Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Identifying Research Priorities to Improve Safety for Pedestrians and Bicyclists Accessing Bus Stops

May 2025

A Report From the
Center for Pedestrian and Bicyclist Safety

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About the Center for Pedestrian and Bicyclist Safety (CPBS)

The Center for Pedestrian and Bicyclist Safety (CPBS) is a consortium of universities committed to eliminating pedestrian and bicyclist fatalities and injuries through cutting-edge research, workforce development, technology transfer, and education. Consortium members include: The University of New Mexico; San Diego State University; The University of California Berkeley; The University of Tennessee Knoxville; and The University of Wisconsin Milwaukee. More information can be found at: https://pedbikesafety.org

Disclaimer

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16. Abstract
Bus stops must be safely accessible to transit passengers who begin and end their trips as pedestrians. Prior studies have analyzed bus stop safety using crash data, but many assumed that all crashes near bus stops were directly related to the stop itself, largely due to the lack of transit-related information in crash data. This research analyzes pedestrian safety at bus stops using databases that explicitly report transit-related crashes. First, a detailed review of relevant datasets was conducted. Then, a nationwide analysis examined fatal "transit bus stop-related" pedestrian crashes from the Fatality Analysis Reporting System (FARS) and compared them with other nearby fatal pedestrian crashes using a binary logit model and hierarchical clustering. The logit model indicated that midblock stops, pedestrians on the roadside, and bus-involved crashes are strong indicators of transit bus stop-related crashes. The clustering revealed three transit bus stop-related crash scenarios: (1) crossing to/from intersection stop, (2) waiting roadside at midblock stop, and (3) crossing to/from midblock stop. The clustering of both transit bus stop-related and nearby crashes showed that scenario 2 clustered separately from nearby crashes, suggesting this scenario is specific to bus stops. Next, using street-level imagery, bus stop infrastructure near fatal bus stop-related crashes was assessed. The results revealed that conditions generally improved after the crash. Last, a state-level analysis was conducted using crash data from Minnesota because this dataset specifically identified crashes with a pedestrian "going to or from public transit". From 2016-2023, there were 38 of these transit-related pedestrian crashes reported in Minnesota, which varied in severity and included one fatal crash. In summary, this report highlights the need for improved data collection to assess pedestrian safety throughout the entire trip to and from transit.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

Identifying Research Priorities to Improve Safety for Pedestrians and Bicyclists Accessing Bus Stops

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Acronyms, Abbreviations, and Symbols

AADT	Annual Average Daily Traffic
APC	Automatic Passenger Counter
ASW	Average Silhouette Width
BRT	Bus Rapid Transit
CARTS	Center for Analytics & Research in Transportation Safety
CRSS	Crash Reporting Sampling System
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FTA	Federal Transit Administration
GDOT	Georgia Department of Transportation
GTFS	General Transit Feed Specification
HSIS	Highway Safety Information System
ITD	Idaho Transportation Department
LAPD	Los Angeles Police Department
LRT	Light Rail Transit
MMUCC	Model Minimum Uniform Crash Criteria
MnDOT	Minnesota Department of Transportation
NCDOT	North Carolina Department of Transportation
NDOT	Nebraska Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
PCW	Pedestrian in Crosswalk Warning
PBCAT	Pedestrian and Bicyclist Crash Analysis Tool
UHSO	Utah Highway Safety Office
UF	University of Florida
WMATA	Washington Metropolitan Area Transit Authority

Abstract

Bus stops must be safely accessible to transit passengers who begin and end their trips as pedestrians. Prior studies have analyzed bus stop safety using crash data, but many assumed that all crashes near bus stops were directly related to the stop itself, largely due to the lack of transit-related information in crash data. This research analyzes pedestrian safety at bus stops using databases that explicitly report transit-related crashes. First, a detailed review of relevant datasets was conducted. Then, a nationwide analysis examined fatal "transit bus stop-related" pedestrian crashes from the Fatality Analysis Reporting System (FARS) and compared them with other nearby fatal pedestrian crashes using a binary logit model and hierarchical clustering. The logit model indicated that midblock stops, pedestrians on the roadside, and bus-involved crashes are strong indicators of transit bus stop-related crashes. The clustering revealed three transit bus stop-related crash scenarios: (1) crossing to/from intersection stop, (2) waiting roadside at midblock stop, and (3) crossing to/from midblock stop. The clustering of both transit bus stop-related and nearby crashes showed that scenario 2 clustered separately from nearby crashes, suggesting this scenario is specific to bus stops. Next, using street-level imagery, bus stop infrastructure near fatal bus stop-related crashes was assessed. The results revealed that conditions generally improved after the crash. Last, a state-level analysis was conducted using crash data from Minnesota because this dataset specifically identified crashes with a "pedestrian going to or from public transit." From 2016-2023, there were 38 of these transit-related pedestrian crashes reported in Minnesota, which varied in severity and included one fatal crash. In summary, this report highlights the need for improved data collection to assess pedestrian safety throughout the entire trip to and from transit.

Executive Summary

The multimodal nature of public transit requires bus stops to be safely accessible to passengers who begin and end their trips as pedestrians. Prior research has analyzed bus stop safety with crash data often assuming that all crashes occurring near bus stops are related to the stops. Instead of depending solely on spatial proximity, this report used data that specifically identifies transit-related pedestrian crashes, focusing on the walking, waiting, and crossing stages of a transit trip.

The research questions guiding this report are as follows:

1. What types of data are currently used to analyze pedestrian safety at bus stops, and what additional data sources are available to support further research?
2. What are the characteristics of fatal transit bus stop-related pedestrian crashes?
3. How do fatal transit bus stop-related pedestrian crashes compare to other nearby fatal pedestrian crashes?
4. What are the characteristics of crashes at different injury severity levels for pedestrians going to and from transit stops, using a unique data code from Minnesota?

Findings from the literature review suggest that there is a lack of transit-related information in crash data, which prompted a review of databases to identify potential sources for this analysis. This review identified two crash typing frameworks that include a crash type specific to bus stops: the Pedestrian and Bicyclist Crash Analysis Tool (PBCAT) and the Model Minimum Uniform Crash Criteria (MMUCC). While these frameworks specify whether a crash was related to a bus stop, many real-world datasets have not adopted the most recent versions of these frameworks. As a result, these crashes may be unreported or miscategorized. Even those who use these frameworks may still underreport transit-related crashes. For instance, the Fatality Analysis Reporting System (FARS) reported only 196 pedestrians involved in fatal transit bus stop-related crashes from 2014-2022. The limited sample is likely due to crash type definitions, such as requiring bus presence at the stop and not considering the entire walking trip to and from the bus stop.

From the review, the fatal *"transit bus stop-related"* pedestrian crashes from FARS and the *"going to or from public transit"* pedestrian crashes in Minnesota were selected for analysis. FARS uses both frameworks, enabling a nationwide analysis focused on risks directly at the bus stop. In contrast, Minnesota does not use these frameworks, but its crash type accounts for the entire walking trip to and from the bus stop, addressing a limitation of the FARS data.

The goal of the FARS analysis was to analyze fatal transit bus stop-related pedestrian crashes and compare them to other fatal pedestrian crashes within a quarter- and half-mile radius. From 2014-2022, there were 196 pedestrians involved in fatal transit bus stop-related crashes. A descriptive analysis and crosstabulations revealed that 162 (83%) of transit bus stop-related crashes occurred on higher-speed roads, 156 (80%) occurred on arterials, 152 (78%) were related to a midblock bus stop, 116 (59%) involved a pedestrian crossing the roadway, and the contact vehicle was a bus in 44 (23%) of crashes.

Then, FARS data was used in binary logit models to compare the characteristics of fatal transit bus stop-related crashes to other nearby fatal pedestrian crashes. Key findings from the models revealed that crash location, peak hour travel, the action of the pedestrian, and bus-involvement were significantly associated with transit bus stop-related crashes. Notably, midblock crashes were significantly more likely to be transit bus stop-related than intersection crashes, with odds 5.2 times higher in the quarter-mile radius and 4.7 times higher in the half-mile radius. Crashes involving pedestrians who were stationary on the roadside were 8.8 and 8.2 times more likely to be transit bus stop-related than those involving pedestrians crossing the roadway, within the same radii. Last, transit/commuter bus crashes are far more likely to be transit bus stop-related compared to those without a bus involved, with odds 13.2 and 28.6 times higher within the same radii.

Next, a hierarchical clustering analysis of the transit bus stop-related crashes reported in FARS revealed three main scenarios: (1) pedestrian hit while crossing to/from an intersection stop, (2) pedestrian hit while waiting at a midblock stop, (3) pedestrian hit while crossing to/from a midblock stop. The clustering of both transit bus stop-related crashes and other nearby fatal pedestrian crashes revealed the same three scenarios. However, the scenario involving pedestrians standing midblock on the roadside formed a distinct cluster, predominantly containing transit bus stop-related crashes, suggesting this scenario is specific to transit stops.

The fatal transit bus stop-related pedestrian crashes in FARS were further analyzed using street-level imagery to manually compile an inventory of bus stop infrastructure at the crash locations. Findings showed that most bus stops underwent improvements after the crash, possibly in response to safety concerns. However, crashes involving pedestrians waiting at the bus stop had already had many of the surveyed amenities at the time of the crash, with minimal improvements made after the crash, while crashes involving pedestrians crossing to/from the stop saw more improvements but still lacked key amenities, particularly in crosswalks, shelters, and seating.

Last, an analysis of the 38 "*going to or from public transit*" pedestrian crashes in Minnesota from 2016 to 2023 characterized different transit-related crash scenarios, which varied in severity and included non-fatal outcomes. Findings showed that transit-related language was used in 26 (70%) of the narratives. In the narratives, pedestrians were primarily described as walking to/from transit (43%), with others waiting at the stop, involved in a crash with the bus, related to light rail transit, or the bus driver was a witness.

The findings from this report build on existing studies and suggest that distinct risks are associated with walking to or from the bus stop, as well as with waiting at the bus stop. This report begins to identify targeted countermeasures for each type of crash. Lowered speed limits and improved access and visibility of marked crossings could benefit both transit passengers traveling to/from bus stops and other pedestrians in areas with transit services. However, pedestrians waiting at midblock stops may face specific risks that differ from those experienced by other pedestrians, such as those not waiting at transit stops. In summary, more research is needed to gather data specifically focused on understanding the risks associated with both the journey to/from the bus stop and waiting at the bus stop.

Introduction

The United States reported 7,522 pedestrian fatalities on American roads in 2022, which was a 41-year high (NHTSA, 2024). The number of pedestrian fatalities has rapidly grown in recent years, with 2022 marking an 83% increase in compared to 2009 (NHTSA, 2024). This is increasingly concerning, as the proportion of traffic fatalities involving pedestrians has been rising in recent years (NHTSA, 2024). This trend warrants action to protect pedestrians and reduce the overall loss of life associated with transportation in the United States.

Numerous prior studies have identified public transit as a strategy to improve the safety of road users. Dickens and Shaum (2018) found that travel by transit is ten times safer per mile than traveling by car. Additionally, Bia and Ferenchak (2022) found an overall reduction in vehicle speeds after the construction of a Bus Rapid Transit (BRT) route in Albuquerque, New Mexico. Building upon this finding, Ferenchak and Woods (2025) identified a notable 19.1% reduction in speeding-related crashes on the same BRT corridor. To realize these and other safety benefits, pedestrians must be able to safely access and egress from bus stops. Not only does safe access to transit impact pedestrian safety, but it also affects transit ridership. Pedestrians tend to avoid walking in areas that are perceived as unsafe (Ferenchak & Marshall, 2019; Kweon et al., 2021). Therefore, if the walking trip to a bus stop is perceived as unsafe, some transit riders may opt for alternative modes of transportation, potentially reducing transit ridership. Hence, addressing safe access to bus stops is a vital consideration for improving pedestrian safety and the overall success of transit systems.

First-mile and last-mile access for transit riders is a critical component of this problem, as many of these trips are made by walking (Goughnour et al., 2022; Pulugurtha & Vanapalli, 2008; Ulak et al., 2021). Bus stops are pedestrian generators (Goughnour et al., 2022; Ulak et al., 2021), and prior studies have consistently established a relationship between pedestrian crashes and transit service through measures such as transit ridership and proximity to bus stops and transit corridors (Anis et al., 2024; Goughnour et al., 2022; Hess et al., 2004; Pulugurtha & Penkey, 2010; Pulugurtha & Vanapalli, 2008; Singh et al., 2022; Ulak et al., 2021; Yu, 2024). However, the pedestrian crash data that has been used in most prior studies does not explicitly state whether the pedestrian was going to, leaving from, or waiting at a transit stop at the time of the crash. Instead, many studies have used pedestrian crash data to infer this relationship based on the distance between all pedestrian crashes and bus stops (Anis et al., 2024; Hess et al., 2004; Pessaro et al., 2017; Pulugurtha & Penkey, 2010; Pulugurtha & Vanapalli, 2008; Salum et al., 2024; Singh et al., 2022; Ulak et al., 2021; Voorhes Transportation Center, 2012; Yu, 2024). This may introduce uncertainty into the analysis, potentially underreporting or possibly overreporting pedestrian involvement. The lack of detail in pedestrian crash data makes it particularly challenging to identify crash characteristics specifically associated with bus stops, rather than characteristics of crashes based solely on proximity to bus stops.

In light of this, the objective of this report is to analyze pedestrian crash data that explicitly identifies crashes related to bus stops. This approach may offer a more accurate evaluation of the connection between pedestrian crashes and bus stops, as it avoids the limitations of methods that depend solely on spatial proximity to bus stops. This report is guided by the following research questions:

1. What types of data are currently used to analyze pedestrian safety at bus stops, and what additional data sources are available to support further research?
2. What are the characteristics of fatal transit bus stop-related pedestrian crashes?
3. How do fatal transit bus stop-related pedestrian crashes compare to other nearby fatal pedestrian crashes?
4. What are the characteristics of crashes at different injury severity levels for pedestrians going to and from transit stops, using a unique data code from Minnesota?

In Section 2, a comprehensive review of the literature on pedestrian safety at bus stops in the United States is presented. In Section 3, a review of transit-related safety datasets is conducted. Additionally, in Section 3, transit-related data from the Fatality Analysis Reporting System (FARS) and raw crash data from the Minnesota Department of Transportation (DOT) are introduced as the primary data sources for the analyses. Next, Section 4 describes the three-part methodology used in the nationwide analysis, which analyzed characteristics of fatal transit bus stop-related pedestrian crashes and compared them to other fatal pedestrian crashes that occurred nearby. Section 4 also describes the methodology for the statewide analysis of Minnesota crash data, focusing on the analysis of the crash narratives to understand the characteristics of transit-related crashes, including those with non-fatal outcomes. In Section 5, the results of the three-part nationwide analysis were presented and discussed. Next, the results of the statewide analysis are presented and discussed in Section 6. Last, Section 7 summarizes the major contributions of this report, as well as limitations and areas for future research. The overarching structure of this report is shown in Figure 1.

Last, it should be noted that some portions of this report (Sections 2, 3, 4, 5 and 7) are adapted from the Master's Thesis by UTK graduate student Allison Rewalt in Spring 2025 titled "Using Fatal Crash Data to Analyze Nationwide Trends in Pedestrian Safety at Bus Stops."

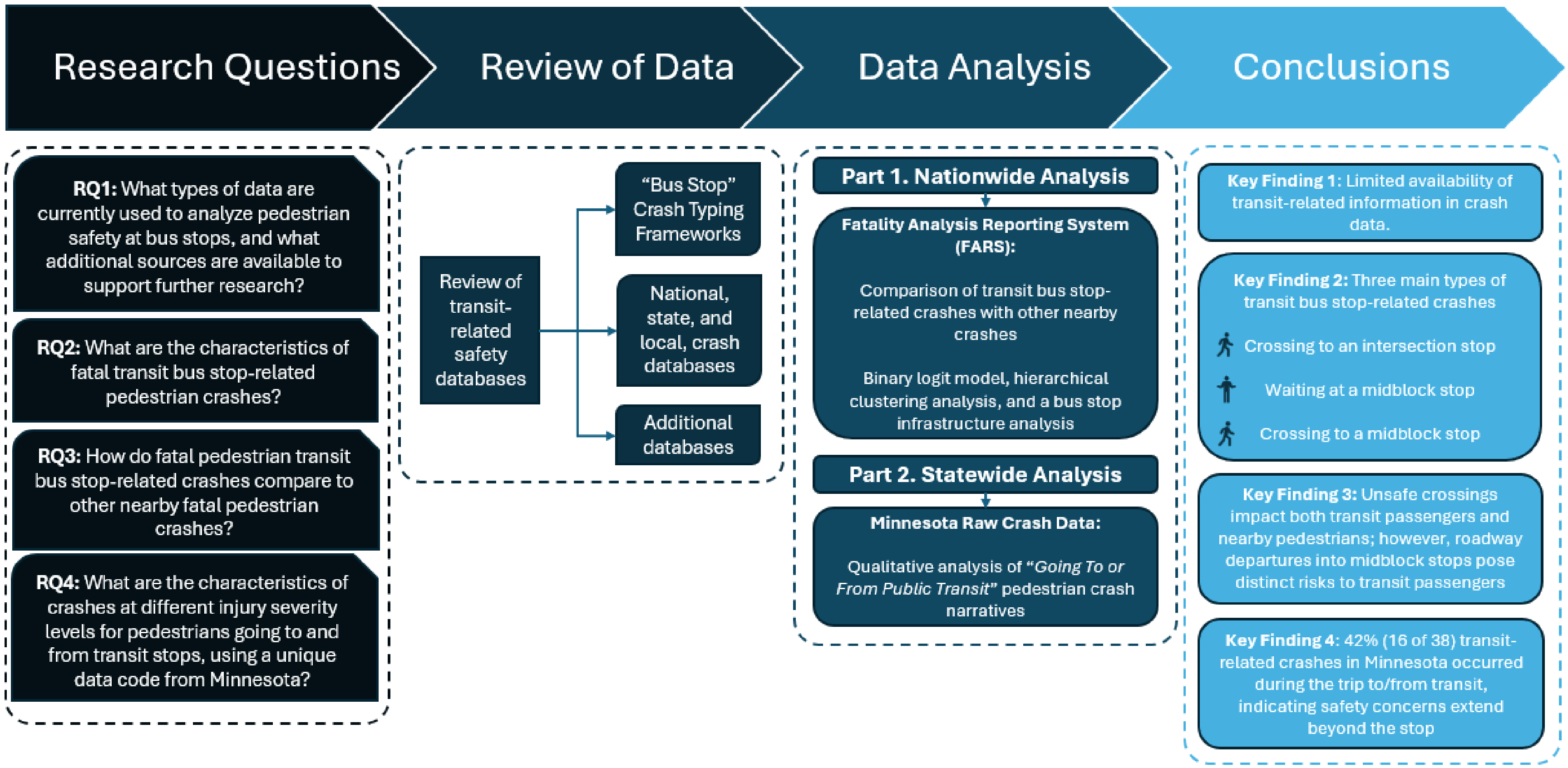

Figure 1. Report framework

Literature Review

This section provides a review of literature from the United States over the past 20 years, including both academic research and studies by state DOTs and their partners, and it is summarized in Table 1. This review focuses on the data sources and methodological approaches used in prior studies. The limitations associated with these data sources and methods are then discussed. Next, a synthesis of key findings from the literature review is provided. Last, key gaps identified in the prior literature are presented.

Scope of the Literature Review

The scope of this literature review is limited to studies from the past 20 years that examine pedestrian safety at bus stops within the United States. While many prior studies have explored the relationship between pedestrian safety and transit, numerous studies have focused specifically on pedestrian-bus crashes rather than safety concerns at bus stops (Kaplan & Prato, 2012; Ragland et al., 1994; Samerei et al., 2021; Strathman et al., 2010; Zhou et al., 2020). Although several international studies address pedestrian safety at bus stops, such research is more limited in the United States (Hazaymeh, 2009; Phillips et al., 2021; Tiboni & Rossetti, 2013; Truong & Somenahalli, 2011). As a result, this review focuses exclusively on studies within the United States.

Data Sources and Methodologies

A major finding from the literature review is that none of the prior studies have used pedestrian crash data that explicitly states that a crash was related to a bus stop. Instead, these studies often relied on assumptions to establish a relationship between pedestrian safety and bus stops. Throughout the literature, this relationship was established using three main approaches: (1) the location-based assumption, (2) analysis of crash narratives, and (3) obtaining field observations. The following section will discuss the use of these approaches and their limitations.

Location-based Assumption

The location-based assumption was the most widely used approach throughout the literature, with ten of the thirteen studies reviewed using this approach (Anis et al., 2024; Hess et al., 2004; Pessaro et al., 2017; Pulugurtha & Penkey, 2010; Pulugurtha & Vanapalli, 2008; Salum et al., 2024; Singh et al., 2022; Ulak et al., 2021; Voorhes Transportation Center, 2012; Yu, 2024). These studies obtained the locations of bus stops and defined a buffer radius around each bus stop. Using pedestrian crash data, any crash that occurred within the buffer zones of these bus stops was considered to be related to the bus stop in the analysis. An example of how this approach was typically used in the prior studies is shown in Figure 2. The relationship between pedestrian safety and bus stops was inferred solely based on the proximity of the bus stop to nearby crashes. This approach may have been used most frequently in the prior literature because of readily available data on pedestrian crashes, bus stop locations, roadway characteristics, ridership, and traffic volumes.

Table 1. Summary of academic literature regarding pedestrian safety at bus stops

Study	Authors	Location	Data	Approach	Methodology	Conclusion
Pedestrian Safety and Transit Corridors (2004)	Hess, Moudon, Matlick	King County, WA	Pedestrian crash data, roadway characteristics, bus stop locations, Automatic Passenger Counters (APC), and land use data	Location-based assumption (250 ft)	Binary logistic regression model	An increase of 10 bus users raises the odds of a pedestrian crash at a nearby highway or arterial by 1.17 times
Hazardous Bus Stops Identification: An Illustration Using GIS (2008)	Pulugurtha, Vanapalli	Las Vegas, NV	Pedestrian crash data, traffic volumes, bus stop locations, ridership, and street centerline data	Location-based assumption (100 ft)	Pedestrian crash/bus stop heat map; Collision frequency, collision rate	Field observations found over 95% of pedestrian trips within 100 ft of bus stops are transit-related; Collision rate better identifies hazardous bus stops
Assessing Use of Pedestrian Crash Data to Identify Unsafe Transit Service Segments for Safety Improvements (2010)	Pulugurtha, Penkey	Charlotte, NC	Street and transit network, traffic volumes, ridership, bus stop locations, pedestrian crash data, and land use data	Location-based assumption (transit corridors)	GIS analysis of road segments with versus without transit	Transit segments have 4.9 times more pedestrian crashes per mile and 2.7 times more per million vehicle miles traveled (MVMT)
Pedestrian Safety and Yielding Near Public Transit Stops (2012)	Craig, Morris, Houten, Mayou	Saint Paul, MN	Average Daily Traffic (ADT), roadway characteristics and field observations of yielding behavior	Field observations	Field observations at unsignalized marked crosswalks; Stepwise regression models	Crosswalks near bus stops showed worse yielding rates (34.6%) than those not located near bus stops (46.3%)
Pedestrian Safety at Bus Stops (2014)	Alan M. Voorhes Transportation Center, Rutgers, University	New Jersey	Pedestrian crash data, bus stop locations, census data on population and employment	Location-based assumption (100 m); crash narratives; field observations	GIS analysis to identify bus stops in high-crash locations; field observations conducted at the high-risk locations	High-crash locations were concentrated on arterials with commercial land uses. Bus passengers engaged in risky midblock crossings, and parallel path conflicts were common at intersections

Table 1. (continued) Summary of academic literature regarding pedestrian safety at bus stops

Study	Authors	Location	Data	Approach	Methodology	Conclusion
Impact of Transit Stop Location on Pedestrian Safety (2017)	Pessaro, Catala, Wang, Spicer	Broward and Palm Beach County, FL	Pedestrian crashes, Annual ADT (AADT), bus stop locations, boardings/alightings, crash narratives, stakeholder survey, road safety audits (RSAs)	Location-based assumption (100 ft); crash narratives; field observations	Bus stop ranking; site specific safety improvement recommendations	Most of the crashes involved a pedestrian crossing at an unmarked location or against the traffic signal
A Stop Safety Index to Address Pedestrian Safety Around Bus Stops (2021)	Ulak, Kocatepe, Yazici, Ozguven, Kumar	Palm Beach County, FL	Pedestrian crash data, bus stop locations from GTFS (General Transit Feed Specification), bus frequency, ridership, population, employment, socio-demographics, facilities, and traffic indicators	Location-based assumption (decay function)	Spatial analysis of bus stops and pedestrian crashes using Cross K function; Stop Safety Index (SSI), using injury severity, pedestrian crashes, bus stop location, and a decay function	Bus stops and pedestrian crash locations have a significant spatio-statistical relationship; SSI ranks hazardous bus stops
Effect of Transit-Oriented Design on Pedestrian and Cyclist Safety Using Bivariate Spatial Models (2022)	Singh, Zhang, Cheng, Li, Clay	Los Angeles County, CA	Pedestrian, bicyclist, and vehicle-only crash data, socioeconomic, employment, land use, built environment, and transit-oriented development characteristics	Location-based assumption (0.5 mi)	Bivariate spatial analysis of pedestrian crashes near transit stops	More households, jobs, and transit stops correspond to more pedestrian crashes; more jobs, population, and express bus stops correspond to more bicyclist crashes
The Impact of Built Environments on Pedestrian Safety Around Bus Stops (2022)	Yu	Austin, TX	Pedestrian crash data, traffic volumes, bus stop, roadway, and land use characteristics	Location-based assumption (200 ft)	Analyzed pedestrian crashes using a negative binomial model; Controlled for variance with a variance inflation test; Excluded highly correlated variables	Crosswalks, sidewalks, and medians were linked to fewer pedestrian crashes near transit stops, while higher speed limits, big box stores, parking, nearside, and midblock stops were linked to more crashes

Table 1. (continued) Summary of academic literature regarding pedestrian safety at bus stops

Study	Authors	Location	Data	Approach	Methodology	Conclusion
Toolkit for the Assessment of Safety at Bus Stops (2023)	Salum, Kisabanzira, Alluri, Sando	Hillsborough, Jacksonville, Miami-Dade, FL	Bus stop characteristics (GTFS) and roadway characteristics inventory, land use, demographics, pedestrian crash data, AADT, ridership	Location-based assumption (100 ft)	Weighted bus stop safety score	The scoring methodology revealed that installing shelters and improving pedestrian facilities could improve the bus stops that performed the poorest.
Neighborhood Walking Environments Around Bus Stops: Report of Findings (2024)	Pilla, Yeager, Fitzpatrick, Steel, Grimes	Kansas City, MO	Inventory of sidewalks, crossings, bus stop amenities, aesthetics; observations of social conditions and perceived safety	Field observations	Audit of street characteristics near bus stops to evaluate conditions in disadvantaged zip codes.	Conditions varied across neighborhoods, with low-income areas facing worse conditions.
Pedestrian Safety and Traffic Operations Near Transit Stops (2024)	Singleton, Mandolakani, Subedi, Mekker	Utah	Video-based behavioral observation data at signalized intersections	Field observations	Aggregation of pedestrian and motorist behavior; bivariate analysis of traffic operations, crossing behavior, and turning vehicle conflicts with nearside/farside stops	While farside bus stops improve traffic operations, they negatively impact pedestrian safety
Safety Performance Functions by Random Parameters Negative Binomial-Lindley Model for Pedestrian Safety Near Bus Stops (2024)	Anis, Geedipally, Lord	Fort Worth, TX	Pedestrian crash data, bus stop data (locations, amenities, wheelchair accessibility), ridership, roadway inventory, AADT, land use characteristics	Location-based assumption (250 ft)	Sample of crash and zero crash bus stops; Random Parameters Negative Binomial-Lindley model	Signalized intersections and bus stop amenities reduced crash frequency. Non-signalized intersections and nearside stops increased crash frequency.

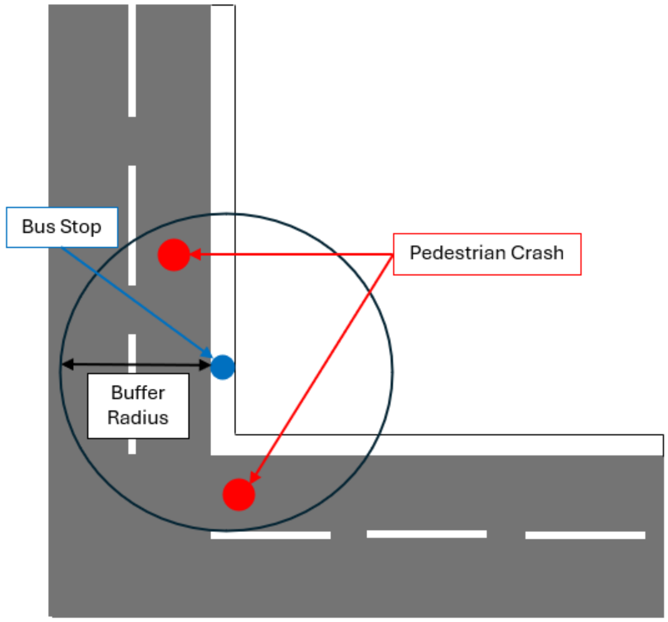

Figure 2. Example of the location-based assumption used in prior studies

The location-based assumption introduces uncertainty in the extent of pedestrian involvement in the analysis. It may overreport pedestrian involvement, given that some crashes within the buffer zones may not have been related to the bus stop. Conversely, crashes may be underreported, as some relevant crashes may have occurred outside the buffer zone. Moreover, the size of the buffer zones varies throughout the literature, with some studies using a buffer as small as 100 feet, and others as large as a half mile (see Table 1). The sensitivity of the buffer zone is also commonly referenced as a limitation throughout the studies (Hess et al., 2004; Pessaro et al., 2017; Pulugurtha & Penkey, 2010; Pulugurtha & Vanapalli, 2008; Voorhes Transportation Center, 2012). Last, many of these studies are conducted locally, where bus stop density is high. As a result, crashes may be duplicated (i.e., the buffer zones of bus stops overlap, therefore the crash falls within the buffer zones of multiple bus stops). Duplication makes it challenging to determine which bus stop takes on the attributes of the crash, which is another limitation of this assumption.

Crash Narratives

Another approach used in existing literature involves analyzing the officer narrative from the crash report to determine whether the crash report indicates that a bus stop was a contributing factor (Pessaro et al., 2017; Voorhes Transportation Center, 2012). This approach is commonly used with the location-based assumption by reviewing the crash reports for all pedestrian crashes within a given distance of a bus stop. However, this approach is time-consuming, as an analyst must review each individual crash narrative. It may also be subjective in that it is the reviewer's discretion to decide whether a crash was related to a bus stop. Moreover, involving multiple reviewers may lead to inconsistencies in this interpretation. The extent of detail provided by the officer in the narrative can also impact the accuracy.

Field Observations

The third approach involves conducting field observations to document pedestrian and motorist behavior near transit stops, as well as to assess the surrounding environmental and infrastructure conditions (Craig et al., 2019; Pessaro et al., 2017; Pilla et al., 2024; Singleton et al., 2024; Voorhes Transportation Center, 2012). This approach is occasionally used in combination with the location-based assumption and the analysis of crash narratives. However, this type of data collection is typically conducted on a local scale, which may limit its generalizability to nationwide trends. Collecting field observations is time-consuming, as it requires analysts to conduct site visits or review extensive video data.

Synthesis of Key Findings

Despite the limitations in available data sources and methods, prior studies have established a relationship between pedestrian safety and transit. Specifically, prior literature has associated increased risks with (1) bus stop locations, (2) ridership levels, (3) pedestrian and motorist behavior, and (4) stop spacing. In some of the prior studies, these factors were used as metrics for prioritizing higher-risk bus stops. The key findings from these studies are synthesized in the following sections.

Bus Stops and Pedestrian Crash Locations

Many studies aimed to explore the relationship between pedestrian crashes and their proximity to bus stops. Hess et al. (2004) established a relationship between bus boardings/alightings and pedestrian crash locations on urban arterials. Ulak et al. (2021) used the Global Cross K function method to establish a significant spatial correlation between bus stops and pedestrian crash locations. Similarly, Singh et al. (2022) identified a positive relationship between pedestrian crash frequency and bus stop density.

Anis et al. (2024) and Yu (2024) both used negative binomial models to assess the factors that increase pedestrian crash frequency near bus stops. Anis et al. (2024) found that increased traffic volume and ridership, and the absence of pedestrian facilities (refuge medians, crosswalks, and street lighting) increased crash frequency near bus stops, while signalized intersections, farside stops, and mixed land uses decreased crash frequency. A positive relationship between crash frequency and large parking supplies, big box stores, and gas stations was identified by Yu (2024). Both studies found that increased sidewalk coverage was associated with decreased crash frequency near bus stops (Anis et al., 2024; Yu, 2024).

Many studies used pedestrian crashes near bus stops as criteria in the ranking methodology to prioritize bus stops of higher risk (Anis et al., 2024; Pessaro et al., 2017; Pulugurtha & Vanapalli, 2008; Salum et al., 2024; Ulak et al., 2021; Voorhes Transportation Center, 2012). For example, using a ranking methodology, one study found that pedestrian crashes were concentrated near bus stops along arterial roadways and in commercial areas. These bus stops were then further examined to identify potential causes of the relatively higher pedestrian crash frequency (Voorhes Transportation Center, 2012).

In summary, the prior literature has often relied on the location-based assumption; however, as mentioned previously, this approach is limited since it assumes that all crashes were related to the bus stops.

Ridership Levels and Pedestrian Crashes Near Bus Stops

Several studies established a link between ridership levels and pedestrian crashes. Hess et al. (2004) found that an increase of 10 transit riders increases the odds of a pedestrian crash on a nearby arterial or state highway by a factor of 1.17. Similarly, Pulugurtha and Penkey (2010) analyzed pedestrian crashes on transit corridors and found that 30.1% of center lane miles on transit corridors experienced more than 5 pedestrian crashes per 1,000 transit riders. Last, Anis et al. (2024) used transit passenger boarding and alighting data as a proxy for pedestrian volumes near bus stops and found that increased boarding and alighting activity was associated with higher crash frequency. Recognizing the potential association between ridership and pedestrian crashes near bus stops, other studies used ridership levels as a measure to prioritize bus stops of higher risk (Pulugurtha & Vanapalli, 2008; Salum et al., 2024). In summary, this relationship has been commonly noted in prior research; therefore, bus stops with higher ridership levels may be a strong consideration to prioritize bus stop safety.

Pedestrian and Motorist Behavior Near Bus Stops

Prior research consistently shows that both pedestrian and motorist behavior near bus stops influences pedestrian safety. Many studies specifically highlight pedestrian crossing behavior as a key area of focus. One study used crash narratives to identify crashes involving bus passengers and concluded that bus passengers are more likely to engage in risky midblock crossings (Voorhes Transportation Center, 2012). Another recent study used video data to observe pedestrian and motorist behavior near bus stops at intersections and concluded that transit riders were slightly more likely to cross midblock near farside stops (Singleton et al., 2024). Additionally, Pessaro et al. (2017) found that pedestrians near bus stops frequently crossed at unmarked locations or crossed against the traffic signal. Subsequently, both Craig et al. (2019) and Singleton et al. (2024) observed poor motorist yielding behavior near bus stops. The pedestrians' tendency to engage in risky crossing behaviors and the motorists' reduced awareness near bus stops raises a particularly significant area of concern for pedestrian safety at bus stops.

Stop Spacing and Pedestrian Safety

Stop spacing is an important consideration for both transit operational efficiency and pedestrian safety. However, there are conflicting findings from prior research on pedestrian safety at nearside and farside bus stops. Singleton et al. (2024) found that there were more severe outcomes for pedestrians crossing at farside stops due to worsened motorist yielding behavior at these locations. Other studies identified increased crash risks at nearside stops, likely due to the visual screen created by the bus in between crossing pedestrians and oncoming vehicular traffic (Voorhes Transportation Center, 2012). Additionally, Anis et al. (2024) established a reduced crash risk near bus stops at signalized intersections. This discrepancy may suggest that the crash risk at bus stops located at intersections are context-dependent and may be challenging to generalize due to various interacting factors like intersection design, pedestrian and motorist behavior, and signalization. Last, the relationship between crossings near midblock bus stops has been thoroughly documented in prior literature, with this action increasing the crash risk for pedestrians (Pessaro et al., 2017; Pulugurtha & Vanapalli, 2008; Voorhes Transportation Center, 2012). Given these findings, midblock bus stops are a particularly important focus area for pedestrian safety, and high-visibility crossings should be provided at these vulnerable locations.

Research Gap and Framework for a Transit Passenger's Journey

This literature review first considered the data sources and methodologies used in prior research on pedestrian safety at bus stops and concluded that most studies utilized pedestrian crash data and employed a location-based assumption by linking crashes to bus stops using a buffer radius. Then, focusing on the key findings from the literature, many studies have established risks associated with (1) bus stop locations, (2) ridership levels, (3) pedestrian and motorist behavior, and (4) stop spacing. Based on this review, prior research has not used pedestrian crash data that explicitly identifies transit bus stop-related crashes. Instead, prior studies have depended on assumptions to infer the relationship between pedestrian safety and bus stops, which could introduce uncertainty into the analysis. The absence of such studies may stem from a lack of crash data that includes trip purpose information, particularly for trips to and from transit. Therefore, the data and methodologies used in previous studies may not fully consider the risks associated with a transit passenger's trip to and from a bus stop, as well as the time spent waiting at the bus stop itself. This report begins to address this gap in the research.

Conceptually, transit passengers can face various safety-related risks during their journey. These risks can perhaps be more clearly identified by considering the various stages of a transit passenger's complete journey (see Figure 3). Although additional risks are associated with boarding, alighting, and traveling on transit (stages that are shaded in black in Figure 3), this report focuses specifically on the walking and waiting portions of the trip (stages that are shaded in blue in Figure 3), which is when they are a pedestrian.

During the first and last stages of a typical trip, a transit passenger typically walks up to a quarter mile to and from a bus stop (Goughnour et al., 2022). Then, as transit passengers wait at the bus stop, they are exposed to passing vehicular traffic, which may influence their risk of being involved in a crash (Yu, 2024). They may also experience greater exposure to buses compared to other pedestrians. Additionally, the environment in which a pedestrian waits, particularly whether the bus stop includes amenities, may influence crash risk. Because transit routes may serve higher-speed arterials, the risks may be exacerbated in these environments (Hess et al., 2004; Pulugurtha & Vanapalli, 2008; Yu, 2024).

Moreover, transit passengers must cross the road at least once during a complete transit trip (see dashed line in Figure 3, which shows the crossing happening on the return trip). Crossing risk may increase when buses are stopped at the bus stop, as they can obstruct the line of sight between motorists and pedestrians (Nabors et al., 2008). Additionally, during the walking stage, pedestrians may engage in risky crossing behavior due to the urgency to reach the bus stop before the bus departs.

To begin to address this gap and to analyze factors influencing pedestrian safety at bus stops, this report focuses specifically on the walking, waiting, and crossing stages of a typical transit passenger's journey. The next section presents a review of safety databases that report transit-related details, upon which the fatal "*transit bus stop-related*" pedestrian crashes in the Fatality Analysis Reporting System (FARS) and the "*going to or from public transit*" pedestrian crashes in the Minnesota statewide crash database were identified for further analysis.

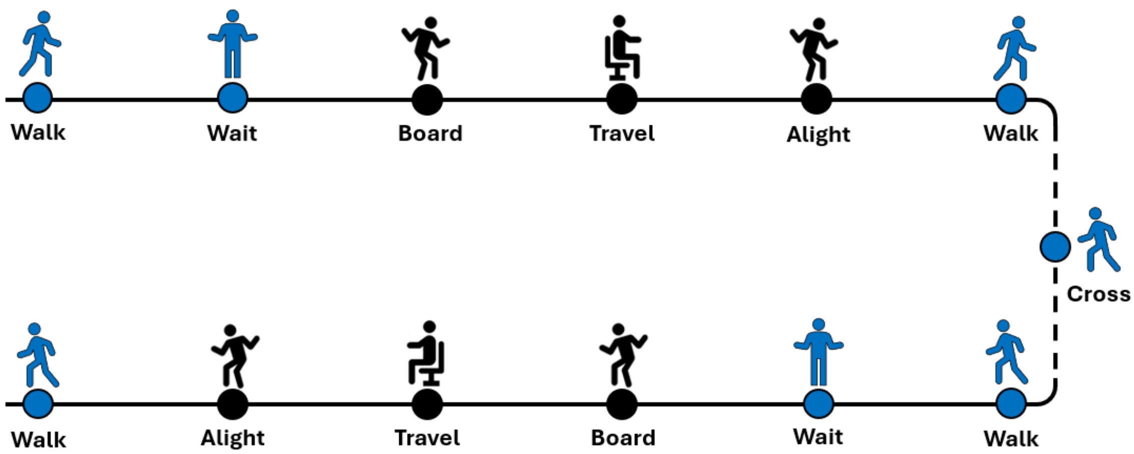

Figure 3. Stages of a transit trip

Adapted from Yendra et al. (2024)

Review of Data

The following section includes a review of transit-related safety databases, from which the primary data source for this report, the transit bus stop-related pedestrian crashes reported in the Fatality Analysis Reporting System (FARS), was selected. Given that the prior literature has not used data that explicitly states that a crash was a factor in a crash, this suggests that there may be a lack of transit-related safety information reported in the data. Therefore, the objective of the review of databases was to identify those applicable to research on pedestrian safety at bus stops. First, crash typing frameworks were reviewed to determine whether any included crash types related to bus stops. Then, crash databases across various geographic scales, including national, state, and local, were then evaluated to assess whether these frameworks are used in reporting. Finally, additional safety databases not primarily focused on crash data were examined for relevant transit-related information.

Transit-Related Crash Typing Frameworks

Crash data is commonly used in traffic safety analysis, offering valuable insights into crash trends and supporting infrastructure and policy decisions. Crash data reporting generally follows a standardized format to ensure consistency and comparability across agencies (local, state, and national). The Pedestrian and Bicyclist Crash Analysis Tool (PBCAT) and Model Minimum Uniform Crash Criteria (MMUCC) are two reporting frameworks commonly used in crash data that contain transit-related information.

Pedestrian and Bicyclist Crash Analysis Tool (PBCAT)

First, the PBCAT framework was introduced in 1999 to support agencies in categorizing vulnerable road user crashes. An updated version was released in 2006 (PBCAT 2.0), including a "*bus-related*" (#340) pedestrian crash group (Harkey et al., 2006). A crash is categorized as bus-related when "*the pedestrian was struck while crossing/walking to a bus or bus stop or while waiting at a bus stop*". Within this crash group, there are two crash types: (1) "*commercial bus-related*" (#341) and (2) "*school bus-related*" (#342) (Harkey et al., 2006). The separate categorization of commercial and school bus-related crashes is particularly beneficial because it supports targeted countermeasures to address the unique characteristics of each crash type. While PBCAT does not specify which types of bus services are classified as commercial bus-related, it is presumed that transit services are included within this scope. This may also include services like charter buses, shuttle services, or tourist buses, making it challenging to draw independent conclusions about transit-related crashes without the ability to isolate these crashes from the others that are included by definition. Additionally, commercial bus-related crashes depend on the presence of the bus, excluding crashes that occur at a bus stop when the bus is not present. This definition may lead to underreporting of crashes and overlooks potentially bus-related crashes that are unrelated to the presence of a bus.

The most recent version of PBCAT, updated in 2021 (PBCAT 3.0), addresses the aforementioned concerns by redefining "*commercial bus-related*" and expanding on the existing definition to create a hierarchical structure specific to "*transit-related*" crashes (Hamilton, 2021). First, "*transit*" is used instead of "*commercial*" to analyze crash risks associated with transit stops exclusively. Transit-related crash types were created to specify the action of both the non-motorist and motorist at the time of the crash, highlighting three main scenarios: [1] “*obstructed view*”, [2] “*bus pullover*”, and [3] “*other*”. This reclassification addresses some pedestrian safety challenges at transit stops and facilitates targeted countermeasures. For example, if "*bus pullover*" crashes are found to be problematic, installing pedestrian detection warning systems on transit buses to alert drivers may improve pedestrian safety around bus stops. On the other hand, frequent or severe "*obstructed view*" crashes may suggest a need for improved visibility of bus stops or nearby crossing facilities.

Model Minimum Uniform Crash Criteria (MMUCC)

Beginning in 2017, MMUCC (5th edition) adopted the crash factor "*related to a bus stop*", which includes many activities leading to a crash associated with a bus stop (e.g. vehicles maneuvering around a bus waiting at the bus stop, pedestrians walking to/from the bus stop, and pedestrians crossing lanes of traffic to access the bus stop) (NHTSA, 2017). This definition is maintained in the most recent version of the framework, released in 2024 (6th edition) (NHTSA, 2025). While the MMUCC framework is more widely used for crash reporting by agencies compared to PBCAT, the "*related to a bus stop*" data element does not differentiate between school and transit bus stop crashes, which is a significant limitation of this framework.

National, State and Local Databases

Many national, state, and local agencies have used these frameworks in their crash data. Additionally, some agencies have reported transit-related information outside the scope of these frameworks. The following sections are a discussion of these datasets that were identified by reviewing publicly available raw data, data dictionaries, and crash dashboards for transit-related data fields. This discussion is limited to fifteen datasets; additional datasets may exist but may not be publicly available or were not identified during this search.

National Databases

The review of nationwide databases revealed three main sources that report transit-related information: the Fatality Analysis Reporting System (FARS), the Crash Reporting Sampling System (CRSS), and the National Transit Database (NTD). Each of these databases is managed by federal agencies and includes several years of data, though they differ in scope and sample size. The following provides an overview of their characteristics and how each contributes to the understanding of pedestrian safety at bus stops.

FARS is a national crash database maintained by NHTSA (NHTSA, 2022c) . Beginning in 1975, FARS has documented a yearly population of police-reported fatal motor vehicle crashes in the United States. To be reported in FARS, a crash must involve a motor vehicle traveling on a trafficway and result in the death of at least one road user within 30 days of the crash (NHTSA, 2022c). Fatal crash information is collected from multiple state sources (including police crash reports, crash report supplements, vehicle registration files, driver records, roadway classification files, death certificates, toxicology reports, and emergency medical service reports) and standardized into over 170 FARS data elements.

In 2014, FARS adopted a version of the PBCAT 2.0 framework for reporting transit-related crashes (NHTSA, 2016). FARS modified the definition specified in PBCAT 2.0 from "*commercial bus-related*" to "*transit bus stop-related*" to narrow the scope to transit stops. The definition clarifies that this crash type applies to all pedestrians, regardless of the pedestrians' intent to ride the bus. It also specifies that the crash type includes all vehicle types and is not limited to pedestrian-bus crashes. FARS has reported 196 pedestrians involved in fatal transit bus stop-related crashes over the nine years of data available. Additionally, in 2020, FARS implemented the MMUCC framework to include the "*related to a bus stop*" crash factor in the data reporting process (NHTSA, 2022a). There have been 122 fatal crashes that were related to a bus stop since the adoption in 2020.

CRSS, also maintained by NHTSA, is a nationally representative sample of motor vehicle crashes in the United States (NHTSA, 2022b). The database was introduced in 2016 as an expansion of its predecessor, the National Automotive Sampling System General Estimates System (NASS GES). CRSS samples police-reported motor vehicle crashes that occur in 60 predefined locations in the United States. These locations are chosen to reflect the geography, population, travel behavior, and crash characteristics of the United States. Additionally, the survey is designed to sample crashes of greater relative importance (e.g. fatal crashes and pedestrian-involved crashes). Trained coders translate the crash reports into 120 CRSS data elements and each crash is assigned a case weight which is representative of the annual estimate of crashes. CRSS documents the same transit-related information that is included in FARS. The adapted definition from PBCAT 2.0 has been documented in CRSS since 2016 and has reported 83 pedestrians involved in transit bus stop-related crashes. The definition from MMUCC was implemented in 2020 and has reported 151 crashes that were related to a bus stop.

NTD, on the other hand, is not a traditional crash dataset; rather it collects data on Safety and Security incidents occurring on public transportation systems. The Federal Transit Administration (FTA) manages NTD, which is a collection of agency-reported annual financial, operational, and asset statistics (Federal Transit Administration, 2025). Among these statistics, agencies are required to report incidents that meet the Safety and Security reporting threshold. These incidents generally include fatalities (including suicides and assaults), injuries, property damage, crashes (resulting in a fatality, injury, or property damage; involving a transit vehicle; involving a security breach), and evacuations. Rather than focusing solely on transit stops, the reporting system covers all aspects of transit operations that meet major safety event reporting thresholds.

Since 2014, NTD has reported 5270 pedestrians involved in crashes with transit vehicles that met the reporting threshold for a major safety event (Federal Transit Administration, 2025). While NTD does not report the same detailed data fields as traditional crash datasets, such as infrastructure (e.g., speed limit, functional classification) and person characteristics (e.g. age, sex, driver/pedestrian impairment) it does specify whether the pedestrian was in a crosswalk at the time of the incident and whether the pedestrian was a transit rider, which adds valuable context for understanding pedestrian safety in transit environments. NTD also provides a description of each event, offering additional insights that may not be captured in structured data fields, which is not provided in FARS or CRSS.

While this search revealed that there are few national crash databases that report transit-related information, FARS, CRSS, and NTD are valuable resources for pedestrian safety research due to their detailed information, larger sample sizes (compared to individual state and local crash databases), and ability to capture nationwide trends, as summarized in Table 2. However, the sample size of transit bus stop-related crashes in FARS and CRSS is limited, which is a significant limitation of these databases. Although NTD offers a substantially larger sample of pedestrian-transit vehicle crashes, it does not have a specific field for crashes that are related to transit stops, which may limit the depth of analysis compared to FARS and CRSS.

Table 2. Summary of national transit-related safety databases

Database	Agency	Years	Description of Data	Transit-Related Definition	Sample Size
Fatality Analysis Reporting System (FARS)	NHTSA	2014-2022	Population of fatal police-reported crashes	· **Transit bus stop-related** (2014): adapted version of PBCAT 2.0: transit bus must be present at the transit stop at the time of the crash · **Related to a bus stop** (2020): definition consistent with MMUCC	n = 197 (pedestrians involved)
Crash Reporting Sampling System (CRSS)	NHTSA	2016-2022	Nationally representative sample of police-reported crashes	· **Transit bus stop-related** (2014): adapted version of PBCAT 2.0: transit bus must be present at the transit stop at the time of the crash · **Related to a bus stop** (2020): definition consistent with MMUCC	n = 83 (pedestrians involved)
National Transit Database (NTD) – Safety and Security	FTA	2014-2024	Collection of annual financial, asset, and operating data from public transit agencies nationwide	· Meets reporting threshold (per Safety and Security manual) OR · Occurs at a transit revenue facility, maintenance facility, or rail yard · Happens on transit right-of-way infrastructure · Occurs during a transit-related maintenance activity	n = 5097 (pedestrians involved)

State Databases

The review of state databases identified at least six crash databases that utilize the PBCAT or MMUCC framework to report transit-related information. North Carolina and Florida use the PBCAT 2.0 framework (“*commercial bus-related*”), while Illinois, Louisiana, Nebraska, and Utah use the MMUCC framework (“*related to a bus stop*”) (Christofferson, 2021; Federal Highway Administration, 2025; GeoPlan Center (University of Florida), 2021; Louisiana Highway Safety Commission, 2023; Nebraska Department of Transportation, 2023; North Carolina Department of Transportation, 2025). While several states utilize these frameworks, the sample sizes were often limited or the datasets were only available upon specific requests.

At least three state agencies report transit-related safety information using classifications beyond the PBCAT and MMUCC frameworks. Idaho’s crash data, managed by the Idaho Transportation Department (ITD), includes a data field that documents damaged infrastructure, including "*bus shelter*" as one of the possible options (Olsen, n.d.). Georgia's crash data, managed by the Georgia Department of Transportation (GDOT), documents crashes involving non-motorists "*entering/exiting a bus*" and specifies which transit agency was involved in the crash (Georgia Department of Transportation, 2025). Minnesota’s crash data, managed by the Minnesota Department of Transportation (MnDOT), documents the action of the pedestrian prior to the crash, with a specific category for individuals "*going to or from public transit*" (Minnesota Department of Transportation, 2025).

Although several state datasets were identified (see Table 3), it is presumed that there are many more states that include the “*related to a bus stop*” data element in their crash reporting, since the MMUCC framework is a standard used by many states. However, this may not be readily apparent because many state crash datasets are private or only available upon request. Moreover, states vary in their implementation of this framework, as it is voluntary. Some states may use an earlier version of MMUCC that was developed prior to the definition of the “*related to a bus stop*” crash type in the 5th edition. A similar pattern was observed with the PBCAT framework. While many states implement PBCAT 2.0, which includes the “*commercial bus-related*” crash type, this review did not identify any states openly using PBCAT 3.0, which classifies transit-related crashes into three distinct types and offers a more detailed level of reporting.

Table 3. Summary of statewide transit-related safety databases

Database	Organization	Years	Description of Data	Transit-Related Definition	Sample Size
Florida Traffic Safety Dashboard (Signal4Analytics)	UF Geoplan Center	2014-2025	Statewide crash dashboard for police-reported crashes	**Commercial bus-related**: definition consistent with PBCAT 2.0	Unavailable (information not public)
Georgia Crash Dashboard	GDOT	2013-2023	Statewide crash dashboard for police-reported crashes	· **Entering/exiting bus:** no details provided; data dictionary not public Transit Agency Involvement	n = 681 (pedestrians involved)
Idaho Crash Dashboard	ITD	2008-2025	Statewide crash dashboard for police-reported crashes	· **Item damaged = bus shelter:** indicates whether property was damaged as a result of the crash	Unavailable (information not public)
Illinois Crash Data	HSIS	2019-2022	Multistate database that contains crash, roadway, and traffic characteristics for a select group of states	· **Related to a bus stop:** definition consistent with MMUCC	Available upon request
Louisiana Crash Data	CARTS	Unknown	Raw statewide police-reported crash data	· **Related to a bus stop:** definition consistent with MMUCC · **Going to or from public transit:** prior action of the non-motorist	Unavailable (information not public)
Minnesota Crash Data	MnDOT	2016-2023	Raw statewide police-reported crash data; publicly available upon request	· **Going to or from public transit:** prior action of the non-motorist	n = 39 (crashes)
Nebraska Crash Data	NDOT	Unknown	Raw statewide police-reported crash data	· **Related to a bus stop:** definition consistent with MMUCC · **Going to or from public transit:** prior action of the non-motorist	Unavailable (information not public)
North Carolina Non-Motorist Crash Map	NCDOT	2007-2022	Map of police-reported pedestrian and bicyclist crashes in North Carolina	· **Commercial bus-related**: definition consistent with PBCAT 2.0	n = 126 (crashes)
Utah Pedestrian Crash Dashboard	UHSO	2010-2025	Statewide crash dashboard for police-reported crashes	· **Related to a bus stop:** definition consistent with MMUCC	Unavailable (information not public)

Local Databases

The review identified at least four relevant local databases. All four of the databases reported transit-related details that are outside of the scope of PBCAT and MMUCC. The Highway Safety Information System (HSIS) provides detailed bus route and bus stop amenity information for Charlotte, North Carolina, which is also supplemented by crash and roadway data for the city (Federal Highway Administration, 2025). In Cleveland, Ohio the Enhanced Transit Safety Retrofit Package (E-TRP) was piloted for six months to assess the safety implications of pedestrian detection warning systems on buses, specifically documenting events from the "Pedestrian in Crosswalk Warning (PCW)" system installed on these buses (U.S. Department of Transportation, 2025). The City of Los Angeles Traffic Collision dataset, maintained by the Los Angeles Police Department, includes a field that specifies the location of the incident, with "*Bus Stop*" being one of the options (Los Angeles Police Department, 2025). The Washington Metropolitan Area Transit Authority (WMATA) established voluntary "close call" reporting system that provides rail transit and bus employees to confidentially report near miss safety and security incidents that had the potential for harm but were narrowly avoided (Bureau of Transportation Statistics, 2025). This system allows WMATA to proactively address safety concerns, with the agency reporting 200 preventable actions since the adoption of the program.

Ultimately, the availability of transit-related information in local databases is limited, as this review did not identify any databases that use the PBCAT or MMUCC frameworks (see Table 4). Instead, local databases provide detailed information outside of crash typing frameworks, many of

Table 4. Summary of local transit-related safety databases

Database	Organization	Years	Description of Data	Transit-Related Definition	Sample Size
Charlotte, NC	HSIS	2018-2022	Multistate database that contains crash, roadway, and traffic characteristics for a select group of States	· Detailed information regarding bus route and bus stop amenities	Available upon request
Enhanced Transit Safety Retrofit Package – Cleveland, OH	FTA	2018	Data from 24 transit buses 3 locations over a 6 month test period	· Pedestrian detection warning systems at crosswalks (Pedestrian in Crossing Warning – PCW)	n = 15,609 (PCW alerts)
City of Los Angeles, CA Traffic Collision Data	LAPD	2010-2025	Traffic collision incidents in the City of Los Angeles; transcribed from original traffic reports	· Crashes occurring at a bus stop: reported in the "premise codes" element: the type of structure or location where the incident took place	n = 7 (crashes)
Confidential Close Call Reporting System	WMATA	2013-2025	Voluntary reporting of "Close Calls" or near miss safety and security events by WMATA employees	· Any event observed by a rail transit or bus system employee that was potentially dangerous but did not result in any serious harm	n = 300 (close call reports)

which can be linked with local crash data to help address pedestrian safety at bus stops, particularly in Charlotte, Cleveland, and Washington D.C. However, these databases may not address the factors directly associated with transit bus stop-related crashes as effectively as databases that use the PBCAT or MMUCC frameworks.

Selection of Data

The review of transit-related safety databases indicates that the availability of data for transit-related pedestrian safety research is limited. While national datasets like FARS and CRSS provide valuable insights through their broad coverage, standardized reporting formats, and ability to identify nationwide trends, they are relatively limited in sample size. Several state and local agencies maintain public crash databases containing transit-related information, supporting a more granular approach to analyzing pedestrian safety in transit environments. However, these datasets generally have very small sample sizes or reported information outside of the PBCAT and MMUCC frameworks. Most importantly, none of the datasets identified in the review have been used to analyze pedestrian safety at bus stops in prior research.

Based on this review, both a national and a state database were selected for further analysis. FARS was selected for the nationwide analysis of transit bus stop-related pedestrian crashes in this report due to its generalizability, longitudinal scope, and focus on fatal crashes. By exclusively reporting crashes that result in at least one fatality, FARS allows for a more focused analysis of the highest-risk scenarios related to transit bus stops. The "*going to or from public transit*" pedestrian crashes reported in the raw crash data from MnDOT were selected for the statewide analysis to analyze pedestrian safety at bus stops from a more localized perspective. The next section of this report will further describe the purpose of using both the FARS and MnDOT crash databases and the corresponding methodology.

Methodology

This report presents an analysis of pedestrian safety at bus stops using both nationwide (FARS data) and statewide (MnDOT crash data) datasets. The nationwide analysis applies a quantitative approach, utilizing statistical models to expand on existing literature regarding pedestrian safety at bus stops. This part of the analysis focuses on crashes that are directly involve a transit bus stop, allowing for an assessment of factors specifically related to pedestrian crashes at bus stops. In contrast, the statewide analysis uses crash data from MnDOT, focusing on a smaller, localized sample of "*going to or from public transit*" pedestrian crashes in Minnesota. While the characteristics of each crash were examined quantitatively using a descriptive analysis, the primary focus of this analysis is on the qualitative assessment of the crash narratives from the police reports to provide context for each crash.

Nationwide Analysis of Fatal Transit Bus Stop-Related Pedestrian Crashes in FARS

This section summarizes the statistical methods used to analyze crash data from FARS in this report, which was done in three parts. Prior to the three-part analysis, crosstabulations were conducted between transit bus stop-related crashes and other nearby fatal pedestrian crashes, which were identified using a nearby "buffer zone." Then, binary logit models were used to assess the characteristics that increase the probability of transit bus stop-related crashes compared to other nearby fatal pedestrian crashes. Next, hierarchical clustering was performed on the transit bus stop-related crashes to identify different crash scenarios. Additionally, the clustering was conducted on the combined samples of the transit bus stop-related crashes and other nearby fatal pedestrian crashes to evaluate whether the clustering would distinguish between the characteristics of transit bus stop-related crashes and other nearby crashes. Finally, a comparison of bus stop infrastructure was conducted at each bus stop where a fatal crash occurred to assess whether any changes in amenities may have been implemented in response to safety concerns at the bus stop.

Buffer Zone Crashes

To compare transit bus stop-related crashes to other nearby fatal pedestrian crashes, a comparison group was established consisting of fatal pedestrian crashes that have occurred near the transit bus stop-related crashes. This involved identifying and extracting relevant pedestrian crashes from the FARS database from 2014 to 2022. The process followed a similar approach to previous studies that used the location-based assumption and was conducted in ArcGIS, as described below:

1. The locations of transit bus stop-related pedestrian crashes were imported as the first layer (n = 175).
2. The full sample of crashes involving vulnerable road users over the same study period were imported as the second layer (n = 66,245).
3. A “buffer zone” with a radius of a quarter- and half-mile was defined around the location of each transit bus stop-related crash. The quarter-mile radius was chosen based on prior literature, which determined that most transit passengers are willing to walk a maximum

of a quarter mile to reach a bus stop (Goughnour et al., 2022). The half-mile radius was also used, as this was the greatest buffer radius identified in the review of previous studies using the location-based assumption (Singh et al., 2022). Two buffer radii were chosen to evaluate the sensitivity of the results as a response to varying buffer zone sizes.

4. A spatial join was performed to identify only those crashes that occurred within the buffer zones.

The study considers "pedestrians involved in fatal crashes" instead of individual crashes. As a result, each pedestrian is treated as a separate observation, rather than evaluating each crash as a whole. This approach is particularly important for crashes involving multiple pedestrians, as it allows for an examination of individual pedestrian-specific characteristics (e.g., demographic factors such as age, sex, and race) as well as circumstances specific to each pedestrian's involvement, such as impairment, distraction, or other contributing factors. This resulted in a final sample of 185 pedestrians involved in crashes within the quarter-mile buffer zone and 420 pedestrians within the half-mile buffer zone. As a result, for every 1 pedestrian involved in a transit bus stop-related crash, there were 0.9 pedestrians involved in a crash in the quarter-mile buffer zone and 2.1 pedestrians involved in a crash in the half-mile buffer zone.

Binary Logit Model

Next, a binary logit model was used to analyze the characteristics of fatal transit bus stop-related crashes and compare them with other nearby fatal crashes. The results of this analysis provide insights into the factors that significantly increase the likelihood of a transit bus stop-related crash, highlighting how they differ from other fatal crashes occurring within close proximity.

Two models were estimated in total, one for each buffer zone. The dependent variable represented the crash type: "1" for transit bus stop-related crashes and "0" for other crashes within the buffer zone. The purpose of the varying buffer zones was to determine whether the results were sensitive to the buffer radius, which may provide insights into whether the characteristics of nearby crashes change significantly as the buffer radius increases. The independent variables were chosen based on their significant association with the crash type in the crosstabulation. Each variable was tested iteratively in the model, and only the significant variables were retained in the final model.

Hierarchical Clustering Analysis

Hierarchical clustering is an unsupervised machine learning technique that groups observations with similar characteristics into clusters (Nielsen, 2016). This method is different than other clustering methods because it emphasizes the nested structure of the data. This study uses agglomerative hierarchical clustering, which assigns each observation to its own cluster and then iteratively combines them until there is a single cluster (Nielsen, 2016). In the context of pedestrian crash data, hierarchical clustering is typically used to identify similar crash types and reveal the underlying hierarchy of crash characteristics that might not be immediately apparent through other statistical models (Manasa et al., 2024; Nafis et al., 2022; Raihan et al., 2018).

First, a distance measure is specified to compute the dissimilarity of each observation. The Gower distance was used in this study because of its ability to handle mixed data types (Gower, 1971). First, the Gower similarity coefficient computes the average contribution of each variable. The result is a number between 0 (completely dissimilar) and 1 (identical observations) that is subtracted from 1 to obtain the Gower distance (Gower, 1971). The Gower distance was computed using the "cluster" package in RStudio (Maechler, 2018). The relationship is defined as follows:

$$d_{ij} = \frac{\sum_{k=1}^{p} w_k \delta_{ij}^{(k)} d_{ij}^{(k)}}{\sum_{k=1}^{p} w_k \delta_{ij}^{(k)}} \tag{1}$$

where d_{ij} is the Gower distance, w_k is the weight associated with the kth variable, $\delta_{ij}^{(k)}$ is an indicator variable for binary variables (0 when both observations have a value of 0, 1 otherwise), and $d_{ij}^{(k)}$ is the dissimilarity between two observations for the kth variable (Gower, 1971; Maechler, 2018).

Then, a linkage method is used to compute the distance between clusters. This study used Ward's linkage method because it reduces variance within clusters (Ward Jr, 1963). After each iteration of merging, Ward's method minimizes within-cluster variance by evaluating the increase in the sum of squared differences.

The results of a hierarchical clustering analysis are typically displayed in a dendrogram, which is a tree-like structure that arranges the hierarchy of clusters based on the similarity within successive clusters. To interpret the dendrogram, first, the optimal number of clusters can be determined by comparing the average silhouette width (ASW) of various cluster configurations (Kassambara, 2017). The ASWs range from -1 to 1, with positive values indicating that the observations are appropriately clustered, and negative values indicate the potential misassignment of observations. Then, the dendrogram can be interpreted by horizontally cutting at the height that corresponds with the cluster configuration with the maximum ASW value. Greater vertical distances between clusters indicate greater dissimilarities, offering insight into the relationships among clusters (Nielsen, 2016).

Before-and-After Analysis of Bus Stop Infrastructure

Although FARS provides data on various crash characteristics, it does not include detailed bus stop information, which is a limitation shared by most crash datasets. Linking bus stop infrastructure data with traditional crash datasets like FARS can support an in-depth analysis of bus stop design and pedestrian safety. Therefore, an inventory of bus stop infrastructure was manually compiled for each bus stop in which a fatal transit bus stop-related crash occurred, and a comparison of the infrastructure from before and after the date of the crash was conducted to assess whether changes were made. This analysis builds upon the findings from parts 1 and 2 of this study by examining the conditions at the bus stop and identifying potential opportunities to implement countermeasures at the bus stop-level.

While FARS does not specify at which bus stop the crash occurred, it does provide coordinates for each transit bus stop-related crash (NHTSA, 2022c). Using this information, a bus stop inventory was compiled by the authors using a visual assessment and the Google Maps Street View application. The bus stop that was related to each crash was determined manually by using the crash details provided in FARS, such as the intersection leg and the direction of travel of both the pedestrian and the motorist. In the case that the bus stop could not be clearly identified using these details, the crash was excluded from the following analysis. At each bus stop, an inventory of the presence of a sidewalk, crosswalk, shelter, seating, bus pad, signage, and street lighting was manually collected. Additionally, the inventory specified if the bus stop was an in-lane or curbside pull-out stop (Nabors et al., 2008).

This information was collected both before and after the date of the crash to determine whether improvements were made to the bus stop following the crash. The "before" sample was collected using available imaging from a date as close as possible to, but before, the crash. The "after" sample was taken from the most recent imaging available after the crash. By making this comparison, this analysis quantifies countermeasures implemented at the bus stop that were potentially a result of pedestrian safety concerns.

Statewide Analysis of Crashes Involving a Pedestrian Going To or From Public Transit in Minnesota

In the review of transit-related safety databases, it was found that MnDOT introduced a "*going to or from public transit*" pedestrian crash type in 2016. This data was selected for a local analysis due to MnDOT's willingness to share the data, as well as the inclusion of officer-reported crash narratives, which supports a deeper understanding of the circumstances surrounding each of the crashes. While this crash type does not fall under the definitions within PBCAT or MMUCC crash typing frameworks, it has advantages because this crash type only includes transit passengers, whereas the definitions within the PBCAT and MMUCC frameworks do not require the pedestrian to be a transit passenger. Moreover, this crash type is not limited to the immediate area surrounding the bus stop like FARS and CRSS, and it addresses the transit passenger's entire trip to and from the bus stop or train station. Last, the data includes the full range of injury severity levels, allowing for comprehensive analysis of crash outcomes.

The "*going to or from public transit*" pedestrian crashes that occurred in Minnesota from 2016-2023 were aggregated from the raw crash data. First, a descriptive analysis was conducted to analyze the distribution of some of the key variables. Then, the characteristics were compared with the findings from the nationwide analysis and prior literature to identify trends.

Next, the crash narratives were analyzed to understand the circumstances around each crash, as well as to understand the transit-related terminology used by the reporting officers. Prior studies have taken a similar approach to obtain more information on crashes occurring in the vicinity of a bus stop; however, this analysis was primarily focused on the language used by the reporting officer. In essence, this qualitative analysis evaluates the extent of detail used by the reporting officers in the crash narratives and helps better understand the characteristics of different types of transit-related crashes, including those with non-fatal outcomes.

Based on the language used in the crash narratives, each crash was manually categorized to identify the most common terminology used by the officers for this type of crash. It was also noted if a crash narrative did not mention public transit, despite being categorized as "*going to or from public transit*". These categories help to identify how officers are describing transit-related pedestrian crashes and provides more context for the various types of "*going to or from public transit*" crashes.

Last, using the Google Street View application and the coordinates provided in the Minnesota crash data, each of the crashes were analyzed from a street level perspective to provide a visual representation of the circumstances surrounding each crash. Although each crash was initially examined using Google Street View, images from KartaView are shown in this section for some of the categories due to licensing restrictions with Google Street View images. KartaView was chosen as an alternative because it is an open-source street-level imagery platform (*KartaView*, 2025). Each crash was analyzed separately; the results discuss only one crash from each of the identified categories as an example for brevity, including a description and visual representation (when available on KartaView).

Nationwide Analysis Results and Discussion

This section presents the results of the analysis of fatal transit bus stop-related pedestrian crashes in FARS, followed by a discussion of the findings. The purpose of this analysis is to examine the characteristics of these crashes and the bus stops where they occurred, and to identify how they differ from other nearby pedestrian crashes. The section begins with a descriptive analysis of transit bus stop-related crashes, followed by a crosstabulation comparing these crashes to those occurring within a nearby buffer zone. It then presents the results from the three-part methodology, which includes a binary logit model, hierarchical clustering analysis, and a before and after analysis of bus stop infrastructure.

Descriptive Analysis of Transit Bus Stop-Related Crashes

Since the introduction of transit bus stop-related crashes into FARS in 2014, and up to the most recent year of available data in 2022, there have been 175 transit bus stop-related crashes involving 196 pedestrians. Figure 4 shows the yearly distribution of pedestrians involved in transit bus stop-related crashes, averaging 21.8 per year. While this is a relatively small sample, this may be because the definition of this crash in FARS requires the transit bus to be present at the bus stop at the time of the crash. Therefore, crashes that may be related to a bus stop but did not occur in the presence of the transit bus were excluded from this sample, and this crash type may be underreported.

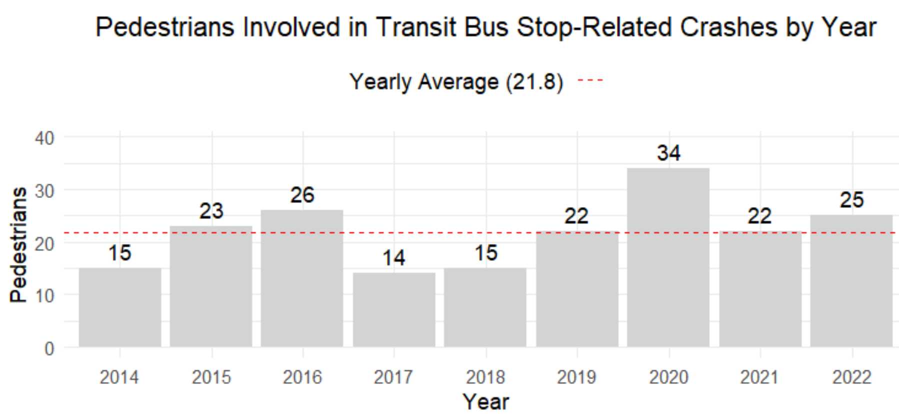

Figure 4. Yearly total of transit bus stop-related crashes in FARS

Figure 5 shows the geographic distribution of pedestrians involved in crashes by USDOT region. A bivariate analysis of crash counts in each region was highly significant, indicating that the geographic distribution of transit bus stop-related crashes is not uniform. Specifically, 58.2% of all pedestrians involved in these crashes occurred in Region 4, Region 5, and Region 9. Further analysis is needed to understand this relationship, including potential differences in population density, ridership, and pedestrian safety measures across regions. Next, several crash characteristics were analyzed to determine the characteristics of transit bus stop-related crashes.

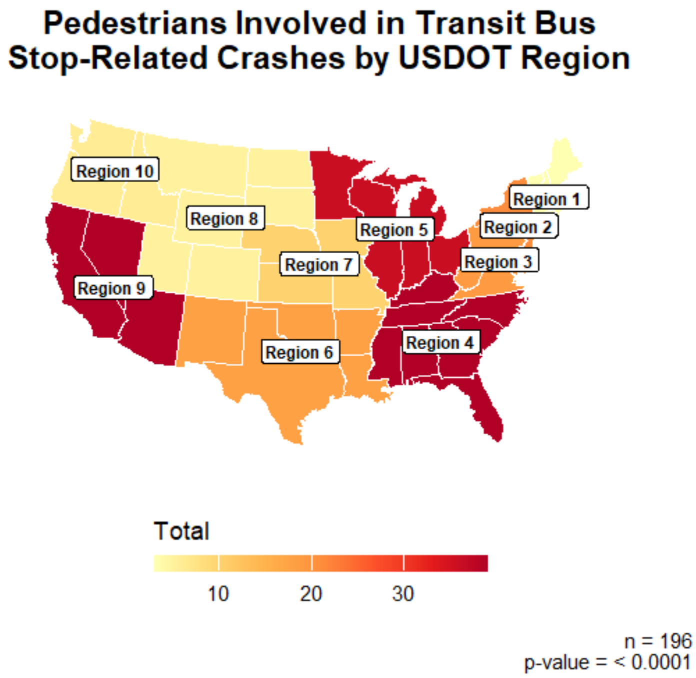

Figure 5. Geographic distribution of transit bus stop-related crashes in FARS

Descriptive statistics are presented for the following key variables: location of the crash, crosswalk and sidewalk presence, position of pedestrian, prior action of the pedestrian, functional system, and the contact vehicle. These variables were selected for the descriptive analysis based on their significance in prior studies. The results of the descriptive analysis are shown in Table 5and discussed in the following paragraphs.

Next, several crash characteristics were analyzed to determine the characteristics of transit bus stop-related crashes. Descriptive statistics are presented for the following key variables: location of the crash, crosswalk and sidewalk presence, position of pedestrian, prior action of the pedestrian, functional system, and the contact vehicle. These variables were selected for the descriptive analysis based on their significance in prior studies. The results of the descriptive analysis are shown in Table 5 and discussed in the following paragraphs.

First, 77.6% of transit bus stop-related crashes occurred at non-intersection locations. As FARS defines "*Not At Intersection*" as the crash occurred at least 50 feet away from an intersection and was unrelated to the flow of traffic through an intersection. Therefore, this suggests that many of these crashes were related to midblock bus stops, where marked crossing facilities, such as crosswalks and pedestrian signals may be less common than bus stops located at intersections.

Table 5. Descriptive statistics of transit bus stop-related crashes in FARS

Variable		Total
Location	At Intersection	24 (12.2%)
	Intersection-Related	20 (10.2%)
	Not At Intersection	152 (77.6%)
Sidewalk Presence	None Noted	55 (28.1%)
	Yes	139 (70.9%)
	Unknown	2 (1.0%)
Crosswalk Presence	None Noted	143 (73.5%)
	Yes	52 (26.5%)
	Unknown	1 (0.5%)
Position of Pedestrian	Crosswalk Area	21 (10.7%)
	Intersection Area	5 (2.6%)
	Paved Shoulder/Bicycle Lane/Parking Lane	5 (2.6%)
	Sidewalk/Shared-Use Path/Driveway Access	43 (21.9%)
	Travel Lane	111 (56.6%)
	Unpaved Right-of-Way	3 (1.5%)
	Other/Unknown	8 (4.1%)
Non-Motorist Prior Action	Crossing Roadway	116 (59.2%)
	Entering/Exiting Parked or Stopped Vehicle	6 (3.1%)
	In Roadway - Other (Working, Playing, Etc.)	11 (5.6%)
	Movement Along Roadway	1 (0.5%)
	Stationary and Adjacent to Roadway (e.g., Shoulder, Median, Sidewalk)	53 (27.0%)
	Other	6 (3.1%)
	Not Reported/Unknown	3 (1.5%)
Functional System	Arterial	156 (79.6%)
	Collector	20 (10.2%)
	Interstate	1 (0.5%)
	Local	19 (9.7%)
Speed Limit	> 40 MPH	74 (37.8%)
	0-19 MPH	1 (0.5%)
	20-29 MPH	21 (10.7%)
	30-39 MPH	88 (44.9%)
	> 40 MPH	74 (37.8%)
	Not Reported/Unknown	12 (6.1%)
Contact Vehicle	Bus	44 (22.5%)
	Heavy Truck	4 (2.0%)
	Light Truck	37 (18.9%)
	Motorcycle	1 (0.5%)
	Sedan/Coupe	64 (32.7%)
	SUV	28 (14.3%)
	Van/Minivan	11 (5.6%)
	Unknown	7 (3.6%)
Bus Involvement	Not a Bus	148 (75.5%)
	Charter/Tour	1 (0.5%)
	Intercity	5 (2.6%)
	Transit/Commuter	37 (18.9%)
	Unknown	4 (2.0%)
	Not Reported	1 (0.5%)

Most transit bus stop-related crashes reported the presence of a sidewalk (70.9%). Sidewalks are typically included in bus stop infrastructure to provide both access to the stop and a designated space for pedestrians to wait for the bus. However, crosswalks were less common near transit bus stop-related crashes. Only 26.5% of transit bus stop-related crashes reported the presence of a crosswalk, supporting the previous finding that many of these crashes may be related to a midblock bus stop where such facilities are relatively scarce.

The majority of pedestrians (56.3%) were hit while in the travel lane, which is expected given that 59.1% of the crashes involved pedestrians crossing the roadway at the time of the crash. Among those crossing, 79.1% were in the travel lane, while 16.5% were in the crosswalk area. These findings highlight the need for improved access to crosswalks and enhanced visibility of crosswalks near transit stops. This relationship is shown in Figure 6.

Despite most of the crashes involving a pedestrian crossing the roadway, many pedestrians were hit on the roadside. Specifically, 21.9% of crashes involved a pedestrian hit while on a sidewalk, shared-use path, and driveway access, and 27.0% of pedestrians were stationary and adjacent to the roadway at the time of the crash. However, some pedestrians were on a paved shoulder, bicycle lane, parking lane, or unpaved right-of-way, as shown in Figure 6. The combination of these factors reflects the scenario in which a passenger was waiting at a bus stop when a vehicle departed the roadway into the bus stop.

Transit bus stop-related crashes predominantly occurred on arterial roadways (79.6%), with many taking place on higher-speed roads, as 82.5% of these crashes occurred on roads with speed limits greater than 30 miles per hour. Prior research has studied these factors and their negative implications for pedestrian safety (Rosén et al., 2011). This finding is particularly important

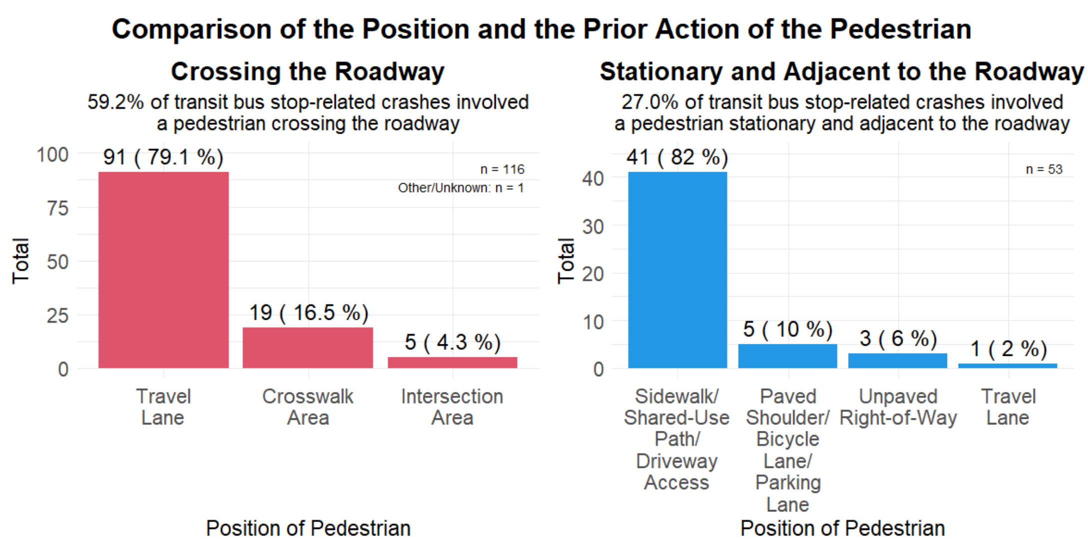

Figure 6. Relationship between the action and the position of the pedestrian during the crash

because bus stops generate pedestrian activity, potentially increasing pedestrian exposure to higher-risk conditions.

Last, in 71.4% of these crashes, a passenger vehicle was the contact vehicle (sedan/coupe, SUV, van/minivan, light trucks). However, buses were relatively common in transit bus stop-related crashes, with 22.5% of these crashes reporting that a bus was the contact vehicle. Moreover, transit/commuter buses were the most common type of bus involved (18.9%). This is a key area of concern, given that the mass and size of a bus can potentially result in more severe outcomes.

Crosstabulation

Next, a crosstabulation was conducted to compare the key characteristics of transit bus stop-related crashes with those of the buffer zone crashes. The crosstabulation was conducted separately for the quarter- and half-mile buffer zones. The relationship between the two groups is tested for significance and the results are shown in Table 6.

Compared to transit bus stop-related crashes, Table 6 shows that a significantly higher proportion of quarter- and half-mile buffer zone crashes occurred at intersections or intersection-related locations. Of the intersection crashes reported in the combined sample of transit bus stop-related and buffer zone crashes, 71% were in the quarter-mile buffer zone, while 84.0% were in the half-mile buffer zone. Similarly, 50.0% of the intersection-related crashes were in the quarter-mile buffer zone, while 73.0% were in the half-mile buffer zone. This comparison reinforces the previous finding that midblock bus stops may be a priority to address pedestrian safety concerns at bus stops, given that transit bus stop-related crashes occur slightly more frequently at midblock locations compared to other nearby pedestrian crashes.

The proportion of sidewalk presence was relatively higher near transit bus stop-related crashes compared to buffer zone crashes. Only 63.3% of quarter-mile and 61.9% of half-mile buffer zone crashes reported the presence of a sidewalk compared to 70.9% of transit bus stop-related crashes. In contrast, crosswalks were more common in buffer zone crashes: 57.0% of crashes that reported the presence of a crosswalk were those within the quarter-mile buffer zone and 74.1% were those within the half-mile buffer zone. This aligns with the previous finding from the descriptive analysis that most of the transit bus stop-related crashes were related to a midblock bus stop, where marked crossing facilities may be less common.

Pedestrians in both the transit bus stop-related crashes and those within the buffer zones were most frequently hit while in the travel lane. In Table 6, pedestrians hit in the travel lane account for 57.7% of crashes in the combined quarter-mile buffer zone sample, and 57.5% in the combined half-mile buffer zone sample. This may be associated with the pedestrian behavior before the crash, as most of both transit bus stop-related as most of both transit bus stop-related crashes and buffer zone crashes involved a pedestrian crossing the roadway, with 68.8% of crashes in the combined quarter-mile sample, and 66.2% in the combined half-mile sample.

Table 6. Crosstabulation of transit bus stop-related crashes and buffer zone crashes using FARS data

		Quarter-Mile Buffer Zone				Half-Mile Buffer Zone			
		BZ	TR	Total	p-value	BZ	TR	Total	p-value
Location	At Intersection	60 (71.4%)	24 (28.6%)	84 (22.1%)	<0.0001	126 (84.0%)	24 (16.0%)	150 (24.4%)	<0.0001
	Intersection-Related	20 (50.0%)	20 (50.0%)	40 (10.5%)		54 (73.0%)	20 (27.0%)	74 (12.0%)	
	Not At Intersection	103 (40.4%)	152 (59.6%)	255 (66.9%)		236 (60.8%)	152 (39.2%)	388 (63.0%)	
	Non-Trafficway Location	-	-	-		2 (100.0%)	0 (0.0%)	2 (0.3%)	
	Unknown/Insufficient Information	2 (100.0%)	0 (0.0%)	2 (0.5%)		2 (100.0%)	0 (0.0%)	2 (0.3%)	
Crosswalk Presence	None Noted	116 (44.8%)	143 (55.2%)	259 (68.0%)	0.0277	269 (65.3%)	143 (34.7%)	412 (66.9%)	0.0734
	Yes	69 (57.0%)	52 (43.0%)	121 (31.8%)		149 (74.1%)	52 (25.9%)	201 (32.6%)	
	Unknown	0 (0.0%)	1 (100.0%)	1 (0.3%)		2 (66.7%)	1 (33.3%)	3 (0.5%)	
Sidewalk Presence	None Noted	64 (53.8%)	55 (46.2%)	119 (31.2%)	0.3526	157 (74.1%)	55 (25.9%)	212 (34.4%)	0.0524
	Yes	119 (46.1%)	139 (53.9%)	258 (67.7%)		260 (65.2%)	139 (34.8%)	399 (64.8%)	
	Unknown	2 (50.0%)	2 (50.0%)	4 (1.1%)		3 (60.0%)	2 (40.0%)	5 (0.8%)	
Position of Pedestrian	Crosswalk Area	49 (70.0%)	21 (30.0%)	70 (18.4%)	<0.0001	107 (83.6%)	21 (16.4%)	128 (20.8%)	<0.0001
	Intersection Area	13 (72.2%)	5 (27.8%)	18 (4.7%)		19 (79.2%)	5 (20.8%)	24 (3.9%)	
	Paved Shoulder/Bicycle Lane/Parking Lane	3 (37.5%)	5 (62.5%)	8 (2.1%)		8 (61.5%)	5 (38.5%)	13 (2.1%)	
	Sidewalk/Shared-Use Path/Driveway Access	5 (10.4%)	43 (89.6%)	48 (12.6%)		26 (37.7%)	43 (62.3%)	69 (11.2%)	
	Travel Lane	109 (49.6%)	111 (50.5%)	220 (57.7%)		243 (68.6%)	111 (31.4%)	354 (57.5%)	
	Unpaved Right-of-Way	1 (25.0%)	3 (75.0%)	4 (1.1%)		1 (25.0%)	3 (75.0%)	4 (0.7%)	
	Other/Unknown	5 (38.5%)	8 (61.5%)	13 (3.4%)		16 (66.7%)	8 (33.3%)	24 (3.9%)	
Non-Motorist Prior Action	Crossing Roadway	146 (55.7%)	116 (44.3%)	262 (68.8%)	<0.0001	292 (71.6%)	116 (28.4%)	408 (66.2%)	<0.0001
	Disabled Vehicle Related	-	-	-		7 (100.0%)	0 (0.0%)	7 (1.1%)	
	Entering/Exiting Parked or Stopped Vehicle	0 (0.0%)	6 (100.0%)	6 (1.6%)		3 (33.3%)	6 (66.7%)	9 (1.5%)	
	Going To or From School (K-12)	-	-	-		1 (100.0%)	0 (0.0%)	1 (0.2%)	
	In Roadway - Other	7 (38.9%)	11 (61.1%)	18 (4.7%)		21 (65.6%)	11 (34.4%)	32 (5.2%)	
	Jogging/Running	2 (100.0%)	0 (0.0%)	2 (0.5%)		3 (100.0%)	0 (0.0%)	3 (0.5%)	
	Movement Along Roadway	6 (85.7%)	1 (14.3%)	7 (1.8%)		25 (96.2%)	1 (3.9%)	26 (4.2%)	
	Stationary and Adjacent to Roadway	5 (8.6%)	53 (91.4%)	58 (15.2%)		18 (25.4%)	53 (74.7%)	71 (11.5%)	
	Waiting to Cross Roadway	2 (100.0%)	0 (0.0%)	2 (0.5%)		3 (100.0%)	0 (0.0%)	3 (0.5%)	
	Other	6 (50.0%)	6 (50.0%)	12 (3.2%)		16 (72.7%)	6 (27.3%)	22 (3.6%)	
	Not Reported/Unknown	11 (78.6%)	3 (21.4%)	14 (3.7%)		31 (91.2%)	3 (8.8%)	34 (5.5%)	

Table 6. (continued) Crosstabulation of transit bus stop-related crashes and buffer zone crashes using FARS data

		Quarter-Mile Buffer Zone				Half-Mile Buffer Zone			
		BZ	TR	Total	p-value	BZ	TR	Total	p-value
Functional System	Arterial	148 (48.7%)	156 (51.3%)	304 (79.8%)	0.2083	313 (66.7%)	156 (33.3%)	469 (76.1%)	0.0073
	Collector	14 (41.2%)	20 (58.8%)	34 (8.9%)		29 (59.2%)	20 (40.8%)	49 (8.0%)	
	Interstate	6 (85.7%)	1 (14.3%)	7 (1.8%)		23 (95.8%)	1 (4.2%)	24 (3.9%)	
	Local	17 (47.2%)	19 (52.8%)	36 (9.5%)		55 (74.3%)	19 (25.7%)	74 (12.0%)	
Speed Limit	0-19 MPH	0 (0.0%)	1 (100.0%)	1 (0.3%)	0.0005	0 (0.0%)	1 (100.0%)	1 (0.2%)	0.0011
	20-29 MPH	24 (53.3%)	21 (46.7%)	45 (11.8%)		71 (77.2%)	21 (22.8%)	92 (14.9%)	
	30-39 MPH	51 (36.7%)	88 (63.3%)	139 (36.5%)		132 (60.0%)	88 (40.0%)	220 (35.7%)	
	> 40 MPH	80 (52.0%)	74 (48.1%)	154 (40.4%)		166 (69.2%)	74 (30.8%)	240 (39.0%)	
	Unknown/Not Reported	30 (71.4%)	12 (28.6%)	42 (11.0%)		51 (81.0%)	12 (19.1%)	63 (10.2%)	
Contact Vehicle	Bus	6 (12.0%)	44 (88.0%)	50 (13.2%)	<0.0001	11 (20.0%)	44 (80.0%)	55 (9.0%)	<0.0001
	Heavy Truck	7 (63.6%)	4 (36.4%)	11 (2.9%)		18 (81.8%)	4 (18.2%)	22 (3.6%)	
	Light Truck	24 (39.3%)	37 (60.7%)	61 (16.1%)		48 (56.5%)	37 (43.5%)	85 (13.9%)	
	Motorcycle	4 (80.0%)	1 (20.0%)	5 (1.3%)		5 (83.3%)	1 (16.7%)	6 (1.0%)	
	Sedan/Coupe	72 (52.9%)	64 (47.1%)	136 (35.9%)		162 (71.7%)	64 (28.3%)	226 (36.9%)	
	SUV	30 (51.7%)	28 (48.3%)	58 (15.3%)		82 (74.6%)	28 (25.5%)	110 (17.9%)	
	Van/Minivan	11 (50.0%)	11 (50.0%)	22 (5.8%)		32 (74.4%)	11 (25.6%)	43 (7.0%)	
	Not Reported/Unknown	29 (80.6%)	7 (19.4%)	36 (9.5%)		59 (89.4%)	7 (10.6%)	66 (10.8%)	
Bus Involvement	Not a Bus	169 (53.3%)	148 (46.7%)	317 (83.2%)	<0.0001	381 (72.0%)	148 (28.0%)	529 (85.9%)	<0.0001
	Charter/Tour	0 (0.0%)	1 (100.0%)	1 (0.3%)		1 (50.0%)	1 (50.0%)	2 (0.3%)	
	Intercity	0 (0.0%)	5 (100.0%)	5 (1.3%)		0 (0.0%)	5 (100.0%)	5 (0.8%)	
	School	2 (100.0%)	0 (0.0%)	2 (0.5%)		2 (100.0%)	0 (0.0%)	2 (0.3%)	
	Transit/Commuter	4 (9.8%)	37 (90.2%)	41 (10.8%)		8 (17.8%)	37 (82.2%)	45 (7.3%)	
	Not Reported/Unknown	10 (66.7%)	5 (33.3%)	15 (3.9%)		28 (84.9%)	5 (15.2%)	33 (5.4%)	
Total		185 (48.6%)	196 (51.4%)	381 (100.0%)		420 (68.2%)	196 (31.8%)	616 (100.0%)	

Note: TR – transit bus stop-related; BZ – buffer zone

Compared to transit bus stop-related crashes, very few buffer zone crashes involved a pedestrian hit while standing on a sidewalk, shared-use path, or driveway. In the combined transit bus stop-related and buffer zone samples, only 10.4% of pedestrians on the roadside in the quarter-mile sample and 37.7% in the half-mile sample were buffer zone crashes. This trend may also be related to pedestrian behavior, as a substantially larger proportion of transit bus stop-related crashes involved pedestrians who were stationary and adjacent to the roadway before the crash. Specifically, 91.4% of these cases in the combined quarter-mile sample and 74.7% in the combined half-mile sample were transit bus stop-related.

Most transit bus stop-related crashes and crashes within the buffer zones occurred on arterial roadways, accounting for 79.9% of the combined quarter-mile sample and 75.1% of the combined half-mile sample. Additionally, these crashes commonly occurred on roads with speed limits greater than 30 miles per hour, accounting for 76.9% of the combined quarter-mile sample and 74.7% of the combined half-mile sample. Therefore, countermeasures targeting higher-speed arterials may benefit both transit passengers and pedestrians in these areas.

Last, the most common vehicle types involved in all of the crashes were passenger vehicles (i.e., sedans/coupes, SUVs, vans/minivans, and pickup trucks). However, there was a significant difference in the proportion of bus-involved crashes. Of the crashes where a bus was reported as the contact vehicle, 88.0% in the combined quarter-mile sample and 80.0% in the combined half-mile sample were transit bus stop-related (see Table 6). Transit/commuter buses were the most frequently involved bus type. In 90.2% of these crashes in the combined quarter-mile sample and 82.2% in the combined half-mile sample, the crashes were related to a transit stop. Therefore, pedestrian-bus crashes are concentrated around bus stops.

Binary Logit Model

Understanding the factors that may influence the likelihood of a crash being related to a bus stop can assist decision-makers in prioritizing specific safety countermeasures. To explore these factors, two binary logit models were estimated to examine the relationship between fatal transit bus stop-related crashes and other nearby crashes. Model 1 evaluated crashes within a quarter-mile buffer zone of transit bus stop-related crashes, and Model 2 evaluated crashes within the half-mile buffer zone. The results of the preferred model are shown in Table 7, where the crash type is evaluated based on crash location, speed limit, pedestrian age, peak hour travel, non-motorist prior action, and bus involvement. This model was preferred over others because it included the most significant variables from the crosstabulation, and the quarter- and half-mile buffer zones had a McFadden's R^2 of 0.264 and 0.258, respectively. The following discussion will interpret the variables that were significant in both Model 1 and Model 2.

Table 7. Results from the binary logit models using FARS data

	Quarter Mile		Half Mile	
	Coef.	OR	Coef.	OR
Intercept	-0.212 (-0.959)	0.809	-2.394*** (-0.632)	0.091***
Pedestrian Location: At Intersection (ref)	-		-	
Pedestrian Location: Intersection-Related	1.418** (-0.574)	4.129	0.637 (-0.481)	1.891
Pedestrian Location: Not At Intersection	1.652*** (-0.428)	5.217	1.542*** (-0.367)	4.674***
Speed Limit: 0-29 MPH (ref)	-		-	
Speed Limit: 30-39 MPH	0.536 (-0.497)	1.709	0.961** (-0.413)	2.614**
Speed Limit: > 40 MPH	-0.18 (-0.505)	0.835	0.666 (-0.429)	1.946
Pedestrian Age: 0-19 years (ref)	-		-	
Pedestrian Age: 20-39 years	-1.972** (-0.864)	0.139	-1.002* (-0.526)	0.367*
Pedestrian Age: 40-59 years	-1.489* (-0.864)	0.226	-0.541 (-0.518)	0.582
Pedestrian Age: 60+ years	-1.758** (-0.867)	0.172	-0.556 (-0.52)	0.573
Peak Hour: Off-Peak (ref)	-		-	
Peak Hour: AM	1.725*** (-0.522)	5.613	1.292*** (-0.373)	3.640***
Peak Hour: PM	0.574 (-0.387)	1.775	0.314 (-0.312)	1.369
Non-Motorist Prior Action: Crossing Roadway (ref)	-		-	
Non-Motorist Prior Action: Stationary and Adjacent to Roadway	2.169*** (-0.566)	8.750	2.105*** (-0.395)	8.207***
Non-Motorist Prior Action: Other	-0.794 (-0.565)	0.452	-1.338*** (-0.436)	0.262***
Bus Involvement: Not a Bus (ref)	-		-	
Bus Involvement: Transit/Commuter	2.583*** (-0.626)	13.237	3.354*** (-0.559)	28.617***
Bus Involvement: Other bus type	16.184 (-682.573)	10681245.451	16.886 (-698.222)	21552448.768
Observations	288		459	
McFadden's Pseudo R^2	0.258		0.264	

Note:
Dependent Variable: Transit Bus Stop-Related Crash = 1; Buffer Zone = 0
*p<0.1; **p<0.05; ***p<0.01
Coef. = Coefficient; OR = Odds Ratio

First, the location of the crash is a significant predictor of transit bus stop-related crashes. Compared to crashes at intersections, crashes occurring at non-intersection locations are 5.2 and 4.7 times more likely to be transit bus stop-related than other nearby crashes within quarter- and half-mile buffer zones, respectively. This aligns with prior research (Yu, 2024), and suggests that midblock bus stops should be a primary focus for improving pedestrian safety. Specifically, midblock bus stops are generally less likely to be equipped with pedestrian facilities like sidewalks and crosswalks compared to bus stops at intersections. Therefore, this is a potential area for infrastructure improvements that may reduce transit bus stop-related crashes.

The age of the pedestrians was also significantly associated with transit bus stop-related crashes. The model suggests that, compared to pedestrians aged 0-19 years, pedestrians aged 20-39 years are less likely to be involved in transit bus stop-related crashes than other nearby crashes. This result indicates a relationship between age and the likelihood of transit bus stop-related crashes, potentially due to behavioral differences or exposure patterns. However, further research is needed to clarify this association.

Peak hour travel was also significantly associated with transit bus stop-related crashes, indicating that, compared to off-peak hours, crashes during the morning peak hour are 5.6 and 3.6 times more likely to be transit bus stop-related than other nearby crashes, within the quarter- and half-mile buffer zones, respectively. During peak periods, transit ridership and vehicular traffic tend to be higher, which increases the risk for pedestrians at bus stops. Given this, countermeasures should address the higher pedestrian risk during peak travel periods.

The pedestrian's action before the crash was significantly associated with transit bus stop-related crashes. Compared to pedestrians hit while crossing the roadway, those hit while stationary and adjacent to the roadway were 8.8 and 8.2 times more likely to be transit bus stop-related in the quarter- and half-mile buffer zones, respectively. This may reflect the added exposure of standing and waiting at bus stops. Moreover, the magnitude of the odds ratios were larger than most other odds ratios in the models, suggesting that this action is a strong indicator of transit bus stop-related crashes. This finding indicates that while crossing improvements are necessary to enhance overall pedestrian safety in these areas, targeted countermeasures should address pedestrians waiting at transit stops.

Compared to crashes that do not involve a bus, transit bus stop-related crashes are 13.2 and 28.6 times more likely to involve a transit or commuter bus than other nearby crashes, within the quarter- and half-mile buffer zones, respectively. Among all of the significant predictors of transit bus stop-related crashes, this predictor had the largest odds ratios in both of the models, indicating that it is the strongest factor influencing the likelihood of transit bus stop-related crashes. This finding may reflect the increased exposure pedestrians experience while waiting at bus stops as transit buses pull into or away from the bus stops. Prior research has identified this interaction as a particularly problematic occurrence at bus stops (Yendra et al., 2024). Safety improvements should be made to mitigate pedestrian-bus interactions and lessen the risk of transit bus stop-related crashes.

Hierarchical Clustering Analysis

The purpose of the hierarchical clustering analysis was two-fold: (1) to identify if there were different types of transit bus stop-related crash scenarios, and (2) to assess whether the clustering distinguished between the characteristics of transit bus stop-related crashes and other nearby fatal pedestrian crashes. The clustering was performed on three subsets of the FARS data: (1) the fatal transit bus stop-related crashes only, (2) the combined sample of transit bus stop-related crashes and quarter-mile buffer zone crashes, and (3) the combined sample of transit bus stop-related crashes and half-mile buffer zone crashes, which will be referred to in this section as Model 1, Model 2, and Model 3, respectively.

For Model 1, the ASWs of various clustering configurations revealed that three clusters was the optimal clustering configuration (see Figure 7). The relatively small number of clusters also assures that the number of observations in each cluster was reasonably large (since there were only 196 pedestrians involved in transit bus stop-related crashes). The ASW for three clusters was approximately 0.156, indicating that, on average, the observations were appropriately clustered. For Models 2 and 3, however, the two-cluster configuration was the optimal clustering configuration (see Figure 7). The ASWs for the two-cluster configuration in Models 2 and 3 are 0.186 and 0.191, respectively, suggesting that larger buffer sizes improve the clustering quality, which may be related to the increasing sample sizes. Despite this, the three-cluster configuration was chosen for presentation to allow for a direct comparison with Model 1 and because the difference in ASW was very small.

The results of Model 1, 2, and 3 are shown in Table 8, Table 9, and Table 10, respectively. The characteristics of each cluster were extracted to evaluate the cluster size and variable distribution. The following tables report the total and percentage of observations in each cluster, along with the count and percentage of crashes for the most frequent category of each variable. In the following discussion, the results will be presented cluster by cluster, rather than model by model, to directly compare how the clustering distinguishes between transit bus stop-related crashes and other nearby crashes.

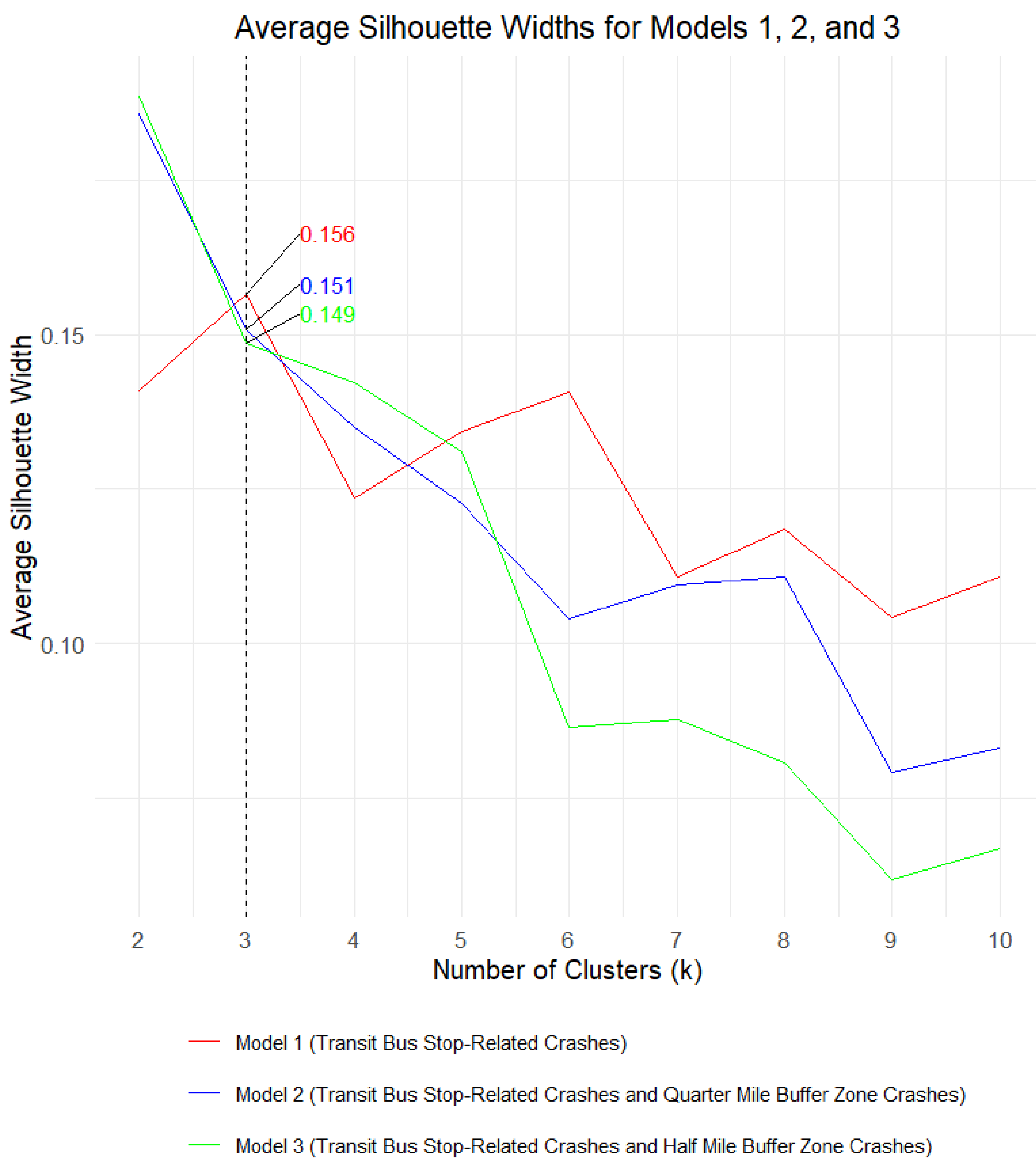

Figure 7. Average silhouette widths for various clustering configurations

Table 8. Hierarchical clustering results for Model 1 (transit bus stop-related crashes only)

Model 1 (ASW = 0.156)	Cluster 1			Cluster 2			Cluster 3		
Variable	**Category**	**f**	**%**	**Category**	**f**	**%**	**Category**	**f**	**%**
Crosswalk Presence	Yes	34	68	None Noted	46	98	None Noted	81	82
Sidewalk Presence	Yes	41	82	Yes	39	83	Yes	59	60
Location	At Intersection	24	48	Not At Intersection	47	100	Not At Intersection	95	96
Position	Crosswalk Area	18	36	Sidewalk/Shared-Use Path/Driveway Access	36	77	Travel Lane	93	94
Relation to Junction (Y/N)	No	50	100	No	47	100	No	99	100
Relation to Junction (Location)	Intersection-Related	35	70	Non-Junction	45	96	Non-Junction	92	93
Type of Intersection	Four-Way Intersection	32	64	Not an Intersection	45	96	Not an Intersection	96	97
Relation to Trafficway	On Roadway	46	92	On Roadside	41	87	On Roadway	98	99
Functional System	Arterial	38	76	Arterial	39	83	Arterial	79	80
Trafficway	Two-Way, Not Divided	30	60	Two-Way, Not Divided	20	43	Two-Way, Not Divided	36	36
Number of Lanes	Two Lanes	21	42	Four Lanes	12	26	Two Lanes	36	36
Speed Limit	30-39 MPH	24	48	30-39 MPH	23	49	> 40 MPH	49	49
Alignment	Straight	48	96	Straight	38	81	Straight	87	88
Profile	Level	43	86	Level	37	79	Level	78	79
Surface Condition	Dry	33	66	Dry	40	85	Dry	82	83
Age of Pedestrian	40-59 years	23	46	40-59 years	18	38	40-59 years	36	36
Sex of Pedestrian	Male	32	64	Male	27	57	Male	62	63
Race of Pedestrian	White	19	38	Not a Fatality (not Applicable)	15	32	White	50	51
Lighting Condition	Dark - Lighted	27	54	Daylight	29	62	Dark - Lighted	42	42
Land Use	Urban	50	100	Urban	47	100	Urban	99	100
Prior Action	Crossing Roadway	38	76	Stationary and Adjacent to Roadway	44	94	Crossing Roadway	78	79
Hit and Run	No	38	76	No	35	74	No	87	88
Speeding Related	No	38	76	No	31	66	No	91	92
Drinking	No (Alcohol Not Involved)	21	42	Not Reported	25	53	No (Alcohol Not Involved)	46	46
Drugs	No (Drugs Not Involved)	20	40	Not Reported	29	62	No (Drugs Not Involved)	48	48
Hour	Off Peak Hours	29	58	Off Peak Hours	33	70	Off Peak Hours	60	61
Vision Obscured	No Obstruction Noted	39	78	No Obstruction Noted	43	91	No Obstruction Noted	77	78
Contact Vehicle	Bus	18	36	Sedan/Coupe	20	43	Sedan/Coupe	35	35
Bus Involvement	Not a Bus	33	66	Not a Bus	45	96	Not a Bus	70	71
Cluster Size		50	100		47	100		99	100

Note: f = frequency; % = percentage

Table 9. Hierarchical clustering results for Model 2 (combined sample of transit bus stop-related and quarter-mile buffer zone crashes)

Model 2 (ASW = 0.151)	Cluster 1			Cluster 2			Cluster 3		
Variable	**Category**	**f**	**%**	**Category**	**f**	**%**	**Category**	**f**	**%**
Crosswalk Presence	Yes	85	66	None Noted	42	98	None Noted	174	83
Sidewalk Presence	Yes	96	75	Yes	40	93	Yes	122	58
Location	At Intersection	83	65	Not At Intersection	42	98	Not At Intersection	201	96
Position	Crosswalk Area	65	51	Sidewalk/Shared-Use Path/Driveway Access	35	81	Travel Lane	188	90
Relation to Junction (Y/N)	No	124	97	No	43	100	No	209	100
Relation to Junction (Location)	Intersection-Related	88	69	Non-Junction	42	98	Non-Junction	192	91
Type of Intersection	Four-Way Intersection	99	77	Not an Intersection	42	98	Not an Intersection	201	96
Relation to Trafficway	On Roadway	123	96	On Roadside	38	88	On Roadway	199	95
Functional System	Arterial	100	78	Arterial	35	81	Arterial	169	80
Trafficway	Two-Way, Not Divided	60	47	Two-Way, Not Divided	19	44	Two-Way, Not Divided	65	31
Number of Lanes	Two Lanes	42	33	Four Lanes	11	26	Two Lanes	54	26
Speed Limit	30-39 MPH	42	33	30-39 MPH	18	42	> 40 MPH	103	49
Alignment	Straight	125	98	Straight	35	81	Straight	190	90
Profile	Level	107	84	Level	36	84	Level	169	80
Surface Condition	Dry	102	80	Dry	38	88	Dry	176	84
Age of Pedestrian	40-59 years	49	38	40-59 years	17	40	60+ years	73	35
Sex of Pedestrian	Male	77	60	Male	23	53	Male	144	69
Race of Pedestrian	White	53	41	Not a Fatality (not Applicable)	13	30	White	99	47
Lighting Condition	Dark - Lighted	76	59	Daylight	27	63	Dark - Lighted	107	51
Land Use	Urban	127	99	Urban	43	100	Urban	208	99
Prior Action	Crossing Roadway	104	81	Stationary and Adjacent to Roadway	41	95	Crossing Roadway	158	75
Hit and Run	No	98	77	No	34	79	No	168	80
Speeding Related	No	98	77	No	27	63	No	177	84
Drinking	No (Alcohol Not Involved)	51	40	Not Reported	23	53	No (Alcohol Not Involved)	84	40
Drugs	No (Drugs Not Involved)	50	39	Not Reported	27	63	No (Drugs Not Involved)	85	40
Hour	Off Peak Hours	87	68	Off Peak Hours	28	65	Off Peak Hours	146	70
Vision Obscured	No Obstruction Noted	106	83	No Obstruction Noted	39	91	No Obstruction Noted	169	80
Contact Vehicle	Sedan/Coupe	32	25	Sedan/Coupe	17	40	Sedan/Coupe	87	41
Bus Involvement	Not a Bus	104	81	Not a Bus	41	95	Not a Bus	172	82
Cluster Size		128	100		43	100		210	100

Note: f = frequency; % = percentage

Table 10. Hierarchical clustering results for Model 3 (combined sample of transit bus stop-related and half-mile buffer zone crashes)

Model 3 (ASW = 0.148)	Cluster 1			Cluster 2			Cluster 3		
Variable	Category	f	%	Category	f	%	Category	f	%
Crosswalk Presence	Yes	160	71	None Noted	56	98	None Noted	292	87
Sidewalk Presence	Yes	177	79	Yes	54	95	Yes	168	50
Location	At Intersection	143	64	Not At Intersection	55	96	Not At Intersection	316	95
Position	Crosswalk Area	120	53	Sidewalk/Shared-Use Path/Driveway Access	41	72	Travel Lane	302	90
Relation to Junction (Y/N)	No	220	98	No	56	98	No	321	96
Relation to Junction (Location)	Intersection-Related	172	76	Non-Junction	56	98	Non-Junction	293	88
Type of Intersection	Four-Way Intersection	168	75	Not an Intersection	57	100	Not an Intersection	315	94
Relation to Trafficway	On Roadway	209	93	On Roadside	42	74	On Roadway	322	96
Functional System	Arterial	172	76	Arterial	42	74	Arterial	255	76
Trafficway	Two-Way, Not Divided	108	48	Two-Way, Not Divided	28	49	Two-Way, Not Divided	90	27
Number of Lanes	Two Lanes	78	35	Two Lanes	21	37	Two Lanes	84	25
Speed Limit	30-39 MPH	81	36	30-39 MPH	27	47	> 40 MPH	171	51
Alignment	Straight	215	96	Straight	48	84	Straight	305	91
Profile	Level	193	86	Level	47	82	Level	250	75
Surface Condition	Dry	182	81	Dry	52	91	Dry	274	82
Age of Pedestrian	60+ years	76	34	40-59 years	20	35	40-59 years	116	35
Sex of Pedestrian	Male	124	55	Male	31	54	Male	239	72
Race of Pedestrian	White	82	36	Not a Fatality (not Applicable)	16	28	White	164	49
Lighting Condition	Dark - Lighted	119	53	Daylight	34	60	Dark - Lighted	172	52
Land Use	Urban	224	100	Urban	57	100	Urban	330	99
Prior Action	Crossing Roadway	174	77	Stationary and Adjacent to Roadway	43	75	Crossing Roadway	234	70
Hit and Run	No	172	76	No	45	79	No	260	78
Speeding Related	No	168	75	No	34	60	No	276	83
Drinking	No (Alcohol Not Involved)	93	41	No (Alcohol Not Involved)	24	42	No (Alcohol Not Involved)	118	35
Drugs	No (Drugs Not Involved)	91	40	Not Reported	28	49	No (Drugs Not Involved)	125	37
Hour	Off Peak Hours	150	67	Off Peak Hours	41	72	Off Peak Hours	242	72
Vision Obscured	No Obstruction Noted	189	84	No Obstruction Noted	53	93	No Obstruction Noted	270	81
Contact Vehicle	Sedan/Coupe	70	31	SUV	18	32	Sedan/Coupe	139	42
Bus Involvement	Not a Bus	196	87	Not a Bus	53	93	Not a Bus	280	84
Cluster Size		225	100		57	100		334	100

Note: f = frequency; % = percentage

Crash Scenario 1: Pedestrian Crossing at an Intersection

In Model 1, the clustering of transit bus stop-related crashes revealed the crash scenario in which pedestrians are hit while crossing at an intersection as they are going to or from a bus stop. Specifically, 48% of this cluster occurred at an intersection and 76% of this cluster involved a pedestrian crossing the roadway. Additionally, 68% of Cluster 1 reported the presence of a crosswalk, which is comparatively more than the other clusters. Lastly, although only 36% of the crashes in this cluster involved a bus as the contact vehicle, this a relatively large share compared to other clusters. Compared to Cluster 1 in Model 1, Cluster 1 in Models 2 and 3 are highly similar, reflecting a similar scenario in which a pedestrian is hit at an intersection while crossing the roadway. However, only 38% of Cluster 1 in Model 2 are transit bus stop-related crashes, and only 22% of Cluster 1 in Model 3 are transit bus stop-related crashes. This suggests that for instances in which a pedestrian is hit while crossing at an intersection, the clustering does not distinguish between transit bus stop-related crashes and other nearby crashes. Given this, these crashes may be similar in nature and safety improvements targeting intersection crossings may benefit both transit passengers and other pedestrians in the immediate area.

Crash Scenario 2: Pedestrian Waiting at a Midblock Bus Stop

Cluster 2 in Model 1 suggested that there is a specific transit bus stop-related crash scenario in which a pedestrian is hit while waiting at a midblock transit stop. Specifically, 100% of this cluster occurred at a non-intersection location, 94% of this cluster involved a pedestrian stationary and adjacent to the roadway, and 77% of this cluster involved a pedestrian standing on a sidewalk, shared-use path, or a driveway. Moreover, the characteristics of Cluster 2 in Models 2 and 3 mirror those of Cluster 2 in Model 1 very closely. Notably, 96% of Cluster 2 in Model 2 are transit bus stop-related crashes, and 71% of Cluster 2 in Model 3 are transit bus stop-related crashes. Given that the distribution of crashes in Cluster 2 is dominantly transit bus stop-related in Models 2 and 3, this suggests that the clustering identified a meaningful distinction between transit bus stop-related crashes and other crashes in the immediate area. Therefore, there is an opportunity to focus on this type of transit bus stop-related crash to improve the safety of waiting transit passengers.

Crash Scenario 3: Pedestrian Crossing Midblock

The characteristics of Cluster 3 in Model 1 suggest that there is a transit bus stop-related crash scenario in which a pedestrian is hit while they are crossing the roadway as they are going to or from a midblock transit stop. The clustering resulted in 96% of Cluster 3 occurring at a non-intersection location, 79% involving a pedestrian crossing the roadway, and 82% reporting that there was not a crosswalk at the crash location. In Models 2 and 3, the characteristics of Cluster 3 reflect what was observed in Model 1. However, in Models 2 and 3, Cluster 3 is a blend of both transit bus stop-related crashes and crashes in the buffer zones. Specifically, 51% of Cluster 3 in Model 2 are transit bus stop-related, and 32% of Cluster 3 in Model 3 are transit bus stop-related. Since the clustering classified transit bus stop-related crashes and other nearby crashes together in Cluster 3, this suggests that crashes involving pedestrians crossing at midblock locations are common to both transit passengers and other pedestrians in areas with transit services.

Countermeasures addressing this crash scenario will likely improve overall pedestrian safety throughout these areas.

Assessment of Clustering Quality

Figure 8 shows the dendrograms for each of the models. The height at which branches merge indicates how similar the crashes are within each cluster. The distance between each successive merge reflects the relative dissimilarity between clusters as they combine. For example, a greater distance between parent clusters and child clusters suggests that the parent cluster was distinct enough to form its own group, while the child clusters (further downstream) may exhibit more variation in their characteristics. In contrast, small distances between successive clusters indicate that the crashes within the successive clusters are highly similar. Additionally, the silhouette plot depicts the clustering quality in Figure 9, with the silhouette width of each observation plotted within its corresponding cluster.

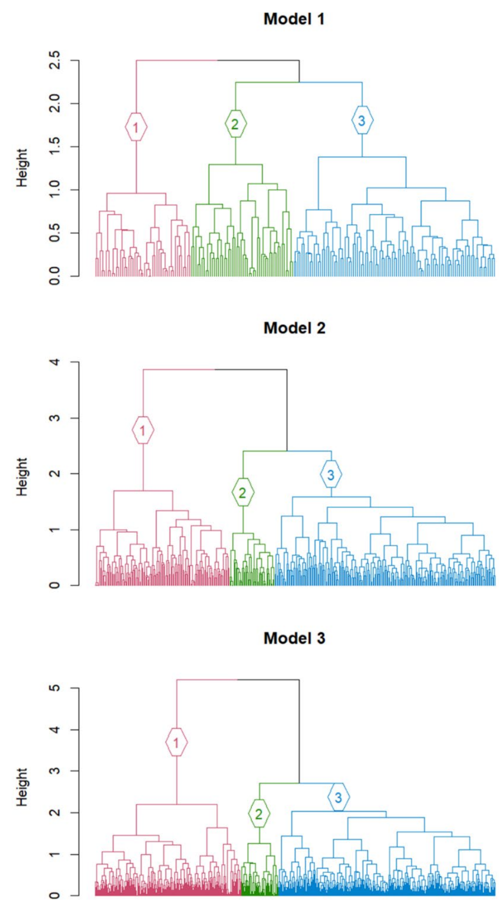

Figure 8. Hierarchical clustering dendrograms for Models 1, 2, and 3

Cluster 2 consistently merges at the lowest height in Models 2 and 3. This suggests that, within the combined samples of transit bus stop-related and buffer zone crashes, the crash scenario involving pedestrians hit while standing on the roadside exhibits the highest relative similarity within the cluster. Additionally, the profile of Cluster 2 across all three models shows that most crashes in this cluster have a silhouette width higher than average. Very few crashes fall within the negative range, suggesting that the crashes were properly clustered. Given that Cluster 2 was predominantly transit bus stop-related in Models 2 and 3, these characteristics further reinforce the conclusion that this scenario is distinct from other nearby crashes and specific to bus stops.

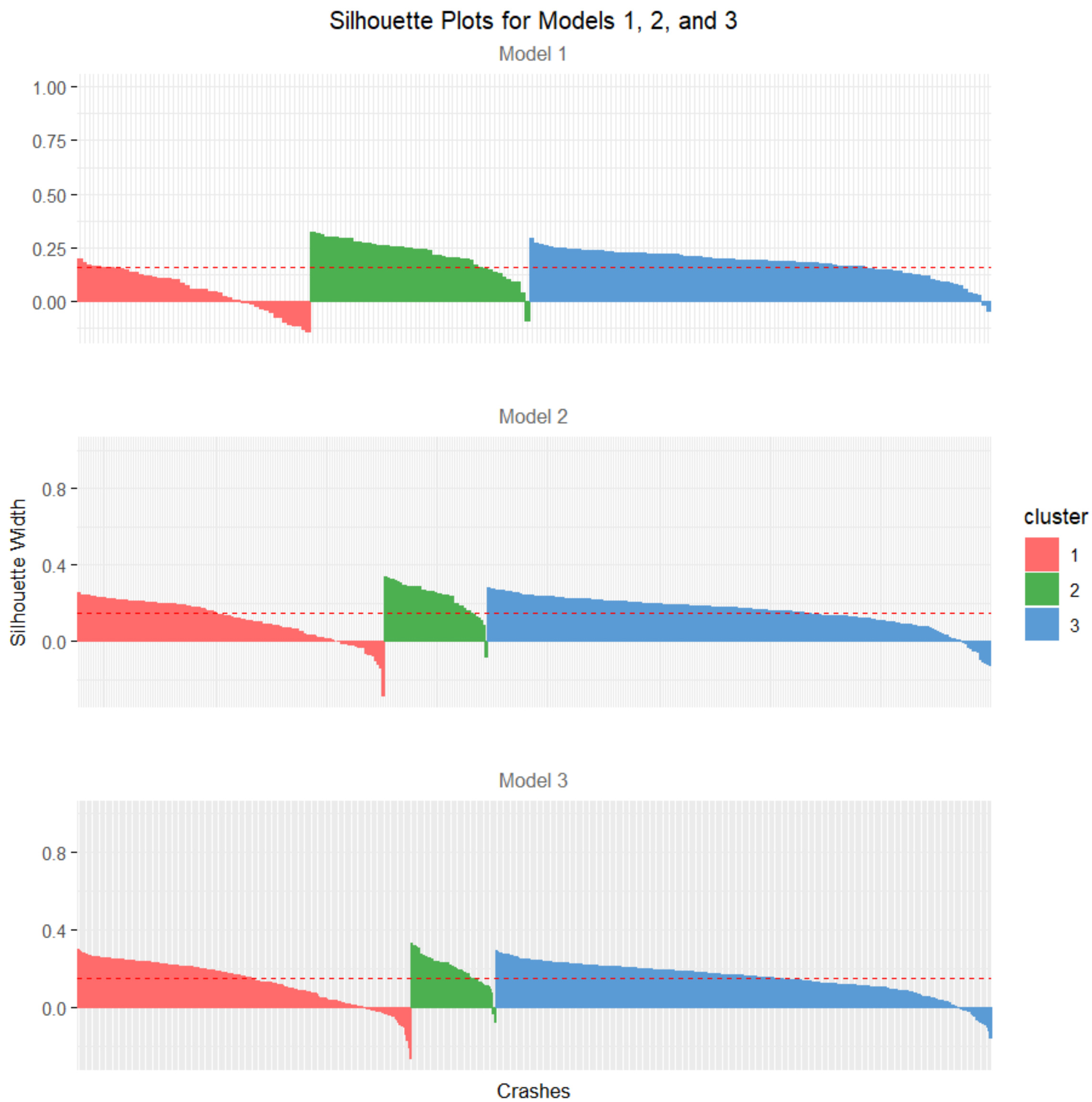

Figure 9. Cluster profiles for Models 1, 2, and 3

Before-and-After Analysis of Bus Stop Infrastructure

Last, a before-and-after inventory of bus stop infrastructure was manually compiled. Expanding on the findings from the first two parts of this analysis, the bus stop inventory not only examines the general conditions of all bus stops but also compares the conditions of stops where a pedestrian was hit while crossing to or from the bus stop with those where a pedestrian was hit while waiting at the bus stop.

Of the 196 pedestrians involved in fatal transit bus stop-related crashes reported in FARS, there were 175 bus stops at which a crash occurred. There were 38 crash locations that were unclear or unavailable on Google Maps and excluded from the analysis. In total, the analysis considered 137 transit bus stops. The results of this analysis are shown in Table 11 and the percentages were computed by dividing the observed number by the total number of crash locations for each type of crash. In general, Table 11 reveals that conditions at each bus stop either remained the same or improved in the after period.

Table 11. Results of the before-and-after bus stop infrastructure analysis

	Pedestrian Crossing Roadway (n = 91)					Pedestrian Stationary and Adjacent to Roadway (n = 30)					All Bus Stops (n = 137)				
	Before		After		Change	Before		After		Change	Before		After		Change
Sidewalk	83	91.2%	83	91.2%	0.0%	30	100.0%	30	100.0%	0.0%	137	93.2%	137	93.2%	0.0%
Crosswalk	58	63.7%	62	68.1%	4.4%	25	83.3%	26	86.7%	3.3%	103	70.1%	108	73.5%	3.4%
Shelter	30	33.0%	34	37.4%	4.4%	16	53.3%	16	53.3%	0.0%	84	57.1%	87	59.2%	2.0%
Seating	51	56.0%	56	61.5%	5.5%	23	76.7%	22	73.3%	-3.3%	90	61.2%	95	64.6%	3.4%
Lighting	80	87.9%	80	87.9%	0.0%	30	100.0%	30	100.0%	0.0%	135	91.8%	135	91.8%	0.0%
Signage	91	100.0%	91	100.0%	0.0%	30	100.0%	30	100.0%	0.0%	147	100.0%	147	100.0%	0.0%
Bus Pad	14	15.4%	14	15.4%	0.0%	5	16.7%	6	20.0%	3.3%	117	79.6%	123	83.7%	4.1%
In-Lane	72	79.1%	72	79.1%	0.0%	25	83.3%	25	83.3%	0.0%	115	78.2%	111	75.5%	-2.7%
Pull Out	19	20.9%	19	20.9%	0.0%	5	16.7%	5	16.7%	0.0%	32	21.8%	36	24.5%	2.7%

Bus Stop Infrastructure at the Crossing-Related Crash Locations

The conditions specifically at crossing-related crash locations (n=91) are shown in Figure 10. Before the crash, almost all bus stops involving a pedestrian who was hit while crossing the road had a sidewalk (92%) but only 64% had a nearby crosswalk. After the crash, no additional sidewalks were noted, but there was a 4% increase in the presence of a crosswalk. This change may suggest that crossing facilities may have been installed in response to safety concerns following the crash while a pedestrian was crossing to or from a bus stop. Nevertheless, many bus stops associated with crossing-related crashes did have access to a crosswalk, suggesting that efforts should either target enhancing crosswalk visibility to improve motorists' yielding behavior or guiding pedestrians to use the existing crosswalks rather than crossing at unmarked locations. Additionally, 33% of these bus stops had a shelter and 56% had seating before the crash, with the presence of these amenities increasing by 4% and 6% after the crash, respectively. Street lighting was present at 88% of these bus stops. Only a small portion of these bus stops had a bus pad (15%), and most were in-lane stops (79%). The presence of street lighting, a bus pad, and the stop type remained unchanged after the crash, suggesting that these features may not have been a priority for pedestrian safety improvements. All of the bus stops had signage.

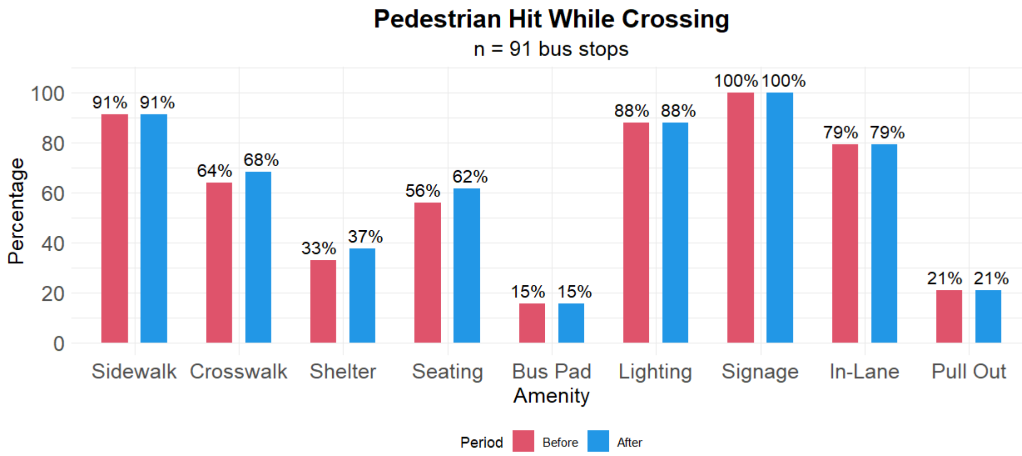

Figure 10. Bus stop infrastructure at crossing-related crash locations

Bus Stop Infrastructure at Waiting-Related Crash Locations

Shown in Figure 11, there were 30 bus stops related to a pedestrian hit while waiting on the roadside. Among these crashes, there were minor differences in the bus stop infrastructure between the before and after periods (see Figure 11). All of the bus stops had sidewalks, street lighting, and signage. Before the crash, 83% of the bus stops had access to a crosswalk, with a 3% increase in the presence of a crosswalk after the crash. Shelter was present at 53% of these bus stops and 77% had seating. After the crash, no additional shelters were installed, and surprisingly, the presence of seating decreased by 3%. Bus pads were present at 17% of bus stops before the crash, and this increased by 3% after the crash. Last, 83% of these bus stops were in-lane stops and this feature did not change after the crash. Given that this crash scenario typically involved vehicles departing from the roadway and hitting pedestrians waiting at the bus stop, many of the amenities documented, such as shelters and seating, may have had a limited impact in preventing this type of crash. If any safety improvements were made at these bus stops, they might have addressed factors beyond the scope of this bus stop inventory. However, the bus stop inventory highlights the potential for many in-lane stops to be converted to curbside pull-out stops, which could improve pedestrian safety in this crash scenario by increasing the physical separation between waiting pedestrians and vehicular traffic (Yendra et al., 2024).

Given that this crash scenario typically involved vehicles departing from the roadway and hitting pedestrians waiting at the bus stop, many of the amenities documented, such as shelters and seating, may have had a limited impact in preventing this type of crash. If any safety improvements were made at these bus stops, they might have addressed factors beyond the scope of this bus stop inventory. However, the bus stop inventory highlights the potential for many in-lane stops to be converted to curbside pull-out stops, which could improve pedestrian safety in by increasing the physical separation between waiting pedestrians and vehicular traffic (Yendra et al., 2024).

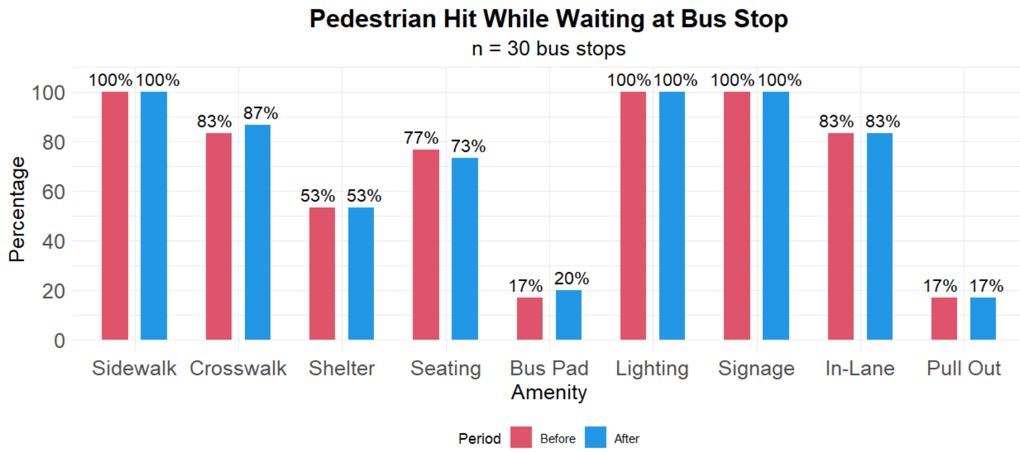

Figure 11. Bus stop infrastructure at waiting-related crash locations

Identifying Bus Stop Infrastructure Priorities to Improve Safety

Comparing the bus stop infrastructure at the crossing- and waiting-related bus stops, notable disparities were observed among certain amenities, with a 20% difference in the presence of crosswalks, a 20% difference in the presence of shelters, and a 21% difference in the presence of seating. Therefore, the substantial gap in crosswalk presence indicates a critical area for improvement to address the crossing-related crash locations. Marked crossing facilities could potentially reduce the risk of this crash scenario, which accounted for 59% of all of the transit bus stop-related crashes.

Statewide Analysis Results and Discussion

In the following section, the "*going to or from public transit*" pedestrian crashes reported in the MnDOT crash data were analyzed. First, descriptive statistics for key variables were tabulated based on factors considered in prior studies and the previous analysis of transit bus stop-related pedestrian crashes from FARS. Given the smaller sample size of the MnDOT crash data, it was feasible to analyze individual crash narratives, specifically focusing on the most common transit-related language used by the reporting officers, as well as crash characteristics that might not have been apparent from structured data fields alone. This qualitative analysis builds upon the FARS analysis by categorizing transit-related pedestrian crashes across various injury severity outcomes.

Descriptive Analysis

From 2016-2023, there were 38 "*going to or from public transit*" pedestrian crashes reported in the raw MN crash data. A descriptive analysis was conducted on the 38 crashes to examine the distribution of some key variables, including crash severity, speed, proximity to an intersection, and the contributing circumstances of both the motorists and the pedestrians. The results are shown in Table 12 and the following discussion addresses the key findings from the descriptive analysis.

Using the KABCO scale, where K represents a fatality, A an incapacitating injury, B a non-incapacitating injury, C a possible injury, and O no apparent injury, most crashes resulted in a non-incapacitating injury (39%). However, a notable portion of crashes resulted in an incapacitating injury (29%), while only one crash (3%) resulted in a fatality (see Table 12). With various injury severity outcomes, this data may be utilized to begin to understand the factors that influence injury severity in crashes involving a transit passenger accessing or egressing from a bus stop/train station.

The majority of "*going to or from public transit*" crashes occurred on higher-speed roads, with 61% of crashes occurring on roads with speed limits greater than 30 mph (see Table 12). This aligns with findings from prior studies as well as the results from the analysis of transit bus stop-related crashes in FARS (Hess et al., 2004; Pulugurtha & Vanapalli, 2008; Yu, 2024). Table 12 also shows that most crashes occurred at an intersection (55%), with many of these being four-way intersections (50%). While the analysis of FARS data found that fatal transit bus stop-related pedestrian crashes more commonly occurred at midblock locations, the Minnesota dataset shows more crashes happening at intersections. Moreover, these crashes reflect the transit entire walking trip to or from the bus stop, not just the crashes occurring at the stop itself.

The case materials indicated that there was not a clear leading contributing circumstance associated with the motorist, with 43% reporting that there was not a contributing circumstance (see Table 12). Among the reports that documented contributing circumstances from the motorists, no single circumstance stood out. The circumstances varied and included failure to yield, failure to obey traffic signs or signals (e.g., stop signs, red lights), failure to maintain lane, carelessness, and speeding.

Table 12. Descriptive analysis of "*going to or from public transit*" pedestrian crashes in MN

Variable		Frequency	Percentage
Crash severity	K- Fatality	1	3%
	A- Incapacitating	11	29%
	B- Non-Incapacitating	15	39%
	C- Possible Injury	10	26%
	O- No apparent injury	1	3%
Speed Limit	0-19 mph	2	5%
	20-29 mph	5	13%
	30-39 mph	22	58%
	40-49 mph	1	3%
	Not Reported	8	21%
Location - Relative to Intersection	Entrance/Exit Ramp	1	3%
	Four-Way Intersection	19	50%
	Intersection Related	4	11%
	Not at Intersection, Interchange or Junction	10	26%
	T Intersection	2	5%
	Other	1	3%
	Unknown	1	3%
Motorist Contributing Circumstances	Driver Speeding	1	2%
	Failed to Keep in Proper Lane	1	2%
	Failure to Yield Right-of-Way	1	2%
	Improper Turn/Merge	2	4%
	No Clear Contributing Action/No Improper Action	20	43%
	Operated Motor Vehicle in Careless, Negligent, or Erratic Manner	2	4%
	Ran Red Light	2	4%
	Other	1	2%
	Not Reported	11	24%
	Unknown	3	7%
Pedestrian Contributing Circumstances	Dart/Dash	8	18%
	Entering/Exiting Parked/Standing Vehicle	1	2%
	Failure to Obey Traffic Signs, Signals, or Officer	2	5%
	Failure to Yield Right-of-Way	5	11%
	In Roadway Improperly (Standing, Lying, Working, Playing)	1	2%
	No Clear Contributing Action/No Improper Action	18	41%
	Not Visible (Dark Clothing, No Lighting, etc.)	1	2%
	Other	2	5%
	Unknown	8	18%

Notes:
Percentages may not sum to 100% due to rounding.
Motorist and Pedestrian Contributing Circumstances variables allow multiple inputs per case.

Meanwhile, in 41% of crashes, there was no clear contributing circumstance from the pedestrian. However, 18% of crashes involved a pedestrian darting or dashing out into traffic, which was the most common cause (see Table 12). This action may reflect the urgency of pedestrians attempting to cross the roadway in order to catch a departing bus, which is a potentially risky behavior. Both prior research and the previous analysis of transit bus stop-related crashes in FARS found that many pedestrians were hit as they were crossing the roadway, which is a similar behavior to darting/dashing into traffic (Pessaro et al., 2017; Singleton et al., 2024; Voorhes Transportation Center, 2012). The other contributing circumstances of the pedestrians varied, including failure to yield, failure to obey traffic signs or signals, entering/exiting parked vehicles, or poor visibility. For both motorists and pedestrians, some crashes reported more than one contributing circumstance.

Analysis of Crash Narratives

The analysis of crash narratives revealed six different categories of transit-related pedestrian crashes (see Figure 12). The following sections include a descriptive example of a crash from each of the categories, which explains the wide range of crashes categorized into "*going to or from public transit*". Upon reviewing the narratives, it was determined that one of the crashes involved a limousine or taxi rather than a transit bus and was unrelated to public transit. As a result, this crash was excluded from the discussion and removed from Figure 12. The following sections provide descriptive examples for each category, demonstrating the range of crashes associated with the pedestrian stages of a transit trip. When available, street-level imagery from KartaView and georeferenced crash maps from OpenStreetMap are included to visually represent the crash locations [38-40].

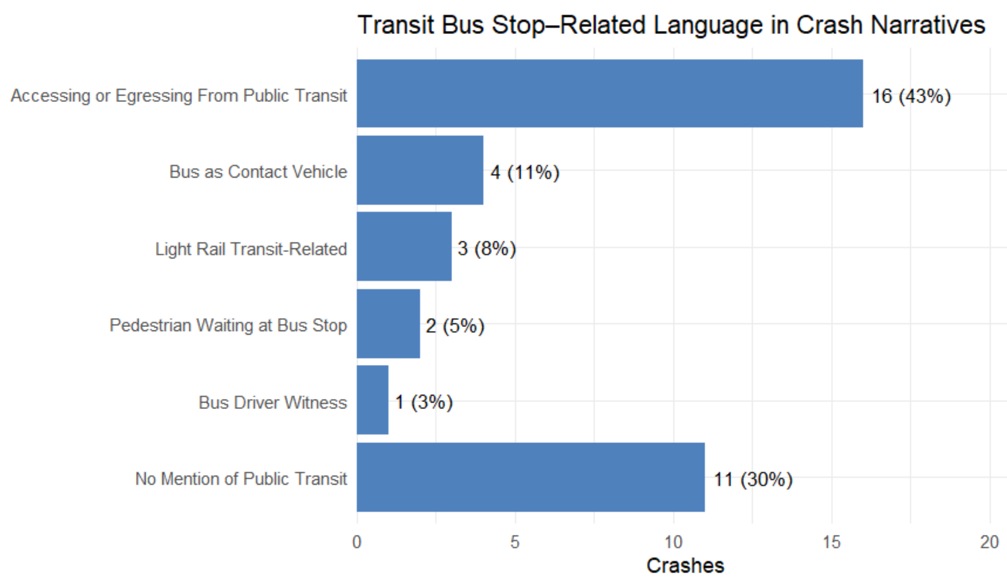

Figure 12. Transit-related language used in the crash narratives

Accessing or Egressing from Public Transit

Crashes were most commonly categorized as "*going to or from public transit*" due to a pedestrian who was hit while accessing or egressing from a bus stop, with 43% of crash narratives using this terminology (see Figure 12). This was the most common category, suggesting that most crashes occurred on the pedestrian's journey to or from a bus stop or train station, rather than at the stop itself.

Bus as Contact Vehicle

There were 4 (11%) crashes in which a bus was the contact vehicle. An example from this category is shown in Figure 13, where a transit bus was traveling on a 30 mph roadway towards a four-way intersection and stopped to pick up passengers at a bus stop. It began to pull away when a pedestrian attempted to flag it down and fell underneath the passenger side of the bus. The pedestrian was transported to the hospital for minor injuries. Such scenarios often involve pedestrians engaging in risky behaviors while trying to board departing buses,

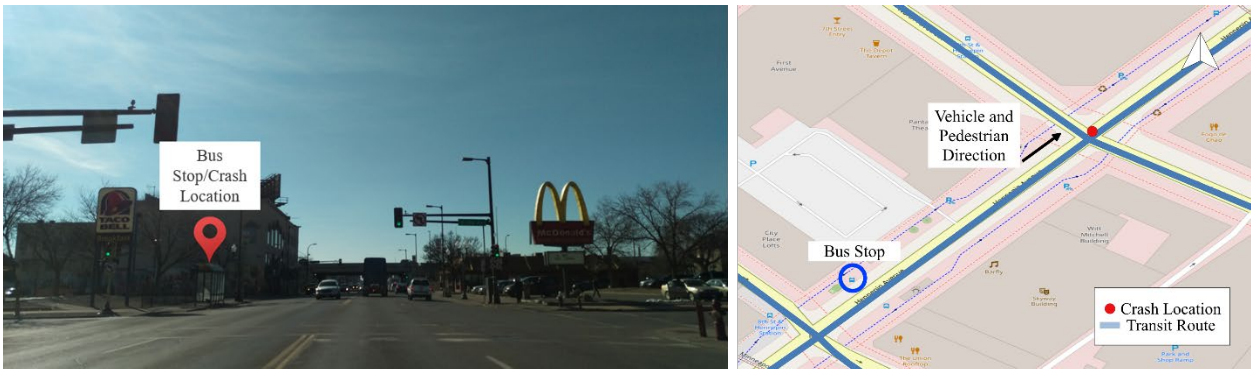

Figure 13. Example of pedestrian crash from the "bus as contact vehicle" category

(Map created using QGIS 3.40 [39] with basemap data © OpenStreetMap (ODbL 1.0) [40] and street-level imagery obtained from © KartaView (CC BY-SA 4.0) [38]

Light Rail Transit-Related

Because Light Rail Transit (LRT) and transit buses have different infrastructure characteristics, LRT-related crashes were categorized separately from transit bus-related crashes to better examine the nature of each type. While this crash type was less common (8%), it was categorized separately to account for the potential differences associated with transit infrastructure. An example of this crash type, shown in Figure 12, involved an SUV driving approximately 30 mph through the Lexington Pkwy intersection when several kids ran into the intersection area from the southeast corner. The light was green while SUV drove through and hit one of the children. The crash narrative specified that the driver believed that the pedestrians may have been trying to catch the nearby LRT.

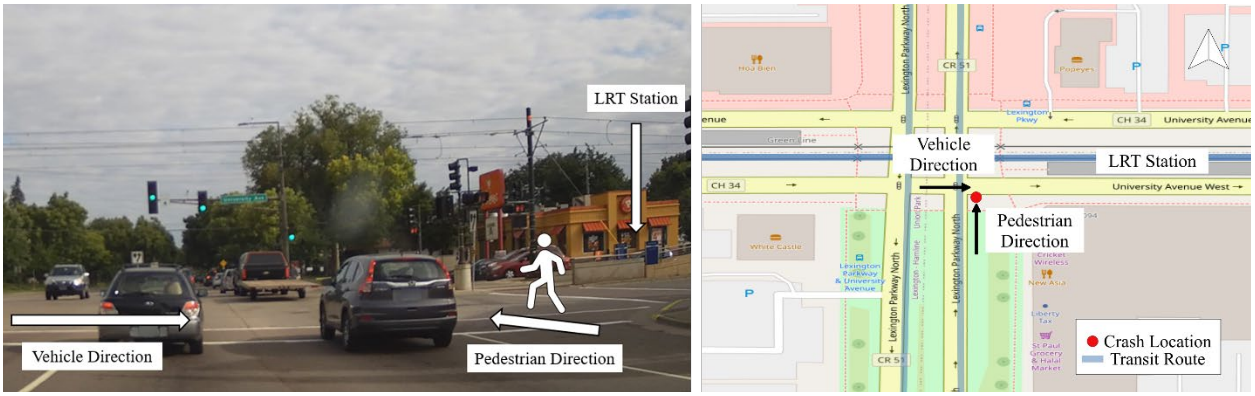

Figure 14. Example of pedestrian crash from the "LRT-related" category

(Map created using QGIS 3.40 [39] with basemap data © OpenStreetMap (ODbL 1.0) [40] and street-level imagery obtained from © KartaView (CC BY-SA 4.0) [38])

Pedestrian Waiting at Bus Stop

Crashes with keywords indicating that a pedestrian was waiting at a bus stop were categorized separately from those suggesting the pedestrian was walking to or from public transit. Specifically, all crashes in this category had specified that a pedestrian was waiting at a bus shelter in the officer narrative. This distinction was also identified in the analysis of transit bus stop-related crashes in the FARS data.

Bus Driver Witness

There was one crash (3%) where a bus driver was a witness to the crash. The crash was likely classified as "*going to or from public transit*" because the bus driver was a witness of the crash, despite the case materials not indicating whether the pedestrian was a transit passenger, nor did it indicate that the bus was picking up or dropping off passengers at a bus stop. This finding suggests some ambiguity in this crash type, as officer interpretation varies and some crashes may not have included transit passengers, as indicated by this example. Such nuances are often overlooked in structured data fields, which demonstrates the importance of analyzing crash narratives for more context.

No Mention of Public Transit

The crashes that were categorized as "no mention of public transit" were classified as such if the crash narrative did not contain any transit-related details. This was the second most common category, with 11 (30%) crashes. All crashes in the dataset were classified as "*going to or from public transit*" based on an officer checking the corresponding box on the crash report form, regardless of whether any transit-related information was included in the crash narrative. For example, a vehicle was approaching a four-way intersection when it struck a pedestrian walking in the crosswalk (see Figure 14). The pedestrian initially reported no injuries but later contacted police about a minor injury. While the narrative lacked transit bus stop-related details, it is possible the pedestrian mentioned going to or from a bus stop or train station, and the officer omitted this detail, relying only on the checkbox. This lack of detail challenges narrative-based analyses, as it may exclude crashes without direct references to transit.

Figure 15. Example of pedestrian crash from the "no mention of public transit" category

(Map created using QGIS 3.40 [39] with basemap data © OpenStreetMap (ODbL 1.0) [40] and street-level imagery obtained from © KartaView (CC BY-SA 4.0) [38])

Summary of Findings from "Going To or From Public Transit" Pedestrian Crashes

The review of the transit-related pedestrian safety database revealed a MnDOT crash database with 38 "*going to or from public transit*" pedestrian crashes across eight years of raw crash data from 2016 to 2023. This database presented a unique opportunity to analyze the characteristics of crashes specifically involving transit passengers, since it is not generalized to all pedestrian crashes in the area of a bus stop (like FARS/CRSS). Therefore, pedestrian safety improvements targeted specifically to transit passengers may be identified with this crash type. Moreover, with the entire range of injury severity reported in this database, this data may be used to begin to understand the factors that influence injury severity for crashes involving transit passengers.

The descriptive analysis found that many of the "*going to or from public transit*" crashes resulted in non-incapacitating injuries (41%). However, 29% of crashes resulted in a serious injury and one (3%) resulted in a fatality. Many of the crashes occurred on a higher-speed road (61%) which aligned with the findings from both prior studies on pedestrian safety at bus stops, and the findings from the analysis of fatal transit bus stop-related pedestrian crashes in FARS (Hess et al., 2004; Pulugurtha & Vanapalli, 2008; Yu, 2024). Moreover, crashes most frequently involved a pedestrian darting/dashing into the roadway (18%), which is a pedestrian behavior that has been reported consistently throughout the literature, and aligns with the finding from the FARS analysis that most transit bus stop-related crashes occurred while the pedestrian was crossing the roadway (Pessaro et al., 2017; Singleton et al., 2024; Voorhes Transportation Center, 2012). Since most crashes occurred on higher-speed arterials and often involved pedestrians darting/dashing into traffic, these findings suggest that safety improvements should focus on lowering speed limits and adding highly visible marked crossings.

While the analysis of FARS data suggests that midblock bus stops should be prioritized for pedestrian safety improvements, the descriptive analysis found that "*going to or from public transit*" crashes most commonly occurred at intersections. This may be due to two factors: (1) the database includes the full range of injury severity, suggesting that more severe crashes may occur at midblock locations while less severe ones occur at intersections, or (2) transit passengers face more conflicts at intersections during their walking trip to or from transit, while risks directly at the bus stop are higher at midblock locations. Although the MnDOT data may not be generalized nationally, the descriptive analysis of these crashes reinforces and extends the FARS findings and indicating that pedestrian safety improvements are needed not only at bus stops but also along the walking route to and from the bus stop, especially at intersections along higher-speed roads.

A review of officer keywords in the crash report narratives was conducted to identify the most common transit-related terms used by the reporting officer to classify different types of crashes related to a pedestrian going to or from public transit. Six categories were identified in this analysis: (1) accessing or egressing from public transit, (2) waiting at bus stop, (3) LRT-related, (4) bus driver witness, (5) bus as contact vehicle, and (6) no mention of public transit in the narrative. The most common category was "accessing or egressing from public transit" (43%), indicating that most crashes occurred while the transit passenger was walking to or from the bus stop or train station. However, the next most common category was "no mention of public transit" (30%), in which the reporting officer simply checked the "*going to or from public transit*" box on the crash report form, based on their judgement from the statements made by the victims, witnesses, and from the evidence at the scene. Although some crashes were categorized as "no mention of public transit," 70% of crash narratives still included some form of transit-related language in the narrative.

The findings from this analysis suggest that pedestrian safety improvements for transit passengers should consider the entire walking conditions to and from bus stops or train stations that are located along transit routes on higher-speed roads. While the FARS analysis highlights midblock bus stops as key locations for addressing more severe outcomes near the stop itself, this analysis points to potential risks along the walking route, particularly at intersections.

A key contribution of this section is the analysis of crash narratives, which identified several categories associated with different types of "*going to or from public transit*" pedestrian crashes. This analysis suggests a potentially promising opportunity for future research to leverage unstructured text data, such as crash narratives, to better identify transit-related crashes in crash data.

Conclusions and Recommendations

Prior research has considered pedestrian safety at bus stops; however, none of the existing studies from the United States have used pedestrian crash data that explicitly identifies bus stops as contributing factors in crashes. Instead, prior studies have used a location-based assumption, analyzed crash narratives, and/or collected field observations to infer the relationship between pedestrian safety and bus stops. This report begins to address this gap in the literature by first conducting a review of transit-related safety datasets. Although such data was somewhat limited, the FARS database and raw crash data from MnDOT were ultimately selected for further analysis to identify the characteristics of pedestrian crashes that are explicitly identified as related to transit.

First, a nationwide analysis is conducted using the FARS data to identify the characteristics of fatal transit bus stop-related crashes and compare these characteristics to other pedestrian crashes in close proximity, revealing similarities and differences between the two groups. This was accomplished with a three-part methodology. First, binary logit models were estimated to compare transit bus stop-related pedestrian crashes to other nearby fatal pedestrian crashes. Hierarchical clustering was then used to identify the primary transit bus stop-related crash scenarios and assess how the clustering distinguished between these crashes and other nearby crashes. Finally, an inventory of bus stop infrastructure was conducted for each bus stop where a fatal transit bus stop-related crash occurred, comparing the infrastructure before and after the crash date to evaluate whether safety improvements were made potentially in response to pedestrian safety concerns.

Next, a statewide analysis was conducted using raw crash data from MnDOT. First, a descriptive analysis was performed to identify the characteristics of crashes involving pedestrians walking to or from public transit. Due to the limited sample size (n = 38), the second part of the statewide analysis took a more qualitative approach. The crash narratives for each crash in the sample were analyzed to categorize the most common transit-related terminology used by reporting officers for "*going to or from public transit*" pedestrian crashes. Additionally, the details in the crash narratives were carefully examined to identify any nuances that may not be fully captured by structured data fields. Ultimately, this analysis began to address the data gap identified in the review of transit-related safety databases by assessing how transit-related details in unstructured text data, such as crash narratives, can be used to better classify these types of pedestrian crashes.

The nationwide and statewide analysis began to address existing research gaps by identifying the characteristics of pedestrian crashes that occur at bus stops or while a pedestrian is walking to or from a bus stop at both the national and state levels. Moreover, this report identified important distinctions between fatal transit bus stop-related pedestrian crashes and other fatal pedestrian crashes in areas with transit services, thereby supporting targeted countermeasures to improve safety not only for transit passengers but also for all pedestrians in surrounding areas. Finally, this research used crash report narratives to better understand and classify pedestrian crashes related to transit. The following sections discuss the key findings from each phase of the analysis, as well as the study's limitations and areas for future research.

Key Findings from the Literature Review and Transit-Related Safety Data Review

The foremost method used in prior literature on pedestrian safety at bus stops involved using a location-based assumption, which assumes that all crashes within a given distance of a bus stop are directly related to the stop itself. This approach may impact the accuracy of the results, since the extent of the pedestrian involvement in bus stop-related crashes may not be accurately captured simply by the distance between the location of a crash and the nearest bus stop. Many studies used this approach since it only required pedestrian crash data and bus stop locations, both of which are typically readily available and easy to access. Further, a comprehensive search of transit-related safety databases revealed the scarcity of data that explicitly identifies transit bus-stop related crashes; these datasets were limited in both sample size and public/private availability. While well-known crash typing frameworks (e.g., PBCAT and MMUCC) do specify whether a crash was related to a bus stop, many real-world datasets have not adopted the most recent versions of these frameworks. As a result, this type of crash may be unreported or miscategorized.

Even databases that use the PBCAT and MMUCC crash typing frameworks may still underreport transit bus-stop related crashes. For instance, FARS and CRSS only reported 196 and 83 pedestrians involved in transit bus stop-related crashes, respectively (2016-2022). However, these databases use an adapted definition of PBCAT 2.0, which requires a transit bus to be present at the bus stop at the time of the crash. This definition excludes other crashes that were potentially related to a bus stop, regardless of the presence of the bus. Furthermore, the scope is limited to the immediate area around bus stops and fails to account for the entire walking trip to or from a transit stop. PBCAT 3.0 addresses both of these issues, but FARS and CRSS have not yet adopted this version.

It is important to recognize that the absence of such crash data does not equate to the absence of pedestrian safety concerns. Prior research found that pedestrians' perception of safety directly influences their walking behavior (Kweon et al., 2021); therefore, it may be that this crash type is underreported because pedestrians are avoiding bus stops that are perceived as unsafe or are choosing not to use transit altogether. Ferenchak and Marshall (2019) explored safety concerns arising from trip suppression using data on suppressed child pedestrian and bicyclist trips, derived from a survey of parental perceptions and trip frequencies. They developed a proactive approach to evaluate safe access to schools by creating a trip-suppression model, a framework that can also be applied to improving safe access to transit. Therefore, while crash data is essential for addressing pedestrian safety at bus stops, a proactive approach could incorporate additional data sources to more fully understand the factors influencing safe access to transit.

Key Findings from the Nationwide Analysis of Fatal Transit Bus Stop-Related Pedestrian Crashes

Although the FARS data has limitations, it was used in this report in binary logit models and hierarchical clustering analysis to provide insights into the characteristics of fatal transit bus stop-related crashes and how they compared to nearby pedestrian crashes. The results revealed that there were three main transit bus stop-related crash scenarios: (1) a pedestrian crossing to or from a transit stop at an intersection, (2) a pedestrian waiting on the roadside at a midblock transit stop, and (3) a pedestrian crossing to or from a midblock transit stop.

Compared to other nearby fatal crashes, the clustering analyses revealed that transit bus stop-related crashes involving a pedestrian crossing at an intersection or midblock location shared similar characteristics with other nearby fatal crashes. This aligns with previous studies that have linked pedestrian crossing behavior with bus stops (Pessaro et al., 2017; Singleton et al., 2024; Voorhes Transportation Center, 2012). However, the binary logit model and the hierarchical clustering revealed that the scenario involving a pedestrian waiting on the roadside at a midblock location was specific to transit bus stop-related crashes. Although fewer crashes were assigned to this cluster scenario (24% of transit bus stop-related crashes), countermeasures targeting this situation could specifically improve the safety of transit passengers waiting at midblock bus stops.

In addition to the binary logit model and the hierarchical clustering analysis, the transit bus stop-related crashes from FARS were further analyzed by compiling a manual inventory of bus stop infrastructure. The results revealed that at the bus stops that were related to a passenger hit while waiting for the bus, many of the surveyed amenities were already in place when the crash occurred, with minor improvements made after the crashes. However, since this crash type involved a vehicle departing the roadway into the bus stop, amenities such as sidewalks and seating may not have had an impact on preventing this type of crash. Therefore, if safety improvements were implemented in response to these crashes, they may not have been captured within the scope of this inventory. To address this crash scenario, the positioning of the bus stop relative to the travel lane may be more relevant than the presence of certain amenities at the bus stops. Bus stops that are offset from the roadway, such as curbside pull-out stops, could reduce the pedestrian's exposure to the path of impact in the event of a roadway departure (Yendra et al., 2024). Additionally, installing barriers or bollards near bus stops may reduce the risk of this crash scenario by creating a clear separation between the roadway and the bus stop and by potentially absorbing some of the impact in the event of a roadway departure (Grzebieta & Rechnitzer, 2013). Since many of these transit bus stop-related crashes occurred on higher-speed arterials, speed reductions may be necessary along these corridors to safely accommodate transit passengers and other pedestrians.

Efforts to address crash scenarios where pedestrians are hit while crossing midblock or at an intersection would benefit not only transit passengers but all pedestrians in areas with transit services. The analysis of bus stop infrastructure where crossing-related crashes occurred revealed that access to crosswalks was limited at some locations. Specifically, only 63.7% of these bus stops had access to a nearby crosswalk at the time of the crash. This suggests that increasing access to marked crosswalks and enhancing the visibility of existing crosswalks could improve pedestrian safety in these areas. Specifically, NHTSA's Proven Safety Countermeasures stated that high-visibility crosswalks have the potential to reduce pedestrian injury crashes by up to 40% (Albee, 2021; Chen et al., 2012). Moreover, to address pedestrian crossing behavior, barriers may be installed along the sidewalks to guide pedestrians to cross at marked crossing facilities, as suggested by a previous study (Pessaro et al., 2017). Last, relocating midblock bus stops to signalized intersections when feasible may reduce the risk of this type of crash, as suggested prior research (Anis et al., 2024; Yu, 2024).

Last, the findings of this report reiterate the importance of inter-agency partnerships to facilitate safer access to transit (Goughnour et al., 2022). Transit agencies, state DOTs, and local government organizations all have important roles in addressing pedestrian safety at bus stops. While transit agencies may have the authority to make improvements to the bus stops themselves, they must collaborate with state and local organizations to ensure that transit routes and bus stops are located on roadways with a connected pedestrian and bicyclist network. For example, while a transit agency may control whether a bus stop has a shelter, collaboration may be needed to ensure access to a sidewalk and/or crosswalk near the bus stop. Increased collaboration between transit agencies, state DOTs, and local government organizations may help to enhance the safety of both the bus stop environment and pedestrian access to it.

Key Findings from Minnesota Crashes Involving Pedestrians Going To or From Public Transit

Despite the relatively smaller sample, the descriptive analysis of the 38 "*going to or from public transit*" pedestrian crashes in Minnesota generally aligned with many of the findings from prior research and the findings from the nationwide analysis of fatal transit bus stop-related pedestrian crashes using FARS. Specifically, these crashes were concentrated on higher-speed roads, and generally involved risky pedestrian crossing behavior, such as darting/dashing into the roadway. These findings further reinforce the potential for lowered speed limits and improved pedestrian crossing facilities on transit corridors. However, one key difference was identified between the statewide and nationwide analyses regarding crash location. In Minnesota, "*going to or from public transit*" crashes most often occurred at intersections, whereas the FARS analysis found that transit bus stop-related crashes were more common at midblock bus stops. This may be a function of injury severity, as the MnDOT data included the full range of injuries. It may also be related to how these crash types are defined in each dataset: FARS captures only crashes occurring in the immediate area of bus stops, while the statewide data considers the entire pedestrian trip to and from the bus stop.

A qualitative analysis of the crash narratives for each crash revealed six common types of crashes within the "*going to or from public transit*" data field. These categories were: (1) accessing or egressing from public transit, (2) waiting at bus stop, (3) LRT-related, (4) bus driver witness, (5) bus as contact vehicle, and (6) no mention of public transit in the narrative. Most commonly, officers reported that a pedestrian was walking to or from the transit stop, highlighting the need to consider the transit passenger's entire trip and not just the time spent in the immediate area of the bus stop. Moreover, 70% of these crashes included some transit-related language in the narrative, suggesting that unstructured text data may be a feasible tool for improving the collection of transit-related information in crash data.

Areas for Improvement and Future Research

While this report provides insights into pedestrian safety at bus stops from the FARS database, several limitations exist. First, the first part of this study only considered fatal pedestrian-involved crashes, as only fatal crashes are included in the FARS database due to its reporting requirements. Therefore, further analysis is needed to understand the factors influencing injury severity outcomes in transit bus stop-related crashes at the national level. Additionally, as previously mentioned, FARS should consider adopting PBCAT 3.0 to address the various types of transit bus stop-related crashes. Moreover, FARS does not provide information about the conditions at the bus stop itself, nor does it indicate whether the affected pedestrian was a passenger or simply a passerby. Last, Sanchez Rodriguez and Ferenchak (2024) conducted a study on pedestrian fatalities from 1999 to 2020 and found that the locations of these crashes are shifting to suburban areas. Given this, FARS should consider redefining land uses to include suburban contexts.

This report considered demographic characteristics and pedestrian/motorist impairment, but no significant associations were identified using the FARS dataset. Therefore, these factors should be explored further in future research using other datasets. Moreover, this study did not address the potential causes of the geographic distribution of transit bus stop-related crashes, which may necessitate further analysis of FARS data or other datasets to understand this relationship. Additionally, the current limitations in reporting transit-related information in safety databases can be addressed by improving data collection methods, which would better support this type of research moving forward.

A significant focus of this report was the comparison of fatal transit bus stop-related crashes with other nearby fatal crashes using FARS data. However, since the sample of nearby crashes was drawn from areas where a transit bus stop-related crash had already occurred, these locations may be higher-risk or "hot spots" for fatal pedestrian crashes. This could introduce bias into the comparison by overrepresenting areas with higher crash frequencies. An alternative approach would be to obtain a randomized sample of pedestrian crashes from FARS rather than selecting crashes based on proximity to transit bus stop-related crashes. This would establish a baseline for comparison between transit bus stop-related crashes and other pedestrian crashes, rather than limiting the analysis to those occurring nearby.

Additionally, this report did not directly assess the accuracy of the location-based assumption that was commonly used in the prior literature. Instead, the research compared characteristics of transit bus stop-related crashes and those in the immediate area by defining a buffer zone around each transit bus stop-related crash location, whereas the location-based assumption defines a buffer zone around each bus stop. Therefore, the two approaches cannot be directly compared, making it challenging to draw conclusions about the accuracy of the location-based assumption. Given the extensive use of this method in prior literature and the limited availability of transit bus stop details in pedestrian crash data, future research should address this gap.

The statewide analysis indicated that many transit passengers were hit while walking to or from public transit, though the sample size was limited. In contrast, the FARS dataset offered a relatively larger sample but only captured crashes occurring directly at bus stops, excluding crashes that potentially occurred along the broader walking trip. Similarly, prior research has focused primarily on the immediate area around bus stops. Future studies should consider the full pedestrian journey to better understand the barriers to safe access to and from transit.

In light of recent trends in rising pedestrian fatalities across the United States and the research gaps surrounding the relationship between pedestrian safety and bus stops, further research is important to ensure that the safety benefits of transit are fully realized for all road users. Data collection plays a critical role in this effort, as trip purpose information, particularly trips made to and from transit, can offer a more direct approach for identifying pedestrian involvement and reducing uncertainties in future research on pedestrian safety at bus stops. Both transit and walking are key components of urban mobility. Therefore, by closing data gaps, future research on pedestrian safety at bus stops can help to support initiatives aimed at achieving zero traffic fatalities and also promote transit as a safer and more attractive mode, potentially encouraging ridership and improving urban mobility.

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