference in the share of junction collisions occurring within 60 m of curbside and layby stops, we used a variable describing whether each collision occurred at a junction, on a roundabout, or on a stretch of road away from junctions or turn-offs. A substantially larger share of collisions near curbside stops occurred at cross-roads (Table 6), in line with the finding that a greater share of collisions near curbside stops are "crossing driving paths without turn-offs" (Table 5). There is a tendency for a greater share of the collisions near layby stops to occur on stretches away from junctions or turnoffs (Table 6).

3.3.4. *Distance of collision from bus stop*

Looking at the distribution of collisions across 60 m from curbside or layby bus stops in built-up areas, we see that the number of collisions tends to increase as we move further away from curbside stops, but as we move closer to layby stops (Fig. 11).

Nearly 25 per cent of layby collisions occur between 0 and 10 m from the stop, but in the case of curbside stops, larger shares of collisions occur between 40 and 60 m away from the stop. To assess whether these collisions could be junction collisions, we performed the same analysis after excluding collisions occurring at junctions, side roads or roundabouts (Fig. 12).

Excluding collisions near junctions, roundabouts or side roads, we see that the distribution of collisions over 60 m from the stop is similar for curbside and layby stops, with 26 and 32 per cent of collisions occurring within 10 m of curbside and layby stops, respectively.

3.3.5. *Other differences*

An analysis of differences in the distribution of collisions occurring on roads with 1, 2, 3 or 4 driving lanes, indicated that more collision on curbside than layby stops occur on roads with 4 lanes, but from available registrations in collision data, we do not know whether these lanes are bus lanes. An analysis of differences in driving conditions under which collisions occurred showed no significant difference in conditions associated with collisions between bus stop types.

Table 6
Location of collisions occurring within 60 m of curbside and layby bus stops in built-up areas on roads with 50 km/h speed limit and traffic volume 2 000 – 10 000 ADT.

Collision location	Curbside (n = 58)	Layby (n = 320)
T-/Y-junction	32.8 %	30.0 %
Crossroads	27.6 %**	10.3 %**
Roundabout	6.9 %	14.4 %
Stretch away from junctions or turn-offs	32.8 %	45.6 %
Total	100.0 %	100.0 %

A Chi-squared test for independence at an alpha level of .05 indicated that the differences in distributions were statistically significant.

** Two-sided test for pairwise difference significant at 1% level.

4. Discussion

We have explored the use of data from publicly available national road databases to assess relative rates of traffic collisions resulting in personal injury occurring near curbside vs. layby bus stops in built-up areas in Norway. These two bus stop types differ fundamentally as to whether the bus stops in or out of the flow of traffic, which may in turn influence the risk of collisions involving surrounding traffic. We found that rates of personal injury collision within 60 m of curbside and layby bus stops in built-up areas are, respectively, 0.32 and 0.22 per 10 million passing vehicles.

This difference in crash rates becomes more acute as traffic volumes increase above 10 000 ADT on 50 km/h roads – in line with guidelines in Norway recommending implementation of curbside stops on roads with traffic volumes less than 10 000 ADT. Regarding speed limit, the elevated rates of collisions near curbside stops is more acute at 30 km/h than at 40 or 50 km/h, but this might be explained by a greater tendency for curbside stops to be located near junctions and side roads on roads with lower speed limits. The following findings support this explanation:

- A greater share of collisions registered within 60 m from bus stops occurred only 0–10 m away from layby stops but as far as 40–60 m away from curbside stops (where junctions and side roads may be located)
- After excluding road, junction and roundabout collisions, we observed a tendency for more collisions to occur only 0–10 m away from both layby and curbside stops
- The share of collisions directly registered as being located as occurring at crossroads was almost three times greater for curbside stops than layby stops (27.6 % vs. 10.3 %).

An important question then is whether curbside bus stop design increases the likelihood that collisions will occur at junctions or side roads within 60 m from the bus stop. A significantly greater share of collisions near curbside than layby stops (9.6 % vs. 5.3 %) were coded as the collision type "crossing driving paths without turn-offs" – a collision typically associated with crossroads with or without nearby bus stops. This, coupled with the fact that collision risks are known to be higher at junctions per se (Høye et al., 2019), implies that our data should not be used to support the idea that collision risks near curbside stops are higher than for layby stops because of the way the bus stop is designed. Rather, elevated rates of collisions near curbside stops in built-up areas may be a consequence of the more complicated traffic situations in which they are typically implemented.

Readers should note that our study says little about the extent to which bus stop activities are directly responsible for the absolute crash rate levels given, i.e. crash rates given are related to bus stops only based on their proximity to the bus stops. Our study did, however, attempt to determine whether types of collision differ in ways that *implicate* bus stop design as contributing to collision risks (cf. end of Introduction). The idea that bus stop design does not strongly influence collision rates is supported by the fact that (i) the share of head-on collisions, pedestrian collisions or rear-end collisions near curbside stops was not significantly greater than the corresponding shares for layby stops (cf. Section 1.4); and (ii) the share of layby collisions classified as "pulling out to the left in front of vehicle travelling in same or opposite direction" – indicative of more side-on collisions occurring due to buses having to force their way out into passing traffic – was not significantly greater for layby than curbside stops.

While we found no large differences in crash type or the severity of

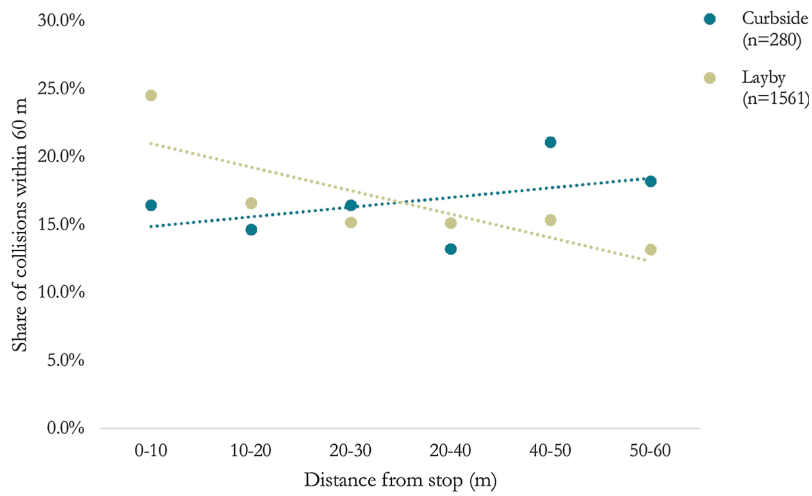

Fig. 11. Share of all collisions within 60 m of curbside or layby bus stops on roads away from junctions or side roads in built-up areas, that occur at different distances from the bus stop, with linear trendline added. For stops on roads with different speed limits and traffic volumes.

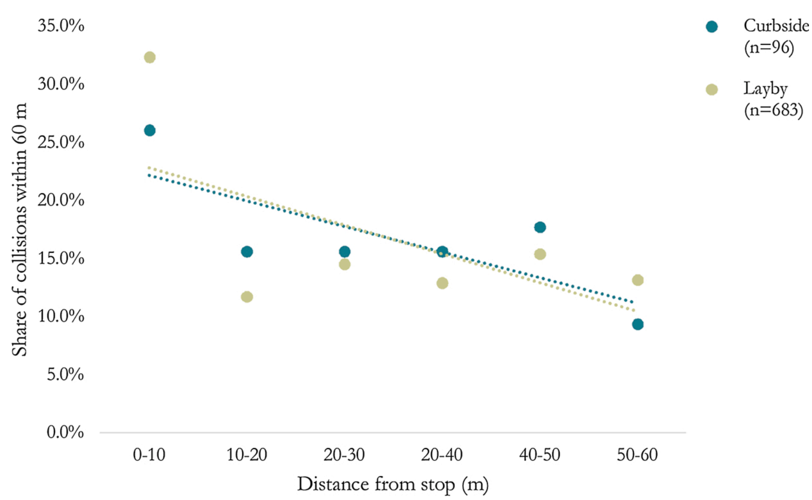

Fig. 12. Share of all collisions within 60 m of curbside or layby bus stops on roads away from junctions or side roads in built-up areas, that occur at different distances from the bus stop, with linear trendline added. For stops on roads with different speed limits and traffic volumes.

injury outcomes for crashes occurring near curbside versus layby stops when controlling for speed and traffic volume (Table 3), the available numbers limited detection of smaller but potentially important differences. Examination of crashes occurring over a longer period, or in a country with more bus stops, would allow more solid conclusions to be drawn about differences in injury outcomes and collision types occurring at various proximities from curbside versus layby stops.

4.1. Pros and cons of using national databases to investigate bus stop collision risk

In preparation for this study, we recognised that data from the National Road Database (Vegkart) afforded two important advantages. First, it allowed the most complete analysis at national level of personal injury collisions occurring at different distances from different types of bus stop. Second, by coupling data from Vegkart to data on built-up areas from Statistics Norway, we could focus on bus stops in built-up areas – an important criterion for our project.

A first main challenge in the use of large databases is related to data registrations. Inevitably there are sources of error and variation in the way data is registered by people in different regional administrations. Further, the degree of error may vary systematically, for example from region to region. For instance, we observed that the shares of bus stops registered as "curbside" stops and "sign only" stops varied widely from region to region. While this might reflect reality, it could also in part be due to varying interpretation by those making registrations. A further potential error in the registered data is that while we know traffic volumes were registered in 2017, the year in which variables describing bus stops are registered can vary, with some being made more recently and others being made up to ten years ago. We therefore cannot rule out the possibility that changes to the road environment have been made in the time between collisions occurring and time at which registrations were made of bus stop characteristics, traffic volume, speed limit or built-up area.

A second main challenge in the use of the national road databases was that data registrations did not allow us to measure and control for bus stop design features other than curbside/layby. As one reviewer pointed, "*A well designed curbside bus stop can perform better in safety than a poorly designed layby bus stop, and vice versa. [One should also consider] the layout, the control and management.*" Our national database fell short in this regard.

A second main challenge in our use of the national road database was related to the procedure used to link large amounts of data based on their geographical location. While we developed this procedure over time to minimize sources of error, there remain imperfections in the data. For example, recall that data on bus stops were linked to data on

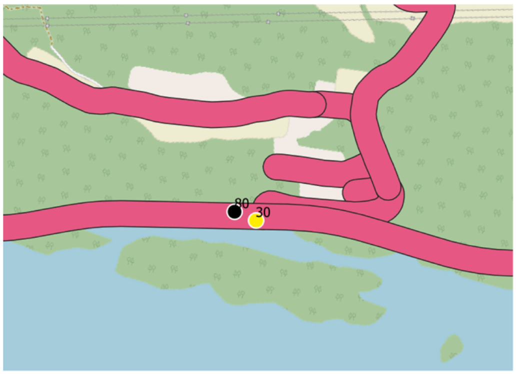

Fig. 13. Bus stops on opposite sides of the same main road assigned two different values for speed limit. The bus stop in black has been assigned a speed limit of 80 km/h (for the main road), while the bus stop in yellow has been assigned the speed limit of the side road (30 km/h).

speed limit or traffic volume if the bus stop location fell within links describing speed limit or ADT for a stretch of road. Because the bus stops are located at the edge of the road, they often fall outside these links, which are centered along the middle of the road. This made it necessary to set a 20 m buffer around the links to "capture" adjacent bus stops. In cases where links overlapped, we assigned to the bus stop the speed limit or traffic volume for the nearest link. We noticed in a few cases, however, that bus stops on main roads located very close to side road junctions had been incorrectly assigned the speed limit for the side road (Fig. 13). The number of bus stops located so closely to side roads is very few, such that we do not expect this to influence our findings. Future work could nevertheless remove such imperfections by prioritizing assignations based on road type.

A powerful advantage of using geographic databases to analyse collisions on national level, is that one can "zoom in" on individual collisions to capture situations misrepresented by national-level data. A good example of this is provided by Fig. 14, which shows a junction collision occurring within the 60 m buffer zone of one of the bus stops, but which also is at the edge of the zones of several other stops. Even if we assume that this collision is the result of a risky traffic situation initiated at one of the bus stops, it would not be possible to know which of these stops would be responsible.

For the most part, however, our inspections of a random selection of collisions showed that the assumptions on which our analyses are based are fair, such that the overall findings should be representative of most of the bus stop collisions.

4.2. Future work

We have attempted to examine whether a fundamental difference between bus stops – whether the bus stops in the road or out of the road – affects surrounding collision rates. To this end we have explored whether data registered in national databases in Norway can be used as the basis for conclusions about this. An advantage of using national databases is that large numbers of stops can be compared, to enable comparison of collision rates due to the stopping position of the bus. Higher rates for curbside stops appear to be attributable to nearby junctions, but our study says little about the extent bus stop activities could have contributed to nearby crashes and crashes at junctions. Such knowledge would be improved by adding to our database data on the number of passing buses, cyclists and pedestrians, and passengers using the bus stop. To investigate the contribution of bus stop design and bus stop activities to collision risk further, database analyses could also be supplemented with in-depth collision analyses, which would enable us to measure and control for other important bus stop design features, or conflict studies (e.g. Phillips et al., 2011). These studies would give empirical basis for hypotheses that can be tested by database analyses, with data registrations and processing improved as indicated above.

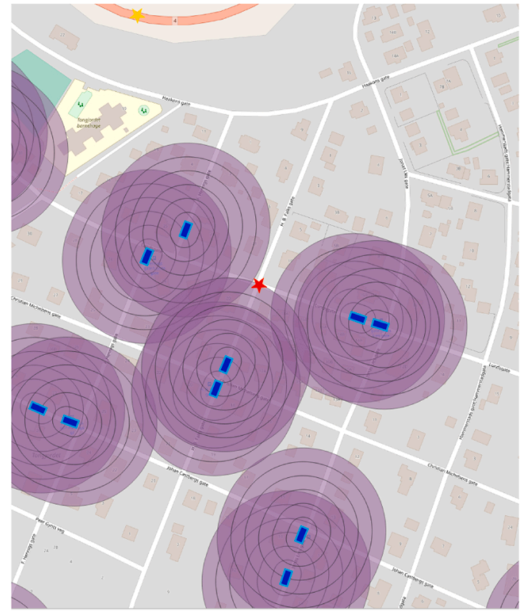

Fig. 14. Junction collision falling within 60 m of a bus stop, but just over 60 m from several other stops.

Bus stops contain features other than whether they allow the bus stop to stop out of or in the road. A well-designed curbside bus stop can perform better in safety than a poorly designed layby bus stop, and vice versa. Our strategy has been to "average out" these effects by comparing large numbers of bus stops, but future studies should consider effects that detailed design of the bus stop, such as the layout, control and management, can have on traffic safety.

Further database analyses could also control for some of the additional confounding variables we describe, not least whether the road has been made "cyclist- "or "walker-friendly" (there are variables available in Vegkart for this), or the number of cars parked nearby. It might also be possible to generate a variable describing bus stop proximity to junctions or side roads, so that the risk for collisions near curbside or layby stops away from side roads or junctions could be analysed. An additional possibility is to perform "in-depth" analyses of a selection of situations in Vegkart, to see whether certain situations are more likely to be associated with collisions (e.g. several bus stops along a busy road). Finally, in cases where bus stops are converted e.g. from layby to curbside stops, before and after analysis of collisions or near misses involving different types of road user would be informative.

5. Conclusion

Relative rates of traffic collisions resulting in personal injury within 60 m is higher for curbside than for layby bus stops built-up areas. This is probably because curbside stops tend to be located closer to junctions and side roads, where collisions are more likely per se. These findings are based on an explorative analysis in which data from national databases have been coupled using common variables on geographical location. Several challenges to such analysis have been identified, which can be improved by future studies.

Credit authorship contribution statement

The study was conceptualized as part of a tender by the authors based on a requirement set by the National Public Roads Administration (NPRA).

Conceptualization: Phillips, Hagen, Berge, NPRA.

Data curation: Hagen.

Investigation: Berge and Phillips
Formal analysis: Phillips, Berge and Hagen
Writing - original draft: Phillips, Hagen and Berge
Writing - review and editing: Phillips

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Declaration of Competing Interest

None.

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