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Report No. UT-23.09

RIGHT-TURN SAFETY FOR WALKING/BICYCLING: IMPACTS OF CURB/CORNER RADII AND OTHER FACTORS

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Final Report
September 2023

DISCLAIMER

ACKNOWLEDGMENTS

The authors acknowledge the Utah Department of Transportation (UDOT) for funding this research, and the following individuals from UDOT on the Technical Advisory Committee for helping to guide the research:

- Glenn Blackwelder (Traffic & Safety Operations Engineer)
- Eric Chaston (Region 2 Traffic Operations Engineer)
- Travis Evans (Active Transportation Safety Program Manager)
- Heidi Goedhart (Planning Division Active Transportation Manager)
- Travis Jensen (Research Consultant Project Manager)
- Matt Luker (Statewide Signal Engineer)
- Marjorie Rasmussen (Region 2 Traffic Engineer)
- Stephanie Tomlin (Planning Division Modeling, Data, & GIS Program Manager)

The authors also thank the following students and faculty at Utah State University (USU):

- Bailey Nielson for leading and managing the observational data collection.
- Gabriel Anderson for drafting the bicycle literature review.
- Matt Hall and Emilie Hill for conducting a preliminary version of the crash data analysis.
- Chandler Hokanson and Aleks Paskett for helping to collect intersection information used to select study locations.

TECHNICAL REPORT ABSTRACT

1. Report No. UT-23.09	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Right-Turn Safety for Walking/Bicycling: Impacts of Curb/Corner Radii and Other Factors		5. Report Date September 2023 6. Performing Organization Code N/A
7. Author(s) Patrick A. Singleton, Michelle Mekker, Alyssa Gaither, Atul Subedi, Ahadul Islam		8. Performing Organization Report No. N/A
9. Performing Organization Name and Address Utah State University Department of Civil and Environmental Engineering 4110 Old Main Hill Logan, Utah 84322-4110		10. Work Unit No. 7369215D 11. Contract or Grant No. 21-8540
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final Dec 2020 to Sept 2023 14. Sponsoring Agency Code UT20.312

15. Supplementary Notes

Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

The objective of this research project is to understand factors (especially curb/corner radii) affecting safety at intersections involving right-turning vehicles and pedestrians/bicyclists. A mixed-methods approach was used, combining crash data analysis with analysis of observational video data. For the crash analysis, data were assembled about more than 1,000 pedestrian and nearly 1,200 bicycle crashes with right-turning vehicles at signalized intersections in Utah from 2010 to 2019, and analyses involved comparisons using chi-square tests and multivariate zero-inflated negative binomial regression models. For the observational analysis, data were transcribed from videos recorded at 34 signalized intersections in Utah in 2021 and 2022 capturing more than 1,500 pedestrian conflicts with right-turning vehicles, and analyses involved correlations as well as multilevel regression models. Too few bicyclists were observed to be able to analyze bicycle–vehicle conflicts.

Pedestrian and bicycle crashes involving right-turning motor vehicles tended to be less severe than crashes involving left-turning or through-moving vehicles. While shorter pedestrian crossings and prohibiting right turns on red (RTOR) reduced all-intersection pedestrian crashes, their effects appeared to be stronger for right-turn crashes. The most severe pedestrian conflicts tended to be those in which the driver crossed the conflict point after the pedestrian did (a situation called "post-encroachment"), the pedestrian sped up or ran, and/or the driver stopped or slowed (to narrowly avoid a collision). Overall, pedestrian–vehicle conflicts were more severe under several important conditions: when pedestrian group sizes were smaller, when pedestrians were leaving the curb (instead of approaching it), when pedestrians were in the second crosswalk that right-turning drivers would cross, when drivers were turning right on green, and when there were longer right-turn queue lengths.

17. Key Words Pedestrian-vehicle crashes, Bicycle crashes, Right turns, Intersections, Regression analysis		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 182	22. Price N/A	

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AADB	Annual Average Daily Bicyclists
AADP	Annual Average Daily Pedestrians
AADT	Annual Average Daily Traffic
ACS	American Community Survey
ATSPM	Automated Traffic Signal Performance Measures
CI	Confidence Interval
DDI	Diverging Diamond Interchange
DF	Degrees of Freedom
DPS	Department of Public Safety
DUI	Driving Under the Influence
ET	Encroachment Time
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
HAWK	High-Intensity Activated Crosswalk
HSRC	Highway Safety Research Center
ITE	Institute of Transportation Engineers
LEHD	Longitudinal Employer Household Dynamics
LL	Log-Likelihood
LPI	Leading Pedestrian Interval
LT	Left Turn
MAJ	Major
MIN	Minor
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NHTSA	National Highway Traffic Safety Administration
OR	Odds Ratio
PET	Post-Encroachment Time
PROWAAC	Public Rights-of-Way Access Advisory Committee
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RRR	Relative Risk Ratio

RT	Right Turn
RTOR	Right Turn on Red
SA	Straight-Ahead
SD	Standard Deviation
SE	Standard Error
SPUI	Single-Point Urban Interchange
SUV	Sport Utility Vehicle
T&F	Taylor & Francis
TRID	Transport Research International Documentation
TTC	Time To Collision
UDOT	Utah Department of Transportation
UDPS	Utah Department of Public Safety
UGRC	Utah Geospatial Resource Center
UNC	University of North Carolina
USC	United States Code
USU	Utah State University
ZINB	Zero-Inflated Negative Binomial

EXECUTIVE SUMMARY

The objective of this research project is to understand factors (especially curb/corner radii) affecting safety at intersections involving right-turning vehicles and pedestrians/bicyclists. A mixed-methods approach was used, combining crash data analysis with analysis of observational video data. For the crash analysis, data were assembled for 1,035 pedestrian crashes and 1,189 bicycle crashes involving right-turning vehicles at signalized intersections in Utah from 2010 to 2019. These crash data were joined with geospatial data from various sources for around 2,000 signals. Data analysis involved univariate/bivariate comparisons using chi-square tests, and multivariate models utilizing zero-inflated negative binomial regression.

For the observational analysis, videos were recorded at 34 signalized intersections in Utah in 2021 and 2022, resulting in a total of 4,198 pedestrian crossing events and 1,683 potential pedestrian-vehicle conflicts observed. For each conflict, information about the conflict severity (as measured by encroachment time, the time difference between when the two road users occupied the same location) and pedestrian and motor vehicle driver behaviors was manually recorded and joined with information about the weather, traffic signal status, and location-specific attributes about corner and intersection design and neighborhood built and social environments. Data analysis involved correlations as well as multilevel regression models. Too few bicyclists were observed to be able to analyze bicycle-vehicle conflicts.

From the crash analysis: Pedestrian and bicycle crashes involving right-turning motor vehicles tended to be less severe than those involving left-turn and straight-ahead movements, likely due to lower speeds during right turns. Regression models for only right-turn pedestrian/bicycle crash frequencies were generally quite similar to those models for all crashes, although some associations were stronger. For instance, while shorter pedestrian crossings and prohibiting right turns on red (RTOR) reduced pedestrian crashes overall, their effects appear to be stronger for right-turn crashes (after controlling for other factors like traffic volume exposure).

From the observational analysis, among all potential conflicts (those with an encroachment time of ten seconds or less), around 21% were considered to be of high severity

(0-3 sec). Although most pedestrians and around half of drivers had no obvious reaction to the conflict, some stopped or slowed down, while a few sped up, ran, or swerved/changed direction to avoid a collision. The most severe pedestrian conflicts tended to be those in which the driver crossed the conflict point after the pedestrian did (a situation called “post-encroachment”), the pedestrian sped up or ran, and/or the driver stopped or slowed (to narrowly avoid a collision). Overall, conflicts were more severe under several important conditions: when pedestrian group sizes were smaller, when pedestrians were leaving the curb (instead of approaching it), when pedestrians were in the second crosswalk that right-turning drivers would cross, when drivers were turning right on green, and when there were longer right-turn queue lengths. Although corner radius was not significantly associated with conflict severity, other findings about locational and design characteristics implied that intersections with more automobile-centric features (e.g., dual right-turn lanes, a receiving lane, a channelized right turn) might discourage driver stopping/yielding and lead to potential pedestrian safety issues.

The findings of this research offer several recommendations to be considered for implementation. Potential design and operational strategies include: discouraging auto-centric right-turn situations (dual right-turn lanes, channelized right turns, receiving lanes), shortening crossing distances, prohibiting right turns on red, and using leading pedestrian intervals. Efforts to encourage more walking and increase pedestrian volumes might improve pedestrian safety through a “safety in numbers” effect. There could be more education about drivers’ responsibilities for ensuring pedestrian safety at intersections. Future research could investigate conflicts between people bicycling and right-turning vehicles in more detail.

1.0 INTRODUCTION

1.1 Problem Statement

A significant portion of roadway crashes occur at intersections, and crashes/conflicts between right-turning vehicles and pedestrians and bicyclists are common. There are limited studies focusing on crashes between right-turning vehicles and pedestrians and bicyclists. In the early 1980s, a national report noted that crashes between motor vehicles and pedestrians increased by 43-107% when right turn on red (RTOR) was implemented (Preusser et al., 1981, 1982). More recently, a study in 2006 found that 32% of 255 vehicle-pedestrian crashes at intersections involved right-turning vehicles (Roudsari et al., 2006). Conceptually, turning speeds could be reduced and yielding behavior (and pedestrian visibility) potentially increased by using smaller curb radii or corner radii (UNC HSRC et al., 2013), but this treatment may have a negative impact on turning for large vehicles. Nevertheless, there are few studies of the impacts of corner radius (or other design and operational factors) on right-turn and pedestrian/bicyclist safety. This research project addresses this gap in understanding right-turn intersection safety using a “mixed-methods” approach, a process that includes analyzing crash data and collecting and analyzing observations of road user behaviors.

1.2 Objectives

The objective of this research project is to understand factors (especially curb/corner radii) affecting safety at intersections involving right-turning vehicles and pedestrians/bicyclists, using a mixed-methods approach.

1.3 Scope

This project accomplishes this research objective through the following major tasks:

- **Review literature**: Review literature on right-turn safety with respect to walking and bicycling, considering corner radii and other right-turn design elements (e.g., dedicated lane, offset distance between the lane and the parallel crosswalk).

- **Assemble and analyze crash data**: Assemble data for crashes involving right-turning vehicles and people walking and bicycling at Utah signalized intersections. Analyze characteristics or situations for which these crashes are over-/under-represented or more/less frequent, compared to other crashes.
- **Record videos and analyze observational data**: Record videos about conflicts between right-turning vehicles and active transportation users at several signalized intersections in Utah. Choose study locations to account for a variety of right-turn designs and sufficient active transportation activity. Measure road user behaviors and note conflicts between right-turning vehicles and active transportation users. Analyze collected data for trends, patterns, and associations with right-turn design elements.
- **Recommend countermeasures**: Based on the results of the multiple analysis methods, recommend design, operational, programmatic, and/or policy actions to improve pedestrian and bicycle safety in right-turn situations.

1.4 Outline of Report

This report is organized into the following chapters:

- Chapter 1.0 (Introduction) presents the research problem statement, project objectives, project scope, and organization of the report.
- Chapter 2.0 (Research Methods) includes separate literature reviews for pedestrian and bicycle safety in the context of right-turning vehicles at intersections, and introduces the data collection and analysis approach.
- Chapter 3.0 (Data Collection) includes details about the assembly of crash and other traffic signal and geospatial data for the crash data analysis, as well as the selection of study locations and recording of videos and road user conflicts/behaviors for the observational data analysis.
- Chapter 4.0 (Data Analysis) includes the results of the crash data analysis, as well as the results of the observational data analysis.

- Chapter 5.0 (Conclusions) summarizes the report by highlighting major findings, comparing those findings with earlier research, noting limitations, and outlining potential steps for future work.
- Chapter 6.0 (Recommendations and Implementation) provides recommendations for implementation of the research findings.
- References follow the main chapters.

2.0 RESEARCH METHODS

2.1 Overview

This chapter contains two literature reviews. The first literature review summarizes research on pedestrian safety in the context of right-turning vehicles at intersections and includes information about the literature search process, the methodologies used to analyze these issues, findings related to curb/corner radii, and research implications. The second literature review does the same for bicycle safety. The chapter ends with an overview of the data collection and analysis approaches presented in subsequent chapters.

2.2 Literature Review on Pedestrian Safety, Intersections, and Right Turns

2.2.1 Introduction

In the last few decades, transportation engineers and planners have sought to identify and prioritize countermeasures to make roads and streets safer for walking. Strides have been made in identifying geometric, behavioral, and cultural factors related to pedestrian safety (Aldred, 2018). Despite those efforts, pedestrian safety is still a concern. Over the last decade, the number and share of pedestrian injuries and fatalities have increased both nationally and in Utah. In 2019, 6,205 pedestrians were killed in road crashes in the US, accounting for 17.2% of all traffic fatalities (NHTSA, 2020c). This was an increase from 4,302 pedestrian deaths in 2010, representing 13% of all traffic fatalities (NHTSA, 2020a). Utah is not immune to this issue and has also seen increases in the number and rate of pedestrian fatalities and injuries over the last 10 years. In 2019, 45 deaths and nearly 900 crashes involving people walking on Utah streets and highways were reported (UDPS, n.d.). When involved in crashes, pedestrians are more likely than other road users to be injured or killed.

A significant portion of roadway crashes nationally involving pedestrians occur at intersections. In 2019, around 41% of fatal pedestrian crashes were at intersections (NHTSA, n.d.). Crashes between pedestrians and right-turning vehicles constitute a significant portion of these intersection crashes: 37%, according to Utah crash data (UDPS, n.d.). However, studies focusing on crashes between right-turning vehicles and pedestrians are lacking. Notably, there are few studies of the impacts of corner radius (or other design and operational factors) on right-turn vehicle–pedestrian safety. This literature review summarizes existing research on pedestrian safety at intersections, with a focus on turning vehicles and how these situations relate to other safety factors and concepts.

2.2.2 Literature Search

Given limited pedestrian safety research studying the effects of curb or corner radii and right-turning vehicles, the literature search process aimed to identify research on the topic of pedestrian safety at intersections broadly. It also focused on the safety implications of geometric design elements and crashes between pedestrians and right-turning vehicles, and concentrated on studies conducted in the US. After testing a variety of search terms, the research team selected three databases for a detailed literature search: Taylor & Francis Online (T&F), Transport Research International Documentation (TRID), and Google Scholar. For T&F, the search term was "Design Factors for Pedestrian Safety". For TRID, the search terms were modified to be "(Curb Radi* OR Factor*) AND (Car* OR Vehicle* OR Transport*) AND (Pedestrian* OR Wayfarer*) AND (Safety OR Security) AND (Intersect* OR Junction) AND (United States OR U.S.) NOT (Bicycl*) NOT (Rail*)." A similar strategy was followed with Google Scholar, using the search terms "(Radius OR Radii) AND (Car* OR Vehic*) AND (Pedestrian*) AND (Safe*) AND (Intersect*) AND (United States OR U.S.) NOT (Bicycl*) NOT (Rail*) NOT (Behavior*) NOT (Distract*)." Due to the large number of results, only the first 200 results were inspected. (In the search terms above, the * symbol allows for multiple suffixes, such as "radii" and "radius.")

Figure 2.1 presents the literature search process. The initial search (conducted in June 2021) detected 508 potential studies: 196 in T&F, 112 in TRID, and 200 in Google Scholar. After removing duplicates, the research team screened the remaining 497 records against the study's inclusion criteria, and for relevance. Inclusion criteria dictated that the documents must be: (1) written in English; (2) a peer-reviewed journal article or a published report; (3) primarily US-centric; and (4) include specific factors relating to pedestrian safety at intersections. Preferably, research was about geometric design factors (including curb/corner radii) and empirical associations with pedestrian safety or interactions with right-turning motor vehicles.

But, given a lack of research on this specific topic, the search relevance was widened to include discussions of the implied safety effects of corner radii. Among the results, 415 were excluded for only briefly mentioning curb or corner radii in passing, while another 55 results were excluded due to the lack of a full-text document being available. In the end, 27 resources were included in the pedestrian literature review.

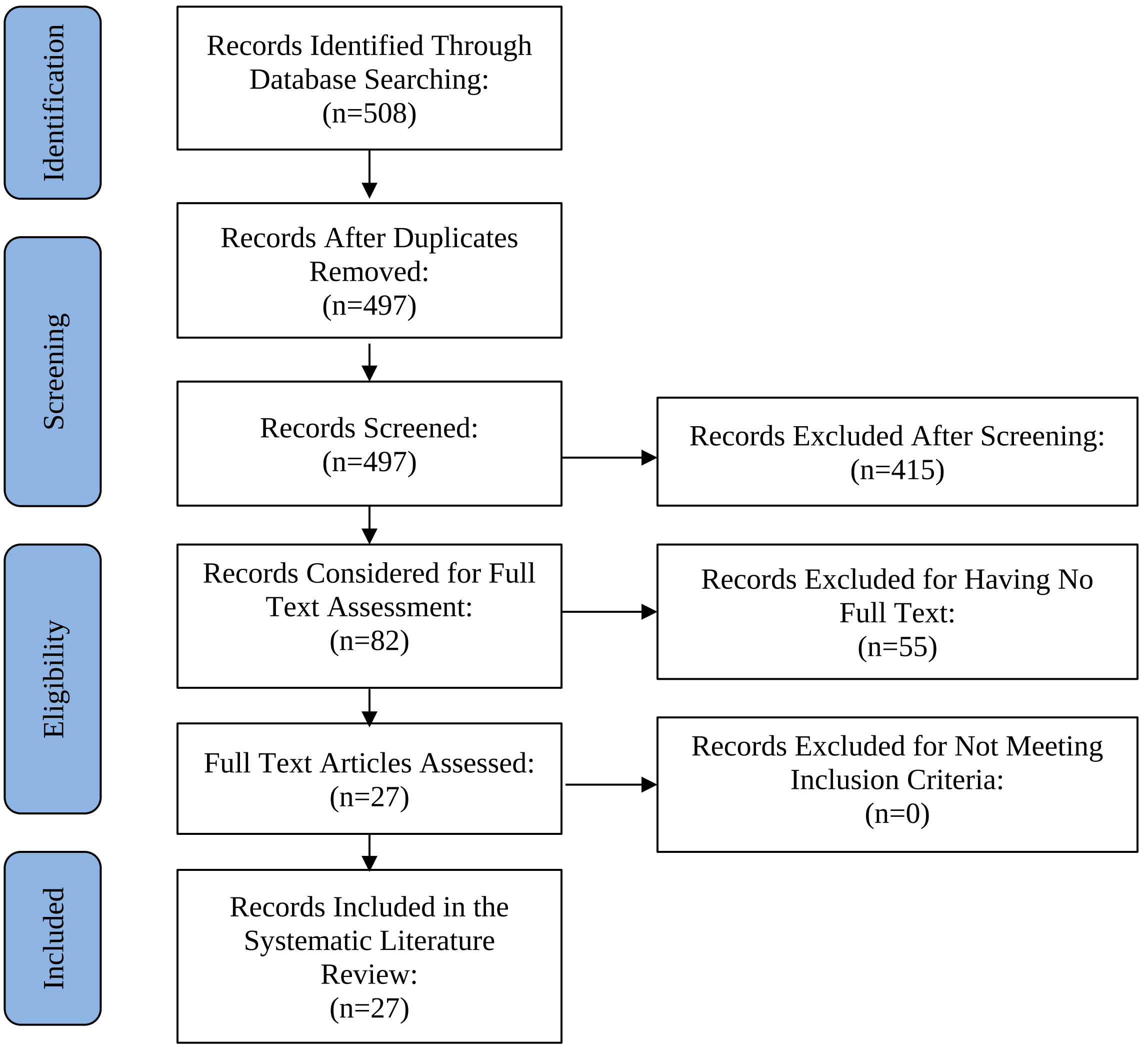

Figure 2.1 PRISMA flow diagram for the systematic literature review

2.2.3 Key Findings

2.2.3.1 Empirical Evidence

The literature search identified just one resource that provided direct empirical evidence about the relationship between corner radii and pedestrian safety. Taquechel (2009) obtained two years of pedestrian crash data for one area of downtown Atlanta, Georgia. The author then calculated a variety of street and intersection design characteristics and calculated "prevalence rates," representing the proportion of locations with each characteristic that had experienced a pedestrian crash during the two-year study period. Corner radius was one of the design variables investigated (among other factors, including traffic control type, transit stops, street width, one- vs. two-way, driveways, and sidewalk design).

Overall, 35% of intersections with a small radius corner (2–9.5 ft) experienced a pedestrian crash. The same prevalence rates were 30% for small/medium radii (9.5–14 ft), 46% for medium/large radii (14–20 ft), and 25% for intersections with large corner radii (20+ ft). Given the lack of an apparent trend, as well as the relatively small sample size (103 intersections, 18 crashes), the author concluded that the analysis was "indecisive" about the impacts of corner radius on pedestrian safety (Taquechel, 2009). This study's method also had limitations beyond just the sample size, since it did not perform any statistical analyses or try to control for multiple factors when investigating the association between corner radius and pedestrian crash occurrence.

2.2.3.2 Inferential Implications

Although empirical studies investigating relationships between curb/corner radii and pedestrian safety are rare, numerous factors associated with or linked to corner radius suggest that smaller radii are better for pedestrian safety. This section reviews and summarizes some of these factors—such as turning speed, crossing distance, and visibility—to present inferential implications about potential pedestrian safety effects related to corner radius.

The most important safety factor linked to curb/corner radius is motor vehicle turning speed. A larger corner radius (or effective corner radius, considering the presence of parked cars and the path that a vehicle travels when turning right) allows motor vehicles to turn at a higher rate of speed (ITE, 2021; ITE, 2010; Gattis & Watts, 1999; Johnson, 2005; Najm et al., 2003; Rodegerdts et al., 2004; UNC HSCR et al., 2013). Speed is related to pedestrian safety in two ways. First, when a vehicle impacts a pedestrian, energy is transferred (causing injury to the pedestrian) at a rate that increases quadratically with speed; doubling the speed quadruples the kinetic energy involved. So, when vehicles are turning at higher speeds, pedestrian injuries and crash severity are likely to increase. Second, a faster turning speed means less time for drivers (and pedestrians) to perceive a potential collision and react to it (Abdulhafedh, 2021; Buehler & Pucher, 2020; Zhang et al., 2015). So, there is less of an opportunity to take evasive action to avoid a vehicle–pedestrian collision. Conversely, smaller corner radii encourage drivers to slow down to make a right-turn, for the comfort of the driver and any passengers, which explains why smaller corner radii are theorized to lead to safer conditions for pedestrians (Ivan et. al., 2017).

Crossing distance has often been discussed as an important factor associated with pedestrian safety (ITE, 2010; UNC HSRC et al., 2013; Zhang et al., 2015). Shorter crossings decrease the distance and time pedestrians are exposed to potential conflicts with motor vehicles, thus improving pedestrian safety (Ivan et al., 2000). The link between crossing distance and corner radius is that smaller radii allow crosswalks to be slightly shorter. This is why some wide streets include pedestrian refuge islands to shorten and simplify crossings, and why curb extensions can also improve pedestrian safety (Buehler & Pucher, 2020; ITE, 2021; ITE, 2010; Rodegerdts et al., 2004).

The last prominent factor linked to corner radius is the visibility of pedestrians to vehicles (ITE, 2021; PROWAAC, 2007; UNC HSRC et al., 2013). Mutual awareness between pedestrians and drivers is a key factor in ensuring pedestrian safety at intersections. People need time to react when a collision is imminent, and even a few extra seconds can significantly change the safety outcomes for the road users involved in a conflict (Abdulhafedh, 2021; ITE, 2010; Ivan et al., 2017; Johnson, 2005; Johnsson et al., 2018; Rodegerdts et al., 2004). The link with corner radius is that smaller radii allow pedestrians to wait closer to the roadway where they may be more visible to drivers. A larger corner radius forces pedestrians back from the curb, away from where drivers may be waiting or looking, where pedestrians may be less visible amid plants, poles, and other street furniture.

2.2.3.3 Other Considerations

As described in the previous section, a smaller corner radius generally implies improved pedestrian safety through slower vehicle turning speeds, shorter pedestrian crossings, and greater sight distances for everyone involved (Dobbs, 2009; Gelinne et al., 2017; Nabors et al., 2007). However, there are a few additional considerations about the link between corner radii and pedestrian safety that may be worth briefly discussing.

One argument against shortening the corner radius is the effect it has on turns made by trucks and other large vehicles. Turning at intersections with smaller corner radii can be more difficult for these vehicles; in some cases, trucks may need to cross into opposing lanes. Some authors argue that this could lead to a hazardous situation when other vehicles are present in the opposing lane of traffic (McAndrews, 2010; Moshiri, 2020). However, the *Urban Street Design Guide* (NACTO, 2013) notes that "a large corner radius should not be used to facilitate a truck turning from the right lane into the right lane." Instead, stop bars for the opposing lane could be set back to prevent conflicts, or the corner can employ a mountable element (outside of the pedestrian waiting area) that trucks may slowly cross over but that restricts the turning speeds of smaller vehicles (NACTO, 2019).

Another argument against shorter corner radii is related to driver preferences and abilities. A preference survey conducted on drivers about corner radii indicated that most respondents were more comfortable at intersections with larger radii for the ease of navigation (Lynott et al., 2009). Another concern is older drivers' abilities to make sharper turns (Brewer et al., 2014). However, there are other studies that suggest drivers pay more attention and drive more cautiously when they are slightly uncomfortable with their environment, such as in shared spaces (Kaparias et al., 2012).

2.2.3.4 Surrogate Safety Measures

A major contributing factor to there being very little empirical evidence linking corner radii to pedestrian crashes is the nature of crash data itself. Crashes are rare events, and it may take years to have sufficient statistical evidence about pedestrian crashes at any given location. Furthermore, crash databases may not always specify precisely where within an intersection the crash occurred, or which directions the pedestrian and/or vehicle were traveling. This makes it difficult to link specific corners with crashes for use in statistical data analysis.

An alternative approach is to use what are called surrogate safety measures. These are easier to measure—they occur more frequently, or are collected in a different way—and are assumed (through logic and/or empirical evidence) to be closely linked to safety outcomes like crashes. By collecting more data faster, findings and recommendations can lead to more immediate safety improvements, rather than waiting for a crash history to develop. A common surrogate safety approach is to study conflicts, which are “near-misses” where a crash almost occurred or would have occurred within a few seconds if not for some evasive action taken by one of the road users involved. Several studies have measured pedestrian–vehicle conflicts at intersections; for example, to study the pedestrian safety effects of different types of pedestrian-related traffic signal phasing (Zhang et al., 2015; Ivan et al., 2017; Ivan et al., 2000). Often, conflict data is recorded on video, and conflicts are identified by their severity. For instance, Zhang et al. (2015) classified pedestrian–vehicle interactions into three conflict categories: “potential” conflicts involving an interaction but low likelihood of a collision; “minor” conflicts requiring some evasive action but taken with enough time; and “serious” conflicts involving late evasive action. Conflict severity is often measured through the shortness of time differences, such as time to collision (time until two road users would collide if no is action taken), and post-encroachment time (time between when two road users occupy the same space) (Ni et al., 2016).

2.2.4 Conclusions

There is a significant research gap in understanding the relationship of curb/corner radii and right-turning vehicles with overall pedestrian safety. The literature search only found a single study with empirical evidence directly related to the topic in the US, which failed to have a conclusive finding. Pedestrian crashes are rare and roadway geometry data are not always readily available to transportation agencies, which makes such studies challenging for researchers. However, transportation engineers mostly agree on three implications of smaller corner radii that are likely related to improved pedestrian safety:

- Slower turning speed, as the cars need to slow down more to make a tighter turn;
- Shorter crossing distance, which decreases pedestrians’ exposure; and

- Greater visibility, which allows pedestrians to wait closer to the intersection.

One way to avoid the limitations inherent in crash data for studying this topic is to measure conflicts and interactions between pedestrians and motor vehicle drivers instead, as these "conflicts" are more common than crashes and provide a larger amount of data to analyze.

When empirical research is done on the relationship between corner or curb radius and pedestrian safety, it is important to control for all of the other potential explanatory variables through rigorous study design, data collection, and multivariate statistical data analysis. Safety studies are challenging because of the variety of potential geometric design, transportation, and road network characteristics (skew angle, lane configurations, speed limits, and other features) of intersections. Complicating factors is that many of these characteristics can sometimes be related to corner radius. For instance, roads with more lanes, greater traffic volumes, and higher speeds may tend to have larger corner radii. It is important for empirical research to collect data at many different locations with varying geometric design features in order to yield useful results about the impact of curb/corner radii on pedestrian safety.

2.3 Literature Review on Bicycle Safety, Intersections, and Right Turns

2.3.1 Introduction

In recent years, traffic fatalities involving people bicycling have increased, with 857 fatalities in 2018 being the highest number since 1990 (NHTSA, 2020b). The US is falling behind: Other countries such as Germany, Denmark, the Netherlands, and the United Kingdom have been able to decrease bicycle fatalities over the same period (Buehler & Pucher, 2020). Beyond fatalities, bicycle injuries are not decreasing (NHTSA, 2020b), and bicycle crashes are underreported (Stutts, 1990, cited in Wang et al., 2017). In Utah in 2018, the leading vehicle maneuver for bicycle crashes was turning right (38%), while the leading contributing factor for drivers was failing to yield the right-of-way to cyclists (60%) (UDPS, 2020). These points call for greater effort and attention to safety measures for people bicycling—especially at intersections and involving right-turning vehicles—to ensure progress toward zero fatalities.

The goal of this literature review is to find and summarize studies on bicycle safety at intersections, with a focus on right-turning vehicles and design/operational factors such as curb/corner radii. By identifying relevant geometric designs or operational practices that traffic engineers can influence, this review can help to suggest intersection modifications that can reduce risks and improve safety outcomes for people bicycling.

The remainder of Section 2.3 is organized into three major subsections. The first subsection summarizes the literature search process. The second (largest) subsection summarizes key findings from the literature search, including research about the data used in various studies, and information about right-hook crashes, bicycle boxes, and corner radii. The third and final subsection summarizes conclusions and identifies important takeaways.

2.3.2 Literature Search

Literature was identified through keyword searches of relevant online research databases. Databases included Scopus, ScienceDirect, and Google Scholar. To filter for just articles related to bicycle safety, keywords included “bicycle crash,” “bicycle safety,” and “bicycle accidents.” Initially, the search also used keywords like “curb radii” or “curb radius,” but this returned too few results. Therefore, the research team expanded the search to be more generic, including keywords such as “geometric design,” “intersection,” etc. The search was conducted in September 2021.

Many initial search results focused on bicycling’s contribution to improving the health and safety of people and the environment, or about general trends in bicycle safety, rather than specific implications in the context of right turns at intersections. Therefore, the research team reviewed article titles and abstracts, and removed those results that were not relevant for this study. In the end, researchers found only a few studies that were relevant for understanding bicycle safety at intersections and right-turning motor vehicles. The next section reviews this research regarding the data used, and findings specific to right-hook crashes, bicycle boxes, and corner radii.

2.3.3 Key Findings

2.3.3.1 Types of Data

Research on bicycle safety can often be challenged by a lack of sufficient data. In most places in the US, bicycling is not as common as driving (in terms of trips, miles traveled, and hours in transit), so there are fewer occasions for unsafe behaviors to be observed. Data used to understand these issues can be classified into: (1) bicycle safety outcomes, and (2) factors affecting those outcomes, most notably exposure/volume and roadway attributes.

One of the most common outcome measures of bicycle safety is crashes recorded in local, state, or federal databases. For example, Cai et al. (2020) studied 159 intersections in Florida and 120 bicycle crashes that occurred at those intersections between 2010 and 2013. Using a random forest machine learning model to first select “important” variables influencing cyclist safety, they then estimated a regression model on intersection bicycle crash frequency. The authors found nine factors that had a significant impact on bicyclist safety: motor vehicle and bicycle volumes, bicycle lane and shared-use path characteristics, number of lanes to cross, and several land use variables (Cai et al., 2020). Nevertheless, one of the challenges of using crash data is that they are sparse. There are many locations with low frequencies, making it difficult to detect statistically significant associations of intersection characteristics with bicycle crash frequencies.

A different approach to measuring bicycle safety outcomes is through the use of surrogate safety measures, namely bicycle–motor vehicle conflicts. Conflicts are interactions between bicycles and motor vehicles in which a collision was narrowly avoided (a “near-miss”) through evasive action(s) taken by the motor vehicle driver and/or the person bicycling. Since conflicts happen much more frequently than collisions, they can avoid some of the issues with low frequencies of crashes; they are also a more proactive approach to the bicyclist safety issue. Two common surrogate safety measures used to detect conflicts are time to collision (TTC) and post-encroachment time (PET). TTC is the estimated time before two road users would collide if they maintained their current speed and trajectory. PET is the measured time difference between when two road users occupy the same space. Data for conflict analysis are typically collected through video recordings of traffic interactions. For example, Rostami et al. (2020) recorded 24 hours of video at 10 different intersections in California and identified 324 bicycle–motor vehicle interactions that could be considered to be conflicts. Presumably, conflicts or near-misses are directly related to crashes and other traditionally measured safety outcomes: The more conflicts, the more crashes are expected. However, this premise is still under investigation in the literature.

A variety of factors may affect the occurrence or likelihood of crashes between people bicycling and motor vehicle drivers. Prati et al. (2018) conducted a literature review on these factors contributing to bicycle–motor vehicle collisions and identified several types of contributing factors: road user behaviors, infrastructure characteristics, exposure, vehicles, and the environment. For example, within the category of road user behaviors, not following the traffic signal, failing to yield the right-of-way, and inattention (on the part of cyclist and/or driver) were commonly cited as causes of bicycle–motor vehicle crashes. Among infrastructure characteristics, more separation of bicycle facilities and the presence of medians seem to decrease collision risks, while arterials and higher-speed streets with more bus stops and driveways see increased bicycle collisions (Prati et al., 2018).

One key factor identified by Prati et al. (2018) was exposure: how much people bicycling are subjected to or exposed to potential risky situations. Exposure can be measured in different ways, but a quantity of cycling such as bicycle volumes on a street or at an intersection tends to be common. Although greater exposure leads to greater overall risk or more frequent bicycle crashes, the relationship appears to be non-linear. In fact, the probability of any one bicyclist being involved in a crash actually decreases as more people cycle in an area, a phenomenon known as “safety in numbers” (Jacobsen, 2003). The challenge with accounting for exposure in crash-based safety analysis is the general lack of bicycle volume data, due to few permanent counters. Therefore, many researchers have turned to crowdsourced data. Nelson et al. (2021) recently reviewed the literature on crowdsourced data for bicycle research, identifying how data from GPS-enabled smartphones and fitness apps can be used to measure ridership or crowdsourced online websites or social media campaigns can be used to self-report bicycle crashes or near-misses.

Strava Metro is one of the most commonly used sources of fitness-app data that has been used to help measure bicycle ridership for safety analyses. For example, Wang et al. (2017) and his team successfully used bicycle exposure from Strava data in their crash count regression models in order to develop bicycle safety performance functions for Seattle and Portland. In another example, Ferster et al. (2021) utilized Strava data in Ottawa to adjust bicycle crash frequencies by exposure, thus identifying new, higher-risk bicycle incident hotspots that could then be investigated for safety treatments. Despite these successes, Prati et al. (2018) also note that crowdsourced data must be used carefully. Because data, such as from Strava Metro, are only used by a portion of the cyclist community that has access to the technology that utilizes crowdsourcing, they may not be representative across populations or locations, a trait which may skew results.

2.3.3.2 Right-Hook Crashes

A "right-hook crash" is the common name for the situation or collision in which a person driving a motor vehicle turns right into the parallel path of a through-moving person riding a bicycle. Right-hook crashes are one of the most common types of bicycle–motor vehicle collisions at intersections (UNC HRSC et al., 2013). For example, Oregon experienced more than 500 bicycle right-hook crashes at signalized intersections (12% of all bicycle crashes) from 2007 to 2011 (Hurwitz et al., 2015). Most of these crashes were caused by drivers not seeing the bicyclist or failing to properly anticipate the behavior of bicyclist (Hurwitz et al., 2015; ITE, 2004). To overcome and understand the causality of right-hook crashes, various studies have been undertaken (Jannat et al., 2018; Subramanian et al., 2020; Warner et al., 2017), as summarized in the following paragraphs.

Jannat et al. (2018) used a driving simulator study to understand the effect of motorists' situational awareness on right-hook bicycle–motor vehicle crashes. The study revealed that motorists have a higher awareness of objects in front of them than objects in their peripheral vision. Therefore, motorists were significantly less aware of bicyclists (in the adjacent bike lane) approaching from behind than riding ahead. Motorist awareness was further compromised if an oncoming vehicle was turning left ahead of them. Failure to detect a rear-approaching bicycle was determined to be a common cause of right-hook crashes (Jannat et al., 2018).

One study by Warner et al. (2017) assessed the impact of four engineering treatments on right-hook bicycle crashes: signage, pavement markings, decrease in corner radius, and protected intersection designs. The inclusion of a “Turning Vehicles Yield to Bicycles” symbol sign increased motorists’ side mirror scanning time for bicyclists by 9% compared to the scenario with no signage. When the bicyclist was visible in the side-view mirror, scanning time increased by 10% when the sign was present versus the scenario with no signage. All tested pavement markings were found to improve drivers’ visual search and crash avoidance, with single- or double-dotted white bicycle lines with bicycle stencil having the greatest impact. The small corner radius treatment was found to increase crash avoidance behavior and decrease potential crash severity by decreasing mean vehicle velocity by 4% during moderate- to high-risk incidents. The relationship between protected intersection designs and crash avoidance behavior was unpredictable. However, the treatments generally decreased the frequency of high-risk time to collision (≤ 0.9 s) (Warner et al., 2017).

Another study (Subramanian et al., 2020) assessed bicyclists’ behaviors in response to vehicles making right-hook turns at intersections. Scenarios included unprotected (pavement marking only) and protected (using raised curbs and islands) bike lanes and both through and right-turning vehicles. The study concluded that the protected design—which offered a smaller effective corner radius—provided greater distance (and greater margin of safety) between bicyclists and turning vehicles compared to the unprotected design.

2.3.3.3 Bicycle Boxes

The “bicycle box” is one engineering countermeasure hypothesized to improve the safety and mobility of bicyclists at intersections. This is a designated area (often filled with green paint in the US) at the head of a travel lane at a signalized intersection, where bicyclists can filter and queue ahead of any potential right-turning motor vehicle traffic. Also referred to as an advanced stop box or advanced stop line in Europe, bike boxes have the potential to reduce motorist and bicycle collisions at intersections, including right-hook crashes. The design of the bicycle box intends to increase motorists’ visibility of bicyclists and helps drivers to anticipate bicyclists’ behavior by locating bicycles at the front of the queue during the red signal. This helps motorists to determine the possible area of conflict with bicycles at the intersection (Dill et al., 2012). Although the safety outcomes (both objective measures of crashes and subjective measures of comfort) of various on-street bicycle facilities and their configurations—including shared lane markings, type, and width of the facility, adjacent traffic, parking turnover rate, land use, etc.—have been extensively studied (Brady et al., 2011; Cai et al., 2021; Dill & Voros, 2007; Duthie et al., 2010; Harkey et al., 1998), research related to the effectiveness of bike boxes has received comparatively less attention in the US. However, a few studies have shed light on knowledge in this area.

A study by Loskorn et al. (2013) was done to understand the effect of bicycle boxes on the behavior of motorists and bicyclists in Austin, Texas. A bicycle box was found to encourage bicyclists to stop in front of motorists where they could be easily noticed. An increase in bicycle volume leaving the intersection before motorists was observed after the implementation of a bicycle box. Moreover, the use of green pavement markings significantly increased the percentage of bicyclists using the bicycle lane to approach the intersection (Loskorn et al., 2013).

The outcome from a study of bicycle boxes done in Portland, Oregon, (Dill et al., 2012) was similar to findings from the Austin study. A decrease in conflicts between motorists and bicyclists was observed, despite a simultaneous increase in the number of bicyclists and right-turning vehicles. Perception of the bicycle boxes by both motorists and bicyclists was higher compared to other studies. This might be due to the rate of bicycle usage in the city of Portland, which is comparatively higher than in other cities. Findings concerning the coloring of bicycle boxes were mixed. The authors assumed that the outcome may be varied due to variation of traffic, location, and road geometry characteristics. However, both motorists and cyclists preferred the use of bicycle boxes with colors due to increased visibility and safety at the crossings. As expected by the authors, motorists were significantly less likely to encroach the crosswalk when the bicycle box was present (Dill et al., 2012).

Conflicts have often been used as surrogate measures to evaluate and analyze safety at intersections (Madsen et al., 2021). One study analyzed the effects of bicycle boxes on conflicts between bicyclists and turning motorists in Denmark. The study concluded that the overall safety improvement provided by bicycle boxes was statistically insignificant. The study observed a 6% decrease in right-hook conflicts and a 12% increase in left-hook conflicts after the installation of a bicycle box. Moreover, locational variation in the results from seven sites across six municipalities in Denmark was observed, which demonstrated that the safety effect of bicycle boxes was not systematic (Madsen et al., 2021).

2.3.3.4 Curb/Corner Radii

Despite the above research on factors affecting bicycle crashes at intersections, little to no research has been identified as having analyzed the safety impacts of corner radius. Instead, corner radius most often appears in design guides with statements explaining why it is expected to have an impact on bicycle safety using deductive reasoning from other relationships with bicycle safety. In fact, these inferences and statements for bicycle safety are even less complete than they are for pedestrians, focusing almost solely on the impact of corner radius on turning vehicle speeds (Thomas & Levine, 2012): Smaller radii require right-turning vehicles to travel more slowly. Slower turns not only allow for more time to notice people bicycling, but they also are likely to yield less severe injury outcomes if a collision occurs. For example, bicycle and urban street design guidelines from the National Association of City Transportation Officials (NACTO) recommend corner radii of no more than 15 feet in urban areas in order to limit vehicle turning speeds to no more than 10 mph (NACTO, 2013, 2014, 2019). In another example, bike lanes to the right of a shared thru-right lane may actually lead to higher right-turning vehicle speeds, since the bike lane would increase the effective corner radius (ITE, 2010): the radius of the actual traveled path used by vehicles. The general lack of studies and mentions of curb/corner radius in relation to bicycle safety suggests that this is an important gap and research need.

2.3.4 Conclusions

To summarize, the biggest takeaway from this review of the literature on bicycle safety at intersections, focusing on corner radii and right-turning vehicles, is that there is very little research on this topic and that more research needs to be conducted. When empirical research is conducted on this topic, the collection and analysis of conflicts between people driving and people bicycling may be more fruitful than relying upon sparse data on reported bicycle–motor vehicle crashes. When needed, crowdsourced data can be a useful source of relative bicycle exposure, as long as researchers are aware of its limitations. In any case, many factors and different variables that can seriously impact bicyclist safety should be investigated, including those related to road user behaviors, vehicle and cyclist volumes, motor vehicle speeds, roadway design, intersection traffic control type, and locational characteristics.

Some research focusing on right-hook crashes or the safety effectiveness of bicycle boxes at intersections has relevance for an understanding of right-turn safety for people bicycling. Bicycle boxes were found to enhance safety effectiveness in places like Austin and Portland in the US but failed in Denmark, where bicycle commuters are significantly more common. Research findings about causation for right-hook crashes were predominantly associated with visual constraint of the motorist. Motorists failing to perceive bicyclists often did so due to factors such as distraction, blind spots, and the geometry of the intersection. Countermeasures such as signage, pavement markings (bike lanes and bicycle boxes), small corner radii, and islands in the intersections were found to significantly improve safety regarding right-hook crashes, by decreasing frequency and/or severity. Moreover, no significant difference was found for the safety effectiveness of pavement markings with solid green color versus simple dotted lines. However, motorists and bicyclists favored colored pavement due to its higher visibility. This discrepancy opens the door for the researchers to further investigate the safety effectiveness of bicycle facility coloring. Furthermore, gaps in the reviewed literature also suggest further study on the association of intersection design with vehicle encroachment on bicycle facilities and while making turns.

Unfortunately, with respect to curb/corner radius and bicycle safety, little to no research exists. While smaller corner radii should reduce motor vehicle turning speeds, thus yielding fewer and less severe bicycle collisions, this hypothesized relationship is deductive rather than empirical. Overall, there is a need to fill this gap with empirical research assessing how intersection operational and design factors, such as corner radius, may impact bicycle safety with right-turning vehicles.

2.4 Data Collection and Analysis Approach

The literature reviews inform the data collection and analysis approaches taken in this research project. The research team took a mixed-methods approach to understanding right-turn intersection safety for people walking and bicycling, by collecting and analyzing two different sets of data: crash and observational. These approaches are summarized in the following paragraphs, with many more details in later chapters.

The crash data analysis utilized reported crashes that occurred on Utah roadways at signalized intersections over a 10-year period from 2010 through 2019. Crashes involving people walking or bicycling were extracted, and crashes involving right-turning motor vehicles were further broken out. Other site characteristics about intersections—roadway geometry, traffic signal timing, land uses, and neighborhood built environment and sociodemographic characteristics—were also assembled. The analysis included descriptive statistics, univariate/bivariate comparisons, and multivariate regression models, comparing right-turn bicycle/pedestrian crashes to other (non-right-turn) bicycle/pedestrian crashes at intersections, and comparing factors associated with all vs. right-turn bicycle/pedestrian crash frequencies. Overall, the crash data analysis identified characteristics or situations for which right-turn crashes involving people walking and bicycling are over-/under-represented or more/less frequent. Together, this information will be useful for identifying a variety of potential countermeasures.

The observational data analysis utilized data collected through manual observations of recorded videos at a random selection of 34 Utah signalized intersections. Study locations were selected to ensure a wide variety of characteristics and situations, including variations in: corner radius, curb ramp type, bike lane presence, right-turn lane configuration, and intersection skew. More than 24 hours of videos were recorded at each study location, utilizing UDOT's traffic camera network. Trained observers then watched the videos and recorded information about road user behaviors, including: conflicts or near-misses between pedestrians and motor vehicles, pedestrian and vehicle characteristics, and pedestrian and vehicle behaviors. Finally, these data were compiled and statistically analyzed to identify trends, patterns, and associations of multiple outcomes (about road user conflicts and behaviors) with intersection design, operational, or locational characteristics. Analysis results will inform the recommended countermeasures to improve active transportation safety in right-turning situations.

2.5 Summary

This chapter presented literature reviews of research, methods, and results about pedestrian and bicycle safety in the context of corner radii and right-turning vehicles at intersections. It also briefly summarized the data collection and analysis approaches that are detailed in the following chapters.

3.0 DATA COLLECTION

3.1 Overview

This chapter contains detailed information about the data collection and assembly processes for the two sets of data: one for the crash data analysis, and another for the observational data analysis. First, for the crash data analysis, this chapter describes the collection of crash data and geospatial data as well as their assembly, along with descriptive statistics. Second, for the observational data analysis, this chapter describes the study location selection process, the collection of observational data regarding road user behaviors and conflicts, and the assembly of such information into a combined dataset (including descriptive statistics).

3.2 Data Collection for Crash Data Analysis

3.2.1 Crash Data Collection

First, data on all reported crashes involving people walking and bicycling in Utah from 2010 through 2019 were obtained from UDOT through the Numetric website (Numetric, n.d.). There was a total of 8,005 pedestrian-involved and 6,648 bicycle-involved crashes in the database. Data from 2020 and 2021 were excluded in order to avoid any potential influence of the COVID-19 pandemic. Each crash record contained information on temporal characteristics, spatial characteristics, contributing factors, crash severity, weather conditions, and crash participants. This information was extracted from police crash reports. No personally identifying information was included. Crash data are protected under 23 USC 409.

Second, pedestrian and bicycle crashes associated with signalized intersections were isolated. This process involved a series of heuristics based on information in the crash record (e.g., occurring at a “traffic control signal,” “intersection-related”) and spatial proximity to signals (i.e., the nearest intersection was a signal). Detailed information about these heuristics and processes can be found in other UDOT research project reports (Singleton, Mekker, & Islam, 2021; Singleton, Rahman, & Burbidge, 2022). This process identified a total of 2,939 (37%)

pedestrian and 2,332 (35%) bicycle crashes that occurred at or near (and related to) signalized intersections over the 10-year period.

Third, pedestrian and bicycle crashes at signalized intersections were further segmented by the movement of the motor vehicle at the time of the collision (as recorded in the crash report): turning right, turning left, or straight ahead. Overall, 1,035 (35%) of pedestrian crashes and 1,189 (51%) of bicycle crashes at signals involved a collision with a right-turning vehicle.

Finally, crashes were tabulated and the 10-year crash frequency by type (pedestrian vs. bicycle, right turn vs. left turn vs. straight thru) were calculated for each signalized intersection studied. At the time of the study, there were approximately 2,200 traffic signals in use across Utah. However, due to a lack of other data about the surrounding location (e.g., those geospatial data described in Section 3.2.2), several hundred signals (and several hundred crashes at those locations) were removed prior to some of the crash data analyses. Since the majority of locations and crashes remained in the dataset, this action should not have biased the results significantly.

3.2.2 Geospatial Data Collection

As previously mentioned, the crash data analysis required site characteristics to be collected and subsequently tested for associations with pedestrian and bicycle crash frequencies in regression models. As a result, intersection information—including roadway geometry, traffic signal timing, land uses, and neighborhood built environment and sociodemographic characteristics—were collected from existing geospatial databases and through manual data collection utilizing aerial and street-level imagery. As explained in the following subsections, these data were originally collected as part of other UDOT research projects (Singleton, Mekker, & Islam, 2021; Singleton, Park, & Lee, 2021).

3.2.2.1 Intersection Characteristics Obtained Through Manual Data Collection

Several potentially relevant intersection and road network characteristics were not available in existing geospatial databases, so they were collected manually utilizing aerial and street-level imagery. These characteristics were: intersection type, crossing distances, crosswalk marking types, the presence of "no RTOR" signs, the presence of a channelized right turn lane, and the presence of bike lanes and nearby bus stops along the roads approaching and leaving the intersections. The following paragraphs briefly summarize these signal characteristics and how their attributes were obtained. For more information, please see a different UDOT report (Singleton, Mekker, & Islam, 2021).

Intersection type is the number or configuration of legs (approaches) that join to form an intersection. Signals with more legs or approaches may be less safe for people walking/bicycling than intersections with fewer legs/approaches, due to greater opportunities for exposure and conflicts and increased intersection complexity. Such complexity may also make it more difficult for motor vehicle operators to process sidewalks or bike lanes where pedestrians/cyclists may be present, thus potentially leading to different yielding behaviors or conflict rates. The vast majority of Utah signals are 4-leg intersections, but there are also 3- and 5-leg intersections with signals. Mid-block signals or pedestrian hybrid beacons (also known as high-intensity activated crosswalks or HAWK signals) are present in the dataset. Also, a few Utah signals are located at single-point urban interchanges or diverging diamond interchanges.

Pedestrians, bicyclists, and drivers may behave differently at intersections with shorter or longer **crossing distances**. Crossing lengths were calculated in Google Earth, measuring the curb-to-curb distance along the center of the crosswalk. The average crosswalk length at Utah signals was 82 ft, reflecting both the location of many signals along multi-lane arterials as well as the fact that Utah city streets are generally wider than elsewhere in the US (Smith, 2015).

While major variations in conflicts or behaviors due to different **crosswalk marking** types were not expected, it could be that certain crosswalk markings are more/less visible to drivers. The nomenclature of marked crosswalks varies across jurisdictions, but a common typology is shown in Figure 3.1. Some agencies may give crosswalks with longitudinal markings different names (e.g., high-visibility crosswalks) or use them in certain typical situations (e.g., at school crossings). In Utah, most crosswalks at signals have standard markings; continental markings are reserved for school zones (UDOT, 2011).

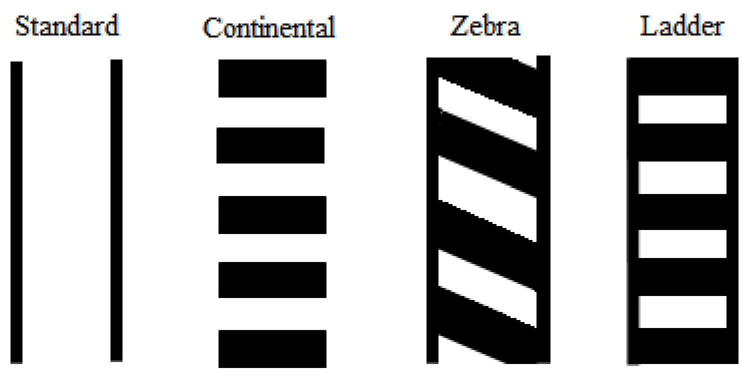

Figure 3.1 Crosswalk marking types

Right-turn geometries and operations are likely to affect pedestrian, cyclist, and driver behaviors, thus affecting conflicts and yielding (and ultimately safety). **Channelized right turns** allow easier movements for right-turning vehicles, which may lead to faster turning speeds but perhaps improved visibility between drivers and pedestrians. Bicycle safety may be improved by shifting a turning conflict at the intersection to a merging conflict in advance of the intersection. At a few intersections, **RTOR** are prohibited in order to improve pedestrian safety. It seems likely that prohibiting RTOR might reduce pedestrian conflicts with right-turning motor vehicles, although conflicts could instead shift from the Red (Don't Walk) interval to the Green (Walk) interval. It is unclear how RTOR prohibitions might affect bicycle right-turn safety.

Several other intersection/roadway characteristics were collected in order to test whether or not they were significantly associated with pedestrian/bicycle safety at signals. The presence of **bike lanes** (of any type) as well as the presence of a **transit stop** on the portion of each leg approaching/leaving the intersection were identified and recorded. This allowed the research team to identify inbound and outbound bike lanes as well as near-side and far-side bus stops.

3.2.2.2 Other Geospatial Data

Several other signalized intersection attributes relevant for the study of factors affecting pedestrian and bicycle crashes and conflicts with right-turning motor vehicles were obtained from existing databases, including: motor vehicle traffic volumes, transportation system characteristics, land use and built environment data, and sociodemographic characteristics. When appropriate, these data were calculated for the area within a quarter-mile of each intersection. The assembly of each of these types of data is described in the paragraphs below. For more detailed information, please see different UDOT research reports (Singleton, Park, & Lee, 2021; Singleton, Rahman, & Burbidge, 2022).

Where available, annual average daily traffic (AADT) volumes and heavy truck percentages for the approaches to the intersections were obtained from UDOT traffic statistics databases. Other data obtained from UDOT geographic information systems (GIS) databases included the number of thru and turn lanes, speed limit, grade, etc. Some of these data were only available for signals on state highways. Annual average daily pedestrian (AADP) traffic volumes were estimated from pedestrian push-button data (Singleton, Runa, & Humagain, 2000), while proxy measures of annual average daily bicycle (AADB) traffic were taken from Strava Metro bicycle trip data (Singleton, Rahman, & Burbidge, 2022).

Additional information about land use, built environment, and neighborhood sociodemographic characteristics near each signal was obtained from a variety of sources and processed. Each variable was calculated for a quarter-mile street network-based buffer around each signalized intersection. The percentages of different types of land use (residential, commercial, industrial, and vacant) around each signal were calculated from parcel-level land use maps obtained from the Utah Geospatial Resource Center (UGRC) website. Population and employment density variables were calculated using block group-level data from the 2013-2017 American Community Survey (ACS) and the 2017 Longitudinal Employer Household Dynamics (LEHD) datasets, respectively. Using similar data from UGRC, the acreage of parks and number of schools and places of worship within a quarter-mile network distance of each signal were also calculated. Intersection density (a measure of connectivity) was also calculated from information about the location of road and street intersections, also from UGRC. Sociodemographic characteristics of nearby neighborhoods were calculated using the same quarter-mile network buffers around each signal. Specifically, 2013-2017 ACS data from the US Census were used to obtain information about median household income, average vehicle ownership, mean household size, percentage of the population with a disability, and percentage of population of Hispanic or non-white race/ethnicity.

3.2.3 Data Assembly

As previously mentioned in Section 2.4, the crash data analysis included descriptive statistics, univariate/bivariate comparisons, and multivariate regression models, comparing right-turn bicycle/pedestrian crashes to other (non-right-turn) bicycle/pedestrian crashes at intersections. In order to estimate the multivariate regression models, the crash frequency data collected in Section 3.2.1 and the geospatial data about signals collected in Section 3.2.2 were merged together, using their common signal ID fields. The resulting combined dataset included, for each signal, information about 10-year total (and right-turn only) pedestrian and bicycle crashes, as well as other intersection and neighborhood characteristics.

Descriptive statistics of the relevant variables in this combined dataset are shown in Table 3.1 for the pedestrian crash frequency data and Table 3.2 for the bicycle crash frequency data.

Table 3.1 Descriptive statistics for pedestrian crash data at signals (*N* = 1,606)

Variable	*Min.*	*Max.*	*Mean*	*Std. Dev.*
Dependent variable, frequency model				
# of pedestrian-involved crashes	0	23	1.62	2.32
Measures of exposure				
AADP, estimated	0.16	6,737	269.95	572.78
AADT in major direction ($AADT_{MAJ}$)	450	186,000	23,312	12,901
AADT in minor direction ($AADT_{MIN}$)	0	57,000	8,565	7,789
Transportation characteristics				
Presence of overhead street lighting	0	1	0.97	0.16
Intersection type				
2-leg (mid-block)	0	1	0.00	0.06
3-leg	0	1	0.09	0.29
4-leg	0	1	0.87	0.33
5-leg	0	1	0.00	0.04
DDI	0	1	0.00	0.07
SPUI	0	1	0.02	0.14
# crosswalks, total	0	4	3.45	0.96
# crosswalks with standard markings	0	4	3.14	1.17
# crosswalks with continental markings	0	4	0.27	0.71
# crosswalks with ladder, zebra, or other markings	0	3	0.01	0.11
# crosswalks with continental, ladder, or zebra markings	0	4	0.29	0.72
Crosswalk length (mean, ft)	20	185	81.83	19.89
# approaches with no pedestrian crossing	0	4	0.44	0.83
# approaches with no RTOR	0	1	0.01	0.12
# approaches with channelized right turns	0	4	0.20	0.69
# approaches with bike lanes	0	4	0.59	1.03
# of bus stops within 300 ft of intersection	0	6	0.93	1.18
# approaches with near-side bus stops	0	4	0.31	0.60
# approaches with far-side bus stops	0	4	0.62	0.89
Intersection density (# per mi^2) [a]	6.07	313.17	97.66	49.12
Land use and built environment characteristics [a]				
% land use residential	0	84	31	23.51
% land use commercial	0	92	28	20.75
% land use industrial	0	83	2.41	10.51
% land use vacant	0	100	4.54	8.74
Population density (1,000 per mi^2)	0.08	23.51	4.51	3.02
Employment density (1,000 per mi^2)	0.02	216.03	7.30	11.51
Park area (acre)	0	37.15	1.45	3.61
# of schools	0	5	0.31	0.61
# of places of worship	0	6	0.51	0.78
Sociodemographic characteristics [a]				
Household income (median, $1,000)	20.5	144.61	61.33	21.87
Vehicle ownership (mean)	0.55	3.00	1.81	0.45
Household size (mean)	1.41	13.72	3.11	0.85
% of the population with a disability	2.51	27.06	10.64	4.12
% of the population of Hispanic or non-white race/ethnicity	0.00	75.66	17.26	13.50

[a] These variables were measured using a quarter-mile network buffer.

Table 3.2 Descriptive statistics for bicycle crash data at signals (*N* = 2,232)

Variable	*Min.*	*Max.*	*Mean*	*Std. Dev.*
Dependent variable, frequency model				
# of bicycle-involved crashes	0	15	1.03	1.58
Measures of exposure				
AADB, Strava	0.014	94.44	6.37	7.96
$AADT_{MAJ}$	10	130,000	21,380	12,075
$AADT_{MIN}$	0	57,000	7,095	7,553
Transportation characteristics				
Presence of overhead street lighting	0	1	0.93	0.25
Intersection type				
2-leg (mid-block)	0	1	0.05	0.21
3-leg	0	1	0.13	0.34
4-leg	0	1	0.79	0.40
5-leg	0	1	0.00	0.04
DDI	0	1	0.00	0.07
SPUI	0	1	0.02	0.14
# crosswalks, total	0	4	3.10	1.27
# crosswalks with standard markings	0	4	2.72	1.46
# crosswalks with continental markings	0	4	0.31	0.73
# crosswalks with ladder, zebra, or other markings	0	3	0.03	0.24
# crosswalks with continental, ladder, or zebra markings	0	4	0.34	0.77
Crosswalk length (mean, ft)	20	185	78.98	20.08
# approaches with no pedestrian crossing	0	4	0.67	1.11
# approaches with no RTOR	0	2	0.01	0.12
# approaches with channelized right turns	0	4	0.19	0.67
# approaches with bike lanes	0	4	0.60	1.05
# of bus stops within 300 ft of intersection	0	6	0.83	1.14
# approaches with near-side bus stops	0	4	0.58	1.02
# approaches with far-side bus stops	0	4	0.58	1.02
Intersection density (# per mi^2) [a]	6.07	313.17	95.20	49.35
Land use and built environment characteristics [a]				
% land use residential	0	84	31	23.76
% land use commercial	0	92	28	20.93
% land use industrial	0	83	2.82	10.45
% land use vacant	0	100	5.49	11.29
Population density (1,000 per mi^2)	0.02	23.44	4.49	3.02
Employment density (1,000 per mi^2)	0.02	216.03	7.70	13
Park area (acre)	0	37.15	1.50	3.65
# of schools	0	5	0.28	0.59
# of places of worship	0	6	0.48	0.78
Sociodemographic characteristics [a]				
Household income (median, $1,000)	15.71	144.61	62.78	22.59
Vehicle ownership (mean)	0.39	2.99	1.73	0.45
Household size (mean)	1.39	13.72	3.13	0.87
% of the population with a disability	2.41	27.06	10.35	4.15
% of the population of Hispanic or non-white race/ethnicity	0.00	75.66	17.37	13.78

[a] These variables were measured using a quarter-mile network buffer.

3.3 Data Collection for Observational Data Analysis

3.3.1 Study Location Selection

In order to collect and analyze observational data at a variety of locations with varying site characteristics, study locations had to be carefully selected. The selection of study locations involved several steps. First, Utah signals were filtered to only keep those with UDOT traffic cameras (the means of recording videos to collect observational data) and with sufficient pedestrian activity (in order to capture some potential conflicts with right-turning vehicles). A lower threshold of 12+ average daily pedestrians was used, calculated using estimates from pedestrian push-button traffic signal data (Singleton, Runa, & Humagain, 2020). While it would have been desirable to have used a similar kind of threshold to ensure sufficient bicycle activity, existing available data sources (like Strava Metro data) may be biased towards recreational bicyclists; also, due to cost constraints for data collection, the research team decided to collect bicycle events from the same videos where pedestrian events were collected. The hope was that a sufficient number of bicycle events could be identified from videos at these locations. (As is mentioned later, bicycle lane presence was one of the site selection criteria.) Overall, this filtering process for 709 signals with cameras and 1,498 signals with sufficient pedestrian activity yielded a total of 525 signals that fulfilled both criteria.

Second, information about these potential study locations was collected from a variety of sources, including existing UDOT and other GIS databases, work from prior UDOT research projects, and using satellite and street-view imagery. This information included, for each intersection and each corner at the intersection:

- Intersection and lane configurations
    - The presence of skewed approaches.
    - The number of shared and/or dedicated right-turn lanes.
    - The number of dedicated receiving lanes.
    - The presence of a channelized right turn.
    - The presence of a bicycle lane.
    - The location of the bicycle lane with respect to a right-turn lane (left or right of it).

- Corner layouts
    - The corner radius in feet.
    - The number and type of curb ramps: blended, diagonal, or directional.
    - The crosswalk offset distance (the distance from the outside edge of the right-most lane to the nearest line of the parallel crosswalk), as a measure of the *sideways distance* a right-turning motor vehicle would travel before reaching the crosswalk. See Figure 3.2 for examples.
    - The stop-bar distance (the distance from the stop bar to the start of the parallel crosswalk), as a measure of the *forward distance* a right-turning vehicle would travel before reaching the crosswalk. See Figure 3.2 for examples.
    - The presence of a curb extension.
- Intersection operations
    - Whether or not RTOR was prohibited.
    - Motor vehicle traffic volumes (AADT) on the major roadway.
    - Pedestrian activity, as measured by estimated AADP crossing volumes (Singleton, Runa, & Humagain, 2020).
    - Bicycle activity, as measured by AADB intersection volumes obtained from Strava Metro data (Singleton, Rahman, & Burbidge, 2022).
    - The speed limit on the faster-moving roadway.

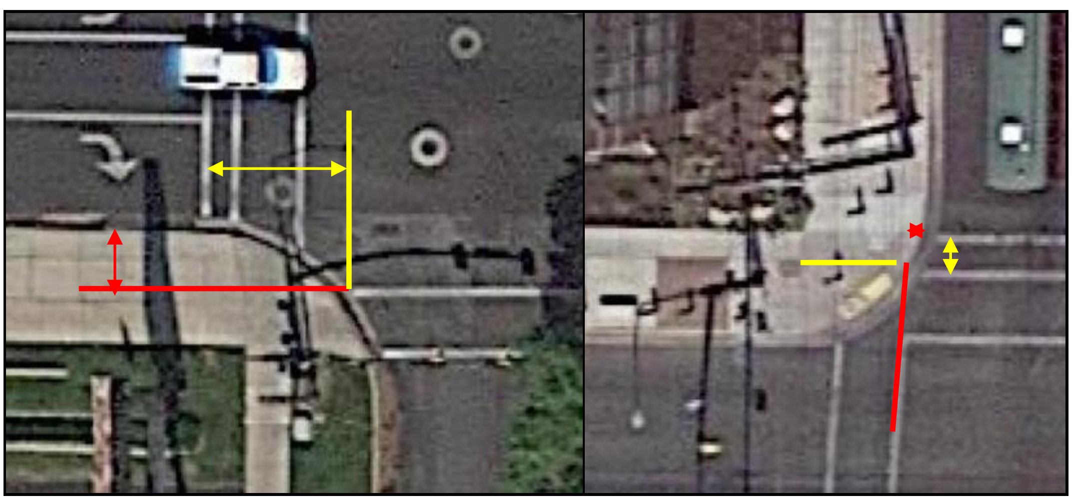

Figure 3.2 Example measurements of corner layouts

(red = crosswalk offset distance, yellow = stop-bar distance)

Third, this information was used to randomly select candidate signals for potential inclusion in the list of study locations. Because a purely random selection of signals from the list of 525 possible sites might yield too few observations for certain less-common attributes or levels, it was decided to randomly sample five locations at a time from locations with specific characteristics. These "preferred attributes" were: large and small corner radii (≤ 15 ft, > 45 ft), blended or directional curb ramps, bike lanes to the left and right of the right-turn lane, shared thru-right and dual right-turn lanes, dedicated receiving lanes, channelized right turn lanes, skewed intersections, curb extensions, and prohibited RTOR. This ensured at least some proposed locations having variations in these geometric and operational characteristics. Also, by randomly selecting locations using these criteria one by one, intersections with the more-common attributes were naturally included.

After performing this random selection and filtering for duplicates, 58 unique signals were chosen as candidate study locations. Unfortunately, due to lack of camera connectivity, construction, and data collection resource limitations, not all of these locations were able to be studied. When a location was determined to be not available, a nearby location with as similar characteristics as possible replaced it. Of the 58 proposed locations, the research team was able to collect data at 25 of them, but not at 33 other locations. Instead, these were replaced with nine additional study locations, for a total of 34 signalized intersections included in the observational analysis, listed in Table 3.3 and mapped in Figure 3.3 and Figure 3.4. The table includes 36 rows, since two different corners were studied at two signals, but only one corner at the other 32 signals.

Table 3.3 List of observational study locations

Signal	***Street E/W***	***Street N/S***	***City***	***Corner***	***Right-turn***
1225	800 S	1300 E / Leopard Ln	Salt Lake City	Southwest	Eastbound
1229	2100 S	1300 E	Salt Lake City	Northwest	Southbound
4522	Grizzlies Blvd / 3100 S	Decker Lake Dr	West Valley City	Southwest	Eastbound
5030	12th St (SR-39)	Washington Blvd (US-89)	Ogden	Northwest	Southbound
5042	12th St (SR-39)	Wall Ave (SR-204)	Ogden	Northeast	Westbound
5093	4800 S	1900 W (SR-126)	Roy	Southeast	Northbound
5139	US-89 (Harrisville Rd)	Wall Ave (SR-204) / Larsen Ln	Harrisville	South	Northbound
5144	4000 S (SR-37)	Midland Dr (SR-108)	Roy	Northwest	Southbound
5205	Shepard Ln	S-89 NB	Farmington	Southeast	Northbound
5306	400 N (US-89)	Main St (US-89/91)	Logan	Southeast	Northbound
5345	Center St	Redwood Rd (SR-68)	North Salt Lake	Northwest	Southbound
5347	2600 S (SR-93)	I-15 NB	Woods Cross	Northeast	Westbound
6046	Canyon Rd (SR-198)	1100 E	Spanish Fork	Southwest	Eastbound
6093	Timpanogos Hwy (SR-92)	1200 E / Micron	Lehi	Southeast	Northbound
6190	Pleasant Grove Blvd	North County Blvd (SR-129)	Pleasant Grove	West	Southeast-bound
6310	Center St	I-15 SB	Orem	Northwest	Southbound
6390	1600 N / 600 S (SR-241)	Geneva Rd (SR-114)	Lindon, Orem	Southeast	Northbound
6398	800 N (SR-52)	1200 W	Orem	Southwest	Eastbound
6407	Center St	University Ave (US-189)	Provo	Southwest	Eastbound
7067	9000 S (SR-209)	Bangerter Hwy (SR-154) NB	West Jordan	Northeast	Westbound
7067	9000 S (SR-209)	Bangerter Hwy (SR-154) SB	West Jordan	Northwest	Southbound
7070	3300 S (SR-171)	I-15 SB	South Salt Lake	Northwest	Southbound
7084	700 N	Redwood Rd (SR-68)	Salt Lake City	Northeast	Westbound
7089	I-80 EB	Redwood Rd (SR-68)	Salt Lake City	Southeast	Northbound
7122	600 N (SR-268)	300 W (US-89)	Salt Lake City	Southwest	Eastbound
7184	900 S	700 E (SR-71)	Salt Lake City	Northeast	Westbound
7211	Van Winkle Expwy (SR-152)	900 E (SR-71)	Murray	Northwest	Southbound
7215	6200 S	Highland Dr / Van Winkle Expwy (SR-152)	Holladay	Southwest	Eastbound
7234	8200 S / Sugar Factory Rd	Redwood Rd (SR-68)	West Jordan	Southeast	Northbound
7252	500 S (SR-269)	Main St	Salt Lake City	Northeast	Westbound
7289	3500 S (SR-171)	Decker Lake Dr / 2200 W	West Valley City	Northeast	Westbound
7355	13800 S	Bangerter Hwy	Draper	Northeast	Westbound
7391	14400 S (SR-140)	Redwood Rd (SR-68)	Bluffdale	Northeast	Westbound
7391	14400 S (SR-140)	Redwood Rd (SR-68)	Bluffdale	Southeast	Northbound
8102	500 N	Bluff St (SR-18)	St. George	Southeast	Northbound
8304	300 S	Main St (US-191)	Moab	Southwest	Eastbound

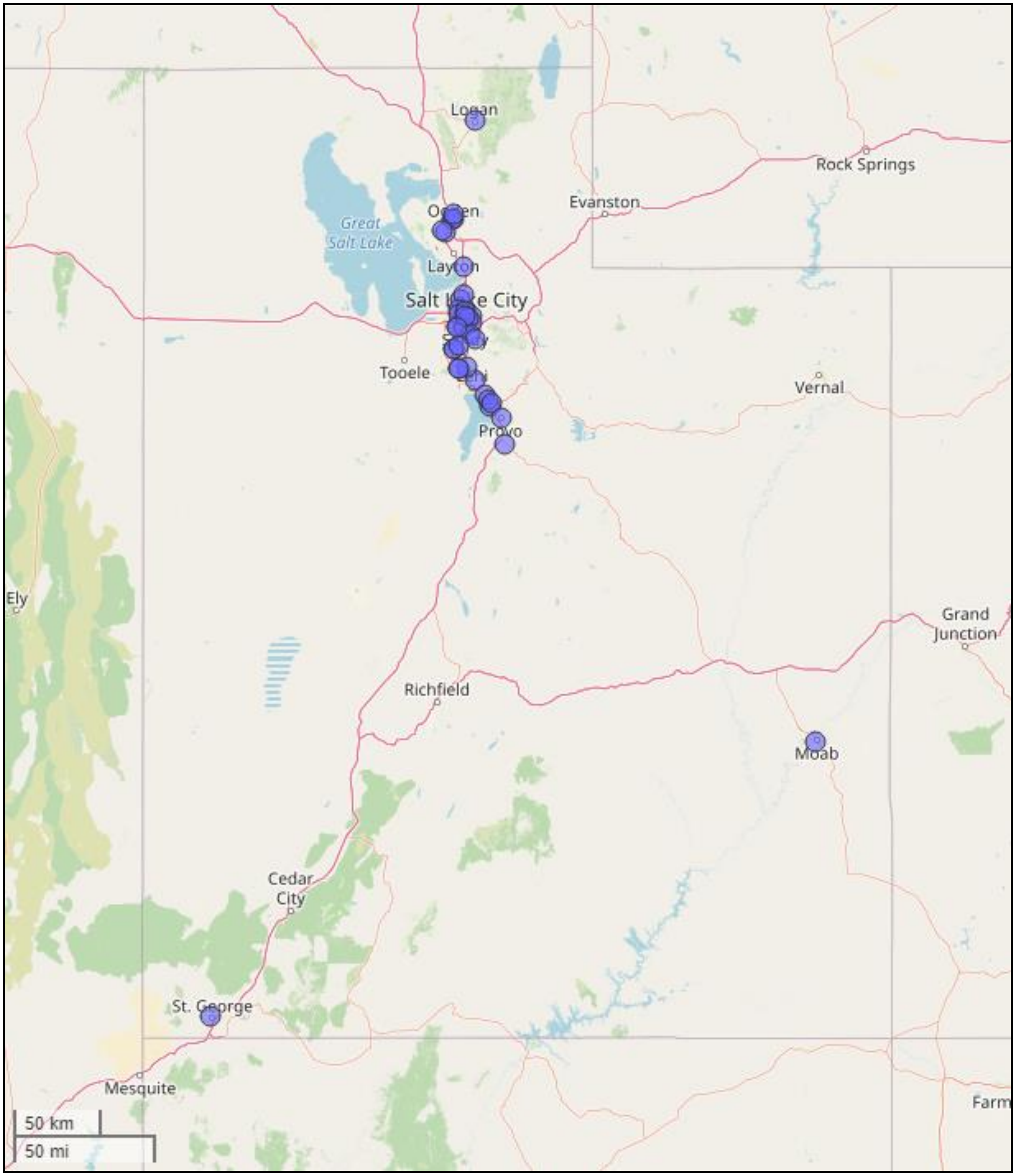

Figure 3.3 Map (Utah) of observational study locations

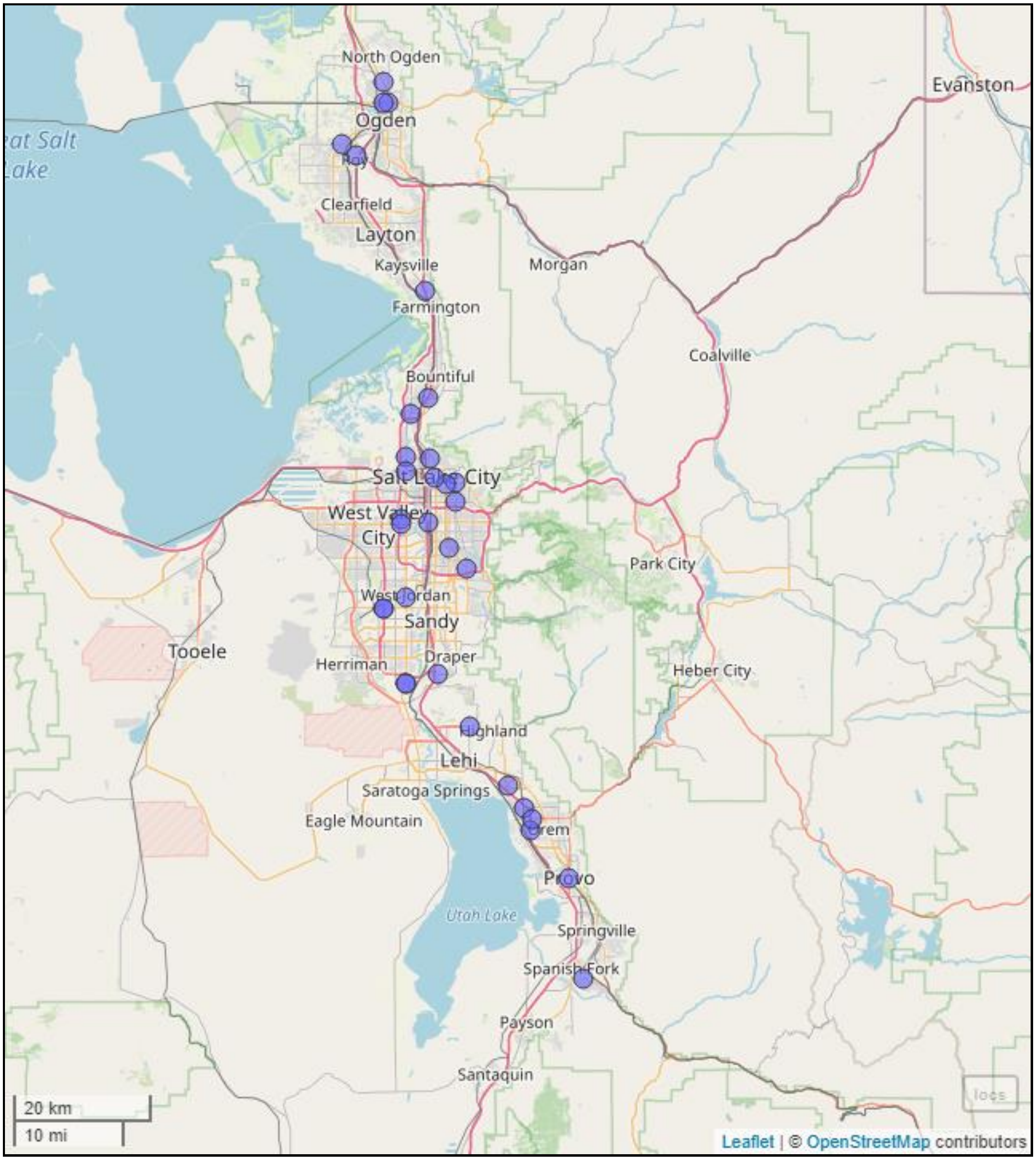

Figure 3.4 Map (Wasatch Front) of observational study locations

3.3.2 Observational Data Collection

For each study location, several hours of live video were recorded using a direct connection to UDOT's traffic camera network. The specific number of hours recorded at each location varied (minimum 28.1, median 31.8, mean 33.5, maximum 41.0), but was at least one full day in order to capture a sufficient sample of conflicts between right-turning motor vehicles and people walking and bicycling at each site. Videos were oriented to point towards one particular corner of the intersection with a view sufficient to see approaching vehicles, bicycles, and pedestrians; see Figure 3.5 for an example. Videos were recorded between September 2021 and June 2022, with the majority of videos being recorded in November 2021 and May/June 2022. All locations were studied during weekdays (Monday–Friday); no data was collected on weekends (Saturday, Sunday).

Figure 3.5 Example screenshot of video

Once videos were recorded, trained observers then watched the videos and recorded information about road user behaviors and conflicts. To maximize consistency, observers had to attend a training event and complete an example hour of data collection (that was checked) before they could start collecting data for real. Most trained observers were undergraduate students. After data collection was finished, a trained graduate student checked the collected data, including doing spot checks of individual records by comparing against a re-watch of the video, as well as broader scans (and automatic checks) for missing records and inconsistent responses. While the research team hopes that most errors were identified and corrected, some errors may remain in the final dataset.

Data were collected using a custom standardized interface linked to online spreadsheets (Google Forms) to reduce coding issues and ensure changes and data were saved automatically. Trained observers were instructed to fill out the form once for every time a pedestrian crossed the street using one of the two crossings seen in the video. Early in the data collection process, the researchers decided to only collect pedestrian crossing events and pedestrian conflicts using this data form. Whenever a person bicycling was observed, the timestamp was recorded for later follow-up data collection. As noted later, unfortunately there were not enough bicyclists and bicycle conflicts observed in the dataset to allow for an observational analysis, so no detailed data collection form was used to collect similar information about bicyclists and bicycle conflicts. Data collectors did consider people bicycling on the sidewalk or in the crosswalk as “pedestrians” and did collect information about those bicycling events.

When collecting the data from the video, there were several key words used that were defined for observers during a pre-data collection training event. For most videos, pedestrians were able to cross using two crosswalks. These were termed the “first crosswalk” and the “second crosswalk” based on which would be encountered first by a right-turning vehicle. For each crosswalk, the conflict point (again named “first” or “second” to correspond with the appropriate crosswalk) was the location where the pedestrian path and the right-turning motor vehicle path meet. Usually, this is at the intersection of the center of the crosswalk and the center of the right-turn lane or subsequent lane being turned into. However, if the pedestrian and/or vehicle took a different path, then the conflict point is where their paths met. For each event, timestamps were recorded to note when the pedestrian and the vehicle were at this conflict point. An example figure from the training materials depicting the meaning of these terms is shown in Figure 3.6.

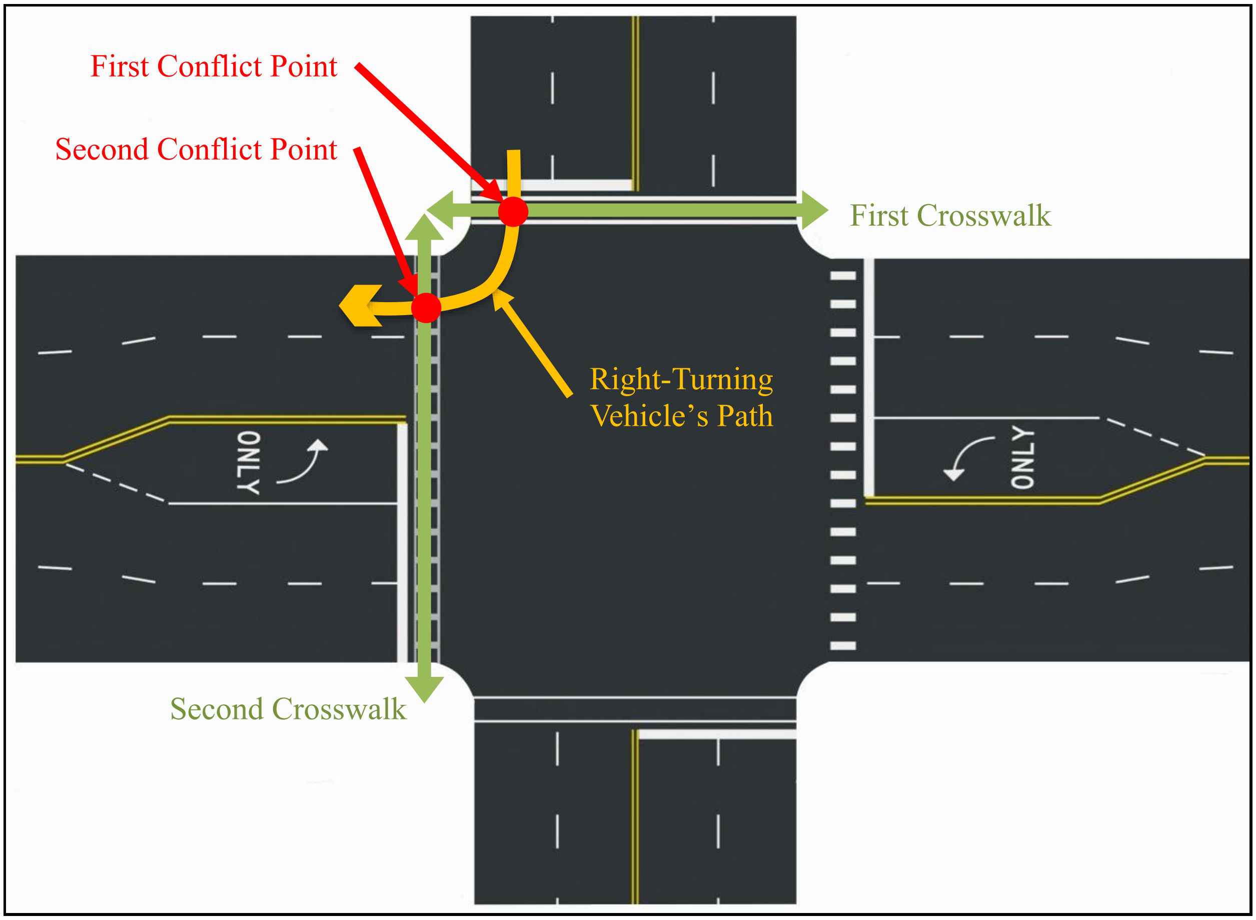

Figure 3.6 Crosswalks and conflict points from training materials

The Google Form was divided into three main sections, each described in more detail in the following paragraphs: general information, pedestrian information, and vehicle information.

3.3.2.1 Section 1: General Information

The first section about general information was filled out every time a pedestrian was observed. This section included questions about:

- Initials of the person doing the data collection.
- Signal ID number of the intersection.
- Date of the video (shown in a timestamp).
- Current weather shown in the video: clear, rain, snow, or other.

At the end of the survey, there was a final section giving data collectors an opportunity to enter any additional information about the conflict in open-text format.

3.3.2.2 Section 2: Pedestrian Information

The second section about pedestrian information was also filled out every time a pedestrian was observed. This section included questions about:

- Group size (number of pedestrians traveling together).
- Age of the pedestrian(s) (select all that apply): child, teenager, young adult, middle-aged adult, older adult, adult of unknown age.
- Gender of the pedestrian(s) (select all that apply): male, female, unknown gender.
- Other characteristics (select all that apply): carrying load, stroller, wheelchair, skateboard, scooter, bicycle, distracted, other.
- Crossing location: in the crosswalk or the crosswalk area, mid-block away from the crosswalk, in the middle of the intersection, other.
- Crossing direction: approaching curb, leaving curb.
- Time when the pedestrian reached the right-turn conflict point (timestamp).
- Right-turn queue length (number of vehicles waiting to turn right) when pedestrian was at conflict point: 0, 1, 2, 3, 4, 5+.

While most of this information could be consistently and objectively recorded, age and gender were more difficult to ascertain, given the view and quality of the video. Trained observers were instructed to make their best guess, but some inaccuracies or inconsistencies in the data for these fields could have happened. This section concluded with an open text response question for anything else that was noted about the pedestrian(s).

3.3.2.3 Section 3: Vehicle Information

The third section about vehicle information was repeated up to four times. It was only filled out if one or more motor vehicles were observed to be passing the conflict point within ten seconds of the pedestrian passing the conflict point (or before the pedestrian reaches the curb, whichever happened first). Up to two vehicles passing the conflict point in the ten seconds before a pedestrian was present, and up to two vehicles in the ten seconds after, were recorded. If no vehicles met these criteria, this section was skipped. The ten seconds was used as the threshold for a possible pedestrian–vehicle conflict. This section included questions about:

- Vehicle stopping location: did not stop, before the first crosswalk, inside the first crosswalk, between the first and second crosswalk, inside the second crosswalk, other
- Time when the front of the vehicle reached the right-turn conflict point (timestamp)
- Any driver reaction to the conflict: no obvious reaction, driver fully stopped, driver slowed down, driver sped up, driver swerved, other
- Any pedestrian reaction to the conflict: no obvious reaction, pedestrian stopped and waited for the vehicle, pedestrian ran to avoid a collision, pedestrian slowed down to avoid a collision, pedestrian changed direction, other
- Vehicle type: large truck (semi-truck, delivery truck, etc.), van (minivan, sprinter van, etc.), sport utility vehicle (SUV), sedan, bus, pickup truck, vehicle pulling a trailer, motorcycle, other

Similarly, some of these questions were more subjective than others, such as the questions about driver and pedestrian reactions. Trained observers were instructed to make their best assessment of these reactions. To aid in the determination of vehicle type, example images were provided, as shown in Figure 3.7. This section also concluded with an open text response question for anything else that was noted about the vehicle or the conflict. Again, this section was repeated for each of up to four vehicles observed within ten seconds of the pedestrian.

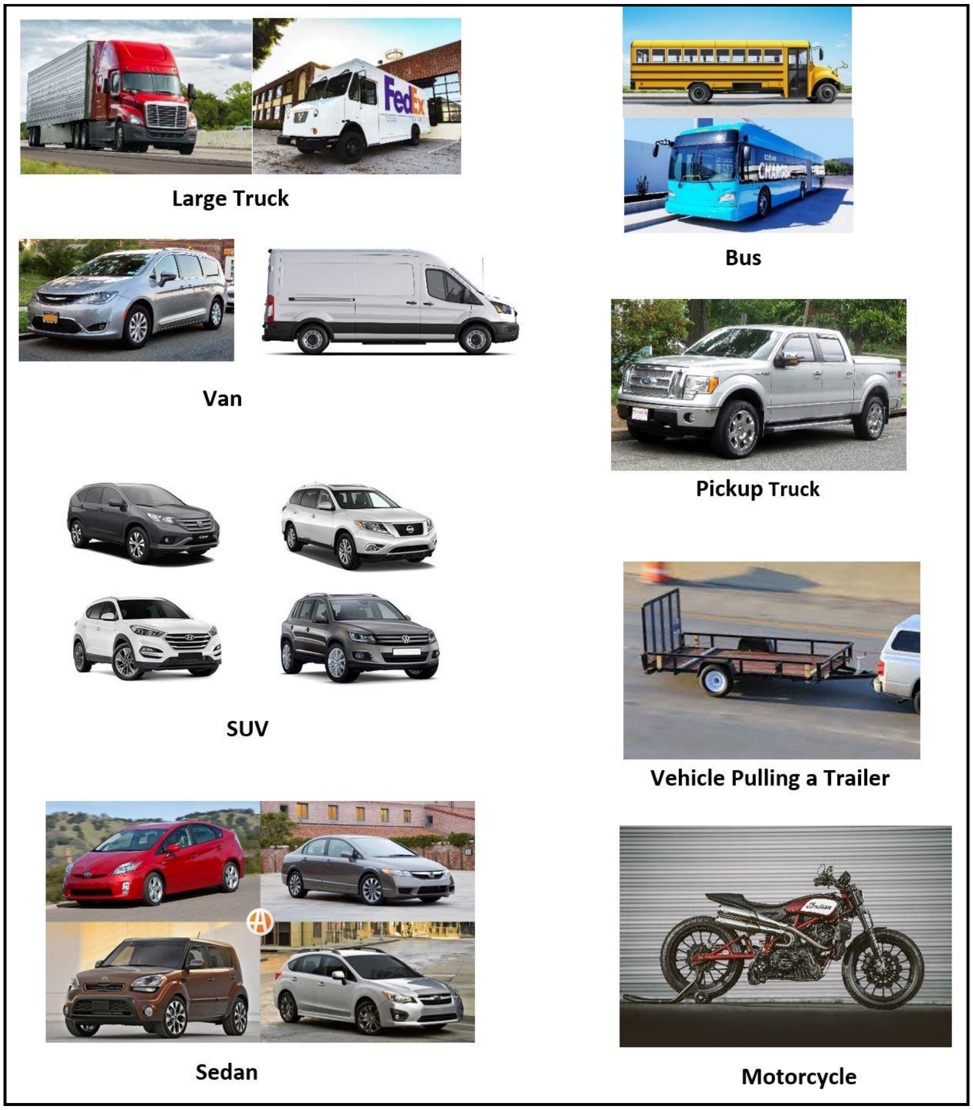

Figure 3.7 Examples of vehicle types

3.3.3 Data Assembly

As previously mentioned, after trained undergraduate students collected observational data about pedestrians and potential pedestrian-vehicle conflicts from the videos, these data were inspected and cleaned by a trained graduate student. Using custom scripts written in the open-source statistical program R, these data were then combined and converted into datasets in wide and long formats. The wide format dataset had each form entry as one row, with a total of 4,198 pedestrian crossing events observed. However, not all of these events had a potential vehicle conflict, and some events had multiple (up to four) potential vehicle conflicts. Therefore, the long format dataset had each combined pedestrian-vehicle conflict information as one row, with a total of 1,683 potential pedestrian-vehicle conflicts observed. Since this study focused on conflicts with right-turning vehicles, the long format dataset was used for all subsequent analyses.

While data collectors were obtaining information about pedestrians and conflicts with right-turning vehicles, they also recorded instances when they observed people riding a bicycle on the street, in a bike lane or a general-purpose travel lane. (Recall, people riding bicycles in the crosswalk were recorded as pedestrians.) The goal was to watch those bicycle events in more detail and extract similar observational data about potential bicycle-vehicle conflicts. Unfortunately, an insufficient number of bicycle events was recorded: only 494 in total. Assuming a similar crossing-event-to-conflict rate as was observed for pedestrians (1,683 potential conflicts ÷ 4,198 crossing events = 40.1%), there might have only been around 200 potential conflicts between right-turning vehicles and people bicycling. Furthermore, only two locations had more than 50 bicycle events (estimated around 20 conflicts), while 50% of locations saw fewer than ten bicycle events from the videos. The research team concluded that, unfortunately, there was insufficient data to estimate a model about bicycle-vehicle conflicts, let alone examine the impact of any locational characteristics like geometric design.

After cleaning, the research team calculated some new variables from other information in the dataset. The most important of these was encroachment time, defined as the time difference between when the pedestrian and the vehicle were at the conflict point. Recall the earlier discussion about how these timestamps were collected, and (from the literature review) the importance of PET as a surrogate safety measure in defining the severity of a potential conflict. Since some vehicles passed the conflict point before the pedestrian while others passed afterwards, multiple encroachment time variables were calculated:

- *Encroachment time* (ET) is simply the absolute value of the time difference between when the pedestrian and vehicle were at the conflict point. It was always non-negative and ranged from zero to ten seconds. (Because the timestamp of the videos had only a one-second resolution, an ET of "zero" just means that there was less than one second between when the two road users were at the same location. This was the case for only ten of 1,640 events (0.6%).)

- *Pre-encroachment time* (pre-ET) is the ET for situations when the vehicle passed the conflict point before the pedestrian did. This was valid for 628 (38.3%) of the events. See the top panel of Figure 3.8.
- *Post-encroachment time* (post-ET) is the ET for situations when the pedestrian crossed the conflict point before the vehicle did. This happened in 1,002 (61.1%) of the events. See the bottom panel of Figure 3.8.
- *Conflict severity* is a categorization of the encroachment time into time bins, informed by the literature (e.g., Rostami et al., 2020). An event with an ET of 0-3 seconds was considered to be a "high" severity conflict, anything with 4-5 seconds was a "mild" severity conflict, and events with 6-10 seconds ET were "low" severity conflicts. This resulted in a fairly even breakdown of conflict severity levels in the dataset: 20.6% (338) were high, 31.0% (508) were mild, and 48.4% (794) were low severity; see Figure 3.9.

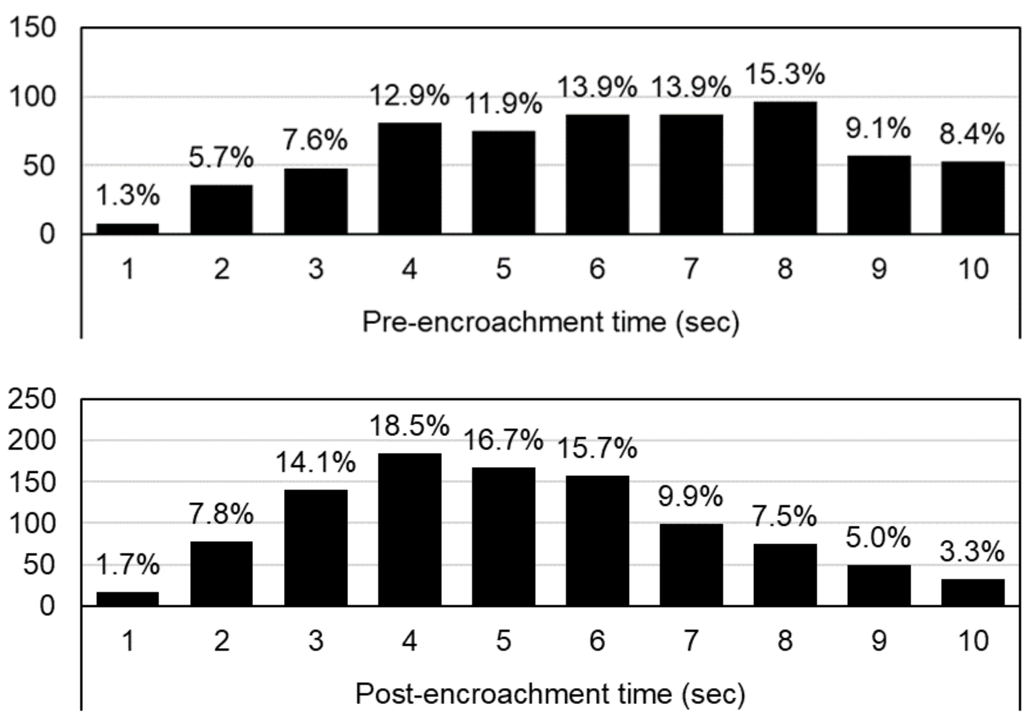

Figure 3.8 Distributions of pre- and post-encroachment times

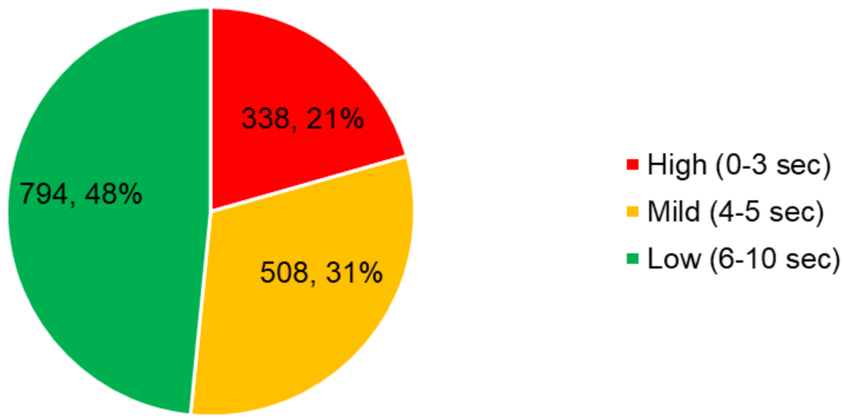

Figure 3.9 Distribution of conflict severity

Next, the research team assembled and linked several other datasets with the pedestrian-vehicle conflict observational data. Linkages were made using common fields, such as signal ID, corner location, and timestamp. Specific data joined are described in more detail in the following paragraphs.

First, researchers added information about the pedestrian and right-turning vehicle traffic signal statuses at the times when the pedestrian and vehicle were at the conflict point. Taking high-resolution traffic signal controller log data from the Automated Traffic Signal Performance Measures (ATSPM) system, and identifying the appropriate phase numbers (for a given signal ID and timestamps), an R script with custom functions was applied to extract the status of the pedestrian signal indication (walk, flashing don't walk, steady don't walk) for when the pedestrian was at the conflict point, and the status of the motor vehicle signal indication that controlled the right-turn movement (green, yellow, red) for when the vehicle was at the conflict point. It should be noted that some (five) of the right turns and pedestrian crossings studied were not signalized. In these situations, rather than discarding the data, dummy variables were included in the analyses to examine if signalization had a significant association with various outcomes of interest (such as encroachment time or conflict severity).

Second, the research team added information about the corner, intersection, and neighborhood attributes for each study location. Much of this information about corner and intersection characteristics had already been collected during the study location selection phase of the project (see Section 3.3.1), but it was verified again and edited as necessary to match the conditions as present during the video recording. Other information about land use, built environment, and sociodemographic neighborhood characteristics had already been assembled for the crash data collection part of the project (see Section 3.2.2). All of this information was linked to the long observational dataset using common fields of signal ID and corner location.

The following tables and figures summarize the final assembled dataset. Table 3.4 presents descriptive statistics for the 1,640 events containing a potential pedestrian-vehicle conflict, including variables about pedestrian characteristics, driver and vehicle characteristics, conflict information, weather information, and traffic signal status information. Figure 3.10 shows the temporal distribution of conflicts. Figure 3.11 presents other characteristics of pedestrians and conflicts. Table 3.5 contains descriptive statistics for the 34 locations contained in the final dataset, including information about corner, intersection, and neighborhood attributes. The numbers of events and locations in the final combined dataset are less than in the original datasets (mentioned earlier) because of missing data for a few events and/or locations.

Table 3.4 Descriptive statistics for pedestrian events with potential conflicts (*N* = 1,640)

Variable	*#*	*%*	*Mean*	*SD*
Pedestrian characteristics				
Group size (# people)			1.58	3.55
Natural log of group size			0.19	0.48
Age				
Child or teenager	298	18.2		
Child	37	2.3		
Teenager	273	16.6		
Adult	1372	83.7		
Young adult	586	35.7		
Middle-aged adult	536	32.7		
Older adult (65+)	42	2.6		
Adult of unknown age	229	14.0		
Gender				
Male	1046	63.8		
Female	495	30.2		
Unknown gender	252	15.4		
Other characteristics				
Carrying load	62	3.8		
Stroller or wheelchair	16	1.0		
Stroller	12	0.7		
Wheelchair	4	0.2		
Skateboard or scooter	85	5.2		
Skateboard	36	2.2		
Scooter	51	3.1		

Bicycle	246	15.0		
Distracted (phone, headphones, conversations, etc.)	73	4.5		
Crosswalk				
First crosswalk	346	21.1		
Second crosswalk	1294	78.9		
Crossing location				
In the crosswalk or the crosswalk area	1593	97.1		
Away from the crosswalk	47	2.9		
Mid-block, away from the crosswalk	34	2.1		
In the middle of the intersection	13	0.8		
Crossing direction				
Leaving curb	1028	62.7		
Approaching curb	612	37.3		
Pedestrian reaction				
No obvious reaction	1424	86.8		
Stopped or slowed	130	7.9		
Stopped and waited for the vehicle	111	6.8		
Slowed down to avoid collision	19	1.2		
Other reaction	86	5.2		
Sped up to avoid collision	40	2.4		
Ran to avoid collision	24	1.5		
Changed direction	22	1.3		
Driver and vehicle characteristics				
Right-turn queue length (# vehicles)			1.70	1.64
Stopping location				
Did not stop	1035	63.1		
Before the first crosswalk	296	18.0		
Inside/between the crosswalks	309	18.8		
Inside the first crosswalk	222	13.5		
Between the first and second crosswalks	87	5.3		
Inside the second crosswalk	0	0.0		
Driver reaction				
No obvious reaction	835	50.9		
Stopped or slowed	725	44.2		
Driver fully stopped	327	19.9		
Driver slowed down	398	24.3		
Other reaction	80	4.9		
Driver sped up	75	4.6		
Driver swerved	5	0.3		
Vehicle type				
Small	651	39.7		
Sedan	646	39.4		
Motorcycle	5	0.3		
Medium	920	56.1		
SUV	545	33.2		
Pickup truck	262	16.0		
Van (minivan, sprinter van, etc.)	113	6.9		
Large	69	4.2		
Large truck (semi-truck, delivery truck, etc.)	27	1.6		
Vehicle pulling a trailer	25	1.5		
Bus	17	1.0		
Conflict information				
Encroachment time (sec)			5.52	2.30
Pre-ET (sec), vehicle before pedestrian			6.15	2.34
Post-ET (sec), vehicle after pedestrian			5.18	2.13
Conflict severity				

Low (5-10 sec)	794	48.4		
Mild (4-5 sec)	508	31.0		
High (0-3 sec)	338	20.6		
Weather and time information				
Weather				
Clear	1604	97.8		
Rain (actively raining, or wet roadways)	36	2.2		
Snow (actively snowing, or snow on the roads)	0	0.0		
Hourly precipitation (in)			0.00	0.00
0.01 in or more	37	2.3		
Temperature (°F)			60.13	15.85
Less than 50°F	618	37.7		
50–64°F	369	22.5		
65–79°F	495	30.2		
80°F or more	158	9.6		
Day of week				
Weekday (Mon, Fri)	515	31.4		
Weekday (Tue, Wed, Thu)	1125	68.6		
Weekend (Sat, Sun)	0	0.0		
Time-of-day				
Morning (06:00–11:59)	522	31.8		
Afternoon (12:00–17:59)	872	53.2		
Evening/overnight (18:00–05:59)	246	15.0		
AM peak hours (07:00–08:59)	168	10.2		
PM peak hours (16:00–17:59)	335	20.4		
Traffic signal status information				
Pedestrian signal status, pedestrian at conflict point				
Walk	748	45.6		
Flashing don't walk	515	31.4		
Steady don't walk	228	13.9		
Crossing not signalized	148	9.0		
Right-turn vehicle signal status, vehicle at conflict point				
Green	1063	64.8		
Yellow	45	2.7		
Red	384	23.4		
Right-turn not signalized	148	9.0		

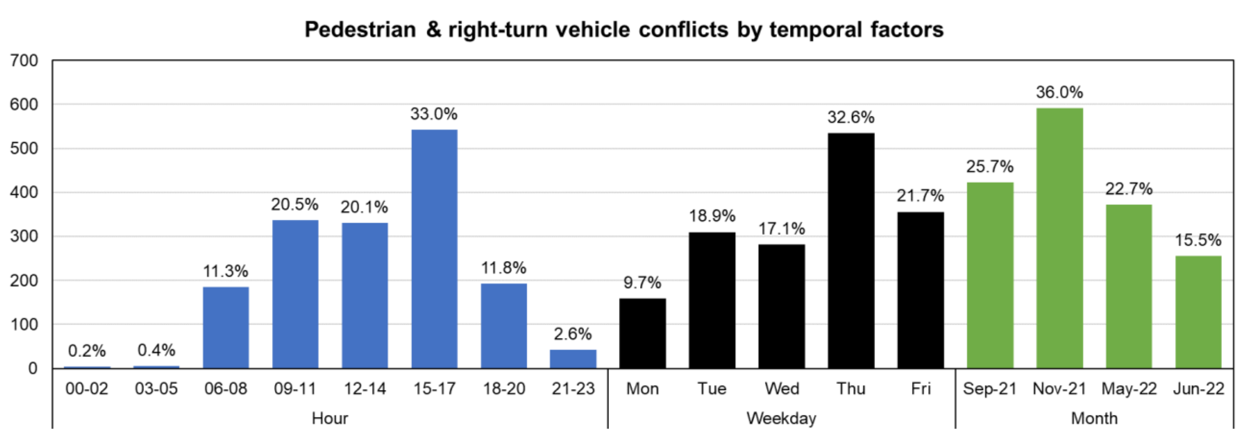

Figure 3.10 Temporal distributions of pedestrian-vehicle conflicts

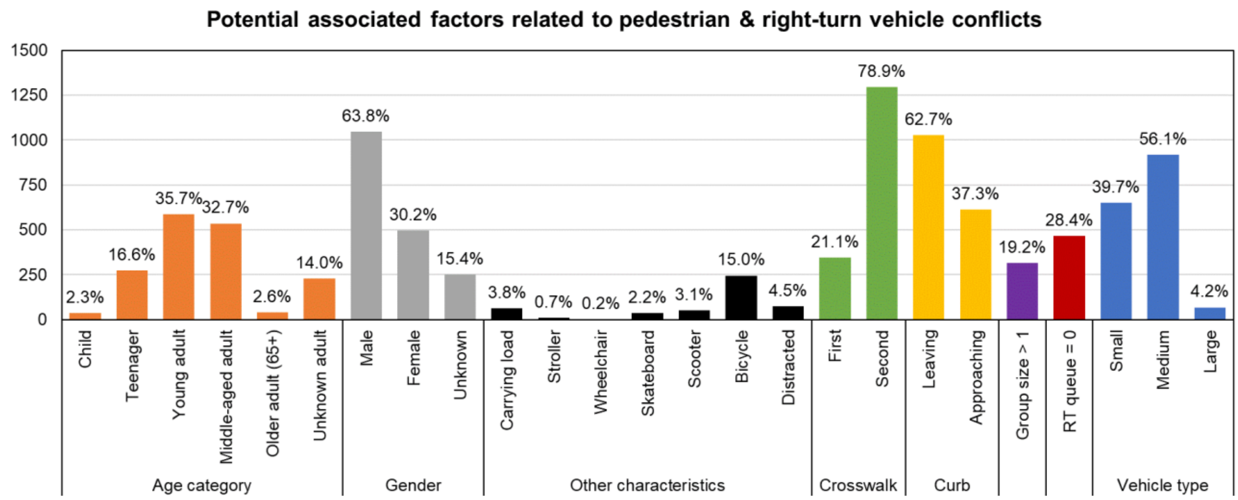

Figure 3.11 Characteristics of pedestrians and pedestrian-vehicle conflicts

Table 3.5 Descriptive statistics for right turns/corners at signals (*N* = 34)

Variable	*#*	*%*	*Mean*	*SD*
Corner and intersection attributes				
Corner radius (ft)			41.09	19.03
Crosswalk offset distance (ft) [a]			7.53	10.32
Channelized right turn (distance not available)	8	23.5		
Stop bar distance (ft) [b]			7.56	12.78
Channelized right turn (distance not available)	8	23.5		
Curb ramps (#)			1.06	0.24
1	32	94.1		
2	2	5.9		
Curb ramp type				
Diagonal (apex)	22	64.7		
Directional	10	29.4		
Blended transition	2	5.9		
First crosswalk type				
Standard markings	27	79.4		
Continental (high-visibility) markings	2	5.9		
No crossing	5	14.7		
Second crosswalk type				
Standard markings	25	73.5		
Continental (high-visibility) markings	3	8.8		
No crossing	6	17.6		
Right-turn lanes (#)			0.94	0.40
0.5 (shared thru-right lane)	10	29.4		
1	21	61.8		
2	3	8.8		
Receiving lanes (#)			0.18	0.39
0	28	82.4		
1	6	17.6		
Channelized right turn	8	23.5		
Skewed intersection	11	32.4		
Curb extension	0	0.0		

Prohibited RTOR	0	0.0		
Presence of street lighting	34	100.0		
Presence of bicycle lane	6	17.6		
AADP (100s)			4.04	6.86
Natural log of AADP			4.99	1.42
AADT (1000s)			26.63	22.85
Natural log of AADT			10.01	0.55
Right turn/crossing not signalized	5	14.7		
On-ramp	3	8.8		
Off-ramp	4	11.8		
Neighborhood attributes [c]				
Population density (1,000 people per mi^2)			4.52	2.46
Employment density (1,000 jobs per mi^2)			7.35	8.04
Land use				
Residential (%)			28.03	21.01
Commercial (%)			32.55	17.04
Industrial (%)			1.75	5.80
Vacant (%)			2.70	4.26
Other (%)			12.31	11.65
Street intersection density (# per mi^2)			87.82	41.34
4-way intersections (%)			32.01	24.04
Transit stops (#)			4.79	3.71
Places of worship (#)			0.45	0.67
Schools (#)			0.18	0.46
Park (acres)			2.10	4.11
Household income (median, $1,000s)			63.40	23.69
Vehicle ownership (mean, cars/household)			1.75	0.43
Household size (mean, people/household)			3.08	0.58

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.

3.4 Summary

This chapter presented details about the processes of data collection and assembly. Pedestrian and bicycle crash data at traffic signals were joined with geospatial data from various sources, for use in the crash data analysis. For the observational data analysis, study locations were selected, videos were recorded, and observations of road user behaviors and conflicts were extracted and merged with other data sources. Analysis methods and results using these data are presented in the following chapter.

4.0 DATA ANALYSIS

4.1 Overview

This chapter presents the results of the crash data analysis and the observational data analysis. First, for the crash data analysis, univariate/bivariate comparisons using chi-square tests are presented, followed by the results of multivariate models utilizing zero-inflated negative binomial regression. Overall, the crash data analysis identifies characteristics or situations for which right-turn crashes involving people walking and bicycling are over- or under-represented and/or more or less frequent. Second, for the observational data analysis, analysis methods are summarized, followed by the results of correlations and multilevel regression models on encroachment time, conflict severity, pedestrian reaction and crossing location, and vehicle driver reaction and stopping location. Overall, the observational data analysis identifies factors (positively or negatively) associated with pedestrian-vehicle conflicts and these other pedestrian and vehicle driver behaviors.

4.2 Crash Data Analysis

4.2.1 Univariate/Bivariate Comparisons

The first analysis of the crash data investigated univariate and bivariate comparisons of right-turn bicycle/pedestrian crashes to other (non-right-turn) bicycle/pedestrian crashes at intersections. Overall, the aim was to identify characteristics or situations for which crashes involving right-turning motor vehicles and people walking and bicycling are over-/under-represented. Such characteristics or situations might indicate a safety issue specific to these right-turn crashes.

To do this, the research team first calculated the percentage of right-turn pedestrian and bicycle crashes that exhibited certain characteristics, and then compared this to the same percentage for non-right-turn crashes (i.e., crashes involving a left-turn or straight-ahead motor vehicle movement). Statistically, this was done using multiple Pearson's chi-squared tests, which compare observed frequencies to what would be expected under a null hypothesis of a set of equal proportions. In these situations, comparisons were among observed frequencies O_{ij} within a cross-tabulation of two categorical variables—right-turn vs. non-right-turn crash, and with vs. without characteristic—where the expected frequencies E_{ij} assumed no relationship between the categorical variables (expected cell values are proportional to row and column totals R_i and C_j), according to the following equation:

$$X^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}}$$

where $E_{ij} = R_i C_j / n$ and X^2 follows the χ^2 distribution with $df = (r-1)(c-1)$. For this study, $r = 2$ and $c = 2$, so $df = 1$. A "statistically-significant" X^2 value ($p < 0.05$) would suggest that the two categorical variables are not independent and that there appears to be an association between right-turn crashes and this characteristic. These calculations were done for left-turn and straight-ahead crashes too, and for a variety of characteristics.

For example, of the overall 2,742 pedestrian crashes, 1,017 (37.1%) involved right-turning motor vehicles, while 1,725 (62.9%) did not (they involved left-turn and straight-ahead vehicle movements). Among right-turn crashes, 65 (6.4%) were fatal or serious injury and 952 (93.6%) were not. Among non-right-turn crashes, 300 (17.4%) were fatal or serious injury and 1,425 (82.6%) were not. In total, there were 365 (13.3%) fatal or serious injury crashes and 2,377 (86.7%) less severe or no-injury crashes. Expected cell frequencies (Table 4.1) are calculated using the row and column percentages, for example: 2,742 total × 37.1% right turn × 13.3% fatal/serious = 135.4 expected right-turn fatal/serious injury crashes.

Table 4.1 Example chi-square test calculation

	Observed			***Expected***		
Crash severity	***RT***	***SA/LT***	***Total***	***RT***	***SA/LT***	***Total***
Fatal or serious injury	65	300	365	135.4	229.6	365.0
Not fatal or serious injury	952	1,425	2,377	881.6	1,495.4	2,377.0
Total	1,017	1,725	2,742	1,017.0	1,725.0	2,742.0

Comparing observed to expected frequencies yields a $X^2(df = 1)$ value of 66.14, which is statistically significant ($p < 0.001$). Thus, one can conclude that the right-turn 6.4% fatal/serious injury crash proportion is statistically significantly different from the non-right-turn

17.4% proportion. In other words, right-turn crashes involving pedestrians tend to be less severe than left-turn and straight-ahead crashes involving pedestrians.

Table 4.2 shows the results of the chi-square comparisons for pedestrian crashes. Overall, right-turn crashes tended to be less severe: fewer (6% vs. 14% overall) involved fatal or serious injuries and more (51% vs. 42% overall) involved possible or no injury. Given the strong association between speed and injury severity, this finding is likely due to the lower speeds at which right-turning vehicles are moving, compared with vehicles moving straight ahead or turning left. Right-turn crashes were also slightly but significantly less likely to occur during rainy weather (7% vs 10% overall), on wet roadways (10% vs 14% overall), or with poor light or unlighted conditions (29% vs. 41% overall). Right-turn crashes were neither over- nor under-represented (compared to straight-ahead and left-turn crashes) for characteristics like driver age (older adult or teenager), impairment (DUI, drowsy, or distracted), or roadway speed limit (< 25 mph).

Table 4.2 Results of chi-square tests for pedestrian crashes

	Percentage[a]				*Chi-square*[b]		
Variable	***All***	***RT***	***SA***	***LT***	***RT***	***SA***	***LT***
Crash severity							
Fatal or serious injury	13.6	**6.4**	**21.1**	14.1	**66.1**	**58.9**	0.7
Possible injury or no injury	41.5	**50.5**	**29.8**	40.4	**59.8**	**59.1**	0.2
Weather condition							
Precipitation	10.2	**6.8**	9.0	**15.5**	**24.2**	3.8	**39.5**
Roadway surface condition							
Wet	13.7	**10.4**	12.3	**19.3**	**16.3**	2.3	**31.7**
Lighting condition							
Poor light or unlighted	40.6	**28.5**	**53.5**	**43.9**	**103.8**	**79.7**	**8.4**
Driver age							
Older adult or teenager	19.1	18.6	**16.4**	**21.0**	0.0	**4.0**	**4.4**
Impairment							
DUI, drowsy, or distracted	7.9	7.4	6.8	7.6	0.0	0.3	0.1
Speed limit							
< 25 mph	15.5	*17.9*	**9.6**	17.5	*5.6*	**20.5**	3.4

[a] Percentages calculated within each vehicle movement (RT = right turn, SA = straight ahead, LT = left turn), summing to 100% across all levels of each variable.
[b] Chi-square tests are for 2-by-2 contingency tables for each vehicle movement vs. all other vehicle movements (e.g., RT vs. SA+LT) and for each variable level vs. all other levels of that variable.
Bold = significant at p < 0.05; *italic* = significant at p < 0.10.

Table 4.3 shows the results of the chi-square comparisons for bicycle crashes. Overall, right-turn crashes tended to be less severe: fewer (5% vs. 8% overall) involved fatal or serious injuries and more (49% vs. 45% overall) involved possible or no injury, although the differences were smaller than for pedestrians. As with pedestrians, this finding is likely partially explained by the slower speeds of right-turning vehicles. Right-turn crashes were slightly but significantly less likely to occur during rainy weather (2% vs 3% overall), occur with poor light or unlighted conditions (17% vs. 23% overall), or involve a DUI or drowsy/distracted driving (3% vs. 5% overall). Right-turn crashes were slightly over-represented for low-speed roadways (23% vs. 19% overall), which could be explained by cyclist preferences for these roadways. No significant differences were found for roadway surface condition (wet) or driver age (older adult or teenager).

Table 4.3 Results of chi-square tests for bicycle crashes

	Percentage[a]				*Chi-square*[b]		
Variable	***All***	***RT***	***SA***	***LT***	***RT***	***SA***	***LT***
Crash severity							
Fatal or serious injury	7.5	**4.7**	**11.2**	**10.5**	**28.9**	**13.2**	**6.7**
Possible injury or no injury	44.7	**48.6**	**39.8**	**38.3**	**19.7**	**5.5**	**8.2**
Weather condition							
Precipitation	3.1	**2.0**	3.3	**5.3**	**16.8**	0.2	**20.4**
Roadway surface condition							
Wet	5.0	4.2	4.6	**7.2**	2.6	0.1	**5.7**
Lighting condition							
Poor light or unlighted	22.9	**17.1**	**27.5**	**32.2**	**51.5**	**10.4**	**29.4**
Driver age							
Older adult or teenager	18.2	17.3	*15.6*	**24.5**	1.9	*3.8*	**14.3**
Impairment							
DUI, drowsy, or distracted	4.5	**3.4**	*5.6*	4.8	**4.1**	*2.8*	0.3
Speed limit							
< 25 mph	18.7	**22.8**	**12.8**	*14.5*	**22.4**	**12.1**	*5.3*

[a] Percentages calculated within each vehicle movement (RT = right turn, SA = straight ahead, LT = left turn), summing to 100% across all levels of each variable.
[b] Chi-square tests are for 2-by-2 contingency tables for each vehicle movement vs. all other vehicle movements (e.g., RT vs. SA+LT) and for each variable level vs. all other levels of that variable.
Bold = significant at $p < 0.05$; *italic* = significant at $p < 0.10$.

Overall, these results suggest that right-turn crashes tend to have less severe injury outcomes (compared to left-turn and straight-ahead crashes) for people walking and bicycling, which is likely explained by the slower vehicle speeds involved in these situations. Environmental conditions (weather, lighting) or driver characteristics (age, impairment) do not seem to be causing any disproportionate safety impacts for right-turn (versus other) crashes. If anything, right-turn crashes make up a smaller share of pedestrian/bicycle crashes under adverse weather or lighting conditions, possibly because of the simpler movements, closer proximity of road users, or slower speeds involved.

Despite these findings, the chi-square comparisons only account for one factor at a time and do not cover other characteristics that may be of interest, including other intersection design factors. Therefore, multivariate regression models may be able to identify additional unique associations with right-turn pedestrian and bicycle crashes.

4.2.2 Multivariate Regression Models

The second analysis of the crash data investigated multivariate associations of various site characteristics about intersections—roadway geometry, traffic signal timing, land uses, and neighborhood built environment and sociodemographic characteristics—with the frequency of right-turn pedestrian/bicycle crashes at those intersections. Overall, the aim was to identify characteristics or situations for which crashes involving right-turning motor vehicles and people walking and bicycling are over-/under-represented or more/less frequent, compared to crashes involving left-turn or straight-ahead vehicle movements. Therefore, separate models for all crashes and for right-turn only crashes were estimated. Factors with substantial differences in associations (stronger or weaker) between the two models might indicate a safety issue specific to right-turn pedestrian/bicycle crashes.

Since the dependent variables of these models were crash frequencies, specific types of generalized linear models are more suited to analyze these count data—involving discrete (integer) and non-negative outcomes—than ordinary linear regression. The Poisson regression model has been widely used to model count data, but it makes the restrictive assumption that the variance of the count is equal to the mean of the count. For crash data, the variance will often be greater than the mean. When this situation (overdispersion) occurs, negative binomial models are often more appropriate, because they add an additional term to account for the degree of overdispersion. (The Poisson model is a special case of the negative binomial model.) When investigating subtypes of crashes, frequencies can be very low, and many sites can have zero crashes reported during the time period being analyzed. In these situations, there may be more zeros than would otherwise be predicted by the statistical distributions assumed by the models (either Poisson or negative binomial). Therefore, a zero-inflated model may be appropriate. These zero-inflated models include a first-stage model predicting the probability of the observation belonging to a separate "zero-count" group, followed by a regular Poisson or negative binomial model predicting the regular count.

For the present study, zero-inflated negative binomial (ZINB) models were used, in order to account for both overdispersion and zero-inflation. Since the count data being studied were small subsets of all crash data—pedestrian and bicycle crashes, involving right-turning motor vehicles—the 10-year intersection crash frequencies were overdispersed and had large shares of locations with zero crashes reported. The probability density function for a ZINB model is:

$$P(Y = y_{it}) = \begin{cases} P_{it} + (1 - P_{it}) \dfrac{1}{(1 + \alpha \mu_{it})^{\frac{1}{\alpha}}} & y_{it} = 0 \\ (1 - P_{it}) \dfrac{\Gamma\left(y_{it} + \left(\frac{1}{\alpha}\right)\right)}{\Gamma(y_{it} + 1)\Gamma\left(\frac{1}{\alpha}\right)} \dfrac{(\alpha \mu_{it})^{y_{it}}}{(1 + \alpha \mu_{it})^{y_{it} + \left(\frac{1}{\alpha}\right)}} & y_{it} > 0 \end{cases}$$

where α is the dispersion parameter and Γ is the gamma function.

Separate models were estimated for pedestrian and bicycle crashes, for all vehicle movements and only right-turning vehicle movements; see list of models in Table 4.4. All models included a variety of independent variables, including measures of exposure, transportation system characteristics, land use and built environment characteristics, and socioeconomic characteristics. Models were also estimated with and without the minor AADT variable, because it was not available for all locations. Model results are shown and discussed in the following subsections.

Table 4.4 Crash data analysis results tables

Table	*Model*	*Outcome*	*Which crashes?*	*Include minor AADT?*
Table 4.5	P-All-A	Pedestrian crash frequency	All vehicle movements	Including
Table 4.6	P-All-B			Excluding
Table 4.7	P-Right-A		Right-turning vehicle movements	Including
Table 4.8	P-Right-B			Excluding
Table 4.10	B-All-A	Bicycle crash frequency	All vehicle movements	Including
Table 4.11	B-All-B			Excluding
Table 4.12	B-Right-A		Right-turning vehicle movements	Including
Table 4.13	B-Right-B			Excluding

4.2.2.1 Results for Pedestrian Crashes

Table 4.5 and Table 4.6 show the results of the ZINB models for all pedestrian crashes, with and without the minor AADT variable. In comparison, Table 4.7 and Table 4.8 show the ZINB model results for only those pedestrian crashes involving right-turning motor vehicles. Given the large number of results—and that the all-crash models have been interpreted in other research (Singleton, Mekker, & Islam, 2021)—the overall significance, direction, and relative magnitude of these results (for just the negative binomial portions of the models) are summarized in Table 4.9.

Table 4.5 Results of ZINB Model P-All-A (N^1 = 1,038, R^{22} = 0.327)

Variables	B^3	SE^4	z^5	p^6
Negative binomial portion				
(Intercept)	-6.8573	0.6995	-9.804	0.000
Measures of exposure				
AADP, estimated [a]	0.4005	0.0387	10.352	0.000
$AADT_{MAJ}$ [a]	0.4063	0.0722	5.624	0.000
$AADT_{MIN}$ [a]	0.0607	0.0212	2.866	0.004
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-1.2396	0.7981	-1.553	0.120
3-leg	-0.2217	0.1507	-1.472	0.141
5-leg	-0.4915	0.5316	-0.925	0.355
DDI	-1.0314	1.0947	-0.942	0.346
SPUI	-0.5658	0.4457	-1.269	0.204
# crosswalks with continental, ladder, or zebra markings	0.1157	0.0360	3.219	0.001
Crosswalk length, mean (ft)	0.0041	0.0018	2.230	0.026
# approaches with no RTOR	-0.4995	0.2694	-1.854	0.064
# approaches with bike lanes	-0.0775	0.0288	-2.692	0.007
# of bus stops within 300 ft of intersection	0.1060	0.0237	4.472	0.000
Land use and built environment characteristics				
% land use vacant [b]	0.0099	0.0055	1.813	0.070
Employment density (1,000 per mi^2) [b]	-0.0099	0.0031	-3.176	0.002
Sociodemographic characteristics				
% of population with a disability [b]	0.0208	0.0079	2.648	0.008
% of population of Hispanic or non-white race/ethnicity [b]	0.0127	0.0025	5.007	0.000
Zero-inflated portion				
(Intercept)	4.0533	0.8469	4.786	0.000
AADP, estimated [a]	-0.9666	0.2167	-4.462	0.000
Population density (1,000 per mi^2) [b]	-0.8187	0.1769	-4.627	0.000
% of population of Hispanic or non-white race/ethnicity [b]	0.0517	0.0169	3.062	0.002

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.
Notes for this and future model results tables:
[1] *N* denotes the number of observations used in the model.
[2] R^2 is the McFadden pseudo-R^2 goodness-of-fit statistic for the model.
[3] *B* is the model estimated parameter used to infer about unknown population characteristics.
[4] *SE* denotes the standard error of the *B* estimate.
[5] *z* value is a Wald test statistic, which divides *B* by *SE*.
[6] *p*-value is the statistical significance of the Wald test.

Table 4.6 Results of ZINB Model P-All-B (N = 1,441, R^2 = 0.314)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-6.3563	0.5582	-11.387	0.000
Measures of exposure				
AADP, estimated [a]	0.4076	0.0337	12.108	0.000
$AADT_{MAJ}$ [a]	0.4015	0.0558	7.194	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-1.7309	0.7654	-2.261	0.024
3-leg	-0.1455	0.1272	-1.144	0.253
5-leg	-0.4678	0.5314	-0.880	0.379
DDI	-0.8080	1.1036	-0.732	0.464
SPUI	0.0010	0.2802	0.004	0.997
# crosswalks with continental, ladder, or zebra markings	0.1267	0.0330	3.843	0.000
Crosswalk length, mean (ft)	0.0044	0.0016	2.690	0.007
# approaches with no pedestrian crossing	-0.2087	0.0676	-3.087	0.002
# approaches with no RTOR	-0.4394	0.2472	-1.777	0.076
# approaches with bike lanes	-0.0680	0.0259	-2.632	0.008
# of bus stops within 300 ft of intersection	0.1465	0.0274	5.353	0.000
# approaches with near-side bus stops	-0.0917	0.0485	-1.892	0.058
Land use and built environment characteristics				
% land use vacant [b]	0.0105	0.0045	2.328	0.020
Employment density (1,000 per mi^2) [b]	-0.0089	0.0028	-3.168	0.002
# of schools [b]	-0.0806	0.0440	-1.833	0.067
# of places of worship [b]	-0.0787	0.0343	-2.297	0.022
Sociodemographic characteristics				
% of population with a disability [b]	0.0297	0.0068	4.342	0.000
% of population of Hispanic or non-white race/ethnicity [b]	0.0100	0.0022	4.634	0.000
Zero-inflated portion				
(Intercept)	5.3043	0.9371	5.661	0.000
AADP, estimated [a]	-1.1678	0.2235	-5.226	0.000
# approaches with no pedestrian crossing	-0.6540	0.3406	-1.920	0.055
% land use industrial [b]	-0.0601	0.0229	-2.622	0.009
Population density (1,000 per mi^2) [b]	-0.8581	0.1550	-5.537	0.000
% of population of Hispanic or non-white race/ethnicity [b]	0.0637	0.0164	3.893	0.000

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.

Table 4.7 Results of ZINB Model P-Right-A (N = 1,038, R^2 = 0.254)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-8.9650	1.0910	-8.216	0.000
Measures of exposure				
AADP, estimated [a]	0.3427	0.0617	5.552	0.000
$AADT_{MAJ}$ [a]	0.4444	0.1095	4.057	0.000
$AADT_{MIN}$ [a]	0.0922	0.0332	2.780	0.005
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-14.69	1,056	-0.014	0.989
3-leg	-0.0242	0.2284	-0.106	0.916
5-leg	-0.6971	0.8103	-0.860	0.390
DDI	-13.98	1,121	-0.012	0.990
SPUI	-0.2983	0.6053	-0.493	0.622
# crosswalks with continental, ladder, or zebra markings	0.1282	0.0504	2.546	0.011
Crosswalk length, mean (ft)	0.0133	0.0026	5.086	0.000
# approaches with no RTOR	-0.7890	0.4579	-1.723	0.085
# of bus stops within 300 ft of intersection	0.0969	0.0332	2.917	0.004
Land use and built environment characteristics				
% land use vacant [b]	0.0167	0.0085	1.956	0.050
Employment density (1,000 per mi^2) [b]	-0.0162	0.0051	-3.155	0.002
Sociodemographic characteristics				
% of population with a disability [b]	0.0280	0.0115	2.448	0.014
% of population of Hispanic or non-white race/ethnicity [b]	0.0084	0.0037	2.287	0.022
Zero-inflated portion				
(Intercept)	5.7410	1.2470	4.604	0.000
AADP, estimated [a]	-1.1726	0.3056	-3.837	0.000
Population density (1,000 per mi^2) [b]	-0.7714	0.2321	-3.323	0.001
% of population of Hispanic or non-white race/ethnicity [b]	0.0363	0.0201	1.802	0.072

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.

Table 4.8 Results of ZINB Model P-Right-B (N = 1,441, R^2 = 0.239)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-8.7379	0.9101	-9.601	0.000
Measures of exposure				
AADP, estimated [a]	0.4102	0.0531	7.727	0.000
$AADT_{MAJ}$ [a]	0.4777	0.0880	5.430	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-14.45	676	-0.021	0.983
3-leg	-0.1760	0.1936	-0.909	0.363
5-leg	-0.5686	0.8295	-0.685	0.493
DDI	-12.94	600	-0.022	0.983
SPUI	0.1391	0.3685	0.377	0.706
# crosswalks with continental, ladder, or zebra markings	0.1452	0.0482	3.012	0.003
Crosswalk length, mean (ft)	0.0131	0.0024	5.536	0.000
# approaches with no RTOR	-0.7881	0.4360	-1.808	0.071
# of bus stops within 300 ft of intersection	0.1635	0.0396	4.131	0.000
# approaches with near-side bus stops	-0.1392	0.0722	-1.928	0.054
Land use and built environment characteristics				
% land use vacant [b]	0.0155	0.0070	2.229	0.026
Employment density (1,000 per mi^2) [b]	-0.0157	0.0047	-3.331	0.001
# of places of worship [b]	-0.1689	0.0540	-3.127	0.002
Sociodemographic characteristics				
% of population with a disability [b]	0.0329	0.0104	3.160	0.002
Zero-inflated portion				
(Intercept)	4.8213	1.1080	4.351	0.000
AADP, estimated [a]	-0.8905	0.2572	-3.462	0.001
Population density (1,000 per mi^2) [b]	-0.7421	0.2265	-3.277	0.001

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.

Table 4.9 Summary of ZINB model results for pedestrian crashes

	All crashes		*Right-turn crashes only*	
	P-All-A	*P-All-B*	*P-Right-A*	*P-Right-B*
Variable	*Direction*		*Direction (relative magnitude)*	
Pedestrian volume	+	+	+	+
Motor vehicle volume	+	+	+	+
Number of intersection legs		+		(weaker)
Crosswalk length	+	+	+ (stronger)	+ (stronger)
High-visibility crosswalks	+	+	+	+
No pedestrian crossings		−		(weaker)
RTOR prohibited	−	−	−	−
Bike lanes	−	−	(weaker)	(weaker)
Bus stops	+	+	+	+
Vacant land use	+	+	+	+
Employment density	−	−	− (stronger)	− (stronger)
Schools		−		(weaker)
Places of worship		−		− (stronger)
Population % with a disability	+	+	+	+
Population % Hispanic/non-white	+	+	+ (weaker)	(weaker)

Notes: + = positive association (more crashes), − = negative association (fewer crashes), blank = no significant association (p > 0.10) or not included in the model. Relative magnitude (stronger) or (weaker) depends on if the right-turn model coefficients are in the 90%-percentile confidence interval of the all model coefficients.

Overall, there were more pedestrian crashes at intersections with greater pedestrian and motor vehicle volumes, although there was a “safety-in-numbers” effect for walking (crashes increased more slowly as pedestrian volume increased). Crashes also were more numerous at intersections with longer crossings, more bus stops, and more high-visibility crosswalks (even after controlling for pedestrian volumes), while fewer crashes were observed in locations with bike lanes and when RTOR was prohibited. Pedestrian crash frequency was positively associated with vacant land use but negatively associated with employment density. More crashes were observed at intersections in neighborhoods with more people with disabilities or of Hispanic or non-white race/ethnicity. A few other significant associations were found in just one of the all-crash models (positive with the number of legs at the intersection, and negative with the number of no-pedestrian crossings, schools, and places of worship).

Results when only analyzing right-turn crashes were generally similar, although some differences were found. Several relationships were weaker or no longer statistically significant; most notably, bike lanes were no longer negatively associated with right-turn pedestrian crashes.

Several other relationships were actually strengthened when focusing on right-turn crashes. The positive association with crosswalk length was stronger, as were the negative relationships with employment density and places of worship (in one model only). It is also notable that the negative coefficient on prohibited RTOR was nearly doubled in the right-turn-only models, although the small sample size meant that the differences were not statistically distinguishable. The model coefficients imply that shortening a crossing by two lanes (24 ft) might decrease all pedestrian crashes by 9-10% (90th-percentile confidence interval (CI): 3-16%) but right-turn pedestrian crashes by 27% (90th-percentile CI: 18-35%). Similarly, prohibiting RTOR for one movement might be expected to reduce all pedestrian crashes by 36-39% (90th-percentile CI: 3–57%) but right-turn pedestrian crashes by 55% (90th-percentile CI: 4-79%).

4.2.2.2 Results for Bicycle Crashes

Table 4.10 and Table 4.11 show the results of the ZINB models for all bicycle crashes, with and without the minor AADT variable. In comparison, Table 4.12 and Table 4.13 show the ZINB model results for only those bicycle crashes involving right-turning motor vehicles. Given the large number of results, the overall significance, direction, and relative magnitude of these results are summarized in Table 4.14.

Table 4.10 Results of ZINB Model B-All-A (N = 1,241, R^2 = 0.223)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-5.8845	0.6575	-8.949	0.000
Measures of exposure				
AADB, Strava [a]	0.1734	0.0477	3.635	0.000
$AADT_{MAJ}$ [a]	0.4416	0.0677	6.524	0.000
$AADT_{MIN}$ [a]	0.0784	0.0171	4.571	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-1.4392	0.3922	-3.670	0.000
3-leg	-0.4989	0.1427	-3.497	0.000
5-leg	-0.3481	0.6876	-0.506	0.613
DDI	1.0848	0.7339	1.478	0.139
SPUI	0.7233	0.4797	1.508	0.132
Crosswalk length, mean (ft)	0.0106	0.0019	5.606	0.000
# approaches with channelized right turn	-0.3038	0.0836	-3.632	0.000
# of bus stops within 300 ft of intersection	0.0607	0.0249	2.441	0.015
Land use and built environment characteristics				
Population density (1,000 per mi^2) [b]	0.0473	0.0121	3.926	0.000
# of places of worship [b]	-0.0776	0.0419	-1.850	0.064
Sociodemographic characteristics				
Household income (median, $1,000) [b]	-0.0061	0.0018	-3.398	0.001
% of population of Hispanic or non-white race/ethnicity [b]	0.0078	0.0026	3.018	0.003
Zero-inflated portion				
(Intercept)	-7.2472	3.2156	-2.254	0.024
AADB, Strava [a]	-2.0562	0.6274	-3.278	0.001
$AADT_{MIN}$ [a]	1.0576	0.3620	2.922	0.003
Crosswalk length, mean (ft)	0.0954	0.0313	3.054	0.002
# of bus stops within 300 ft of intersection	-1.7647	0.8007	-2.204	0.027
% land use commercial [b]	-0.0539	0.0254	-2.119	0.034
Population density (1,000 per mi^2) [b]	-1.7295	0.5741	-3.013	0.002
Employment density (1,000 per mi^2) [b]	-0.3520	0.1589	-2.216	0.027
# of schools [b]	-4.9133	2.5931	-1.895	0.058
% of population of Hispanic or non-white race/ethnicity [b]	-0.1165	0.0393	-2.962	0.003

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.

Table 4.11 Results of ZINB Model B-All-B (N = 1,728, R^2 = 0.205)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-5.9742	0.5988	-9.977	0.000
Measures of exposure				
AADB, Strava [a]	0.2078	0.0420	4.946	0.000
$AADT_{MAJ}$ [a]	0.4854	0.0570	8.520	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-2.0315	0.3698	-5.493	0.000
3-leg	-0.4530	0.1180	-3.839	0.000
5-leg	-0.4800	0.6965	-0.689	0.491
DDI	0.7995	0.7301	1.095	0.273
SPUI	0.5993	0.3723	1.610	0.107
# approaches with no pedestrian/bicycle crossing	-0.1168	0.0536	-2.177	0.030
Crosswalk length, mean (ft)	0.0117	0.0019	6.212	0.000
# approaches with channelized right turn	-0.2100	0.0750	-2.802	0.005
# of bus stops within 300 ft of intersection	0.1034	0.0294	3.518	0.000
# approaches with near-side bus stops	-0.0877	0.0532	-1.647	0.100
Land use and built environment characteristics				
Population density (1,000 per mi^2) [b]	0.0412	0.0119	3.454	0.001
# of places of worship [b]	-0.0873	0.0378	-2.308	0.021
Sociodemographic characteristics				
Household income (median, $1,000) [b]	-0.0063	0.0018	-3.396	0.001
% of population with a disability [b]	0.0189	0.0083	2.280	0.023
% of population of Hispanic or non-white race/ethnicity [b]	0.0067	0.0023	2.942	0.003
Zero-inflated portion				
(Intercept)	0.5268	1.5758	0.334	0.738
AADB, Strava [a]	-0.6101	0.2431	-2.510	0.012
Crosswalk length, mean (ft)	0.0276	0.0159	1.737	0.082
Population density (1,000 per mi^2) [b]	-0.7999	0.1975	-4.051	0.000
Employment density (1,000 per mi^2) [b]	-0.1336	0.0635	-2.105	0.035
% of population of Hispanic or non-white race/ethnicity [b]	-0.0676	0.0341	-1.979	0.048

[a] The natural log of these variables (+1) entered into the model.

[b] These variables were measured using a quarter-mile network buffer.

Table 4.12 Results of ZINB Model B-Right-A (N = 1,241, R^2 = 0.211)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-9.0286	0.9994	-9.034	0.000
Measures of exposure				
AADB, Strava [a]	0.0828	0.0641	1.293	0.196
$AADT_{MAJ}$ [a]	0.7732	0.1019	7.586	0.000
$AADT_{MIN}$ [a]	0.1028	0.0254	4.055	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-1.8925	0.7467	-2.534	0.011
3-leg	-0.5014	0.1940	-2.585	0.010
5-leg	-0.0374	0.8433	-0.044	0.965
DDI	1.3010	1.0178	1.278	0.201
SPUI	0.9843	0.6058	1.625	0.104
Crosswalk length, mean (ft)	0.0063	0.0025	2.468	0.014
# approaches with channelized right turn	-0.4109	0.1224	-3.356	0.001
Land use and built environment characteristics				
Sociodemographic characteristics				
Household income (median, $1,000) [b]	-0.0087	0.0025	-3.522	0.000
% of population of Hispanic or non-white race/ethnicity [b]	0.0068	0.0035	1.956	0.050
Zero-inflated portion				
(Intercept)	2.8459	0.6894	4.128	0.000
Population density (1,000 per mi^2) [b]	-1.2151	0.3548	-3.425	0.001
Employment density (1,000 per mi^2) [b]	-0.1418	0.0718	-1.977	0.048

[a] The natural log of these variables (+1) entered into the model.

[b] These variables were measured using a quarter-mile network buffer.

Table 4.13 Results of ZINB Model B-Right-B (N = 1,728, R^2 = 0.198)

Variables	*B*	*SE*	*z*	*p*
Negative binomial portion				
(Intercept)	-8.1954	0.8370	-9.792	0.000
Measures of exposure				
AADB, Strava [a]	0.1289	0.0554	2.327	0.020
$AADT_{MAJ}$ [a]	0.7627	0.0859	8.883	0.000
Transportation system characteristics				
Intersection type (ref. = 4-leg)				
2-leg (mid-block)	-2.6177	0.7223	-3.624	0.000
3-leg	-0.4786	0.1515	-3.160	0.002
5-leg	-0.0621	0.8714	-0.071	0.943
DDI	0.9914	1.0777	0.920	0.358
SPUI	0.9168	0.5029	1.823	0.068
Crosswalk length, mean (ft)	0.0101	0.0022	4.502	0.000
# approaches with channelized right turn	-0.3364	0.1078	-3.120	0.002
# of bus stops within 300 ft of intersection	0.0552	0.0313	1.763	0.078
Land use and built environment characteristics				
# of places of worship [b]	-0.1233	0.0522	-2.364	0.018
Sociodemographic characteristics				
Household income (median, $1,000) [b]	-0.0119	0.0022	-5.498	0.000
Zero-inflated portion				
(Intercept)	2.6766	0.5392	4.964	0.000
Population density (1,000 per mi^2) [b]	-1.1881	0.2779	-4.275	0.000
Employment density (1,000 per mi^2) [b]	-0.0990	0.0474	-2.086	0.037

[a] The natural log of these variables (+1) entered into the model.
[b] These variables were measured using a quarter-mile network buffer.

Table 4.14 Summary of ZINB model results for bicycle crashes

	All crashes		***Right-turn crashes only***	
	B-All-A	***B-All-B***	***B-Right-A***	***B-Right-B***
Variable	***Direction***		***Direction (relative magnitude)***	
Bicycle volume	+	+	+ (weaker)	+ (weaker)
Motor vehicle volume	+	+	+ (stronger)	+ (stronger)
Number of intersection legs	+	+	+	+
Crosswalk length	+	+	+ (weaker)	+
Channelized right turns	−	−	−	− (stronger)
No pedestrian crossings		−		(weaker)
Bus stops	+	+	(weaker)	+
Population density	+	+	(weaker)	(weaker)
Places of worship	−	−	(weaker)	−
Household income	−	−	−	− (stronger)
Population % with a disability		+		(weaker)
Population % Hispanic/non-white	+	+	+	(weaker)

Notes: + = positive association (more crashes), − = negative association (fewer crashes), blank = no significant association (p > 0.10) or not included in the model. Relative magnitude (stronger) or (weaker) depends on if the right-turn model coefficients are in the 90%-percentile confidence interval of the all model coefficients.

Overall, there were more bicycle crashes at intersections with greater bicycle (Strava) and motor vehicle volumes, although there was a “safety in numbers” effect for bicycling (crashes increased more slowly as Strava bicycle volume increased). Crashes were also more numerous at intersections with 4 legs (compared to 2- or 3-leg intersections), longer crossings, and more bus stops, while fewer crashes were observed in locations with channelized right turn lanes. Bicycle crash frequency was positively associated with population density but negatively associated with nearby places of worship. More crashes were observed at intersections in neighborhoods with lower household incomes and more people of Hispanic or non-white race/ethnicity. A few other significant associations were found in just one of the all-crashes models (negative with the number of no-pedestrian crossings, and positive with people with disabilities).

Results when only analyzing right-turn crashes were generally in similar directions, although several differences in magnitude or statistical significance were found. Several relationships were weaker or no longer significant in one or both of the models; most notably, population density was no longer positively associated with right-turn bicycle crashes. Also, right-turn crashes were less strongly influenced by bicycle volumes than bicycle crashes overall. A few other relationships were actually strengthened when focusing on right-turn crashes. The positive association with motor vehicle volume was much stronger, as were the negative relationships (in one model only) for channelized right turns and household income. The model coefficients imply that a doubling (100% increase) in motor vehicle volume on the major roadway might increase all bicycle crashes by 44-49% (90th-percentile CI: 33-58%) but right--turn bicycle crashes by 76-77% (90th-percentile CI: 61–94%). Similarly, the presence of one channelized right turn might be expected to reduce all bicycle crashes by 19-26% (90th-percentile CI: 8-36%) but right-turn bicycle crashes by 29-34% (90th-percentile CI: 15-46%).

4.3 Observational Data Analysis

This section contains the methods and results of the observational data analysis. The first subsection describes the methods used for the bivariate and multivariate analyses. Subsequent sections present and summarize the results of analyses of each of the following five conflict outcomes and/or pedestrian/driver behaviors that were investigated in this study:

- Encroachment time and conflict severity.
- Pedestrian reaction.
- Pedestrian crossing location.
- Vehicle driver reaction.
- Vehicle driver stopping location.

Each section presents and discusses the correlation results and the results from the multilevel regression models. Overall, this analysis is intended to identify factors that are significantly associated with each of these conflict outcomes and pedestrian/driver behaviors of interest for understanding right-turn conflicts and behaviors. While correlation does not imply causation, correlation is an important step towards determining causation. Later, Chapter 5.0 will discuss potential causal explanations for these identified associations, including which are supported by previous research and which make sense given an understanding of what happens during conflicts between crosswalk users and right-turning motor vehicles.

4.3.1 Analysis Methods

To analyze results of the observational data, the research team performed two types of statistical analyses. First, bivariate analysis (correlation) identified characteristics that were significantly associated with each conflict outcome or pedestrian/driver behavior. Second, multivariate regression analysis (multilevel modeling) identified which of these factors were still significantly associated with each outcome/behavior when controlling for the data structure and other significant factors. The methods underlying each of these analyses are discussed in the following subsections.

4.3.1.1 Bivariate Analysis: Correlations

The purpose of this first bivariate analysis was to identify which factors (from Table 3.4 and Table 3.5) were significantly associated (on their own) with various conflict outcomes and pedestrian/driver behaviors. One statistical measure of association is correlation, which measures the association between two variables on a scale ranging from −1 to +1, where positive numbers reflect a positive association (as one variable increases, so does the other), negative numbers reflect a negative association (as one variable increases, the other decreases), and zero reflects no association. There are different types of correlations, depending on the types of variables being considered. The study employed three different correlation measures:

- The Pearson (product moment) correlation coefficient measures the association between two variables, both measured on a continuous numerical scale.
- The point biserial correlation coefficient measures the association between two variables, one that is continuous and one that is dichotomous (1/0 or True/False).
- The phi (correlation) coefficient measures the association between two variables, both being dichotomous.

Mathematically, all three of these correlation coefficients are calculated in the same way, assuming the dichotomous (also known as binary or dummy) variables are represented numerically (1 = True, 0 = False). Therefore, all categorical variables in Table 3.4 and Table 3.5 were converted into binary variables. Finally, the correlation r was calculated between each pair of independent variables x and dependent variables y, and assessed the statistical significance of the correlation (versus a null hypothesis of no association, $r = 0$) using a Student's t-distribution (with degrees of freedom equal to the sample size n minus 2). These calculations are represented by the following equations:

$$corr = r_{x,y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

$$t = r_{x,y}\sqrt{\frac{n-2}{1-\left(r_{x,y}\right)^2}}$$

4.3.1.2 Multivariate Analysis: Multilevel Regression Models

The purpose of this second multivariate analysis was similar: to identify factors (Table 3.4 and Table 3.5) having significant associations with various conflict outcomes and pedestrian/driver behaviors. However, the use of multilevel regression models achieved two advantages over the bivariate analysis. First, the multivariate analysis allowed the identification of significant associations while controlling for all other significant associations, simultaneously. Second, the multilevel regression models appropriately handled the statistical association between the two types or levels of independent variables, each with its own sample size: (1) data collected for every pedestrian event, and (2) data collected for every right turn/corner.

Multilevel regression models can represent two or more levels or ways in which the records within a dataset are nested. This study recorded information about each potential pedestrian-driver conflict event (level one units i), nested within or observed for each studied right turn/corner (level two units j). Through a multilevel model, one can relate the outcomes of interest (Y_{ij}) measured for each level one unit (e.g., conflict outcome, pedestrian/driver behaviors) to other factors or variables measured for either level one (x_{ij}) units (for instance, group size or queue length) or level two (z_j) units (for instance, corner radius or population density). Relationships are represented by the strength, direction, and significance of the intercept and slope coefficients, and such coefficients can be the same for all observations (β_0, β_h) or different for observations within each level two unit (β_{0j}, β_{hj}), assuming either fixed or random coefficients. If assuming random coefficients, there can be multiple random components to the equation, one overall and one for each random intercept or slope coefficient in the model. For instance, this study applies multilevel models containing a random intercept term and no random slopes (or cross-level interactions). For a linear model, this specific situation can be represented by the following equations:

$Y_{ij} = \beta_{0j} + \sum_h \beta_h x_{hij} + R_{ij}$, where

$\beta_{0j} = \gamma_{00} + \sum_g \gamma_{g0}\, z_{gj} + U_{0j}$, or (combining into one equation)

$Y_{ij} = \gamma_{00} + \sum_h \beta_h x_{hij} + \sum_g \gamma_{g0}\, z_{gj} + R_{ij} + U_{0j}$

One way to interpret this multilevel model is as follows. Level one factors (x_{hij})—pedestrian characteristics, driver and vehicle characteristics, weather information, and traffic signal status information—affect the outcome of each conflict or the likelihood of each pedestrian/driver behavior. Level two factors (z_{gj})—corner and intersection attributes, and neighborhood attributes—affect which locations tended to see higher or lower values for each conflict outcome or more or fewer instances of each pedestrian/driver behavior (represented by the location-specific intercept β_{0j}), after controlling for significant level one factors.

4.3.2 Encroachment Time and Conflict Severity

One way to define surrogate measures of safety like conflicts is through encroachment time (ET), the time difference between when two road users were in the same location. As previously described in Section 3.3.3, the research team calculated multiple indicators of conflict outcomes: (1) *ET* (overall), (2) *pre-ET* (for events where the vehicle passed before the pedestrian), (3) *post-ET* (for events where the vehicle passed after the pedestrian), and (4) *conflict severity* (a categorical version of ET). The following subsections analyze factors associated with each of these outcomes through bivariate and multivariate statistical analyses.

4.3.2.1 Bivariate Correlation Results

Table 4.15 summarizes the results of the correlation analysis for the first three measures of ET (overall), pre-ET, and post-ET. Ranging from zero to ten seconds, recall that a lower value means there was less time between the pedestrian and vehicle at the same point in space. Therefore, a positive correlation implies more time and a less severe conflict, while a negative correlation implies less time and a more severe conflict. The following paragraphs highlight some notable results.

Several pedestrian characteristics were significantly associated with encroachment time. ET (overall) and pre-ET were positively correlated with (the natural log of) group size, but only marginally so for post-ET. A positive correlation was also found for the presence of a child for post-ET (marginally significant for overall ET). Gender (as identified by data collectors) was a significant factor: ET overall (and post-ET) was negatively correlated with the presence of male pedestrians, while pre-ET was positively correlated with female pedestrians. Among other characteristics, people bicycling had shorter (overall, pre-, and post-) ET; otherwise, carrying a load, pushing a stroller, and using a scooter were positively, positively, and negatively correlated (respectively) with post-ET. Consistently, ET was larger for pedestrians using the first crosswalk and smaller for those using the second crosswalk. Crossing location was not associated with ET, but crossing direction was: post-ET was shorter when pedestrians were approaching the curb, while pre-ET was shorter when pedestrians were leaving the curb. Not surprisingly, ET was significantly correlated with pedestrian reactions. Generally, ET was longer when pedestrians had no obvious reaction, and it was shorter when they stopped or slowed (overall and pre-), and sped up, ran, or changed directions (overall and post-).

Driver and vehicle characteristics were also significantly associated with encroachment time. While ET overall was negatively correlated with right-turn queue length, there was a positive correlation for pre-ET. Similar to the findings about pedestrian reactions, stopping locations and driver reactions were associated with ET. Specifically, ET (overall) was longer when drivers did not stop and/or had no obvious reaction, while ET was shorter when drivers stopped (either before the first crosswalk or inside/between the crosswalks), and when drivers stopped, slowed down, or swerved. While these findings tended to hold for post-ET, pre-ET was generally not correlated with these driver behaviors (except for a negative correlation with swerving). Considering vehicle type, the presence of a large vehicle was positively associated with overall and pre-ET, while there was a negative association between medium vehicles and overall ET.

Considering other level one variables: precipitation was positively associated with overall ET. Post-ET was a little longer (and pre-ET a little shorter) when the temperature was 50–64°F, while post-ET was shorter for hot hours (80°F or more). On Mondays and Fridays, post-ETs tended to be longer than in the middle of the week (no observations were made on weekends). ET (overall) was positively associated with PM peak hours, while post-ET was positively associated with evening/overnight hours. The only significant associations with pedestrian signal status were positive correlations with pre-ET for flashing don't walk and with post-ET for walk. Results for right-turn vehicle signal status were more consistent across all outcomes: ET was shorter when vehicles were turning on green, and longer when vehicles were turning on red.

Only a few corner and intersection attributes were significantly associated with encroachment times. Overall and post-ET were positively correlated with corner radius and crosswalk offset distance, while post-ET was also positively associated with stop bar distance. Pre-ET was higher for corners with diagonal (or apex) curb ramps and lower for those with directional ramps. There was a negative association between overall and post-ET and the number of right-turn lanes, but this was mostly the result of dedicated right-turn lanes having shorter ET than shared thru-right lanes. Post-ET was shorter in the presence of a bicycle lane and as motor vehicle traffic volumes increased. Overall ET was also negatively correlated with (the natural log of) traffic volumes. There were no significant associations between ET and: number of curb ramps, crosswalk marking type, number of receiving lanes, channelized right turns, skewed intersections, on-ramps, off-ramps, right turns/crossings that were not signalized, and pedestrian volumes.

Considering neighborhood attributes, both population and employment density were negatively correlated with overall ET (but not correlated with pre- or post-ET). There were positive correlations between pre-ET and both the percentage of residential land use and street intersection density. Overall and post-ET were both correlated negatively with the percentage of four-way intersections and positively with neighborhood average household size. Signals near more schools tended to have longer pre- and shorter post-ET. There was a negative correlation between post-ET and neighborhood average household income. Other characteristics (other land uses, transit stops, places of worship, parks, and vehicle ownership) were not significantly associated with any measure of ET.

Table 4.15 Correlation results for encroachment time

			ET (sec)			*Pre-ET (sec), vehicle before pedestrian*			*Post-ET (sec), vehicle after pedestrian*		
Independent variable	*Test*	*df*	*Corr*	*t*	*p*	*Corr*	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics											
Group size (# people)	Pearson	[d]	0.020	0.790	0.430	**0.079**	**1.981**	**0.048**	-0.017	-0.547	0.585
Natural log of group size	Pearson	[d]	**0.069**	**2.792**	**0.005**	**0.101**	**2.543**	**0.011**	*0.055*	*1.735*	*0.083*
Age											
Child or teenager	Point-Biserial	[d]	0.020	0.819	0.413	*0.074*	*1.850*	*0.065*	-0.025	-0.783	0.434
Child	Point-Biserial	[d]	*0.048*	*1.942*	*0.052*	0.002	0.062	0.951	**0.085**	**2.687**	**0.007**
Teenager	Point-Biserial	[d]	0.010	0.414	0.679	*0.074*	*1.856*	*0.064*	-0.046	-1.446	0.148
Adult	Point-Biserial	[d]	0.003	0.118	0.906	*-0.066*	*-1.653*	*0.099*	**0.063**	**1.999**	**0.046**
Young adult	Point-Biserial	[d]	*-0.043*	*-1.730*	*0.084*	-0.031	-0.767	0.443	*-0.059*	*-1.856*	*0.064*
Middle-aged adult	Point-Biserial	[d]	0.030	1.235	0.217	0.053	1.316	0.189	*0.060*	*1.896*	*0.058*
Older adult (65+)	Point-Biserial	[d]	0.037	1.512	0.131	0.029	0.718	0.473	0.050	1.585	0.113
Adult of unknown age	Point-Biserial	[d]	0.016	0.657	0.512	**-0.092**	**-2.301**	**0.022**	**0.064**	**2.039**	**0.042**
Gender											
Male	Point-Biserial	[d]	**-0.069**	**-2.819**	**0.005**	-0.037	-0.930	0.353	**-0.070**	**-2.211**	**0.027**
Female	Point-Biserial	[d]	0.034	1.386	0.166	**0.122**	**3.082**	**0.002**	-0.015	-0.463	0.644
Unknown gender	Point-Biserial	[d]	**0.075**	**3.056**	**0.002**	-0.039	-0.968	0.333	**0.132**	**4.216**	**0.000**
Other characteristics											
Carrying load	Point-Biserial	[d]	0.021	0.836	0.403	-0.049	-1.221	0.222	**0.065**	**2.047**	**0.041**
Stroller or wheelchair	Point-Biserial	[d]	0.037	1.499	0.134	0.033	0.815	0.415	*0.058*	*1.839*	*0.066*
Stroller	Point-Biserial	[d]	*0.043*	*1.739*	*0.082*	0.033	0.815	0.415	**0.062**	**1.978**	**0.048**
Wheelchair	Point-Biserial	[d]	0.000	-0.016	0.987	--	--	--	0.010	0.305	0.761
Skateboard or scooter	Point-Biserial	[d]	-0.018	-0.733	0.464	-0.003	-0.072	0.942	*-0.061*	*-1.918*	*0.055*
Skateboard	Point-Biserial	[d]	-0.003	-0.123	0.902	0.006	0.144	0.885	-0.008	-0.241	0.809
Scooter	Point-Biserial	[d]	-0.027	-1.082	0.280	-0.018	-0.451	0.652	**-0.077**	**-2.458**	**0.014**
Bicycle	Point-Biserial	[d]	**-0.141**	**-5.766**	**0.000**	**-0.121**	**-3.050**	**0.002**	**-0.172**	**-5.510**	**0.000**
Distracted (phone, headphones, conversations, etc.)	Point-Biserial	[d]	-0.002	-0.098	0.922	0.049	1.218	0.224	*-0.060*	*-1.898*	*0.058*
Crosswalk											
First crosswalk	Point-Biserial	[d]	**0.144**	**5.869**	**0.000**	**0.157**	**3.969**	**0.000**	**0.128**	**4.089**	**0.000**
Second crosswalk	Point-Biserial	[d]	**-0.144**	**-5.869**	**0.000**	**-0.157**	**-3.969**	**0.000**	**-0.128**	**-4.089**	**0.000**
Crossing location											
In the crosswalk or the crosswalk area	Point-Biserial	[d]	-0.004	-0.168	0.866	0.017	0.414	0.679	-0.002	-0.076	0.939
Away from the crosswalk	Point-Biserial	[d]	0.004	0.168	0.866	-0.017	-0.414	0.679	0.002	0.076	0.939
Mid-block, away from the crosswalk	Point-Biserial	[d]	-0.012	-0.501	0.616	-0.032	-0.809	0.419	-0.011	-0.353	0.724
In the middle of the intersection	Point-Biserial	[d]	0.028	1.122	0.262	0.019	0.474	0.635	0.024	0.758	0.449
Crossing direction											

Leaving curb	Point-Biserial	d	*-0.043*	*-1.722*	*0.085*	**-0.222**	**-5.706**	**0.000**	**0.101**	**3.220**	**0.001**
Approaching curb	Point-Biserial	d	*0.043*	*1.722*	*0.085*	**0.222**	**5.706**	**0.000**	**-0.101**	**-3.220**	**0.001**
Pedestrian reactions											
No obvious reaction	Point-Biserial	d	**0.165**	**6.770**	**0.000**	**0.290**	**7.572**	**0.000**	**0.124**	**3.951**	**0.000**
Stopped or slowed	Point-Biserial	d	**-0.080**	**-3.251**	**0.001**	**-0.274**	**-7.128**	**0.000**	0.022	0.700	0.484
Stopped and waited for the vehicle	Point-Biserial	d	*-0.044*	*-1.782*	*0.075*	**-0.205**	**-5.249**	**0.000**	0.039	1.230	0.219
Slowed down to avoid collision	Point-Biserial	d	**-0.099**	**-4.023**	**0.000**	**-0.202**	**-5.171**	**0.000**	-0.020	-0.635	0.525
Other reaction	Point-Biserial	d	**-0.153**	**-6.276**	**0.000**	*-0.076*	*-1.917*	*0.056*	**-0.145**	**-4.619**	**0.000**
Sped up to avoid collision	Point-Biserial	d	**-0.077**	**-3.128**	**0.002**	**0.066**	**1.649**	**0.100**	**-0.087**	**-2.757**	**0.006**
Ran to avoid collision	Point-Biserial	d	**-0.085**	**-3.454**	**0.001**	0.012	0.296	0.767	**-0.104**	**-3.314**	**0.001**
Changed direction	Point-Biserial	d	**-0.105**	**-4.267**	**0.000**	**-0.140**	**-3.530**	**0.000**	*-0.054*	*-1.702*	*0.089*
Driver and vehicle characteristics											
Right-turn queue length (# vehicles)	Pearson	d	**-0.054**	**-2.184**	**0.029**	**0.085**	**2.146**	**0.032**	-0.024	-0.746	0.456
Stopping location											
Did not stop	Point-Biserial	d	**0.145**	**5.942**	**0.000**	-0.038	-0.946	0.345	**0.176**	**5.644**	**0.000**
Before the first crosswalk	Point-Biserial	d	**-0.062**	**-2.509**	**0.012**	0.045	1.129	0.259	**-0.069**	**-2.180**	**0.029**
Inside/between the crosswalks	Point-Biserial	d	**-0.118**	**-4.826**	**0.000**	0.008	0.200	0.842	**-0.143**	**-4.554**	**0.000**
Inside the first crosswalk	Point-Biserial	d	**-0.079**	**-3.221**	**0.001**	-0.012	-0.296	0.768	**-0.079**	**-2.514**	**0.012**
Between the first and second crosswalks	Point-Biserial	d	**-0.085**	**-3.472**	**0.001**	0.034	0.859	0.391	**-0.124**	**-3.960**	**0.000**
Driver reaction											
No obvious reaction	Point-Biserial	d	**0.221**	**9.164**	**0.000**	0.058	1.464	0.144	**0.245**	**7.981**	**0.000**
Stopped or slowed	Point-Biserial	d	**-0.225**	**-9.356**	**0.000**	-0.023	-0.564	0.573	**-0.238**	**-7.751**	**0.000**
Driver fully stopped	Point-Biserial	d	**-0.165**	**-6.755**	**0.000**	-0.002	-0.039	0.969	**-0.147**	**-4.693**	**0.000**
Driver slowed down	Point-Biserial	d	**-0.107**	**-4.376**	**0.000**	-0.024	-0.604	0.546	**-0.109**	**-3.475**	**0.001**
Other reaction	Point-Biserial	d	0.007	0.274	0.784	-0.058	-1.460	0.145	-0.022	-0.689	0.491
Driver sped up	Point-Biserial	d	0.027	1.085	0.278	-0.036	-0.894	0.372	0.004	0.122	0.903
Driver swerved	Point-Biserial	d	**-0.075**	**-3.049**	**0.002**	**-0.103**	**-2.603**	**0.009**	**-0.067**	**-2.113**	**0.035**
Vehicle type											
Small	Point-Biserial	d	0.017	0.685	0.493	-0.025	-0.624	0.533	0.040	1.257	0.209
Sedan	Point-Biserial	d	0.013	0.545	0.586	-0.030	-0.749	0.454	0.038	1.208	0.227
Motorcycle	Point-Biserial	d	0.031	1.249	0.212	0.035	0.876	0.382	0.017	0.547	0.584
Medium	Point-Biserial	d	**-0.052**	**-2.090**	**0.037**	-0.041	-1.016	0.310	*-0.056*	*-1.784*	*0.075*
SUV	Point-Biserial	d	-0.002	-0.087	0.931	-0.021	-0.532	0.595	0.016	0.518	0.605
Pickup truck	Point-Biserial	d	*-0.045*	*-1.819*	*0.069*	0.010	0.262	0.793	**-0.081**	**-2.566**	**0.010**
Van (minivan, sprinter van, etc.)	Point-Biserial	d	-0.032	-1.301	0.194	-0.056	-1.407	0.160	-0.021	-0.668	0.504
Large	Point-Biserial	d	**0.086**	**3.504**	**0.000**	**0.154**	**3.910**	**0.000**	0.044	1.392	0.164
Large truck (semi-truck, delivery truck, etc.)	Point-Biserial	d	**0.050**	**2.029**	**0.043**	**0.080**	**2.019**	**0.044**	0.042	1.332	0.183
Vehicle pulling a trailer	Point-Biserial	d	0.030	1.231	0.218	**0.090**	**2.255**	**0.024**	0.000	0.002	0.999
Bus	Point-Biserial	d	**0.071**	**2.892**	**0.004**	**0.095**	**2.395**	**0.017**	0.040	1.266	0.206
Weather and time information											

Weather											
Clear	Point-Biserial	[d]	-0.002	-0.097	0.923	0.037	0.930	0.353	-0.024	-0.757	0.449
Rain (actively raining, or wet roadways)	Point-Biserial	[d]	0.002	0.097	0.923	-0.037	-0.930	0.353	0.024	0.757	0.449
Hourly precipitation (in)	Pearson	[d]	**0.051**	**2.064**	**0.039**	*0.066*	*1.658*	*0.098*	0.029	0.931	0.352
0.01 in or more	Point-Biserial	[d]	**0.050**	**2.015**	**0.044**	0.065	1.620	0.106	0.028	0.900	0.369
Temperature (°F)	Pearson	[d]	*-0.041*	*-1.670*	*0.095*	-0.025	-0.625	0.532	-0.050	-1.577	0.115
Less than 50°F	Point-Biserial	[d]	0.032	1.294	0.196	*0.070*	*1.762*	*0.078*	-0.005	-0.143	0.886
50–64°F	Point-Biserial	[d]	-0.006	-0.244	0.807	**-0.091**	**-2.289**	**0.022**	**0.068**	**2.158**	**0.031**
65–79°F	Point-Biserial	[d]	-0.002	-0.090	0.928	-0.022	-0.560	0.575	0.002	0.072	0.942
80°F or more	Point-Biserial	[d]	-0.040	-1.640	0.101	0.041	1.015	0.311	**-0.093**	**-2.941**	**0.003**
Day of week											
Weekday (Mon, Fri)	Point-Biserial	[d]	0.030	1.223	0.222	-0.014	-0.338	0.735	**0.098**	**3.130**	**0.002**
Weekday (Tue, Wed, Thu)	Point-Biserial	[d]	-0.030	-1.223	0.222	0.014	0.338	0.735	**-0.098**	**-3.130**	**0.002**
Time of day											
Morning (06:00-11:59)	Point-Biserial	[d]	-0.009	-0.366	0.714	0.039	0.975	0.330	-0.042	-1.326	0.185
Afternoon (12:00-17:59)	Point-Biserial	[d]	-0.023	-0.937	0.349	-0.041	-1.037	0.300	-0.011	-0.363	0.717
Evening/overnight (18:00-05:59)	Point-Biserial	[d]	*0.044*	*1.788*	*0.074*	0.007	0.166	0.868	**0.070**	**2.220**	**0.027**
AM peak hours (07:00-08:59)	Point-Biserial	[d]	0.019	0.774	0.439	0.046	1.158	0.247	-0.005	-0.170	0.865
PM peak hours (16:00-17:59)	Point-Biserial	[d]	**0.049**	**1.980**	**0.048**	0.035	0.873	0.383	*0.053*	*1.674*	*0.094*
Traffic signal status information											
Pedestrian signal status, pedestrian at conflict point											
Walk	Point-Biserial	[d]	-0.002	-0.068	0.946	-0.022	-0.549	0.583	**0.063**	**1.981**	**0.048**
Flashing don't walk	Point-Biserial	[d]	0.015	0.620	0.535	**0.095**	**2.375**	**0.018**	-0.037	-1.157	0.248
Steady don't walk	Point-Biserial	[d]	-0.036	-1.440	0.150	*-0.068*	*-1.712*	*0.087*	-0.044	-1.400	0.162
Crossing not signalized	Point-Biserial	[d]	0.024	0.983	0.326	-0.018	-0.455	0.649	0.006	0.179	0.858
Right-turn vehicle signal status, vehicle at conflict point											
Green	Point-Biserial	[d]	**-0.128**	**-5.210**	**0.000**	**-0.112**	**-2.819**	**0.005**	**-0.089**	**-2.839**	**0.005**
Yellow	Point-Biserial	[d]	0.009	0.372	0.710	0.056	1.408	0.160	-0.025	-0.802	0.423
Red	Point-Biserial	[d]	**0.124**	**5.058**	**0.000**	**0.114**	**2.860**	**0.004**	**0.111**	**3.545**	**0.000**
Right turn not signalized	Point-Biserial	[d]	0.024	0.983	0.326	-0.018	-0.455	0.649	0.006	0.179	0.858
Corner and intersection attributes											
Corner radius (ft)	Pearson	[d]	*0.048*	*1.928*	*0.054*	-0.031	-0.769	0.442	**0.072**	**2.270**	**0.023**
Crosswalk offset distance (ft) [a]	Pearson	[d]	**0.053**	**2.165**	**0.031**	-0.040	-1.005	0.315	**0.155**	**4.959**	**0.000**
Channelized right turn (distance not available)	Point-Biserial	[d]	0.026	1.068	0.286	-0.003	-0.069	0.945	-0.014	-0.433	0.665
Stop bar distance (ft) [b]	Pearson	[d]	0.018	0.714	0.476	-0.021	-0.516	0.606	**0.076**	**2.422**	**0.016**
Channelized right turn (distance not available)	Point-Biserial	[d]	0.026	1.068	0.286	-0.003	-0.069	0.945	-0.014	-0.433	0.665
Curb ramps (#)	Pearson	[d]	-0.022	-0.880	0.379	-0.063	-1.581	0.114	0.014	0.455	0.649
1	Point-Biserial	[d]	0.022	0.880	0.379	0.063	1.581	0.114	-0.014	-0.455	0.649
2	Point-Biserial	[d]	-0.022	-0.880	0.379	-0.063	-1.581	0.114	0.014	0.455	0.649
Curb ramp type											

Diagonal (apex)	Point-Biserial	d	0.018	0.712	0.477	**0.101**	**2.543**	**0.011**	-0.030	-0.965	0.335
Directional	Point-Biserial	d	-0.004	-0.156	0.876	**-0.083**	**-2.073**	**0.039**	0.024	0.770	0.441
Blended transition	Point-Biserial	d	-0.023	-0.943	0.346	-0.035	-0.882	0.378	0.012	0.388	0.698
Crosswalk type											
Standard markings	Point-Biserial	d	-0.011	-0.448	0.654	-0.053	-1.337	0.182	*0.061*	*1.945*	*0.052*
Continental (high-visibility) markings	Point-Biserial	d	0.014	0.547	0.584	0.053	1.337	0.182	*-0.057*	*-1.820*	*0.069*
No crossing	Point-Biserial	d	-0.038	-1.533	0.125	--	--	--	-0.047	-1.492	0.136
Right-turn lanes (#)	Pearson	d	**-0.050**	**-2.013**	**0.044**	0.012	0.305	0.761	**-0.113**	**-3.589**	**0.000**
0.5 (shared thru-right lane)	Point-Biserial	d	**0.068**	**2.762**	**0.006**	0.006	0.154	0.878	**0.111**	**3.528**	**0.000**
1	Point-Biserial	d	**-0.070**	**-2.831**	**0.005**	-0.017	-0.424	0.671	**-0.099**	**-3.138**	**0.002**
2	Point-Biserial	d	0.009	0.377	0.706	0.028	0.706	0.481	-0.040	-1.279	0.201
Receiving lanes (#)	Pearson	d	0.015	0.588	0.556	-0.020	-0.488	0.625	0.005	0.143	0.887
0	Point-Biserial	d	-0.015	-0.588	0.556	0.020	0.488	0.625	-0.005	-0.143	0.887
1	Point-Biserial	d	0.015	0.588	0.556	-0.020	-0.488	0.625	0.005	0.143	0.887
Channelized right turn	Point-Biserial	d	0.026	1.068	0.286	-0.003	-0.069	0.945	-0.014	-0.433	0.665
Skewed intersection	Point-Biserial	d	-0.003	-0.118	0.906	-0.045	-1.132	0.258	-0.016	-0.515	0.607
Presence of bicycle lane	Point-Biserial	d	-0.033	-1.356	0.175	0.057	1.431	0.153	**-0.120**	**-3.825**	**0.000**
AADP (100s)	Pearson	d	-0.040	-1.625	0.104	-0.017	-0.435	0.664	-0.025	-0.805	0.421
Natural log of AADP	Pearson	d	-0.029	-1.163	0.245	0.022	0.545	0.586	-0.017	-0.526	0.599
AADT (1000s)	Pearson	e	-0.026	-1.068	0.286	0.014	0.357	0.721	**-0.081**	**-2.568**	**0.010**
Natural log of AADT	Pearson	e	**-0.059**	**-2.382**	**0.017**	-0.007	-0.184	0.854	**-0.116**	**-3.682**	**0.000**
Right turn/crossing not signalized	Point-Biserial	d	0.024	0.983	0.326	-0.018	-0.455	0.649	0.006	0.179	0.858
On-ramp	Point-Biserial	d	0.003	0.136	0.892	-0.045	-1.136	0.256	0.001	0.047	0.962
Off-ramp	Point-Biserial	d	0.019	0.766	0.444	0.056	1.400	0.162	*-0.057*	*-1.810*	*0.071*
Neighborhood attributes [c]											
Population density (1,000 people per mi^2)	Pearson	e	**-0.054**	**-2.198**	**0.028**	-0.027	-0.666	0.506	-0.027	-0.856	0.392
Employment density (1,000 jobs per mi^2)	Pearson	e	**-0.062**	**-2.493**	**0.013**	-0.057	-1.432	0.153	*-0.055*	*-1.728*	*0.084*
Land use											
Residential (%)	Pearson	e	*0.046*	*1.841*	*0.066*	0.058	1.452	0.147	**0.070**	**2.228**	**0.026**
Commercial (%)	Pearson	e	-0.037	-1.501	0.134	-0.054	-1.348	0.178	-0.048	-1.511	0.131
Industrial (%)	Pearson	e	0.016	0.650	0.516	0.015	0.371	0.711	0.010	0.329	0.743
Vacant (%)	Pearson	e	0.031	1.240	0.215	-0.005	-0.119	0.905	0.026	0.816	0.415
Other (%)	Pearson	e	-0.001	-0.045	0.964	0.041	1.035	0.301	-0.032	-1.024	0.306
Street intersection density (# per mi^2)	Pearson	e	0.018	0.722	0.470	*-0.067*	*-1.666*	*0.096*	**0.101**	**3.198**	**0.001**
4-way intersections (%)	Pearson	e	**-0.078**	**-3.164**	**0.002**	-0.018	-0.456	0.648	**-0.109**	**-3.466**	**0.001**
Transit stops (#)	Pearson	e	-0.007	-0.289	0.773	0.042	1.059	0.290	-0.001	-0.029	0.977
Places of worship (#)	Pearson	e	-0.016	-0.646	0.518	0.063	1.582	0.114	-0.048	-1.507	0.132
Schools (#)	Pearson	e	0.003	0.106	0.916	**0.084**	**2.109**	**0.035**	**-0.077**	**-2.437**	**0.015**
Park (acres)	Pearson	e	-0.020	-0.825	0.409	0.008	0.212	0.832	-0.029	-0.921	0.357
Household income (median, $1,000s)	Pearson	e	0.013	0.533	0.594	0.061	1.519	0.129	**-0.071**	**-2.236**	**0.026**

Vehicle ownership (mean, cars/household)	Pearson	[e]	0.031	1.263	0.207	0.060	1.491	0.136	-0.004	-0.120	0.904
Household size (mean, people/household)	Pearson	[e]	**0.092**	**3.713**	**0.000**	0.051	1.285	0.199	**0.100**	**3.181**	**0.002**

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.
[d] df = 1638 for ET, 626 for pre-ET, 1000 for post-ET
[e] df = 1632 for ET, 623 for pre-ET, 997 for post-ET

Table 4.16 presents correlation results for the categorized version of ET: conflict severity. Here, key results will be summarized by comparing significant correlations across the conflict severity levels (low, mild, high). A positive correlation means a higher likelihood to have that level of conflict severity, while a negative correlation means a lower chance to have that conflict severity level.

Among pedestrian characteristics, a larger (natural log of) group size increased the chances of having a low-severity conflict, while conflicts for smaller group sizes were more likely to be of mild or high severity. High-severity conflicts were more likely in the presence of young adult pedestrians. For men, high-severity conflicts were more likely; while, for women, mild-severity conflicts were more likely and high-severity conflicts were less likely. The only significant correlations for other characteristics were that the presence of a bicycle decreased the chances of a low and increased the chances of a high-severity conflict. The first crosswalk tended to have more low-severity conflicts, while the second crosswalk had more high-severity conflicts. High-severity conflicts were more likely when leaving the curb, while mild-severity conflicts were more likely when approaching the curb. Conflict severity was lower when pedestrians had no obvious reaction but tended to be higher when pedestrians slowed down or had other reactions. There was no association between conflict severity and crossing location.

As for driver behaviors, low-severity conflicts were more common when drivers did not stop and/or had no obvious reaction, but mild- and high-severity conflicts were often more likely when drivers stopped (before the first crosswalk or inside/between the crosswalks), slowed down, or swerved. Only a few vehicle types were significant: low-severity conflicts were less likely in the presence of medium vehicles and more likely when large vehicles were present.

Regarding other level one variables (weather, time, signal status): high-severity conflicts were less likely during hours when it rained and/or had cold temperatures (below 50°F), but they were more likely as temperature increased. The only significant temporal conditions were that conflict severity tended to be lower during PM peak hours. Mild conflicts were less likely when the pedestrian was crossing on a walk signal. High-severity conflicts were more common when pedestrians were crossing on steady don’t walk or vehicles were turning right on green, but low-severity conflicts were more common when vehicles were turning right on red.

Just a few corner and intersection characteristics were significantly associated with conflict severity. Places with larger crosswalk offset distances tended to have more low-severity conflicts. Crossings with standard markings were more likely to have high-severity conflicts, while conflicts in crosswalks with continental (high-visibility) markings tended to be of medium severity (less likely to be high severity). Low-severity conflicts were somewhat less common as (the natural log of) traffic volume increased. Finally, when right turns were channelized and when the right turn and crossing were not signalized, mild conflicts were more likely and high-severity conflicts were less likely. No associations with conflict severity were found for other kinds of corner or intersection attributes: corner radius, stop bar distance, number and type of curb ramps, number of right-turn lanes and receiving lanes, skewed intersections, the presence of a bicycle lane, pedestrian traffic volumes, and on-/off-ramps.

Similarly, most neighborhood attributes—population density, all land use types, intersection density, percent 4-way intersections, transit stops, places of worship, schools, parks, household income, and vehicle ownership—were not significantly associated with conflict severity. Places with greater employment density tended to have fewer low- and more high-severity conflicts. Conversely, places in neighborhoods with higher average household sizes had more low- and fewer high-severity conflicts.

Table 4.16 Correlation results for conflict severity

Independent variable	*Test*	*df*	*Conflict severity: Low (6–10 sec)*			*Conflict severity: Mild (4–5 sec)*			*Conflict severity: High (0–3 sec)*		
			Corr	*t*	*p*	*Corr*	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics											
Group size (# people)	Point-Biserial	1638	0.013	0.508	0.612	-0.003	-0.131	0.896	-0.012	-0.477	0.633
Natural log of group size	Point-Biserial	1638	**0.049**	**1.977**	**0.048**	-0.024	-0.977	0.329	-0.033	-1.324	0.186
Age											
Child or teenager	Phi	1638	0.009	0.349	0.727	0.019	0.788	0.431	-0.033	-1.332	0.183
Child	Phi	1638	*0.042*	*1.693*	*0.091*	-0.031	-1.244	0.214	-0.017	-0.668	0.504
Teenager	Phi	1638	-0.001	-0.023	0.982	0.026	1.066	0.287	-0.029	-1.190	0.234
Adult	Phi	1638	0.006	0.234	0.815	-0.025	-1.009	0.313	0.021	0.864	0.388
Young adult	Phi	1638	-0.009	-0.382	0.702	*-0.048*	*-1.953*	*0.051*	**0.067**	**2.708**	**0.007**
Middle-aged adult	Phi	1638	0.004	0.158	0.875	0.025	1.021	0.307	-0.034	-1.362	0.173
Older adult (65+)	Phi	1638	0.036	1.460	0.145	-0.017	-0.679	0.497	-0.025	-1.026	0.305
Adult of unknown age	Phi	1638	0.004	0.161	0.872	0.012	0.472	0.637	-0.018	-0.739	0.460
Gender											
Male	Phi	1638	-0.037	-1.482	0.138	-0.038	-1.556	0.120	**0.089**	**3.622**	**0.000**
Female	Phi	1638	-0.002	-0.070	0.944	**0.057**	**2.291**	**0.022**	**-0.062**	**-2.533**	**0.011**
Unknown gender	Phi	1638	**0.061**	**2.469**	**0.014**	-0.018	-0.749	0.454	**-0.054**	**-2.192**	**0.029**
Other characteristics											
Carrying load	Phi	1638	0.038	1.550	0.121	-0.022	-0.897	0.370	-0.022	-0.889	0.374
Stroller or wheelchair	Phi	1638	0.040	1.636	0.102	-0.013	-0.519	0.604	-0.035	-1.427	0.154
Stroller	Phi	1638	*0.046*	*1.850*	*0.064*	-0.011	-0.449	0.653	*-0.044*	*-1.772*	*0.077*
Wheelchair	Phi	1638	0.002	0.063	0.949	-0.006	-0.259	0.796	0.005	0.217	0.828
Skateboard or scooter	Phi	1638	-0.012	-0.480	0.632	0.016	0.643	0.520	-0.004	-0.143	0.887
Skateboard	Phi	1638	-0.020	-0.819	0.413	0.026	1.038	0.299	-0.004	-0.175	0.861
Scooter	Phi	1638	-0.005	-0.197	0.844	0.002	0.062	0.950	0.004	0.172	0.864
Bicycle	Phi	1638	**-0.117**	**-4.748**	**0.000**	0.003	0.120	0.905	**0.141**	**5.747**	**0.000**
Distracted (phone, headphones, conversations, etc.)	Phi	1638	-0.002	-0.082	0.935	-0.010	-0.417	0.677	0.014	0.578	0.563
Crosswalk											
First crosswalk	Phi	1638	**0.097**	**3.950**	**0.000**	-0.010	-0.415	0.678	**-0.108**	**-4.409**	**0.000**
Second crosswalk	Phi	1638	**-0.097**	**-3.950**	**0.000**	0.010	0.415	0.678	**0.108**	**4.409**	**0.000**
Crossing location											
In the crosswalk or the crosswalk area	Phi	1638	-0.002	-0.073	0.942	0.004	0.179	0.858	-0.003	-0.115	0.909
Away from the crosswalk	Phi	1638	0.002	0.073	0.942	-0.004	-0.179	0.858	0.003	0.115	0.909
Mid-block, away from the crosswalk	Phi	1638	-0.004	-0.160	0.873	-0.014	-0.574	0.566	0.021	0.853	0.394
In the middle of the intersection	Phi	1638	0.010	0.393	0.694	0.014	0.586	0.558	-0.029	-1.156	0.248
Crossing direction											

Leaving curb	Phi	1638	-0.014	-0.582	0.560	**-0.053**	**-2.147**	**0.032**	**0.078**	**3.180**	**0.002**
Approaching curb	Phi	1638	0.014	0.582	0.560	**0.053**	**2.147**	**0.032**	**-0.078**	**-3.180**	**0.002**
Pedestrian reactions											
No obvious reaction	Phi	1638	**0.150**	**6.141**	**0.000**	*-0.043*	*-1.752*	*0.080*	**-0.136**	**-5.551**	**0.000**
Stopped or slowed	Phi	1638	**-0.072**	**-2.921**	**0.004**	0.013	0.540	0.589	**0.074**	**2.991**	**0.003**
Stopped and waited for the vehicle	Phi	1638	*-0.047*	*-1.917*	*0.055*	0.014	0.556	0.578	*0.043*	*1.732*	*0.084*
Slowed down to avoid collision	Phi	1638	**-0.071**	**-2.868**	**0.004**	0.001	0.057	0.954	**0.086**	**3.482**	**0.001**
Other reaction	Phi	1638	**-0.140**	**-5.736**	**0.000**	**0.049**	**2.004**	**0.045**	**0.117**	**4.761**	**0.000**
Sped up to avoid collision	Phi	1638	**-0.090**	**-3.653**	**0.000**	**0.065**	**2.638**	**0.008**	0.037	1.487	0.137
Ran to avoid collision	Phi	1638	**-0.057**	**-2.315**	**0.021**	-0.016	-0.637	0.524	**0.089**	**3.598**	**0.000**
Changed direction	Phi	1638	**-0.092**	**-3.729**	**0.000**	0.025	1.014	0.311	**0.085**	**3.441**	**0.001**
Driver and vehicle characteristics											
Right-turn queue length (# vehicles)	Point-Biserial	1638	**-0.049**	**-1.987**	**0.047**	0.032	1.291	0.197	0.024	0.976	0.329
Stopping location											
Did not stop	Phi	1638	**0.141**	**5.780**	**0.000**	**-0.103**	**-4.181**	**0.000**	**-0.057**	**-2.319**	**0.021**
Before the first crosswalk	Phi	1638	**-0.064**	**-2.613**	**0.009**	**0.059**	**2.407**	**0.016**	0.012	0.475	0.635
Inside/between the crosswalks	Phi	1638	**-0.111**	**-4.524**	**0.000**	**0.068**	**2.775**	**0.006**	**0.059**	**2.394**	**0.017**
Inside the first crosswalk	Phi	1638	**-0.077**	**-3.110**	**0.002**	**0.063**	**2.538**	**0.011**	0.023	0.936	0.350
Between the first and second crosswalks	Phi	1638	**-0.077**	**-3.120**	**0.002**	0.024	0.965	0.335	**0.068**	**2.747**	**0.006**
Driver reaction											
No obvious reaction	Phi	1638	**0.207**	**8.555**	**0.000**	**-0.110**	**-4.473**	**0.000**	**-0.130**	**-5.304**	**0.000**
Stopped or slowed	Phi	1638	**-0.211**	**-8.749**	**0.000**	**0.118**	**4.808**	**0.000**	**0.126**	**5.149**	**0.000**
Driver fully stopped	Phi	1638	**-0.169**	**-6.936**	**0.000**	**0.134**	**5.488**	**0.000**	**0.055**	**2.234**	**0.026**
Driver slowed down	Phi	1638	**-0.087**	**-3.549**	**0.000**	0.011	0.463	0.644	**0.095**	**3.856**	**0.000**
Other reaction	Phi	1638	0.007	0.291	0.771	-0.017	-0.689	0.491	0.011	0.428	0.668
Driver sped up	Phi	1638	0.022	0.872	0.383	-0.014	-0.570	0.569	-0.011	-0.426	0.670
Driver swerved	Phi	1638	**-0.054**	**-2.171**	**0.030**	-0.013	-0.531	0.595	**0.081**	**3.297**	**0.001**
Vehicle type											
Small	Phi	1638	*0.042*	*1.699*	*0.089*	-0.037	-1.490	0.136	-0.010	-0.395	0.693
Sedan	Phi	1638	0.038	1.541	0.123	-0.035	-1.432	0.152	-0.007	-0.267	0.789
Motorcycle	Phi	1638	0.035	1.415	0.157	-0.013	-0.531	0.595	-0.028	-1.141	0.254
Medium	Phi	1638	**-0.070**	**-2.834**	**0.005**	*0.048*	*1.941*	*0.052*	0.032	1.278	0.201
SUV	Phi	1638	-0.018	-0.719	0.472	0.015	0.587	0.557	0.005	0.217	0.828
Pickup truck	Phi	1638	*-0.043*	*-1.733*	*0.083*	0.028	1.143	0.253	0.021	0.833	0.405
Van (minivan, sprinter van, etc.)	Phi	1638	*-0.042*	*-1.699*	*0.089*	0.026	1.053	0.292	0.022	0.894	0.371
Large	Phi	1638	**0.070**	**2.859**	**0.004**	-0.029	-1.163	0.245	**-0.054**	**-2.198**	**0.028**
Large truck (semi-truck, delivery truck, etc.)	Phi	1638	*0.047*	*1.915*	*0.056*	-0.024	-0.992	0.322	-0.030	-1.230	0.219
Vehicle pulling a trailer	Phi	1638	0.019	0.764	0.445	-0.008	-0.324	0.746	-0.014	-0.574	0.566
Bus	Phi	1638	**0.057**	**2.329**	**0.020**	-0.016	-0.667	0.505	**-0.052**	**-2.113**	**0.035**
Weather and time information											

Weather											
Clear	Phi	1638	0.004	0.145	0.885	-0.008	-0.309	0.757	0.004	0.175	0.861
Rain (actively raining, or wet roadways)	Phi	1638	-0.004	-0.145	0.885	0.008	0.309	0.757	-0.004	-0.175	0.861
Hourly precipitation (in)	Point-Biserial	1638	*0.048*	*1.956*	*0.051*	-0.006	-0.224	0.822	**-0.053**	**-2.160**	**0.031**
0.01 in or more	Phi	1638	*0.042*	*1.693*	*0.091*	-0.004	-0.166	0.868	*-0.047*	*-1.902*	*0.057*
Temperature (°F)	Point-Biserial	1638	-0.025	-1.015	0.310	-0.018	-0.708	0.479	**0.051**	**2.065**	**0.039**
Less than 50°F	Phi	1638	0.010	0.387	0.699	0.040	1.606	0.108	**-0.057**	**-2.316**	**0.021**
50–64°F	Phi	1638	0.007	0.278	0.781	-0.033	-1.317	0.188	0.029	1.162	0.245
65–79°F	Phi	1638	0.006	0.253	0.801	-0.010	-0.387	0.699	0.003	0.130	0.896
80°F or more	Phi	1638	-0.035	-1.423	0.155	-0.004	-0.170	0.865	*0.048*	*1.953*	*0.051*
Day of week											
Weekday (Mon, Fri)	Phi	1638	*0.041*	*1.668*	*0.095*	-0.030	-1.211	0.226	-0.017	-0.676	0.499
Weekday (Tue, Wed, Thu)	Phi	1638	*-0.041*	*-1.668*	*0.095*	0.030	1.211	0.226	0.017	0.676	0.499
Time of day											
Morning (06:00-11:59)	Phi	1638	0.003	0.135	0.892	-0.022	-0.882	0.378	0.021	0.841	0.401
Afternoon (12:00-17:59)	Phi	1638	-0.032	-1.305	0.192	*0.047*	*1.916*	*0.056*	-0.014	-0.577	0.564
Evening/overnight (18:00-05:59)	Phi	1638	0.041	1.647	0.100	-0.038	-1.526	0.127	-0.007	-0.290	0.771
AM peak hours (07:00-08:59)	Phi	1638	0.023	0.923	0.356	-0.022	-0.887	0.375	-0.003	-0.126	0.900
PM peak hours (16:00-17:59)	Phi	1638	**0.051**	**2.062**	**0.039**	-0.003	-0.102	0.919	**-0.060**	**-2.432**	**0.015**
Traffic signal status information											
Pedestrian signal status, pedestrian at conflict point											
Walk	Phi	1638	*0.041*	*1.673*	*0.095*	**-0.057**	**-2.329**	**0.020**	0.015	0.593	0.553
Flashing don't walk	Phi	1638	-0.014	-0.568	0.570	0.038	1.551	0.121	-0.026	-1.070	0.285
Steady don't walk	Phi	1638	-0.037	-1.483	0.138	-0.006	-0.251	0.802	**0.052**	**2.121**	**0.034**
Crossing not signalized	Phi	1638	-0.003	-0.113	0.910	*0.047*	*1.894*	*0.058*	**-0.050**	**-2.026**	**0.043**
Right-turn vehicle signal status, vehicle at conflict point											
Green	Phi	1638	**-0.091**	**-3.702**	**0.000**	-0.004	-0.142	0.887	**0.117**	**4.749**	**0.000**
Yellow	Phi	1638	0.009	0.367	0.714	0.009	0.347	0.729	-0.021	-0.850	0.396
Red	Phi	1638	**0.101**	**4.113**	**0.000**	-0.031	-1.254	0.210	**-0.089**	**-3.637**	**0.000**
Right turn not signalized	Phi	1638	-0.003	-0.113	0.910	*0.047*	*1.894*	*0.058*	**-0.050**	**-2.026**	**0.043**
Corner and intersection attributes											
Corner radius (ft)	Point-Biserial	1638	0.027	1.100	0.272	0.004	0.174	0.862	-0.038	-1.559	0.119
Crosswalk offset distance (ft) [a]	Point-Biserial	1638	**0.064**	**2.607**	**0.009**	*-0.045*	*-1.821*	*0.069*	-0.028	-1.134	0.257
Channelized right turn (distance not available)	Phi	1638	-0.008	-0.319	0.749	**0.052**	**2.087**	**0.037**	**-0.049**	**-1.991**	**0.047**
Stop bar distance (ft) [b]	Point-Biserial	1638	0.031	1.265	0.206	-0.012	-0.478	0.633	-0.025	-1.016	0.310
Channelized right turn (distance not available)	Phi	1638	-0.008	-0.319	0.749	**0.052**	**2.087**	**0.037**	**-0.049**	**-1.991**	**0.047**
Curb ramps (#)	Point-Biserial	1638	0.005	0.205	0.838	-0.015	-0.625	0.532	0.011	0.462	0.644
1	Phi	1638	-0.005	-0.205	0.838	0.015	0.625	0.532	-0.011	-0.462	0.644
2	Phi	1638	0.005	0.205	0.838	-0.015	-0.625	0.532	0.011	0.462	0.644
Curb ramp type											

Diagonal (apex)	Phi	1638	0.001	0.030	0.976	-0.009	-0.365	0.715	0.009	0.380	0.704
Directional	Phi	1638	0.006	0.224	0.823	0.000	-0.004	0.997	-0.007	-0.271	0.786
Blended transition	Phi	1638	-0.010	-0.410	0.682	0.015	0.619	0.536	-0.005	-0.201	0.841
Crosswalk type											
Standard markings	Phi	1638	0.019	0.755	0.450	**-0.066**	**-2.687**	**0.007**	**0.053**	**2.135**	**0.033**
Continental (high-visibility) markings	Phi	1638	-0.017	-0.693	0.488	**0.067**	**2.734**	**0.006**	**-0.056**	**-2.265**	**0.024**
No crossing	Phi	1638	-0.024	-0.969	0.333	-0.017	-0.670	0.503	*0.048*	*1.964*	*0.050*
Right-turn lanes (#)	Point-Biserial	1638	*-0.044*	*-1.785*	*0.075*	0.023	0.944	0.345	0.028	1.124	0.261
0.5 (shared thru-right lane)	Phi	1638	*0.048*	*1.929*	*0.054*	-0.016	-0.663	0.507	-0.040	-1.624	0.105
1	Phi	1638	*-0.043*	*-1.745*	*0.081*	0.010	0.398	0.691	*0.042*	*1.701*	*0.089*
2	Phi	1638	-0.011	-0.459	0.646	0.020	0.791	0.429	-0.008	-0.337	0.736
Receiving lanes (#)	Point-Biserial	1638	0.007	0.290	0.772	0.007	0.269	0.788	-0.016	-0.666	0.506
0	Phi	1638	-0.007	-0.290	0.772	-0.007	-0.269	0.788	0.016	0.666	0.506
1	Phi	1638	0.007	0.290	0.772	0.007	0.269	0.788	-0.016	-0.666	0.506
Channelized right turn	Phi	1638	-0.008	-0.319	0.749	**0.052**	**2.087**	**0.037**	**-0.049**	**-1.991**	**0.047**
Skewed intersection	Phi	1638	-0.010	-0.415	0.678	0.014	0.570	0.569	-0.003	-0.139	0.890
Presence of bicycle lane	Phi	1638	-0.040	-1.604	0.109	0.017	0.707	0.480	0.029	1.173	0.241
AADP (100s)	Point-Biserial	1638	-0.038	-1.556	0.120	0.021	0.842	0.400	0.024	0.958	0.338
Natural log of AADP	Point-Biserial	1638	-0.021	-0.831	0.406	0.015	0.622	0.534	0.008	0.316	0.752
AADT (1000s)	Point-Biserial	1632	-0.035	-1.410	0.159	0.028	1.123	0.262	0.011	0.459	0.646
Natural log of AADT	Point-Biserial	1632	**-0.051**	**-2.082**	**0.037**	0.025	1.030	0.303	0.034	1.394	0.164
Right turn/crossing not signalized	Phi	1638	-0.003	-0.113	0.910	*0.047*	*1.894*	*0.058*	**-0.050**	**-2.026**	**0.043**
On-ramp	Phi	1638	-0.010	-0.401	0.689	0.028	1.130	0.259	-0.020	-0.796	0.426
Off-ramp	Phi	1638	-0.013	-0.506	0.613	0.028	1.151	0.250	-0.017	-0.690	0.490
Neighborhood attributes [c]											
Population density (1,000 people per mi ^{2})	Point-Biserial	1632	-0.023	-0.918	0.359	-0.002	-0.091	0.928	0.031	1.238	0.216
Employment density (1,000 jobs per mi ^{2})	Point-Biserial	1632	**-0.062**	**-2.511**	**0.012**	0.026	1.032	0.302	**0.047**	**1.920**	**0.055**
Land use											
Residential (%)	Point-Biserial	1632	0.040	1.621	0.105	-0.023	-0.947	0.344	-0.023	-0.921	0.357
Commercial (%)	Point-Biserial	1632	-0.027	-1.092	0.275	-0.001	-0.046	0.963	0.035	1.402	0.161
Industrial (%)	Point-Biserial	1632	0.004	0.168	0.867	-0.005	-0.212	0.832	0.001	0.035	0.972
Vacant (%)	Point-Biserial	1632	0.006	0.238	0.812	0.019	0.770	0.442	-0.029	-1.174	0.241
Other (%)	Point-Biserial	1632	-0.003	-0.119	0.905	0.030	1.207	0.227	-0.030	-1.232	0.218
Street intersection density (# per mi ^{2})	Point-Biserial	1632	0.033	1.351	0.177	-0.030	-1.192	0.233	-0.008	-0.306	0.759
4-way intersections (%)	Point-Biserial	1632	*-0.048*	*-1.930*	*0.054*	0.015	0.622	0.534	*0.041*	*1.672*	*0.095*
Transit stops (#)	Point-Biserial	1632	0.004	0.159	0.874	0.001	0.030	0.976	-0.006	-0.230	0.818
Places of worship (#)	Point-Biserial	1632	-0.025	-1.024	0.306	0.034	1.361	0.174	-0.007	-0.290	0.772
Schools (#)	Point-Biserial	1632	-0.011	-0.456	0.649	*0.042*	*1.708*	*0.088*	-0.034	-1.386	0.166
Park (acres)	Point-Biserial	1632	-0.034	-1.386	0.166	0.001	0.060	0.952	0.041	1.644	0.100
Household income (median, $1,000s)	Point-Biserial	1632	-0.030	-1.229	0.219	*0.043*	*1.732*	*0.083*	-0.011	-0.458	0.647

Vehicle ownership (mean, cars/household)	Point-Biserial	1632	0.025	0.992	0.321	-0.021	-0.862	0.389	-0.006	-0.240	0.810
Household size (mean, people/household)	Point-Biserial	1632	**0.070**	**2.854**	**0.004**	-0.004	-0.162	0.871	**-0.082**	**-3.342**	**0.001**

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.

4.3.2.2 Multivariate Regression Results

Table 4.17 reports the result of the multilevel model for encroachment time. Since the dependent variable was continuous, this was a linear model with a random intercept term. Coefficient estimates (Est.) represent the expected change in ET for a one unit increase in the relevant variable. Recall that a higher (more positive) value reflects more time given between the road users (less severe conflict), while a lower (less positive) value reflects less time and a more severe conflict.

Statistically significant positive associations were found between encroachment time and (the natural log of) group size, the first crosswalk, a pedestrian approaching the curb, large vehicle type, evening peak hour, and red right-turn vehicle signal status. Negative associations were found for people using bicycles, the right-turn queue length, and a pedestrian crossing when the signal status was steady don't walk. These findings mean that ET was longer when more pedestrians were crossing the street (an increase of 0.21 sec for each doubling of the group size) but 0.84 sec shorter when the crosswalk user was riding a bicycle. Conflicts in the first crosswalk had longer ETs (by 0.54 sec) than conflicts in the second crosswalk. Similarly, the ET was about 0.19 sec longer when pedestrians were approaching the curb than when they were leaving it. On average, the ET was shorter when more vehicles were waiting to turn right (-0.08 sec/vehicle, or 0.5 sec less for six waiting vehicles) and 0.92 sec longer when the right-turning vehicle was large. ET was also longer by 0.23 sec when pedestrians were crossing during evening peak hours (4-6 PM) compared to other times of day. When pedestrians were crossing on steady don't walk, ETs were around 0.54 sec shorter (vs. walk or flashing don't walk), while ETs were around 0.53 sec longer when the vehicle turned right on red (vs. green or yellow). None of the intersection-level variables were revealed to have a significant association with ET in the multilevel model.

Table 4.17 Regression results for encroachment time

Variable	*Est.*	*SE*	*df*	*t*	*p*
Intercept (SD = 0.375)	5.347	0.143	83	37.472	<0.001
Natural log of group size (# people)	0.309	0.124	1430	2.504	0.012
Other characteristics: Bicycle	-0.833	0.159	1570	-5.227	<0.001
Crosswalk: First crosswalk	0.544	0.197	417	2.760	0.006
Crossing direction: Approaching curb	0.191	0.116	1617	1.650	0.099
Right-turn queue length (# vehicles)	-0.084	0.037	952	-2.282	0.023
Vehicle type: Large	0.923	0.279	1620	3.312	<0.001
Time of day: PM peak hours (16:00-17:59)	0.273	0.140	1525	1.954	0.051
Pedestrian signal status: Steady don't walk	-0.535	0.174	1574	-3.080	0.002
Right-turn vehicle signal status: Red	0.525	0.184	1096	2.855	0.004

N (level 1) = 1,633; N (level 2) = 33.
LL (model) = -3,624.0; LL (intercept only) = -3,675.6; McFadden's pseudo-R^2 = 0.014.

Table 4.18 shows the estimates of a similar multilevel model but for pre-encroachment time, representing just those events where the vehicle passed the conflict point sometime in the ten seconds before the pedestrian(s). Many results were quite similar to the overall ET model. Pre-ET was positively associated with the first crosswalk, a pedestrian approaching the curb, large vehicle type, and red right-turn vehicle signal status; and it was negatively associated with people using bicycles. Other variables were no longer significant (group size, right-turn queue length, time of day, pedestrian signal status), and some variables were newly significant. Pedestrians identified as female experienced longer pre-ETs (0.36 sec, on average), while pre-ET was about 0.40 sec shorter when the temperature was between 50–64°F. The impacts of crossing direction and vehicle type were stronger for pre-ET than overall ET—1.1 sec longer when approaching curb than leaving it (was +0.2 sec); 1.7 sec longer for large vehicles (was +0.9 sec)—while the impact of a bicycle user was weaker (0.51 sec shorter pre-ET). Like ET, none of the intersection-level variables had a significant association with pre-ET.

Table 4.18 Regression results for pre-encroachment time

Variable	*Est.*	*SE*	*df*	*t*	*p*
Intercept (SD = 0.104)	5.328	0.171	42	31.246	<0.001
Gender: Female	0.356	0.203	345	1.756	0.080
Other characteristics: Bicycle	-0.513	0.244	502	-2.105	0.036
Crosswalk: First crosswalk	0.711	0.231	144	3.077	0.003
Crossing direction: Approaching curb	1.130	0.183	607	6.171	<0.001
Vehicle type: Large	1.690	0.421	521	4.015	<0.001
Temperature: 50–64°F	-0.397	0.228	123	-1.743	0.084
Right-turn vehicle signal status: Red	0.465	0.220	345	2.115	0.035

N (level 1) = 625; N (level 2) = 33.
LL (model) = -1,378.5; LL (intercept only) = -1,417.4; McFadden's pseudo-R^2 = 0.027.

Table 4.19 contains results of the same kind of model for post-encroachment time, when vehicles passed the conflict point in the ten seconds after the pedestrian. Again, there were quite a few similar results as for ET overall. Post-ET was positively associated with (the natural log of) group size and red right-turn vehicle signal status; and it was negatively associated with people using bicycles and for conflicts when the pedestrian signal status was steady don't walk. There were also several new results. As with bicycles, people using a skateboard or scooter had shorter pre-ETs (by 0.92 sec). Additionally, events with pedestrian(s) crossing the street on flashing don't walk had about 0.35 sec shorter post-ET than those crossing the street on walk. Interestingly, and contrary to the results for pre-ET, when the pedestrian was approaching the curb, on average they experienced about 0.37 sec shorter post-ET than if they were leaving the curb. (Recall, pre-ET was longer for pedestrians approaching the curb.) This time, the only significant location variable was crosswalk offset distance: at corners with more lateral or sideways distance between the lane and the second crosswalk, the post-ET was a little bit longer (about 0.4 sec more per 12 ft).

Table 4.19 Regression results for post-encroachment time

Variable	*Est.*	*SE*	*df*	*t*	*p*
Intercept (SD = 0.632)	5.172	0.200	26	25.883	<0.001
Natural log of group size (# people)	0.349	0.144	980	2.417	0.016
Other characteristics: Skateboard or scooter	-0.915	0.332	976	-2.756	0.006
Other characteristics: Bicycle	-1.124	0.192	987	-5.846	<0.001
Crossing direction: Approaching curb	-0.368	0.146	989	-2.515	0.012
Pedestrian signal status: Flashing don't walk	-0.354	0.168	906	-2.106	0.035
Pedestrian signal status: Steady don't walk	-0.796	0.244	988	-3.258	0.001
Right-turn vehicle signal status: Red	0.767	0.203	953	3.785	<0.001
Crosswalk offset distance (ft)	0.033	0.014	18	2.463	0.024

N (level 1) = 998; N (level 2) = 31.
LL (model) = -2,112.1; LL (intercept only) = -2,171.2; McFadden's pseudo-R^2 = 0.027.

Table 4.20 reports the results of the multilevel model for conflict severity. Given that the dependent variable was an ordered categorical variable (low < mild < high), this was an ordinal logit model with a random intercept term. In ordered logit models, the scale of the coefficient estimates is not directly interpretable. Instead, one can interpret the odds ratio (OR)—calculated as $e^{Est.}$—as the amount the odds of being in a higher category (vs. a lower category) would be multiplied by given a one unit increase in the relevant variable. In this instance, negative estimates (Est.) and odds ratios (OR) less than 1 imply greater chance for a less severe conflict, while positive estimates and OR > 1 imply greater chance for a more severe conflict. (Recall this is opposite to the interpretation of the (pre-/post-) encroachment time models.)

Several variables were negatively associated with conflict severity: (the natural log of) group size, stroller or wheelchair, large vehicle type, measurable hourly precipitation, PM peak hour, red right-turn vehicle signal status, crosswalk offset distance, and household size. Conversely, variables positively associated with conflict severity were: bicycle, right-turn queue length, and steady don't walk pedestrian signal status. Most of these results match findings from the earlier encroachment time models. Conflicts tended to be less severe when more pedestrians were in the group and fewer vehicles were waiting to turn right. Large vehicles increased the chances of a less severe conflict, while bicycle riders and pedestrians crossing on steady don't walk tended to be involved in more severe conflicts. Conflicts during evening peak hours and involving vehicles turning right on red were generally less severe. Similarly, conflicts in locations with larger households and more sideways crosswalk offset distance also tended to be less severe. Among the newly significant factors were that conflicts tended to be less severe when there was measurable precipitation or the user was in a wheelchair or pushing a stroller.

Table 4.20 Regression results for conflict severity

Variable	*Est.*	*SE*	z	*p*	*OR*
Threshold: Low (6-10 sec) vs. Mild (4-5 sec)	-1.258	0.419	-3.001	0.003	--
Threshold: Mild (4-5 sec) vs. High (0-3 sec)	0.242	0.420	0.576	0.565	--
Natural log of group size (# people)	-0.179	0.108	-1.665	0.096	0.836
Other characteristics: Stroller or wheelchair	-1.074	0.540	-1.988	0.047	0.342
Other characteristics: Bicycle	0.756	0.136	5.560	<0.001	2.130
Right-turn queue length (# vehicles)	0.068	0.031	2.208	0.027	1.070
Vehicle type: Large	-0.743	0.260	-2.853	0.004	0.476
Hourly precipitation: 0.01 in or more	-0.581	0.348	-1.670	0.095	0.559
Time of day: PM peak hours (16:00-17:59)	-0.319	0.122	-2.604	0.009	0.727
Pedestrian signal status: Steady don't walk	0.514	0.150	3.431	<0.001	1.671
Right-turn vehicle signal status: Red	-0.652	0.129	-5.054	<0.001	0.521
Crosswalk offset distance (ft)	-0.013	0.007	-2.012	0.044	0.987
Household size (mean, people/household)	-0.353	0.137	-2.573	0.010	0.702

N (level 1) = 1,633; N (level 2) = 33. Intercept SD = 0.186.
LL (model) = -1,636.8; LL (intercept only) = -1,697.0; McFadden's pseudo-R^2 = 0.035.

4.3.2.3 Summary

Table 4.21 summarizes the significant factors identified in the bivariate and multivariate analyses of ET (overall) and conflict severity. Table 4.22 summarizes the significant factors identified in the bivariate and multivariate analyses of pre-ET and post-ET.

Table 4.21 Summary of results for encroachment time and conflict severity

*ET**	*Conflict severity**
Negative	Positive
• **Other characteristics: Bicycle**	• **Other characteristics: Bicycle**
• *Pedestrian reaction: Stopped or slowed*	• *Pedestrian reaction: Stopped or slowed*
• *Pedestrian reaction: Other reaction*	• *Pedestrian reaction: Other reaction*
• **Right-turn queue length (# vehicles)**	• **Right-turn queue length (# vehicles)**
• *Stopping location: Before the first crosswalk*	• *Stopping location: Before the first crosswalk*
• *Stopping location: Inside/between the crosswalks*	• *Stopping location: Inside/between the crosswalks*
• *Driver reaction: Stopped or slowed.*	• *Driver reaction: Stopped or slowed*
• Vehicle type: Medium	• Vehicle type: Medium
• Pedestrian signal status: Steady don't walk	• Temperature
• Natural log of AADT	• **Pedestrian signal status: Steady don't walk**
• Population density (people per mi^2)	• Natural log of AADT
• Employment density (jobs per mi^2)	• Employment density (jobs per mi^2)
• 4-way intersections (%)	
Positive	Negative
• **Natural log of group size (# people)**	• **Natural log of group size (# people)**
• **Crosswalk: First crosswalk**	• Gender: Female
• Crossing direction: Approaching curb	• Other characteristics: Stroller or wheelchair
• **Vehicle type: Large**	• Crosswalk: First crosswalk
• Hourly precipitation: 0.01 in or more	• Crossing direction: Approaching curb
• **Time ofday: PM peak hours (16:00-17:59)**	• **Vehicle type: Large**
• **Right-turn vehicle signal status: Red**	• **Hourly precipitation: 0.01 in or more**
• Crosswalk offset distance	• **Time of day: PM peak hours (16:00-17:59)**
• Right-turn lanes: 0.5 (shared thru-right lane)	• **Right-turn vehicle signal status: Red**
• Household size (mean, people/household)	• **Crosswalk offset distance**
	• Crosswalk type: Continental markings
	• Channelized right turn
	• Right turn/crossing not signalized
	• **Household size (mean, people/household)**

* A negative association for ET and a positive association for conflict severity means a shorter time difference between road users in the same location, thus a more severe conflict. A positive association for ET and a negative association for conflict severity means a longer time difference and a less severe conflict.
Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

Table 4.22 Summary of results for pre-/post-encroachment time

*Pre-ET**	*Post-ET**
Negative • **Other characteristics: Bicycle** • *Pedestrian reaction: Stopped or slowed* • **Temperature: 50–64°F** • Curb ramp type: Directional	Negative • Other characteristics: Skateboard or scooter • **Other characteristics: Bicycle** • **Crossing direction: Approaching curb** • *Pedestrian reaction: Other reaction* • *Stopping location: Before the first crosswalk* • *Stopping location: Inside/between the crosswalks* • *Driver reaction: Stopped or slowed.* • Pedestrian signal status: Flashing don't walk • Pedestrian signal status: Steady don't walk • Temperature: 80°F or more • Presence of bicycle lane • Natural log of AADT • 4-way intersections (%) • Schools (#) • Household income (median)
Positive • Natural log of group size (# people) • **Gender: Female** • **Crosswalk: First crosswalk** • **Crossing direction: Approaching curb** • Right-turn queue length (# vehicles) • **Vehicle type: Large** • Pedestrian signal status: Flashing don't walk • **Right-turn vehicle signal status: Red** • Schools (#)	Positive • Natural log of group size (# people) • Other characteristics: Carrying load • Crosswalk: First crosswalk • Temperature: 50–64°F • Day of week: Weekday (Mon, Fri) • Time of day: Evening/overnight (18:00-05:59) • **Right-turn vehicle signal status: Red** • Corner radius • **Crosswalk offset distance** • Stop bar distance • Right-turn lanes: 0.5 (shared thru-right lane) • Land use: Residential (%) • Street intersection density (# per mi^2) • Household size (mean, people/household)

* A negative association for pre-/post-ET means a shorter time difference between road users in the same location, thus a more severe conflict. A positive association for pre-/post-ET means a longer time difference and a less severe conflict.
Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

4.3.3 Pedestrian Reaction

As part of the observational data collection, the research team also measured any pedestrian reactions to the conflict: no obvious reaction, stopped and waited for the vehicle, slowed down to avoid collision, sped up to avoid collision, ran to avoid collision, and/or changed direction. These behaviors may reflect actions taken (or not taken) to avoid a collision with a motor vehicle. However, the relationship between these pedestrian reactions and the conflict itself is complex: While it is assumed that most of them are reactions to the conflict—a conflict was imminent, so the pedestrian changed their behavior (implying the conflict caused the reaction)—the pedestrian reaction likely changed (perhaps increased) the measured encroachment time (implying the reaction changed the measure of a conflict). Because of this complexity, the research team decided to analyze pedestrian reactions separately from encroachment time and conflict severity. Also, due to small sample sizes (see Figure 4.1), researchers grouped pedestrian reactions into three categories when performing the bivariate and multivariate statistical analyses presented in the following subsections:

- *No obvious reaction* was recorded for nearly 87% of pedestrian events.
- Researchers combined "stopped and waited for the vehicle" and "slowed down to avoid collision" into a single category. Around 8% of pedestrian events involved a *stopped or slowed* reaction.
- *Other reaction* included "sped up to avoid collision," "ran to avoid collision," and "changed direction," and was recorded for only around 5% of pedestrian events.

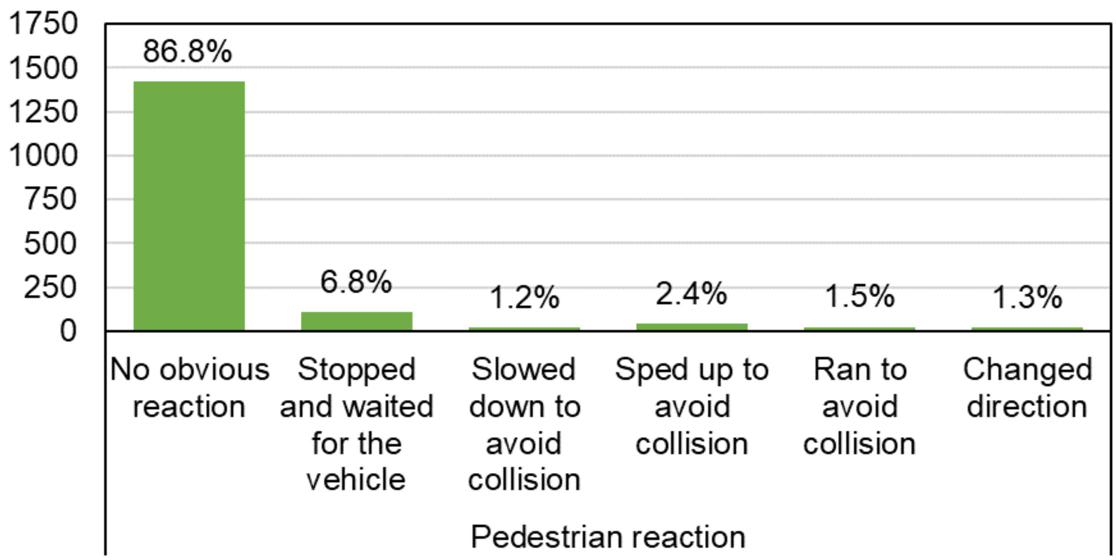

Figure 4.1 Pedestrian reaction

4.3.3.1 Bivariate Correlation Results

Table 4.23 reports results of the correlation analysis for pedestrian reactions. Given the categorical nature of the dependent variable (pedestrian reaction), positive/negative correlations imply a greater/lesser chance of having that kind of reaction, respectively.

A few pedestrian characteristics were significantly associated with pedestrian reactions. Age was a significant factor: no reaction was more likely for adults and less likely for children or teens; while other reactions were more likely for children/teens and less likely for adults. While men were more likely to have no reaction and less likely to stop or slow, the results were only marginally significant. People bicycling were less likely to have some other reaction. Compared to no reaction, stopping or slowing was more common in the first crosswalk and when leaving the curb, and less common in the second crosswalk and when approaching the curb. Some other reaction was more common when approaching the curb. Among crossing locations, other reactions were more common when pedestrians were crossing mid-block. There was no association between pedestrian reaction and group size.

Considering driver and vehicle characteristics, when the right-turn queue length was longer, stopping or slowing was a less common pedestrian reaction than no reaction or some other reaction. When drivers did not stop, pedestrians were more likely to stop or slow down. Conversely, when drivers stopped inside or between the crosswalks, pedestrians were more likely to have some other reaction. Unsurprisingly, pedestrian reactions and driver reactions were strongly linked. Pedestrians were more likely to have no reaction when drivers also had no obvious reaction. Pedestrians stopping or slowing were positively linked to drivers speeding up or swerving. When drivers stopped or slowed, pedestrians were more likely to have some other reaction (sped up, ran, or changed direction). In general, pedestrian reactions didn’t tend to significantly differ according to vehicle type (small, medium, or large).

Since pedestrian reactions are linked to conflicts, it is not surprising that conflict information was significantly correlated with pedestrian reactions. Pedestrians having no reactions tended to experience larger ETs and lower-severity conflicts. Conversely, pedestrians stopping, slowing, or having other reactions tended to experience shorter ETs (fewer low- and more high-severity conflicts).

When it was raining or the ground was wet, pedestrians were more likely to stop/slow (and less likely to have no reaction) than when the weather was clear. No reaction was more likely as temperature increased: having some other reaction was more likely during cold temperatures (below 50°F) and less likely during warmer temperatures (65°F and above). Day of week and time of day were not associated with pedestrian reactions. It also makes sense that pedestrian reactions were significantly linked to pedestrian and vehicle signal statuses. No obvious reaction was more common when pedestrians were crossing on walk or flashing don’t walk, and when vehicles were turning right on green. Conversely, stopping or slowing was a more common pedestrian reaction when pedestrians were crossing on steady don’t walk and when drivers were turning right on red.

Pedestrian reactions were significantly associated with several corner and intersection attributes. Stopping/slowing was more common at intersections with larger corner radii, continental crosswalk markings, shared thru-right or two right-turn lanes, a receiving lane, a channelized right turn, a skewed intersection configuration, larger motor vehicle traffic volumes, on-ramps and off-ramps, and where the right turn/crossing was not signalized. Other pedestrian reactions were more common at locations with continental crosswalk markings, a channelized right turn, a skewed intersection, and where the right turn/crossing was not signalized. No obvious reaction was more common in places with larger crosswalk offset distances, larger stop bar distances, two curb ramps, standard crosswalk markings, one right-turn lane, and higher pedestrian volumes. There were no significant associations with curb ramp type or the presence of a bicycle lane.

Several neighborhood characteristics were also significantly associated with pedestrian reactions. No obvious reaction was more common in places with greater population density and more transit stops; while other pedestrian reactions were more common in locations with more places of worship and higher median household incomes. Stopping/slowing was more common in places with more vacant land uses, more and larger parks, higher income households, and larger household sizes.

Table 4.23 Correlation results for pedestrian reaction

Independent variable	*Test*	*df*	*Pedestrian reaction: No obvious reaction*			*Pedestrian reaction: Stopped or slowed*			*Pedestrian reaction: Other reaction*		
			Corr	*t*	*p*	*Corr*	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics											
Group size (# people)	Point-Biserial	1638	0.021	0.832	0.405	-0.024	-0.976	0.329	-0.002	-0.080	0.936
Natural log of group size	Point-Biserial	1638	-0.008	-0.323	0.747	-0.018	-0.735	0.462	0.034	1.381	0.167
Age											
Child or teenager	Phi	1638	**-0.078**	**-3.180**	**0.002**	0.002	0.090	0.929	**0.116**	**4.733**	**0.000**
Child	Phi	1638	**-0.087**	**-3.515**	**0.000**	*0.047*	*1.889*	*0.059*	**0.075**	**3.035**	**0.002**
Teenager	Phi	1638	**-0.053**	**-2.167**	**0.030**	-0.010	-0.402	0.688	**0.093**	**3.786**	**0.000**
Adult	Phi	1638	**0.057**	**2.313**	**0.021**	0.014	0.554	0.579	**-0.103**	**-4.198**	**0.000**
Young adult	Phi	1638	0.027	1.094	0.274	-0.026	-1.039	0.299	-0.010	-0.400	0.690
Middle-aged adult	Phi	1638	**0.114**	**4.634**	**0.000**	**-0.075**	**-3.025**	**0.003**	**-0.082**	**-3.341**	**0.001**
Older adult (65+)	Phi	1638	**0.063**	**2.561**	**0.011**	*-0.048*	*-1.927*	*0.054*	-0.038	-1.545	0.123
Adult of unknown age	Phi	1638	**-0.160**	**-6.578**	**0.000**	**0.181**	**7.463**	**0.000**	0.024	0.956	0.339
Gender											
Male	Phi	1638	*0.048*	*1.940*	*0.052*	*-0.047*	*-1.886*	*0.059*	-0.016	-0.657	0.511
Female	Phi	1638	0.016	0.667	0.505	-0.036	-1.441	0.150	0.018	0.734	0.463
Unknown gender	Phi	1638	**-0.094**	**-3.823**	**0.000**	**0.113**	**4.595**	**0.000**	0.006	0.241	0.810
Other characteristics											
Carrying load	Phi	1638	0.002	0.063	0.949	0.013	0.520	0.603	-0.018	-0.726	0.468
Stroller or wheelchair	Phi	1638	0.020	0.822	0.411	-0.006	-0.249	0.803	-0.023	-0.945	0.345
Stroller	Phi	1638	0.012	0.497	0.619	0.001	0.052	0.958	-0.020	-0.818	0.414
Wheelchair	Phi	1638	0.019	0.780	0.436	-0.015	-0.587	0.557	-0.012	-0.471	0.638
Skateboard or scooter	Phi	1638	0.018	0.723	0.470	0.003	0.108	0.914	-0.030	-1.228	0.220
Skateboard	Phi	1638	0.009	0.369	0.712	0.002	0.091	0.927	-0.017	-0.671	0.502
Scooter	Phi	1638	0.007	0.301	0.763	0.012	0.504	0.614	-0.026	-1.068	0.286
Bicycle	Phi	1638	0.027	1.104	0.270	0.009	0.384	0.701	**-0.053**	**-2.142**	**0.032**
Distracted (phone, headphones, conversations, etc.)	Phi	1638	-0.030	-1.198	0.231	0.002	0.095	0.925	*0.042*	*1.704*	*0.089*
Crosswalk											
First crosswalk	Phi	1638	**-0.077**	**-3.127**	**0.002**	**0.103**	**4.180**	**0.000**	-0.008	-0.310	0.756
Second crosswalk	Phi	1638	**0.077**	**3.127**	**0.002**	**-0.103**	**-4.180**	**0.000**	0.008	0.310	0.756
Crossing location											
In the crosswalk or the crosswalk area	Phi	1638	-0.002	-0.083	0.934	0.037	1.493	0.136	*-0.042*	*-1.684*	*0.092*
Away from the crosswalk	Phi	1638	0.002	0.083	0.934	-0.037	-1.493	0.136	*0.042*	*1.684*	*0.092*
Mid-block, away from the crosswalk	Phi	1638	-0.019	-0.780	0.436	-0.027	-1.087	0.277	**0.062**	**2.504**	**0.012**
In the middle of the intersection	Phi	1638	0.035	1.410	0.159	-0.026	-1.062	0.288	-0.021	-0.851	0.395
Crossing direction											

Leaving curb	Phi	1638	**-0.069**	**-2.814**	**0.005**	**0.128**	**5.240**	**0.000**	**-0.050**	**-2.042**	**0.041**
Approaching curb	Phi	1638	**0.069**	**2.814**	**0.005**	**-0.128**	**-5.240**	**0.000**	**0.050**	**2.042**	**0.041**
Driver and vehicle characteristics											
Right-turn queue length (# vehicles)	Point-Biserial	1638	**0.079**	**3.201**	**0.001**	**-0.162**	**-6.646**	**0.000**	**0.077**	**3.117**	**0.002**
Stopping location											
Did not stop	Phi	1638	0.012	0.502	0.616	**0.070**	**2.839**	**0.005**	**-0.104**	**-4.216**	**0.000**
Before the first crosswalk	Phi	1638	0.005	0.187	0.852	-0.026	-1.061	0.289	0.025	1.001	0.317
Inside/between the crosswalks	Phi	1638	-0.020	-0.803	0.422	**-0.061**	**-2.456**	**0.014**	**0.104**	**4.212**	**0.000**
Inside the first crosswalk	Phi	1638	-0.030	-1.229	0.219	*-0.044*	*-1.763*	*0.078*	**0.099**	**4.019**	**0.000**
Between the first and second crosswalks	Phi	1638	0.012	0.475	0.635	-0.039	-1.589	0.112	0.030	1.205	0.229
Driver reaction											
No obvious reaction	Phi	1638	**0.133**	**5.446**	**0.000**	*-0.046*	*-1.864*	*0.063*	**-0.147**	**-5.997**	**0.000**
Stopped or slowed	Phi	1638	**-0.093**	**-3.765**	**0.000**	-0.016	-0.638	0.523	**0.160**	**6.544**	**0.000**
Driver fully stopped	Phi	1638	**-0.058**	**-2.366**	**0.018**	**-0.050**	**-2.042**	**0.041**	**0.150**	**6.124**	**0.000**
Driver slowed down	Phi	1638	**-0.053**	**-2.144**	**0.032**	0.029	1.162	0.245	*0.045*	*1.843*	*0.066*
Other reaction	Phi	1638	**-0.096**	**-3.902**	**0.000**	**0.143**	**5.852**	**0.000**	-0.028	-1.129	0.259
Driver sped up	Phi	1638	**-0.070**	**-2.844**	**0.005**	**0.119**	**4.869**	**0.000**	-0.038	-1.555	0.120
Driver swerved	Phi	1638	**-0.109**	**-4.450**	**0.000**	**0.107**	**4.339**	**0.000**	0.037	1.483	0.138
Vehicle type											
Small	Phi	1638	-0.016	-0.635	0.525	0.034	1.382	0.167	-0.018	-0.710	0.478
Sedan	Phi	1638	-0.018	-0.734	0.463	0.036	1.458	0.145	-0.016	-0.652	0.515
Motorcycle	Phi	1638	0.022	0.872	0.383	-0.016	-0.657	0.511	-0.013	-0.527	0.599
Medium	Phi	1638	0.008	0.319	0.750	-0.027	-1.091	0.275	0.021	0.838	0.402
SUV	Phi	1638	-0.035	-1.429	0.153	0.023	0.931	0.352	0.026	1.039	0.299
Pickup truck	Phi	1638	*0.042*	*1.696*	*0.090*	*-0.042*	*-1.689*	*0.091*	-0.013	-0.526	0.599
Van (minivan, sprinter van, etc.)	Phi	1638	0.021	0.831	0.406	-0.035	-1.428	0.153	0.012	0.470	0.639
Large	Phi	1638	0.019	0.759	0.448	-0.017	-0.669	0.504	-0.008	-0.341	0.733
Large truck (semi-truck, delivery truck, etc.)	Phi	1638	0.008	0.319	0.750	-0.020	-0.819	0.413	0.013	0.508	0.611
Vehicle pulling a trailer	Phi	1638	**0.048**	**1.963**	**0.050**	-0.037	-1.478	0.139	-0.029	-1.185	0.236
Bus	Phi	1638	-0.031	-1.269	0.204	0.037	1.491	0.136	0.003	0.119	0.906
Conflict information											
Encroachment time (sec)	Point-Biserial	1638	**0.165**	**6.770**	**0.000**	**-0.080**	**-3.251**	**0.001**	**-0.153**	**-6.276**	**0.000**
Pre-ET (sec), vehicle before pedestrian	Point-Biserial	626	**0.290**	**7.572**	**0.000**	**-0.274**	**-7.128**	**0.000**	*-0.076*	*-1.917*	*0.056*
Post-ET (sec), vehicle after pedestrian	Point-Biserial	1000	**0.124**	**3.951**	**0.000**	0.022	0.700	0.484	**-0.145**	**-4.619**	**0.000**
Conflict severity											
Low (5-10 sec)	Phi	1638	**0.150**	**6.141**	**0.000**	**-0.072**	**-2.921**	**0.004**	**-0.140**	**-5.736**	**0.000**
Mild (4-5 sec)	Phi	1638	*-0.043*	*-1.752*	*0.080*	0.013	0.540	0.589	**0.049**	**2.004**	**0.045**
High (0-3 sec)	Phi	1638	**-0.136**	**-5.551**	**0.000**	**0.074**	**2.991**	**0.003**	**0.117**	**4.761**	**0.000**
Weather and time information											
Weather											

Clear	Phi	1638	**0.102**	**4.134**	**0.000**	**-0.095**	**-3.849**	**0.000**	-0.039	-1.597	0.110
Rain (actively raining, or wet roadways)	Phi	1638	**-0.102**	**-4.134**	**0.000**	**0.095**	**3.849**	**0.000**	0.039	1.597	0.110
Hourly precipitation (in)	Point-Biserial	1638	-0.003	-0.129	0.898	-0.019	-0.764	0.445	0.028	1.121	0.262
0.01 in or more	Phi	1638	-0.002	-0.062	0.950	-0.014	-0.574	0.566	0.020	0.790	0.430
Temperature (°F)	Point-Biserial	1638	**0.099**	**4.025**	**0.000**	**-0.055**	**-2.246**	**0.025**	**-0.083**	**-3.370**	**0.001**
Less than 50°F	Phi	1638	**-0.084**	**-3.416**	**0.001**	0.033	1.323	0.186	**0.088**	**3.576**	**0.000**
50-64°F	Phi	1638	-0.028	-1.119	0.263	0.031	1.258	0.208	0.004	0.172	0.863
65-79°F	Phi	1638	**0.103**	**4.186**	**0.000**	**-0.080**	**-3.242**	**0.001**	**-0.059**	**-2.406**	**0.016**
80°F or more	Phi	1638	0.017	0.695	0.487	0.027	1.076	0.282	**-0.058**	**-2.362**	**0.018**
Day of week											
Weekday (Mon, Fri)	Phi	1638	0.027	1.074	0.283	-0.009	-0.359	0.720	-0.030	-1.195	0.232
Weekday (Tue, Wed, Thu)	Phi	1638	-0.027	-1.074	0.283	0.009	0.359	0.720	0.030	1.195	0.232
Time of day											
Morning (06:00-11:59)	Phi	1638	0.011	0.431	0.666	-0.036	-1.448	0.148	0.027	1.100	0.271
Afternoon (12:00-17:59)	Phi	1638	0.010	0.417	0.677	0.008	0.344	0.731	-0.026	-1.049	0.294
Evening/overnight (18:00-05:59)	Phi	1638	-0.028	-1.145	0.252	0.035	1.408	0.159	0.001	0.031	0.975
AM peak hours (07:00-08:59)	Phi	1638	0.019	0.753	0.452	-0.017	-0.698	0.485	-0.007	-0.296	0.768
PM peak hours (16:00-17:59)	Phi	1638	0.005	0.203	0.839	0.008	0.327	0.743	-0.017	-0.705	0.481
Traffic signal status information											
Pedestrian signal status, pedestrian at conflict point											
Walk	Phi	1638	**0.089**	**3.606**	**0.000**	**-0.051**	**-2.074**	**0.038**	**-0.073**	**-2.947**	**0.003**
Flashing don't walk	Phi	1638	**0.069**	**2.810**	**0.005**	**-0.111**	**-4.520**	**0.000**	0.029	1.192	0.234
Steady don't walk	Phi	1638	**-0.094**	**-3.807**	**0.000**	**0.104**	**4.228**	**0.000**	0.016	0.654	0.513
Crossing not signalized	Phi	1638	**-0.154**	**-6.317**	**0.000**	**0.144**	**5.885**	**0.000**	**0.060**	**2.415**	**0.016**
Right-turn vehicle signal status, vehicle at conflict point											
Green	Phi	1638	**0.174**	**7.139**	**0.000**	**-0.181**	**-7.442**	**0.000**	*-0.044*	*-1.797*	*0.073*
Yellow	Phi	1638	-0.001	-0.033	0.974	0.006	0.242	0.809	-0.006	-0.244	0.807
Red	Phi	1638	**-0.091**	**-3.708**	**0.000**	**0.104**	**4.243**	**0.000**	0.012	0.487	0.626
Right turn not signalized	Phi	1638	**-0.154**	**-6.317**	**0.000**	**0.144**	**5.885**	**0.000**	**0.060**	**2.415**	**0.016**
Corner and intersection attributes											
Corner radius (ft)	Point-Biserial	1638	-0.036	-1.453	0.146	**0.060**	**2.434**	**0.015**	-0.018	-0.742	0.458
Crosswalk offset distance (ft) [a]	Point-Biserial	1638	**0.129**	**5.274**	**0.000**	**-0.102**	**-4.159**	**0.000**	**-0.072**	**-2.928**	**0.003**
Channelized right turn (distance not available)	Phi	1638	**-0.230**	**-9.578**	**0.000**	**0.237**	**9.860**	**0.000**	**0.063**	**2.535**	**0.011**
Stop bar distance (ft) [b]	Point-Biserial	1638	**0.066**	**2.682**	**0.007**	**-0.064**	**-2.582**	**0.010**	-0.023	-0.938	0.348
Channelized right turn (distance not available)	Phi	1638	**-0.230**	**-9.578**	**0.000**	**0.237**	**9.860**	**0.000**	**0.063**	**2.535**	**0.011**
Curb ramps (#)	Point-Biserial	1638	**0.130**	**5.319**	**0.000**	**-0.106**	**-4.324**	**0.000**	**-0.069**	**-2.796**	**0.005**
1	Phi	1638	**-0.130**	**-5.319**	**0.000**	**0.106**	**4.324**	**0.000**	**0.069**	**2.796**	**0.005**
2	Phi	1638	**0.130**	**5.319**	**0.000**	**-0.106**	**-4.324**	**0.000**	**-0.069**	**-2.796**	**0.005**
Curb ramp type											
Diagonal (apex)	Phi	1638	-0.012	-0.469	0.639	-0.011	-0.459	0.646	0.031	1.269	0.205

Directional	Phi	1638	0.008	0.325	0.745	0.015	0.609	0.543	-0.030	-1.231	0.218
Blended transition	Phi	1638	0.007	0.264	0.792	-0.005	-0.210	0.834	-0.004	-0.146	0.884
Crosswalk type											
Standard markings	Phi	1638	**0.134**	**5.461**	**0.000**	**-0.063**	**-2.574**	**0.010**	**-0.126**	**-5.138**	**0.000**
Continental (high-visibility) markings	Phi	1638	**-0.135**	**-5.494**	**0.000**	**0.064**	**2.597**	**0.009**	**0.126**	**5.160**	**0.000**
No crossing	Phi	1638	0.010	0.389	0.697	-0.007	-0.293	0.769	-0.006	-0.235	0.814
Right-turn lanes (#)	Point-Biserial	1638	*-0.043*	*-1.727*	*0.084*	**0.063**	**2.553**	**0.011**	-0.012	-0.471	0.638
0.5 (shared thru-right lane)	Phi	1638	**-0.072**	**-2.908**	**0.004**	**0.068**	**2.753**	**0.006**	0.026	1.071	0.284
1	Phi	1638	**0.132**	**5.371**	**0.000**	**-0.138**	**-5.657**	**0.000**	-0.032	-1.288	0.198
2	Phi	1638	**-0.192**	**-7.905**	**0.000**	**0.225**	**9.339**	**0.000**	0.018	0.741	0.459
Receiving lanes (#)	Point-Biserial	1638	*-0.047*	*-1.893*	*0.059*	**0.051**	**2.055**	**0.040**	0.009	0.381	0.703
0	Phi	1638	*0.047*	*1.893*	*0.059*	**-0.051**	**-2.055**	**0.040**	-0.009	-0.381	0.703
1	Phi	1638	*-0.047*	*-1.893*	*0.059*	**0.051**	**2.055**	**0.040**	0.009	0.381	0.703
Channelized right turn	Phi	1638	**-0.230**	**-9.578**	**0.000**	**0.237**	**9.860**	**0.000**	**0.063**	**2.535**	**0.011**
Skewed intersection	Phi	1638	**-0.204**	**-8.441**	**0.000**	**0.209**	**8.658**	**0.000**	**0.056**	**2.279**	**0.023**
Presence of bicycle lane	Phi	1638	0.002	0.075	0.940	-0.026	-1.041	0.298	0.028	1.147	0.251
AADP (100s)	Point-Biserial	1638	**0.060**	**2.414**	**0.016**	**-0.049**	**-1.967**	**0.049**	-0.031	-1.275	0.202
Natural log of AADP	Point-Biserial	1638	**0.106**	**4.320**	**0.000**	**-0.092**	**-3.733**	**0.000**	**-0.050**	**-2.015**	**0.044**
AADT (1000s)	Point-Biserial	1632	**-0.127**	**-5.167**	**0.000**	**0.148**	**6.042**	**0.000**	0.013	0.543	0.587
Natural log of AADT	Point-Biserial	1632	**-0.068**	**-2.772**	**0.006**	**0.073**	**2.942**	**0.003**	0.016	0.643	0.520
Right turn/crossing not signalized	Phi	1638	**-0.154**	**-6.317**	**0.000**	**0.144**	**5.885**	**0.000**	**0.060**	**2.415**	**0.016**
On-ramp	Phi	1638	**-0.095**	**-3.854**	**0.000**	**0.088**	**3.576**	**0.000**	0.037	1.505	0.132
Off-ramp	Phi	1638	**-0.192**	**-7.898**	**0.000**	**0.232**	**9.664**	**0.000**	0.009	0.368	0.713
Neighborhood attributes [c]											
Population density (1,000 people per mi^2)	Point-Biserial	1632	**0.051**	**2.047**	**0.041**	-0.037	-1.508	0.132	-0.032	-1.276	0.202
Employment density (1,000 jobs per mi^2)	Point-Biserial	1632	0.037	1.484	0.138	-0.031	-1.269	0.205	-0.018	-0.713	0.476
Land use											
Residential (%)	Point-Biserial	1632	0.017	0.685	0.493	-0.034	-1.362	0.174	0.015	0.606	0.544
Commercial (%)	Point-Biserial	1632	0.027	1.090	0.276	-0.039	-1.575	0.116	0.006	0.251	0.802
Industrial (%)	Point-Biserial	1632	-0.004	-0.170	0.865	0.032	1.292	0.197	-0.032	-1.302	0.193
Vacant (%)	Point-Biserial	1632	**-0.102**	**-4.150**	**0.000**	**0.115**	**4.673**	**0.000**	0.016	0.645	0.519
Other (%)	Point-Biserial	1632	-0.022	-0.883	0.377	-0.010	-0.420	0.675	*0.046*	*1.845*	*0.065*
Street intersection density (# per mi^2)	Point-Biserial	1632	0.016	0.641	0.522	0.009	0.357	0.721	-0.035	-1.402	0.161
4-way intersections (%)	Point-Biserial	1632	0.033	1.339	0.181	-0.037	-1.514	0.130	-0.005	-0.199	0.842
Transit stops (#)	Point-Biserial	1632	**0.105**	**4.261**	**0.000**	**-0.117**	**-4.747**	**0.000**	-0.018	-0.721	0.471
Places of worship (#)	Point-Biserial	1632	**-0.052**	**-2.096**	**0.036**	0.023	0.928	0.354	**0.051**	**2.051**	**0.040**
Schools (#)	Point-Biserial	1632	0.001	0.038	0.970	-0.029	-1.190	0.234	0.034	1.380	0.168
Park (acres)	Point-Biserial	1632	**-0.056**	**-2.250**	**0.025**	**0.054**	**2.172**	**0.030**	0.019	0.781	0.435
Household income (median, $1,000s)	Point-Biserial	1632	**-0.136**	**-5.557**	**0.000**	**0.091**	**3.693**	**0.000**	**0.096**	**3.911**	**0.000**
Vehicle ownership (mean, cars/household)	Point-Biserial	1632	-0.012	-0.501	0.617	0.000	0.011	0.991	0.018	0.745	0.456

Household size (mean, people/household)	Point-Biserial	1632	**-0.112**	**-4.556**	**0.000**	**0.105**	**4.280**	**0.000**	*0.042*	*1.714*	*0.087*

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.

4.3.3.2 Multivariate Regression Results

Table 4.24 presents results of the multilevel model for pedestrian reaction. This outcome was an unordered categorical variable, so the research team used a mixed multinomial logit model with random intercept terms. In such models, one must designate a base or reference category against which to compare results; researchers picked the most frequent pedestrian reaction, no obvious reaction. Also, instead of interpreting the estimates (Est.) directly, it is often easier to consider the relative risk ratios (RRR), calculated as $e^{Est.}$, just like in the ordered logit model of conflict severity. An RRR value shows the amount the relative risk (ratio of being in one category vs. the base/reference category) would be multiplied by given a one unit increase in the relevant variable. Positive estimates and RRR > 1 imply greater chance of being in that category, while negative estimates and RRR < 1 imply lower chances of being in that category, compared to the base or reference category (in this case, no obvious reaction).

Several variables showed significant associations with pedestrian reactions. When pedestrians were approaching the curb, and when there were more vehicles waiting to turn right, the pedestrian was less likely to stop or slow (more likely to have no obvious reaction). Conversely, longer right-turn queue lengths increased the chances of the pedestrian speeding up, running, or changing direction (other reaction). Stopping or slowing was more likely (than no reaction) when the pedestrian was crossing on steady don't walk, for crossings with two right-turn lanes, and in locations with higher median household incomes. Conversely, the other reactions (sped up, ran, changed direction) were more likely than no reaction when a child or teenager was crossing, and for intersections with channelized right turns. Pedestrians were also more likely to speed up, run, or change direction (than to have no obvious reaction) while crossing on steady don't walk or flashing don't walk. However, pedestrians showed a greater tendency to have no obvious reaction when faced with conflict (rather than speeding up, running or changing direction) when the temperature was 80°F or higher.

Table 4.24 Regression results for pedestrian reaction

Variable	*Est.*	*SE*	z	*p*	*RRR*
Stopped or slowed (vs. No obvious reaction)					
Intercept (SD = 0.891)	-3.598	0.627	-5.737	<0.001	--
Crossing direction: Approaching curb	-1.502	0.269	-5.575	<0.001	0.223
Right-turn queue length (# vehicles)	-0.416	0.093	-4.488	<0.001	0.660
Pedestrian signal status: Steady don't walk	0.943	0.269	3.508	<0.001	2.569
Right-turn lanes (#): 2	3.069	0.756	4.058	<0.001	21.514
Household income (median, $1,000s)	0.026	0.009	2.815	0.005	1.026
Other reaction (vs. No obvious reaction)					
Intercept (SD = 0.460)	-3.918	0.312	-12.554	<0.001	--
Age: Child or teenager	0.902	0.284	3.175	0.001	2.466
Right-turn queue length (# vehicles)	0.241	0.071	3.378	<0.001	1.273
Temperature: 80°F or more	-1.660	0.752	-2.207	0.027	0.190
Pedestrian signal status: Flashing don't walk	0.584	0.285	2.051	0.040	1.792
Pedestrian signal status: Steady don't walk	0.625	0.361	1.732	0.083	1.869
Channelized right turn	1.492	0.442	3.379	<0.001	4.445

N (level 1) = 1,633; N (level 2) = 33.

LL (model) = -622.8; LL (intercept only) = -780.8; McFadden's pseudo-R^2 = 0.202.

4.3.3.3 Summary

Table 4.25 summarizes the significant factors identified in the bivariate and multivariate analyses for pedestrian reaction.

Table 4.25 Summary of results for pedestrian reaction

*Stopped or slowed**	*Other reaction**
Positive	Positive
• Crosswalk: First crosswalk	• **Age: Child or teenager**
• *Driver reaction: Other reaction*	• Crossing direction: Approaching curb
• *Conflict severity*	• **Right-turn queue length (# vehicles)**
• Weather: Rain (actively raining, or wet roadways)	• *Stopping location: Inside/between the crosswalks*
• **Pedestrian signal status: Steady don't walk**	• *Driver reaction: Stopped or slowed*
• Right-turn vehicle signal status: Red	• *Conflict severity*
• Corner radius	• Pedestrian signal status: Flashing don't walk
• Crosswalk type: Continental markings	• Pedestrian signal status: Steady don't walk
• Right-turn lanes: 0.5 (shared thru-right lane)	• Temperature: Less than 50°F
• **Right-turn lanes: 2**	• Crosswalk type: Continental markings
• Receiving lanes: 1	• **Channelized right turn**
• Channelized right turn	• Skewed intersection
• Skewed intersection	• Right turn/crossing not signalized
• Natural log of AADT	• Places of worship (#)
• Right turn/crossing not signalized	• Household income (median)
• On-ramp	
• Off-ramp	
• Land use: Vacant (%)	
• Parks (acres)	
• **Household income (median)**	
• Household size (mean, people/household)	
Negative	Negative
• **Crossing direction: Approaching curb**	• Other characteristics: Bicycle
• **Right-turn queue length (# vehicles)**	• *Encroachment time*
• *Stopping location: Inside/between the crosswalks*	• *Post-ET*
• *Encroachment time*	• Temperature: 65-79°F
• *Pre-ET*	• **Temperature: 80°F or more**
• Temperature: 65–79°F	• Crosswalk offset distance
• Pedestrian signal status: Flashing don't walk	• Curb ramps: 2
• Crosswalk offset distance	• Natural log of AADP
• Stop bar distance	
• Curb ramps: 2	
• Natural log of AADP	
• Transit stops (#)	

* A positive association means more likely to have this pedestrian reaction than no reaction. A negative association means less likely to have this pedestrian reaction than no reaction.
Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

4.3.4 Pedestrian Crossing Location

Another pedestrian behavior the research observed in the videos was pedestrian crossing location: in the crosswalk or the crosswalk area, mid-block away from the crosswalk, and in the middle of the intersection. While not directly related to the conflict, it was useful to analyze factors associated with this pedestrian behavior separately. Due to the small sample sizes, researchers grouped the few pedestrian crossing events that didn't happen in *the crosswalk or crosswalk area* (97%) into a single category *away from the crosswalk* (3%) for the purposes of the following bivariate and multivariate statistical analyses.

4.3.4.1 Bivariate Correlation Results

Table 4.26 shows correlation analysis results for the choice of pedestrian crossing location. Notice that since there are only two categories, the correlations for one category are the opposite of that for the other category. Therefore, it is easier to interpret results for just one category: crossing away from the crosswalk. As before, positive correlations make this outcome more likely, while negative correlations indicate that the outcome is less likely, for each condition or as each continuous variable increases.

Overall, few level one variables were significantly associated with pedestrian crossing location. Among pedestrian characteristics, people riding bicycles were more likely to cross away from the crosswalk. Crossing away from the crosswalk was also more likely for pedestrians crossing the first street vs. those crossing the second street. (Although, this could also reflect the fact that many videos showed more of the first street than the second street.) Among pedestrian reactions, only changing directions was more likely for pedestrians crossing away from the crosswalk. Only a couple of driver and vehicle characteristics were significantly associated with crossing location. As the right-turn queue length increased, pedestrians were more likely to cross in the crosswalk or the crosswalk area and less likely to cross farther away. Conversely, the presence of large trucks was positively associated with crossing away from the crosswalk. Conflict information, weather, and most temporal factors were not significantly associated with crossing location. The only exception was that crossing away from the crosswalk was a little more likely when the temperature was 65-79°F. When crossing away from the crosswalk, pedestrians were more likely to cross when the pedestrian signal showed steady don't walk, but also when the right-turn vehicle wasn't turning on green.

More level two variables had significant bivariate associations with pedestrian crossing location. Among corner and intersection attributes, crossing away from the crosswalk was more likely in places with: larger corner radii, one curb ramp, directional curb ramps, no crosswalk, a receiving lane, a channelized right turn, a skewed intersection, and where the right turn and crossing were not signalized. Conversely, crossing away from the crosswalk was less likely in places with: two curb ramps, diagonal (apex) curb ramps, and higher pedestrian volumes. Several neighborhood characteristics were also linked to pedestrian crossing locations. Crossing away from the crosswalk was more common in locations with: lower population and employment densities, higher shares of industrial or other land uses, lower street intersection density, fewer four-way intersections, fewer transit stops, fewer places of worship, and neighborhoods with higher vehicle ownership and larger household sizes.

Table 4.26 Correlation results for pedestrian crossing location

Independent variable	Test	df	Crossing location: In the crosswalk or the crosswalk area			Crossing location: Away from the crosswalk		
			Corr	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics								
Group size (# people)	Point-Biserial	1638	0.021	0.837	0.403	-0.021	-0.837	0.403
Natural log of group size	Point-Biserial	1638	0.036	1.450	0.147	-0.036	-1.450	0.147
Age								
Child or teenager	Phi	1638	-0.014	-0.560	0.576	0.014	0.560	0.576
Child	Phi	1638	0.026	1.057	0.291	-0.026	-1.057	0.291
Teenager	Phi	1638	-0.021	-0.864	0.388	0.021	0.864	0.388
Adult	Phi	1638	0.023	0.928	0.353	-0.023	-0.928	0.353
Young adult	Phi	1638	-0.009	-0.372	0.710	0.009	0.372	0.710
Middle-aged adult	Phi	1638	0.018	0.745	0.457	-0.018	-0.745	0.457
Older adult (65+)	Phi	1638	0.005	0.191	0.849	-0.005	-0.191	0.849
Adult of unknown age	Phi	1638	0.016	0.667	0.505	-0.016	-0.667	0.505
Gender								
Male	Phi	1638	-0.031	-1.239	0.216	0.031	1.239	0.216
Female	Phi	1638	*0.041*	*1.672*	*0.095*	*-0.041*	*-1.672*	*0.095*
Unknown gender	Phi	1638	0.033	1.322	0.186	-0.033	-1.322	0.186
Other characteristics								
Carrying load	Phi	1638	-0.004	-0.173	0.863	0.004	0.173	0.863
Stroller or wheelchair	Phi	1638	0.017	0.690	0.490	-0.017	-0.690	0.490
Stroller	Phi	1638	0.015	0.597	0.551	-0.015	-0.597	0.551
Wheelchair	Phi	1638	0.008	0.344	0.731	-0.008	-0.344	0.731
Skateboard or scooter	Phi	1638	0.040	1.627	0.104	-0.040	-1.627	0.104
Skateboard	Phi	1638	0.026	1.042	0.298	-0.026	-1.042	0.298
Scooter	Phi	1638	0.031	1.246	0.213	-0.031	-1.246	0.213
Bicycle	Phi	1638	**-0.133**	**-5.412**	**0.000**	**0.133**	**5.412**	**0.000**
Distracted (phone, headphones, conversations, etc.)	Phi	1638	0.037	1.501	0.133	-0.037	-1.501	0.133
Crosswalk								
First crosswalk	Phi	1638	**-0.090**	**-3.671**	**0.000**	**0.090**	**3.671**	**0.000**
Second crosswalk	Phi	1638	**0.090**	**3.671**	**0.000**	**-0.090**	**-3.671**	**0.000**
Crossing direction								
Leaving curb	Phi	1638	-0.034	-1.389	0.165	0.034	1.389	0.165
Approaching curb	Phi	1638	0.034	1.389	0.165	-0.034	-1.389	0.165
Pedestrian reactions								
No obvious reaction	Phi	1638	-0.002	-0.083	0.934	0.002	0.083	0.934

Stopped or slowed	Phi	1638	0.037	1.493	0.136	-0.037	-1.493	0.136
Stopped and waited for the vehicle	Phi	1638	0.032	1.285	0.199	-0.032	-1.285	0.199
Slowed down to avoid collision	Phi	1638	0.019	0.753	0.452	-0.019	-0.753	0.452
Other reaction	Phi	1638	*-0.042*	*-1.684*	*0.092*	*0.042*	*1.684*	*0.092*
Sped up to avoid collision	Phi	1638	0.003	0.140	0.888	-0.003	-0.140	0.888
Ran to avoid collision	Phi	1638	0.021	0.847	0.397	-0.021	-0.847	0.397
Changed direction	Phi	1638	**-0.107**	**-4.357**	**0.000**	**0.107**	**4.357**	**0.000**
Driver and vehicle characteristics								
Right-turn queue length (# vehicles)	Point-Biserial	1638	**0.080**	**3.240**	**0.001**	**-0.080**	**-3.240**	**0.001**
Stopping location								
Did not stop	Phi	1638	-0.033	-1.331	0.183	0.033	1.331	0.183
Before the first crosswalk	Phi	1638	0.033	1.340	0.180	-0.033	-1.340	0.180
Inside/between the crosswalks	Phi	1638	0.008	0.324	0.746	-0.008	-0.324	0.746
Inside the first crosswalk	Phi	1638	0.015	0.589	0.556	-0.015	-0.589	0.556
Between the first and second crosswalks	Phi	1638	-0.008	-0.334	0.738	0.008	0.334	0.738
Driver reaction								
No obvious reaction	Phi	1638	-0.030	-1.205	0.228	0.030	1.205	0.228
Stopped or slowed	Phi	1638	0.013	0.529	0.597	-0.013	-0.529	0.597
Driver fully stopped	Phi	1638	0.022	0.878	0.380	-0.022	-0.878	0.380
Driver slowed down	Phi	1638	-0.005	-0.205	0.838	0.005	0.205	0.838
Other reaction	Phi	1638	0.039	1.575	0.115	-0.039	-1.575	0.115
Driver sped up	Phi	1638	0.038	1.523	0.128	-0.038	-1.523	0.128
Driver swerved	Phi	1638	0.009	0.384	0.701	-0.009	-0.384	0.701
Vehicle type								
Small	Phi	1638	-0.003	-0.104	0.917	0.003	0.104	0.917
Sedan	Phi	1638	-0.004	-0.147	0.883	0.004	0.147	0.883
Motorcycle	Phi	1638	0.009	0.384	0.701	-0.009	-0.384	0.701
Medium	Phi	1638	0.010	0.407	0.684	-0.010	-0.407	0.684
SUV	Phi	1638	0.005	0.194	0.846	-0.005	-0.194	0.846
Pickup truck	Phi	1638	-0.005	-0.198	0.843	0.005	0.198	0.843
Van (minivan, sprinter van, etc.)	Phi	1638	0.018	0.723	0.470	-0.018	-0.723	0.470
Large	Phi	1638	-0.019	-0.754	0.451	0.019	0.754	0.451
Large truck (semi-truck, delivery truck, etc.)	Phi	1638	**-0.064**	**-2.593**	**0.010**	**0.064**	**2.593**	**0.010**
Vehicle pulling a trailer	Phi	1638	0.021	0.865	0.387	-0.021	-0.865	0.387
Bus	Phi	1638	0.018	0.712	0.477	-0.018	-0.712	0.477
Conflict information								
Encroachment time (sec)	Point-Biserial	1638	-0.004	-0.168	0.866	0.004	0.168	0.866
Pre-ET (sec), vehicle before pedestrian	Point-Biserial	626	0.017	0.414	0.679	-0.017	-0.414	0.679
Post-ET (sec), vehicle after pedestrian	Point-Biserial	1000	-0.002	-0.076	0.939	0.002	0.076	0.939
Conflict severity								

Low (5-10 sec)	Phi	1638	-0.002	-0.073	0.942	0.002	0.073	0.942
Mild (4-5 sec)	Phi	1638	0.004	0.179	0.858	-0.004	-0.179	0.858
High (0-3 sec)	Phi	1638	-0.003	-0.115	0.909	0.003	0.115	0.909
Weather and time information								
Weather								
Clear	Phi	1638	-0.001	-0.032	0.974	0.001	0.032	0.974
Rain (actively raining, or wet roadways)	Phi	1638	0.001	0.032	0.974	-0.001	-0.032	0.974
Hourly precipitation (in)	Point-Biserial	1638	0.022	0.903	0.367	-0.022	-0.903	0.367
0.01 in or more	Phi	1638	0.026	1.057	0.291	-0.026	-1.057	0.291
Temperature (°F)	Point-Biserial	1638	*-0.045*	*-1.830*	*0.068*	*0.045*	*1.830*	*0.068*
Less than 50°F	Phi	1638	0.036	1.439	0.150	-0.036	-1.439	0.150
50-64°F	Phi	1638	0.023	0.912	0.362	-0.023	-0.912	0.362
65-79°F	Phi	1638	**-0.070**	**-2.847**	**0.004**	**0.070**	**2.847**	**0.004**
80°F or more	Phi	1638	0.019	0.766	0.444	-0.019	-0.766	0.444
Day of week								
Weekday (Mon, Fri)	Phi	1638	-0.002	-0.077	0.939	0.002	0.077	0.939
Weekday (Tue, Wed, Thu)	Phi	1638	0.002	0.077	0.939	-0.002	-0.077	0.939
Time of day								
Morning (06:00-11:59)	Phi	1638	-0.016	-0.648	0.517	0.016	0.648	0.517
Afternoon (12:00-17:59)	Phi	1638	0.015	0.590	0.555	-0.015	-0.590	0.555
Evening/overnight (18:00-05:59)	Phi	1638	0.001	0.021	0.983	-0.001	-0.021	0.983
AM peak hours (07:00-08:59)	Phi	1638	0.034	1.374	0.170	-0.034	-1.374	0.170
PM peak hours (16:00-17:59)	Phi	1638	-0.013	-0.513	0.608	0.013	0.513	0.608
Traffic signal status information								
Pedestrian signal status, pedestrian at conflict point								
Walk	Phi	1638	**0.069**	**2.809**	**0.005**	**-0.069**	**-2.809**	**0.005**
Flashing don't walk	Phi	1638	**0.100**	**4.087**	**0.000**	**-0.100**	**-4.087**	**0.000**
Steady don't walk	Phi	1638	**-0.132**	**-5.376**	**0.000**	**0.132**	**5.376**	**0.000**
Crossing not signalized	Phi	1638	**-0.112**	**-4.550**	**0.000**	**0.112**	**4.550**	**0.000**
Right-turn vehicle signal status, vehicle at conflict point								
Green	Phi	1638	**0.111**	**4.508**	**0.000**	**-0.111**	**-4.508**	**0.000**
Yellow	Phi	1638	-0.016	-0.643	0.520	0.016	0.643	0.520
Red	Phi	1638	*-0.043*	*-1.746*	*0.081*	*0.043*	*1.746*	*0.081*
Right turn not signalized	Phi	1638	**-0.112**	**-4.550**	**0.000**	**0.112**	**4.550**	**0.000**
Corner and intersection attributes								
Corner radius (ft)	Point-Biserial	1638	**-0.137**	**-5.598**	**0.000**	**0.137**	**5.598**	**0.000**
Crosswalk offset distance (ft) [a]	Point-Biserial	1638	-0.032	-1.309	0.191	0.032	1.309	0.191
Channelized right turn (distance not available)	Phi	1638	**-0.088**	**-3.592**	**0.000**	**0.088**	**3.592**	**0.000**
Stop bar distance (ft) [b]	Point-Biserial	1638	*0.048*	*1.942*	*0.052*	*-0.048*	*-1.942*	*0.052*
Channelized right turn (distance not available)	Phi	1638	**-0.088**	**-3.592**	**0.000**	**0.088**	**3.592**	**0.000**

Curb ramps (#)	Point-Biserial	1638	**0.049**	**1.974**	**0.049**	**-0.049**	**-1.974**	**0.049**
1	Phi	1638	**-0.049**	**-1.974**	**0.049**	**0.049**	**1.974**	**0.049**
2	Phi	1638	**0.049**	**1.974**	**0.049**	**-0.049**	**-1.974**	**0.049**
Curb ramp type								
Diagonal (apex)	Phi	1638	**0.072**	**2.936**	**0.003**	**-0.072**	**-2.936**	**0.003**
Directional	Phi	1638	**-0.065**	**-2.617**	**0.009**	**0.065**	**2.617**	**0.009**
Blended transition	Phi	1638	-0.017	-0.705	0.481	0.017	0.705	0.481
Crosswalk type								
Standard markings	Phi	1638	0.006	0.233	0.816	-0.006	-0.233	0.816
Continental (high-visibility) markings	Phi	1638	0.004	0.142	0.887	-0.004	-0.142	0.887
No crossing	Phi	1638	**-0.144**	**-5.881**	**0.000**	**0.144**	**5.881**	**0.000**
Right-turn lanes (#)	Point-Biserial	1638	*0.042*	*1.714*	*0.087*	*-0.042*	*-1.714*	*0.087*
0.5 (shared thru-right lane)	Phi	1638	-0.036	-1.442	0.150	0.036	1.442	0.150
1	Phi	1638	0.026	1.072	0.284	-0.026	-1.072	0.284
2	Phi	1638	0.026	1.071	0.284	-0.026	-1.071	0.284
Receiving lanes (#)	Point-Biserial	1638	**-0.105**	**-4.259**	**0.000**	**0.105**	**4.259**	**0.000**
0	Phi	1638	**0.105**	**4.259**	**0.000**	**-0.105**	**-4.259**	**0.000**
1	Phi	1638	**-0.105**	**-4.259**	**0.000**	**0.105**	**4.259**	**0.000**
Channelized right turn	Phi	1638	**-0.088**	**-3.592**	**0.000**	**0.088**	**3.592**	**0.000**
Skewed intersection	Phi	1638	**-0.090**	**-3.653**	**0.000**	**0.090**	**3.653**	**0.000**
Presence of bicycle lane	Phi	1638	-0.026	-1.032	0.302	0.026	1.032	0.302
AADP (100s)	Point-Biserial	1638	**0.072**	**2.905**	**0.004**	**-0.072**	**-2.905**	**0.004**
Natural log of AADP	Point-Biserial	1638	**0.117**	**4.786**	**0.000**	**-0.117**	**-4.786**	**0.000**
AADT (1000s)	Point-Biserial	1632	*0.045*	*1.836*	*0.067*	*-0.045*	*-1.836*	*0.067*
Natural log of AADT	Point-Biserial	1632	**0.065**	**2.621**	**0.009**	**-0.065**	**-2.621**	**0.009**
Right turn/crossing not signalized	Phi	1638	**-0.112**	**-4.550**	**0.000**	**0.112**	**4.550**	**0.000**
On-ramp	Phi	1638	*-0.043*	*-1.731*	*0.084*	*0.043*	*1.731*	*0.084*
Off-ramp	Phi	1638	0.035	1.402	0.161	-0.035	-1.402	0.161
Neighborhood attributes [c]								
Population density (1,000 people per mi^2)	Point-Biserial	1632	**0.058**	**2.359**	**0.018**	**-0.058**	**-2.359**	**0.018**
Employment density (1,000 jobs per mi^2)	Point-Biserial	1632	**0.066**	**2.671**	**0.008**	**-0.066**	**-2.671**	**0.008**
Land use								
Residential (%)	Point-Biserial	1632	0.018	0.741	0.459	-0.018	-0.741	0.459
Commercial (%)	Point-Biserial	1632	0.034	1.361	0.174	-0.034	-1.361	0.174
Industrial (%)	Point-Biserial	1632	**-0.051**	**-2.075**	**0.038**	**0.051**	**2.075**	**0.038**
Vacant (%)	Point-Biserial	1632	-0.014	-0.562	0.574	0.014	0.562	0.574
Other (%)	Point-Biserial	1632	**-0.056**	**-2.262**	**0.024**	**0.056**	**2.262**	**0.024**
Street intersection density (# per mi^2)	Point-Biserial	1632	**0.072**	**2.935**	**0.003**	**-0.072**	**-2.935**	**0.003**
4-way intersections (%)	Point-Biserial	1632	**0.068**	**2.736**	**0.006**	**-0.068**	**-2.736**	**0.006**
Transit stops (#)	Point-Biserial	1632	**0.085**	**3.448**	**0.001**	**-0.085**	**-3.448**	**0.001**

Places of worship (#)	Point-Biserial	1632	**0.049**	**1.997**	**0.046**	**-0.049**	**-1.997**	**0.046**
Schools (#)	Point-Biserial	1632	0.040	1.605	0.109	-0.040	-1.605	0.109
Park (acres)	Point-Biserial	1632	*0.045*	*1.822*	*0.069*	*-0.045*	*-1.822*	*0.069*
Household income (median, $1,000s)	Point-Biserial	1632	-0.026	-1.055	0.292	0.026	1.055	0.292
Vehicle ownership (mean, cars/household)	Point-Biserial	1632	**-0.128**	**-5.206**	**0.000**	**0.128**	**5.206**	**0.000**
Household size (mean, people/household)	Point-Biserial	1632	**-0.078**	**-3.144**	**0.002**	**0.078**	**3.144**	**0.002**

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.

[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.

[c] These variables were measured using a quarter-mile network buffer.

4.3.4.2 Multivariate Regression Results

Table 4.27 shows multilevel model results for pedestrian crossing location. Given the dichotomous outcome variable, the research team used a mixed binary logit model with a random intercept term. Like the multinomial logit model of pedestrian reactions, researchers had to pick a reference category, which was the most frequent one (in the crosswalk or the crosswalk area). Like the ordered logit model of conflict severity, researchers calculated ORs to aid in interpretation.

Only a few variables were significantly associated with greater or lesser likelihood of crossing away from the crosswalk. Pedestrians crossing on flashing don't walk were less likely to cross away from the crosswalk, whereas those crossing on steady don't walk were more likely. Sidewalk users riding a bicycle were also overrepresented among those crossing away from the crosswalk. Among locational characteristics, crossing away from the crosswalk was more common when the right turn (and crossing) was not signalized (i.e., yield only).

Table 4.27 Regression results for pedestrian crossing location

Variable	*Est.*	*SE*	z	*p*	*OR*
Away from the crosswalk (vs. In the crosswalk or the crosswalk area)					
Intercept (SD = 1.453)	-4.929	0.543	-9.076	<0.001	--
Other characteristics: Bicycle	1.149	0.400	2.871	0.004	3.156
Pedestrian signal status: Flashing don't walk	-1.374	0.810	-1.696	0.090	0.253
Pedestrian signal status: Steady don't walk	1.607	0.477	3.372	<0.001	4.986
Right turn/crossing not signalized	2.499	0.955	2.616	0.009	12.165

N (level 1) = 1,633; N (level 2) = 33.

LL (model) = -159.9; LL (intercept only) = -206.0; McFadden's pseudo-R^2 = 0.224.

4.3.4.3 Summary

Table 4.28 summarizes the significant factors identified in the bivariate and multivariate analyses for pedestrian crossing location.

Table 4.28 Summary of results for pedestrian crossing location

Away from the crosswalk *	
Positive	Negative
• **Other characteristics: Bicycle** • Crosswalk: First crosswalk • Temperature: 65-79°F • **Pedestrian signal status: Steady don't walk** • Corner radius (ft) • Curb ramp type: Directional • Receiving lanes: 1 • Channelized right turn • Skewed intersection • **Right turn/crossing not signalized** • Land use: Industrial (%) • Land use: Other (%) • Vehicle ownership (mean, cars/household) • Household size (mean, people/household)	• Right-turn queue length (# vehicles) • **Pedestrian signal status: Flashing don't walk** • Curb ramps: 2 • Natural log of AADP • Natural log of AADT • Population density (people per mi^2) • Employment density (jobs per mi^2) • Street intersection density (# per mi^2) • 4-way intersection (%) • Transit stops (#) • Places of worship (#)

* A positive association means more likely to cross away from the crosswalk than in the crosswalk or the crosswalk area. A negative association means less likely to cross away from the crosswalk.
Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

4.3.5 Vehicle Driver Reaction

As was done for pedestrians, the research team also measured any reactions made by the vehicle driver in response to the conflict: no obvious reaction, driver fully stopped, driver slowed down, driver sped up, and/or driver swerved. Again, these behaviors may reflect actions taken (or not taken) to avoid a collision with a pedestrian. Yet, their relationship with the conflict is complex, and may both reflect reactions to the conflict (conflict → reaction) and changes in how the conflict was measured (reaction → conflict indicator). Once again, due to this complexity, researchers analyzed driver reactions separately from encroachment time and conflict severity. To match the categories of pedestrian reactions and address some small sample sizes (see Figure 4.2), researchers grouped driver reactions into three categories for the subsequent bivariate and multivariate analyses:

- *No obvious reaction* was recorded for around 51% of potential conflict events.
- Researchers combined "driver fully stopped" and "driver slowed down" into a single category called *stopped or slowed*, which was observed around 44% of the time.
- The *other reaction* category, which was observed in around 5% of incidents, included "driver sped up" and "driver swerved."

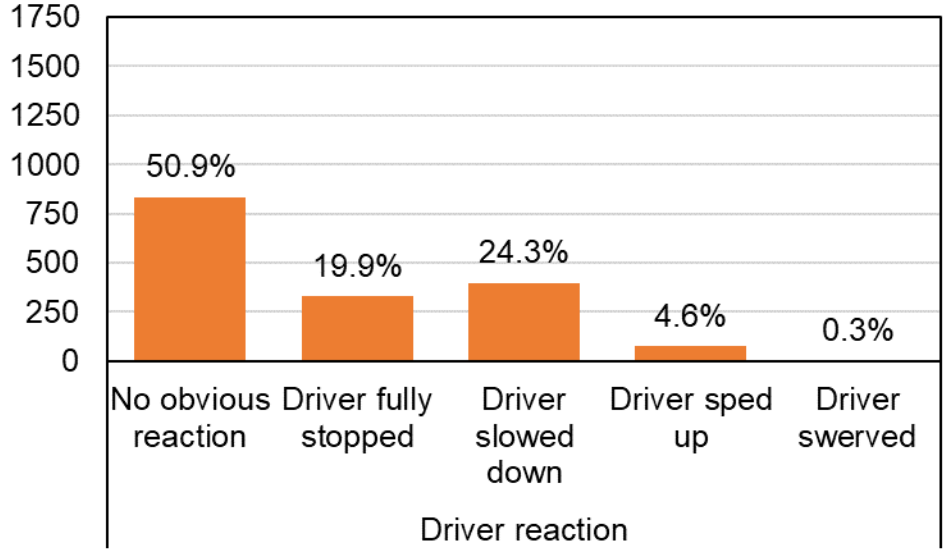

Figure 4.2 Driver reaction

4.3.5.1 Bivariate Correlation Results

Table 4.29 reports results of the correlation analysis for vehicle driver reactions. Just like for pedestrian reactions, positive correlations imply a greater chance of having that kind of reaction, while negative correlations suggest a lower likelihood of that reaction happening.

Many pedestrian characteristics were significantly associated with driver reactions. When faced with larger group sizes, when children or teens were present, or when a pedestrian was identified as female, drivers were more likely to stop/slow or have some other reaction and less likely to have no reaction. Conversely, when adults were present, drivers were more likely to have no obvious reaction. Considering other characteristics, stopping/slowing was more common in the presence of strollers, some other reaction was more common in the presence of distracted pedestrians, and no reaction was more common for pedestrians bicycling and skateboarding. Other driver reactions were more common when pedestrians were using the second crosswalk and approaching the curb, but there were no significant associations between driver reaction and pedestrian crossing location. As previously mentioned, driver and pedestrian reactions were closely linked. Specifically, no obvious reactions (for both parties) were more likely to occur together. Drivers tended to stop or slow when pedestrians had other reactions; whereas drivers tended to have other reactions when pedestrians stopped or slowed.

Considering driver and vehicle characteristics, when the right-turn queue length was longer, stopping or slowing was a more common driver reaction than no reaction. Unsurprisingly, driver reaction was closely tied to driver stopping behavior: Not stopping was positively correlated with no obvious driver reaction, while stopping somewhere (before, inside, or between the crosswalks) was positively associated with stopping or slowing. Vehicle type (small, medium, large) did not seem to affect driver reactions, except that some other reaction was more likely in the presence of large vehicles.

Since driver reactions are linked to conflicts, it is not surprising that conflict information was significantly correlated with driver reactions. Having no obvious driver reaction was associated with longer (overall and post-) ETs and more low-severity conflicts. Conversely, when drivers stopped or slowed, these events tended to have shorter ETs and more mild- or high-severity conflicts.

When it was raining or the roadway was wet, drivers were more likely to stop/slow (and less likely to have no reaction) than when the weather was clear. Temperature also seemed linked to vehicle reactions: some other reaction was more likely during cold temperatures (below 50°F); stopping/slowing was more likely when the temperature was 50-64°F, and no reaction was more common for temperatures between 65 and 79°F. Regarding day of week, Mondays and Fridays saw more drivers stop/slow, while no obvious reaction was more common in the middle of the week. Having some other driver reaction was more common during morning and AM peak hours, whereas having no reaction was more frequent in the afternoon and stopping/slowing was more common in the evening and overnight. Drivers were more likely to make some other reaction when pedestrians were crossing on steady don't walk. Some other reaction was more common when drivers were turning right on green, while stopping/slowing was a more common reaction when turning right on red.

Several corner and intersection attributes were significantly associated with driver reactions. Stopping/slowing was more common at intersections with: smaller corner radii, shorter crosswalk offset distance, one curb ramp, diagonal (apex) curb ramps, shared thru-right or two right-turn lanes, no receiving lanes, skewed intersection configurations, higher pedestrian and motor vehicle traffic volumes, and off-ramps. Some other driver reaction was more common at locations with: smaller corner radii, shorter crosswalk offset and stop bar distances, one curb ramp, diagonal (apex) curb ramps, continental crosswalk markings, and bicycle lanes. In comparison, no obvious reaction was more common in places with: larger corner radii, a longer crosswalk offset distance, two curb ramps, directional curb ramps, standard crosswalk markings, a single right-turn lane, receiving lanes, on-ramps, and when the right turn and crossing was not signalized.

Neighborhood attributes were also linked to driver reactions. No reaction was more common in places with higher employment density, more commercial land uses, and greater street intersection density. Stopping/slowing was more common in places with more residential land uses, more places of worship, more and larger parks, higher household income, and larger household sizes. Other driver reactions were more common in places with more residential land uses, more places of worship, more schools, higher household income, lower vehicle ownership, and larger household sizes.

Table 4.29 Correlation results for vehicle driver reaction

			Driver reaction: No obvious reaction			*Driver reaction: Stopped or slowed*			*Driver reaction: Other reaction*		
Independent variable	*Test*	*df*	*Corr*	*t*	*p*	*Corr*	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics											
Group size (# people)	Point-Biserial	1638	**-0.074**	**-3.001**	**0.003**	0.025	1.026	0.305	**0.113**	**4.611**	**0.000**
Natural log of group size	Point-Biserial	1638	**-0.140**	**-5.741**	**0.000**	**0.080**	**3.252**	**0.001**	**0.141**	**5.775**	**0.000**
Age											
Child or teenager	Phi	1638	**-0.183**	**-7.516**	**0.000**	**0.109**	**4.442**	**0.000**	**0.172**	**7.077**	**0.000**
Child	Phi	1638	**-0.064**	**-2.611**	**0.009**	**0.080**	**3.237**	**0.001**	-0.034	-1.393	0.164
Teenager	Phi	1638	**-0.174**	**-7.132**	**0.000**	**0.093**	**3.794**	**0.000**	**0.188**	**7.729**	**0.000**
Adult	Phi	1638	**0.170**	**6.970**	**0.000**	**-0.091**	**-3.715**	**0.000**	**-0.183**	**-7.541**	**0.000**
Young adult	Phi	1638	**0.070**	**2.854**	**0.004**	*-0.041*	*-1.666*	*0.096*	**-0.068**	**-2.776**	**0.006**
Middle-aged adult	Phi	1638	**0.055**	**2.224**	**0.026**	-0.037	-1.479	0.139	*-0.043*	*-1.747*	*0.081*
Older adult (65+)	Phi	1638	0.020	0.818	0.414	-0.020	-0.808	0.419	-0.001	-0.035	0.972
Adult of unknown age	Phi	1638	-0.016	-0.654	0.513	0.038	1.544	0.123	**-0.050**	**-2.042**	**0.041**
Gender											
Male	Phi	1638	0.021	0.866	0.386	-0.027	-1.076	0.282	0.012	0.471	0.638
Female	Phi	1638	**-0.112**	**-4.548**	**0.000**	**0.078**	**3.168**	**0.002**	**0.079**	**3.218**	**0.001**
Unknown gender	Phi	1638	0.036	1.465	0.143	-0.015	-0.607	0.544	**-0.049**	**-2.002**	**0.045**
Other characteristics											
Carrying load	Phi	1638	-0.016	-0.665	0.506	0.004	0.154	0.878	0.029	1.187	0.235
Stroller or wheelchair	Phi	1638	**-0.076**	**-3.096**	**0.002**	**0.074**	**3.005**	**0.003**	0.006	0.256	0.798
Stroller	Phi	1638	**-0.059**	**-2.385**	**0.017**	**0.068**	**2.744**	**0.006**	-0.019	-0.787	0.431
Wheelchair	Phi	1638	**-0.050**	**-2.041**	**0.041**	0.031	1.241	0.215	*0.046*	*1.871*	*0.061*
Skateboard or scooter	Phi	1638	0.031	1.275	0.203	-0.020	-0.802	0.423	-0.027	-1.110	0.267
Skateboard	Phi	1638	**0.056**	**2.251**	**0.025**	*-0.041*	*-1.668*	*0.095*	-0.034	-1.374	0.170
Scooter	Phi	1638	0.000	0.010	0.992	0.003	0.130	0.897	-0.008	-0.322	0.748
Bicycle	Phi	1638	**0.088**	**3.574**	**0.000**	**-0.061**	**-2.475**	**0.013**	**-0.063**	**-2.572**	**0.010**
Distracted (phone, headphones, conversations, etc.)	Phi	1638	**-0.125**	**-5.107**	**0.000**	*0.046*	*1.864*	*0.062*	**0.184**	**7.596**	**0.000**
Crosswalk											
First crosswalk	Phi	1638	-0.018	-0.746	0.456	*0.045*	*1.834*	*0.067*	**-0.062**	**-2.498**	**0.013**
Second crosswalk	Phi	1638	0.018	0.746	0.456	*-0.045*	*-1.834*	*0.067*	**0.062**	**2.498**	**0.013**
Crossing location											
In the crosswalk or the crosswalk area	Phi	1638	-0.030	-1.205	0.228	0.013	0.529	0.597	0.039	1.575	0.115
Away from the crosswalk	Phi	1638	0.030	1.205	0.228	-0.013	-0.529	0.597	-0.039	-1.575	0.115
Mid-block, away from the crosswalk	Phi	1638	0.032	1.279	0.201	-0.017	-0.708	0.479	-0.033	-1.334	0.182
In the middle of the intersection	Phi	1638	0.005	0.212	0.832	0.004	0.142	0.887	-0.020	-0.819	0.413
Crossing direction											

Leaving curb	Phi	1638	**0.085**	**3.442**	**0.001**	*-0.042*	*-1.692*	*0.091*	**-0.100**	**-4.082**	**0.000**
Approaching curb	Phi	1638	**-0.085**	**-3.442**	**0.001**	*0.042*	*1.692*	*0.091*	**0.100**	**4.082**	**0.000**
Pedestrian reactions											
No obvious reaction	Phi	1638	**0.133**	**5.446**	**0.000**	**-0.093**	**-3.765**	**0.000**	**-0.096**	**-3.902**	**0.000**
Stopped or slowed	Phi	1638	*-0.046*	*-1.864*	*0.063*	-0.016	-0.638	0.523	**0.143**	**5.852**	**0.000**
Stopped and waited for the vehicle	Phi	1638	-0.032	-1.281	0.200	-0.015	-0.607	0.544	**0.108**	**4.397**	**0.000**
Slowed down to avoid collision	Phi	1638	*-0.042*	*-1.696*	*0.090*	-0.005	-0.185	0.853	**0.108**	**4.386**	**0.000**
Other reaction	Phi	1638	**-0.147**	**-5.997**	**0.000**	**0.160**	**6.544**	**0.000**	-0.028	-1.129	0.259
Sped up to avoid collision	Phi	1638	**-0.106**	**-4.301**	**0.000**	**0.122**	**4.971**	**0.000**	-0.036	-1.450	0.147
Ran to avoid collision	Phi	1638	**-0.104**	**-4.224**	**0.000**	**0.096**	**3.904**	**0.000**	0.020	0.791	0.429
Changed direction	Phi	1638	-0.034	-1.374	0.169	*0.046*	*1.848*	*0.065*	-0.026	-1.069	0.285
Driver and vehicle characteristics											
Right-turn queue length (# vehicles)	Point-Biserial	1638	**-0.061**	**-2.458**	**0.014**	**0.062**	**2.499**	**0.013**	-0.001	-0.056	0.955
Stopping location											
Did not stop	Phi	1638	**0.210**	**8.689**	**0.000**	**-0.205**	**-8.475**	**0.000**	-0.015	-0.591	0.555
Before the first crosswalk	Phi	1638	**-0.129**	**-5.269**	**0.000**	**0.125**	**5.098**	**0.000**	0.011	0.465	0.642
Inside/between the crosswalks	Phi	1638	**-0.132**	**-5.390**	**0.000**	**0.130**	**5.306**	**0.000**	0.007	0.272	0.786
Inside the first crosswalk	Phi	1638	**-0.111**	**-4.505**	**0.000**	**0.104**	**4.214**	**0.000**	0.018	0.727	0.467
Between the first and second crosswalks	Phi	1638	**-0.061**	**-2.493**	**0.013**	**0.069**	**2.787**	**0.005**	-0.016	-0.636	0.525
Vehicle type											
Small	Phi	1638	0.014	0.560	0.576	-0.015	-0.588	0.557	0.001	0.057	0.954
Sedan	Phi	1638	0.013	0.514	0.607	-0.012	-0.466	0.641	-0.003	-0.120	0.904
Motorcycle	Phi	1638	0.010	0.407	0.684	-0.027	-1.091	0.275	0.039	1.572	0.116
Medium	Phi	1638	-0.001	-0.041	0.967	0.011	0.430	0.667	-0.022	-0.895	0.371
SUV	Phi	1638	0.014	0.578	0.563	-0.015	-0.626	0.532	0.002	0.101	0.920
Pickup truck	Phi	1638	-0.021	-0.862	0.389	0.034	1.381	0.167	-0.029	-1.183	0.237
Van (minivan, sprinter van, etc.)	Phi	1638	0.002	0.091	0.928	0.000	0.009	0.993	-0.006	-0.232	0.817
Large	Phi	1638	-0.031	-1.262	0.207	0.009	0.371	0.711	**0.051**	**2.077**	**0.038**
Large truck (semi-truck, delivery truck, etc.)	Phi	1638	0.012	0.486	0.627	-0.019	-0.756	0.450	0.015	0.615	0.539
Vehicle pulling a trailer	Phi	1638	-0.027	-1.100	0.272	0.030	1.196	0.232	-0.005	-0.205	0.837
Bus	Phi	1638	*-0.044*	*-1.783*	*0.075*	0.006	0.238	0.812	**0.089**	**3.601**	**0.000**
Conflict information											
Encroachment time (sec)	Point-Biserial	1638	**0.221**	**9.164**	**0.000**	**-0.225**	**-9.356**	**0.000**	0.007	0.274	0.784
Pre-ET (sec), vehicle before pedestrian	Point-Biserial	626	0.058	1.464	0.144	-0.023	-0.564	0.573	-0.058	-1.460	0.145
Post-ET (sec), vehicle after pedestrian	Point-Biserial	1000	**0.245**	**7.981**	**0.000**	**-0.238**	**-7.751**	**0.000**	-0.022	-0.689	0.491
Conflict severity											
Low (5-10 sec)	Phi	1638	**0.207**	**8.555**	**0.000**	**-0.211**	**-8.749**	**0.000**	0.007	0.291	0.771
Mild (4-5 sec)	Phi	1638	**-0.110**	**-4.473**	**0.000**	**0.118**	**4.808**	**0.000**	-0.017	-0.689	0.491
High (0-3 sec)	Phi	1638	**-0.130**	**-5.304**	**0.000**	**0.126**	**5.149**	**0.000**	0.011	0.428	0.668
Weather and time information											

Weather											
Clear	Phi	1638	**0.061**	**2.474**	**0.013**	**-0.051**	**-2.066**	**0.039**	-0.024	-0.973	0.331
Rain (actively raining, or wet roadways)	Phi	1638	**-0.061**	**-2.474**	**0.013**	**0.051**	**2.066**	**0.039**	0.024	0.973	0.331
Hourly precipitation (in)	Point-Biserial	1638	0.003	0.114	0.909	-0.001	-0.022	0.983	-0.005	-0.214	0.830
0.01 in or more	Phi	1638	0.026	1.051	0.293	-0.028	-1.124	0.261	0.004	0.151	0.880
Temperature (°F)	Point-Biserial	1638	*0.047*	*1.902*	*0.057*	-0.006	-0.229	0.819	**-0.096**	**-3.900**	**0.000**
Less than 50°F	Phi	1638	-0.004	-0.168	0.866	**-0.049**	**-1.971**	**0.049**	**0.122**	**4.967**	**0.000**
50-64°F	Phi	1638	**-0.125**	**-5.109**	**0.000**	**0.147**	**6.000**	**0.000**	*-0.047*	*-1.923*	*0.055*
65-79°F	Phi	1638	**0.104**	**4.214**	**0.000**	**-0.088**	**-3.567**	**0.000**	-0.038	-1.535	0.125
80°F or more	Phi	1638	0.023	0.930	0.353	0.009	0.363	0.717	**-0.074**	**-3.001**	**0.003**
Day of week											
Weekday (Mon, Fri)	Phi	1638	**-0.064**	**-2.580**	**0.010**	**0.080**	**3.258**	**0.001**	-0.037	-1.512	0.131
Weekday (Tue, Wed, Thu)	Phi	1638	**0.064**	**2.580**	**0.010**	**-0.080**	**-3.258**	**0.001**	0.037	1.512	0.131
Time of day											
Morning (06:00-11:59)	Phi	1638	-0.036	-1.461	0.144	0.006	0.239	0.811	**0.070**	**2.844**	**0.005**
Afternoon (12:00-17:59)	Phi	1638	**0.054**	**2.182**	**0.029**	*-0.048*	*-1.943*	*0.052*	-0.014	-0.582	0.560
Evening/overnight (18:00-05:59)	Phi	1638	-0.028	-1.141	0.254	**0.059**	**2.405**	**0.016**	**-0.071**	**-2.895**	**0.004**
AM peak hours (07:00-08:59)	Phi	1638	**-0.062**	**-2.534**	**0.011**	0.011	0.448	0.654	**0.120**	**4.873**	**0.000**
PM peak hours (16:00-17:59)	Phi	1638	0.013	0.543	0.587	0.003	0.112	0.911	-0.038	-1.519	0.129
Traffic signal status information											
Pedestrian signal status, pedestrian at conflict point											
Walk	Phi	1638	0.027	1.106	0.269	-0.012	-0.466	0.641	-0.037	-1.493	0.136
Flashing don't walk	Phi	1638	-0.032	-1.299	0.194	0.022	0.892	0.372	0.024	0.958	0.338
Steady don't walk	Phi	1638	*-0.043*	*-1.726*	*0.085*	0.011	0.461	0.645	**0.073**	**2.948**	**0.003**
Crossing not signalized	Phi	1638	**0.054**	**2.182**	**0.029**	-0.028	-1.115	0.265	**-0.061**	**-2.491**	**0.013**
Right-turn vehicle signal status, vehicle at conflict point											
Green	Phi	1638	0.025	1.011	0.312	**-0.051**	**-2.076**	**0.038**	**0.060**	**2.439**	**0.015**
Yellow	Phi	1638	**-0.052**	**-2.091**	**0.037**	0.038	1.555	0.120	0.031	1.266	0.206
Red	Phi	1638	*-0.045*	*-1.810*	*0.070*	**0.062**	**2.498**	**0.013**	-0.038	-1.552	0.121
Right turn not signalized	Phi	1638	**0.054**	**2.182**	**0.029**	-0.028	-1.115	0.265	**-0.061**	**-2.491**	**0.013**
Corner and intersection attributes											
Corner radius (ft)	Point-Biserial	1638	**0.101**	**4.111**	**0.000**	**-0.071**	**-2.895**	**0.004**	**-0.070**	**-2.841**	**0.005**
Crosswalk offset distance (ft) [a]	Point-Biserial	1638	**0.146**	**5.990**	**0.000**	**-0.107**	**-4.373**	**0.000**	**-0.092**	**-3.744**	**0.000**
Channelized right turn (distance not available)	Phi	1638	0.001	0.047	0.963	0.026	1.062	0.288	**-0.063**	**-2.561**	**0.011**
Stop bar distance (ft) [b]	Point-Biserial	1638	0.029	1.184	0.236	-0.003	-0.103	0.918	**-0.062**	**-2.514**	**0.012**
Channelized right turn (distance not available)	Phi	1638	0.001	0.047	0.963	0.026	1.062	0.288	**-0.063**	**-2.561**	**0.011**
Curb ramps (#)	Point-Biserial	1638	**0.130**	**5.312**	**0.000**	**-0.091**	**-3.715**	**0.000**	**-0.091**	**-3.710**	**0.000**
1	Phi	1638	**-0.130**	**-5.312**	**0.000**	**0.091**	**3.715**	**0.000**	**0.091**	**3.710**	**0.000**
2	Phi	1638	**0.130**	**5.312**	**0.000**	**-0.091**	**-3.715**	**0.000**	**-0.091**	**-3.710**	**0.000**
Curb ramp type											

Diagonal (apex)	Phi	1638	**-0.170**	**-6.973**	**0.000**	**0.114**	**4.650**	**0.000**	**0.131**	**5.342**	**0.000**
Directional	Phi	1638	**0.155**	**6.350**	**0.000**	**-0.107**	**-4.343**	**0.000**	**-0.114**	**-4.633**	**0.000**
Blended transition	Phi	1638	0.035	1.421	0.155	-0.020	-0.793	0.428	-0.036	-1.470	0.142
Crosswalk type											
Standard markings	Phi	1638	**0.067**	**2.736**	**0.006**	0.002	0.068	0.945	**-0.160**	**-6.577**	**0.000**
Continental (high-visibility) markings	Phi	1638	**-0.069**	**-2.803**	**0.005**	0.000	-0.011	0.991	**0.161**	**6.601**	**0.000**
No crossing	Phi	1638	0.024	0.982	0.326	-0.022	-0.890	0.374	-0.006	-0.226	0.821
Right-turn lanes (#)	Point-Biserial	1638	0.027	1.108	0.268	-0.036	-1.458	0.145	0.020	0.790	0.430
0.5 (shared thru-right lane)	Phi	1638	**-0.099**	**-4.042**	**0.000**	**0.115**	**4.691**	**0.000**	-0.035	-1.410	0.159
1	Phi	1638	**0.129**	**5.284**	**0.000**	**-0.147**	**-6.030**	**0.000**	0.039	1.592	0.112
2	Phi	1638	**-0.100**	**-4.072**	**0.000**	**0.108**	**4.386**	**0.000**	-0.016	-0.650	0.516
Receiving lanes (#)	Point-Biserial	1638	**0.105**	**4.282**	**0.000**	**-0.093**	**-3.790**	**0.000**	-0.029	-1.183	0.237
0	Phi	1638	**-0.105**	**-4.282**	**0.000**	**0.093**	**3.790**	**0.000**	0.029	1.183	0.237
1	Phi	1638	**0.105**	**4.282**	**0.000**	**-0.093**	**-3.790**	**0.000**	-0.029	-1.183	0.237
Channelized right turn	Phi	1638	0.001	0.047	0.963	0.026	1.062	0.288	**-0.063**	**-2.561**	**0.011**
Skewed intersection	Phi	1638	-0.020	-0.797	0.425	**0.052**	**2.111**	**0.035**	**-0.074**	**-3.018**	**0.003**
Presence of bicycle lane	Phi	1638	**-0.089**	**-3.611**	**0.000**	0.002	0.082	0.935	**0.202**	**8.331**	**0.000**
AADP (100s)	Point-Biserial	1638	-0.032	-1.302	0.193	**0.053**	**2.141**	**0.032**	*-0.047*	*-1.912*	*0.056*
Natural log of AADP	Point-Biserial	1638	**-0.049**	**-1.999**	**0.046**	**0.049**	**1.968**	**0.049**	0.003	0.103	0.918
AADT (1000s)	Point-Biserial	1632	**-0.063**	**-2.530**	**0.011**	**0.090**	**3.637**	**0.000**	**-0.061**	**-2.488**	**0.013**
Natural log of AADT	Point-Biserial	1632	0.015	0.618	0.537	0.027	1.102	0.271	**-0.098**	**-3.985**	**0.000**
Right turn/crossing not signalized	Phi	1638	**0.054**	**2.182**	**0.029**	-0.028	-1.115	0.265	**-0.061**	**-2.491**	**0.013**
On-ramp	Phi	1638	**0.073**	**2.943**	**0.003**	**-0.061**	**-2.484**	**0.013**	-0.027	-1.096	0.273
Off-ramp	Phi	1638	**-0.092**	**-3.734**	**0.000**	**0.106**	**4.311**	**0.000**	-0.031	-1.256	0.209
Neighborhood attributes [c]											
Population density (1,000 people per mi^2)	Point-Biserial	1632	-0.013	-0.527	0.598	0.010	0.423	0.673	0.006	0.250	0.803
Employment density (1,000 jobs per mi^2)	Point-Biserial	1632	**0.070**	**2.838**	**0.005**	**-0.056**	**-2.268**	**0.023**	-0.033	-1.350	0.177
Land use											
Residential (%)	Point-Biserial	1632	**-0.187**	**-7.680**	**0.000**	**0.122**	**4.952**	**0.000**	**0.153**	**6.243**	**0.000**
Commercial (%)	Point-Biserial	1632	**0.136**	**5.563**	**0.000**	**-0.090**	**-3.640**	**0.000**	**-0.110**	**-4.452**	**0.000**
Industrial (%)	Point-Biserial	1632	0.013	0.543	0.587	-0.010	-0.393	0.695	-0.009	-0.354	0.723
Vacant (%)	Point-Biserial	1632	0.006	0.239	0.811	0.009	0.379	0.705	-0.035	-1.427	0.154
Other (%)	Point-Biserial	1632	**-0.077**	**-3.136**	**0.002**	**0.053**	**2.133**	**0.033**	**0.058**	**2.346**	**0.019**
Street intersection density (# per mi^2)	Point-Biserial	1632	**0.147**	**6.001**	**0.000**	**-0.095**	**-3.845**	**0.000**	**-0.122**	**-4.981**	**0.000**
4-way intersections (%)	Point-Biserial	1632	0.023	0.950	0.342	-0.021	-0.846	0.398	-0.006	-0.253	0.801
Transit stops (#)	Point-Biserial	1632	**-0.056**	**-2.257**	**0.024**	0.040	1.617	0.106	0.037	1.506	0.132
Places of worship (#)	Point-Biserial	1632	**-0.164**	**-6.725**	**0.000**	**0.096**	**3.902**	**0.000**	**0.159**	**6.514**	**0.000**
Schools (#)	Point-Biserial	1632	**-0.112**	**-4.545**	**0.000**	0.028	1.112	0.266	**0.196**	**8.060**	**0.000**
Park (acres)	Point-Biserial	1632	**-0.073**	**-2.947**	**0.003**	**0.094**	**3.826**	**0.000**	*-0.048*	*-1.957*	*0.051*
Household income (median, $1,000s)	Point-Biserial	1632	**-0.199**	**-8.220**	**0.000**	**0.114**	**4.629**	**0.000**	**0.200**	**8.246**	**0.000**

Vehicle ownership (mean, cars/household)	Point-Biserial	1632	0.026	1.036	0.301	0.001	0.037	0.970	**-0.062**	**-2.489**	**0.013**
Household size (mean, people/household)	Point-Biserial	1632	**-0.199**	**-8.198**	**0.000**	**0.153**	**6.244**	**0.000**	**0.109**	**4.442**	**0.000**

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.

4.3.5.2 Multivariate Regression Results

Table 4.30 includes results of the multilevel model for vehicle driver reaction. Just like for pedestrian reactions, this was a mixed multinomial logit model with random intercept terms, and results can be more easily interpreted using RRRs. The base or reference category was no obvious reaction.

Several characteristics were significantly associated with stopping or slowing, compared to no reaction. Drivers were more likely to stop or slow when there were more vehicles waiting to turn right (longer queue length). Stopping or slowing was also a more likely driver behavior when pedestrians were pushing a stroller or using a wheelchair, when they were approaching the curb (vs. leaving it), and when the right-turn vehicle signal status was red. Intersections with higher motor vehicle traffic volumes saw more drivers who stopped or slowed for the pedestrian(s), while stopping or slowing was a less common driver reaction for right turns involving a receiving lane.

Some similar but other different characteristics were significantly linked to other driver reactions (mostly speeding up and a few swerving behaviors). Compared to no reaction, these driver reactions were more likely when the pedestrian was: using a stroller or wheelchair, approaching the curb (instead of leaving the curb), crossing the intersection when the temperature was 65-79°F, and crossing when pedestrian signal status was steady don’t walk. Conversely, evening/overnight hours (18:00-05:59) had fewer right-turning drivers speeding up and swerving during a conflict with a pedestrian.

Table 4.30 Regression results for vehicle driver reaction

Variable	*Est.*	*SE*	z	*p*	*RRR*
Stopped or slowed (vs. No obvious reaction)					
Intercept (SD = 0.934)	-0.572	0.327	-1.751	0.080	--
Other characteristics: Stroller or wheelchair	2.103	0.798	2.634	0.008	8.187
Crossing direction: Approaching curb	0.271	0.119	2.281	0.023	1.312
Right-turn queue length (# vehicles)	0.075	0.038	1.973	0.049	1.078
Right-turn vehicle signal status: Red	0.311	0.145	2.137	0.033	1.364
Receiving lanes (#): 1	-0.877	0.488	-1.798	0.072	0.416
AADT (1000s)	0.014	0.009	1.600	0.110	1.015
Other reaction (vs. No obvious reaction)					
Intercept (SD = 1.92)	-3.923	0.513	-7.644	<0.001	--
Other characteristics: Stroller or wheelchair	2.591	1.335	1.941	0.052	13.341
Crossing direction: Approaching curb	0.711	0.270	2.636	0.008	2.035
Temperature: 65-79°F	1.086	0.445	2.440	0.015	2.963
Time of day: Evening/overnight (18:00–05:59)	-1.458	0.624	-2.337	0.019	0.233
Pedestrian signal status: Steady don’t walk	0.734	0.314	2.335	0.020	2.082

N (level 1) = 1,633; N (level 2) = 33.
LL (model) = -1,132.7; LL (intercept only) = -1,391.6; McFadden’s pseudo-R^2 = 0.186.

4.3.5.3 Summary

Table 4.31 summarizes the significant factors identified in the bivariate and multivariate analyses for vehicle driver reaction.

Table 4.31 Summary of results for vehicle driver reaction

*Stopped or slowed**	*Other reaction**
Positive • Natural log of group size (# people) • Age: Child or teenager • Gender: Female • **Other characteristics: Stroller or wheelchair** • Crossing direction: Approaching curb • *Pedestrian reaction: Other reaction* • **Right-turn queue length (# vehicles)** • *Stopping location: Before the first crosswalk* • *Stopping location: Inside/between the crosswalks* • *Conflict severity* • Weather: Rain (actively raining, or wet roadways) • Temperature: 50-64°F • Day of week: Weekday (Mon, Fri) • Time of day: Evening/overnight (18:00-05:59) • **Right-turn vehicle signal status: Red** • Right-turn lanes: 0.5 (shared thru-right lane) • Right-turn lanes: 2 • Skewed intersection • AADP • **AADT** • Off-ramp • Land use: Residential (%) • Land use: Other (%) • Places of worship (#) • Park (acres) • Household income (median) • Household size (mean, people/household)	Positive • Natural log of group size (# people) • Age: Child or teenager • Gender: Female • Other characteristics: Stroller or wheelchair • Other characteristics: Distracted • **Crossing direction: Approaching curb** • *Pedestrian reaction: Stopped or slowed* • Vehicle type: Large • Temperature: Less than 50°F • Temperature: 65-79°F • Time of day: Morning (06:00-11:59) • Time of day: AM peak hours (07:00-08:59) • **Pedestrian signal status: Steady don't walk** • Crosswalk type: Continental markings • Presence of bicycle lane • Land use: Residential (%) • Land use: Other (%) • Places of worship (#) • Schools (#) • Household income (median) • Household size (mean, people/household)
Negative • Other characteristics: Bicycle • *Encroachment time* • *Post-ET* • Temperature: Less than 50°F • Temperature: 65-79°F • Corner radius • Crosswalk offset distance • Curb ramps: 2 • Curb ramp type: Directional • **Receiving lanes: 1** • On-ramp • Employment density (jobs per mi^2) • Land use: Commercial (%) • Street intersection density (# per mi^2)	Negative • Other characteristics: Bicycle • Crosswalk: First crosswalk • Temperature: 80°F or more • **Time of day: Evening/overnight (18:00-05:59)** • Corner radius • Crosswalk offset distance • Stop bar distance • Curb ramps: 2 • Curb ramp type: Directional • Channelized right turn • Skewed intersection • Natural log of AADT • Right turn/crossing not signalized • Land use: Commercial (%) • Street intersection density (# per mi^2) • Vehicle ownership (mean, cars/household)

* A positive association means more likely to have this vehicle driver reaction than no reaction. A negative association means less likely to have this vehicle driver reaction than no reaction.
Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

4.3.6 Vehicle Driver Stop Behavior and Location

Another driver behavior measured through the observational data collection was stopping behavior. While almost two-thirds of right-turning vehicles *did not stop* fully (63.5%) when in proximity to a pedestrian, for those vehicles that did stop, data collectors recorded the stopping location. About half of these (17.8%) stopped *before the first crosswalk*, as is expected when drivers are faced with a red light. The other half (18.8%) stopped *inside/between the crosswalks*: most inside the first crosswalk (13.4%), some between the first and second crosswalks (5.4%), and none inside the second crosswalk (0.0%). It was expected that whether and where a driver stops might be another indicator of the potential for conflicts between right-turning vehicles and pedestrians. Thus, in the following bivariate and multivariate analyses, researchers analyzed these three levels of vehicle driver stopping behavior and location.

4.3.6.1 Bivariate Correlation Results

Table 4.32 shows how vehicle driver stopping location was linked to various pedestrian, driver, vehicle conflict, weather, traffic signal, corner, intersection, and neighborhood characteristics. Like most previous categorical outcomes, positive/negative correlations can be interpreted as variables that when they are present or increase, lead to greater/lower chances of having that outcome happen.

Several pedestrian characteristics were linked to driver stopping behavior and location. In the presence of larger pedestrian group sizes, stopping before the first crosswalk was more common and not stopping was less common. The presence of children or teens decreased the chances of not stopping, while the presence of adults increased those chances. Drivers were more likely to not stop (and less likely to stop before the first crosswalk) in the presence of people carrying a load, while not stopping was less likely when pedestrians were identified as being distracted. Unsurprisingly, drivers were more likely to stop before the first crosswalk for people in the first crosswalk; whereas drivers were more likely to not stop before the first crosswalk for pedestrians in the second crosswalk. When pedestrians were leaving the curb, drivers were more likely to not stop; whereas, when pedestrians were approaching the curb, drivers were more likely to stop inside/between the crosswalks. Pedestrians stopping or slowing increased the chances of drivers not stopping and decreased the chances of drivers stopping inside/between the crosswalks, while pedestrians having some other reaction had the opposite effect on driver stopping location.

As mentioned before, driver reactions and driver stopping behaviors were closely linked. Specifically, no obvious reaction was positively correlated with not stopping. When the right-turn queue length was longer, drivers were more likely to stop somewhere than to not stop. Large vehicles (especially buses) were more likely to stop before the first crosswalk and less likely to not stop.

As expected, conflict information was connected with driver stopping location. Drivers who did not stop tended to experience longer ETs and greater chance of lower-severity conflicts. Conversely, drivers who stopped (either before the first crosswalk or inside/between the crosswalks) tended to have shorter (overall and post-) ETs and more mild and/or high-severity conflicts.

Several other level one variables were significantly associated with driver stopping location. While precipitation was not linked to stopping behavior, temperature was. Specifically, not stopping was more likely for temperatures between 50 and 64°F, while stopping before the first crosswalk was more common when the temperature was colder than 50°F. On Mondays and Fridays, drivers were more likely to stop inside/between the crosswalks, whereas stopping before the first crosswalk was relatively more common in the middle of the week. Stopping somewhere tended to happen more during AM peak hours, whereas not stopping was more common during PM peak hours and in the evening/overnight. Drivers were less likely to not stop for pedestrians crossing on steady don’t walk (although this was just marginally significant). When drivers were turning right on red, stopping somewhere was more common, and not stopping was less likely.

Many corner and intersection attributes were significantly associated with driver stopping location. Stopping before the first crosswalk was more common at intersections with: smaller corner radii, one curb ramp, diagonal (apex) curb ramps, continental crosswalk markings, two right-turn lanes, no receiving lane, a bicycle lane, higher motor vehicle traffic volumes, and off-ramps. Stopping inside or between the crosswalks was more common at locations with: smaller corner radii, longer crosswalk offset and stop bar distances, two curb ramps, blended transition curb ramps, one right-turn lane, no receiving lane, and higher pedestrian volumes. Not stopping was more common in places with: larger corner radii, shorter crosswalk offset and stop bar distances, directional curb ramps, standard crosswalk markings, a shared thru-right-turn lane, a receiving lane, a channelized right turn, a skewed intersection, an on-ramp, and where the right turn and crossing were not signalized.

Various neighborhood attributes were also significantly associated with driver stopping location. Stopping before the first crosswalk was more common in places with: higher population and employment densities, fewer commercial land uses, more places of worship, and smaller household sizes. Stopping inside or between the crosswalks was more common in places with: higher population density, fewer industrial and vacant land uses, lower intersection density, more four-way intersections, more transit stops, more places of worship, more schools, fewer or smaller parks, lower household incomes, and lower vehicle ownership levels. Conversely, drivers were more likely to not stop in places with: lower population and employment densities, less residential and more commercial or vacant land uses, higher intersection density, fewer four-way intersections, fewer transit stops, fewer places of worship, fewer schools, more and larger parks, higher household incomes, and greater vehicle ownership.

Table 4.32 Correlation results for vehicle driver stopping location

			Stopping location: Did not stop			*Stopping location: Before the first crosswalk*			*Stopping location: Inside/between the crosswalks*		
Independent variable	*Test*	*df*	*Corr*	*t*	*p*	*Corr*	*t*	*p*	*Corr*	*t*	*p*
Pedestrian characteristics											
Group size (# people)	Point-Biserial	1638	**-0.068**	**-2.765**	**0.006**	**0.078**	**3.164**	**0.002**	0.007	0.301	0.763
Natural log of group size	Point-Biserial	1638	**-0.092**	**-3.731**	**0.000**	**0.098**	**4.001**	**0.000**	0.017	0.669	0.504
Age											
Child or teenager	Phi	1638	**-0.089**	**-3.604**	**0.000**	**0.058**	**2.369**	**0.018**	**0.052**	**2.106**	**0.035**
Child	Phi	1638	0.006	0.224	0.823	0.014	0.571	0.568	-0.021	-0.838	0.402
Teenager	Phi	1638	**-0.086**	**-3.485**	**0.001**	**0.050**	**2.023**	**0.043**	**0.057**	**2.302**	**0.021**
Adult	Phi	1638	**0.079**	**3.210**	**0.001**	**-0.050**	**-2.021**	**0.043**	**-0.049**	**-1.966**	**0.049**
Young adult	Phi	1638	**0.051**	**2.049**	**0.041**	**-0.059**	**-2.383**	**0.017**	-0.005	-0.186	0.853
Middle-aged adult	Phi	1638	-0.009	-0.356	0.722	0.021	0.856	0.392	-0.010	-0.402	0.687
Older adult (65+)	Phi	1638	-0.036	-1.460	0.145	0.034	1.390	0.165	0.011	0.434	0.664
Adult of unknown age	Phi	1638	*0.045*	*1.843*	*0.065*	-0.006	-0.247	0.805	**-0.050**	**-2.032**	**0.042**
Gender											
Male	Phi	1638	-0.040	-1.611	0.107	0.020	0.829	0.407	0.029	1.171	0.242
Female	Phi	1638	-0.040	-1.605	0.109	0.040	1.631	0.103	0.009	0.376	0.707
Unknown gender	Phi	1638	**0.049**	**1.983**	**0.048**	0.007	0.270	0.787	**-0.067**	**-2.715**	**0.007**
Other characteristics											
Carrying load	Phi	1638	**0.059**	**2.383**	**0.017**	**-0.051**	**-2.085**	**0.037**	-0.022	-0.888	0.375
Stroller or wheelchair	Phi	1638	-0.014	-0.571	0.568	0.018	0.726	0.468	0.000	-0.009	0.993
Stroller	Phi	1638	-0.038	-1.545	0.122	0.034	1.382	0.167	0.014	0.547	0.584
Wheelchair	Phi	1638	0.038	1.531	0.126	-0.023	-0.939	0.348	-0.024	-0.965	0.335
Skateboard or scooter	Phi	1638	0.008	0.313	0.754	0.026	1.059	0.290	-0.035	-1.429	0.153
Skateboard	Phi	1638	-0.006	-0.251	0.802	0.038	1.535	0.125	-0.030	-1.199	0.231
Scooter	Phi	1638	0.020	0.829	0.407	-0.002	-0.076	0.940	-0.023	-0.949	0.343
Bicycle	Phi	1638	0.003	0.107	0.914	-0.037	-1.511	0.131	0.033	1.353	0.176
Distracted (phone, headphones, conversations, etc.)	Phi	1638	**-0.080**	**-3.252**	**0.001**	**0.076**	**3.066**	**0.002**	0.025	0.994	0.321
Crosswalk											
First crosswalk	Phi	1638	**-0.088**	**-3.569**	**0.000**	**0.134**	**5.484**	**0.000**	-0.024	-0.958	0.338
Second crosswalk	Phi	1638	**0.088**	**3.569**	**0.000**	**-0.134**	**-5.484**	**0.000**	0.024	0.958	0.338
Crossing location											
In the crosswalk or the crosswalk area	Phi	1638	-0.033	-1.331	0.183	0.033	1.340	0.180	0.008	0.324	0.746
Away from the crosswalk	Phi	1638	0.033	1.331	0.183	-0.033	-1.340	0.180	-0.008	-0.324	0.746
Mid-block, away from the crosswalk	Phi	1638	0.023	0.913	0.361	-0.024	-0.962	0.336	-0.004	-0.180	0.857
In the middle of the intersection	Phi	1638	0.026	1.036	0.300	-0.024	-0.974	0.330	-0.008	-0.320	0.749

Crossing direction											
Leaving curb	Phi	1638	**0.076**	**3.100**	**0.002**	-0.015	-0.603	0.547	**-0.080**	**-3.232**	**0.001**
Approaching curb	Phi	1638	**-0.076**	**-3.100**	**0.002**	0.015	0.603	0.547	**0.080**	**3.232**	**0.001**
Pedestrian reactions											
No obvious reaction	Phi	1638	0.012	0.502	0.616	0.005	0.187	0.852	-0.020	-0.803	0.422
Stopped or slowed	Phi	1638	**0.070**	**2.839**	**0.005**	-0.026	-1.061	0.289	**-0.061**	**-2.456**	**0.014**
Stopped and waited for the vehicle	Phi	1638	**0.070**	**2.847**	**0.004**	-0.032	-1.287	0.198	**-0.055**	**-2.243**	**0.025**
Slowed down to avoid collision	Phi	1638	0.012	0.482	0.630	0.008	0.342	0.732	-0.023	-0.932	0.351
Other reaction	Phi	1638	**-0.104**	**-4.216**	**0.000**	0.025	1.001	0.317	**0.104**	**4.212**	**0.000**
Sped up to avoid collision	Phi	1638	**-0.068**	**-2.740**	**0.006**	0.059	2.409	0.016	0.025	1.008	0.314
Ran to avoid collision	Phi	1638	*-0.044*	*-1.768*	*0.077*	0.009	0.357	0.721	*0.045*	*1.830*	*0.067*
Changed direction	Phi	1638	**-0.065**	**-2.621**	**0.009**	*-0.041*	*-1.658*	*0.097*	**0.120**	**4.893**	**0.000**
Driver and vehicle characteristics											
Right-turn queue length (# vehicles)	Point-Biserial	1638	**-0.154**	**-6.316**	**0.000**	**0.059**	**2.373**	**0.018**	**0.133**	**5.417**	**0.000**
Driver reaction											
No obvious reaction	Phi	1638	**0.210**	**8.689**	**0.000**	**-0.129**	**-5.269**	**0.000**	**-0.132**	**-5.390**	**0.000**
Stopped or slowed	Phi	1638	**-0.205**	**-8.475**	**0.000**	**0.125**	**5.098**	**0.000**	**0.130**	**5.306**	**0.000**
Driver fully stopped	Phi	1638	**-0.650**	**-34.58**	**0.000**	**0.405**	**17.91**	**0.000**	**0.403**	**17.85**	**0.000**
Driver slowed down	Phi	1638	**0.368**	**16.02**	**0.000**	**-0.232**	**-9.669**	**0.000**	**-0.225**	**-9.366**	**0.000**
Other reaction	Phi	1638	-0.015	-0.591	0.555	0.011	0.465	0.642	0.007	0.272	0.786
Driver sped up	Phi	1638	-0.026	-1.061	0.289	0.019	0.757	0.449	0.014	0.565	0.572
Driver swerved	Phi	1638	*0.042*	*1.713*	*0.087*	-0.026	-1.051	0.294	-0.027	-1.079	0.281
Vehicle type											
Small	Phi	1638	0.039	1.586	0.113	-0.031	-1.246	0.213	-0.018	-0.730	0.466
Sedan	Phi	1638	0.034	1.394	0.163	-0.028	-1.129	0.259	-0.015	-0.609	0.543
Motorcycle	Phi	1638	*0.042*	*1.713*	*0.087*	-0.026	-1.051	0.294	-0.027	-1.079	0.281
Medium	Phi	1638	-0.014	-0.578	0.563	0.006	0.252	0.801	0.011	0.465	0.642
SUV	Phi	1638	*0.043*	*1.745*	*0.081*	-0.008	-0.322	0.747	*-0.045*	*-1.835*	*0.067*
Pickup truck	Phi	1638	*-0.043*	*-1.725*	*0.085*	0.012	0.475	0.635	*0.041*	*1.661*	*0.097*
Van (minivan, sprinter van, etc.)	Phi	1638	*-0.046*	*-1.883*	*0.060*	0.010	0.407	0.684	*0.047*	*1.923*	*0.055*
Large	Phi	1638	**-0.060**	**-2.436**	**0.015**	**0.060**	**2.416**	**0.016**	0.016	0.629	0.530
Large truck (semi-truck, delivery truck, etc.)	Phi	1638	-0.030	-1.222	0.222	0.039	1.578	0.115	-0.001	-0.043	0.966
Vehicle pulling a trailer	Phi	1638	-0.008	-0.325	0.746	0.019	0.779	0.436	-0.009	-0.366	0.714
Bus	Phi	1638	**-0.071**	**-2.900**	**0.004**	*0.046*	*1.859*	*0.063*	*0.043*	*1.744*	*0.081*
Conflict information											
Encroachment time (sec)	Point-Biserial	1638	**0.145**	**5.942**	**0.000**	**-0.062**	**-2.509**	**0.012**	**-0.118**	**-4.826**	**0.000**
Pre-ET (sec), vehicle before pedestrian	Point-Biserial	626	-0.038	-0.946	0.345	0.045	1.129	0.259	0.008	0.200	0.842
Post-ET (sec), vehicle after pedestrian	Point-Biserial	1000	**0.176**	**5.644**	**0.000**	**-0.069**	**-2.180**	**0.029**	**-0.143**	**-4.554**	**0.000**
Conflict severity											
Low (5-10 sec)	Phi	1638	**0.141**	**5.780**	**0.000**	**-0.064**	**-2.613**	**0.009**	**-0.111**	**-4.524**	**0.000**

Mild (4-5 sec)	Phi	1638	**-0.103**	**-4.181**	**0.000**	**0.059**	**2.407**	**0.016**	**0.068**	**2.775**	**0.006**
High (0-3 sec)	Phi	1638	**-0.057**	**-2.319**	**0.021**	0.012	0.475	0.635	**0.059**	**2.394**	**0.017**
Weather and time information											
Weather											
Clear	Phi	1638	-0.011	-0.447	0.655	-0.027	-1.096	0.273	0.040	1.631	0.103
Rain (actively raining, or wet roadways)	Phi	1638	0.011	0.447	0.655	0.027	1.096	0.273	-0.040	-1.631	0.103
Hourly precipitation (in)	Point-Biserial	1638	0.010	0.424	0.672	0.003	0.130	0.897	-0.016	-0.651	0.515
0.01 in or more	Phi	1638	0.006	0.224	0.823	0.003	0.139	0.889	-0.010	-0.413	0.680
Temperature (°F)	Point-Biserial	1638	**0.086**	**3.512**	**0.000**	**-0.078**	**-3.172**	**0.002**	-0.030	-1.207	0.227
Less than 50°F	Phi	1638	**-0.112**	**-4.569**	**0.000**	**0.113**	**4.592**	**0.000**	0.028	1.115	0.265
50-64°F	Phi	1638	**0.064**	**2.593**	**0.010**	**-0.082**	**-3.330**	**0.001**	0.002	0.072	0.943
65-79°F	Phi	1638	*0.043*	*1.740*	*0.082*	-0.039	-1.587	0.113	-0.014	-0.586	0.558
80°F or more	Phi	1638	0.027	1.090	0.276	-0.008	-0.330	0.741	-0.025	-1.020	0.308
Day of week											
Weekday (Mon, Fri)	Phi	1638	-0.019	-0.773	0.440	**-0.058**	**-2.348**	**0.019**	**0.081**	**3.269**	**0.001**
Weekday (Tue, Wed, Thu)	Phi	1638	0.019	0.773	0.440	**0.058**	**2.348**	**0.019**	**-0.081**	**-3.269**	**0.001**
Time of day											
Morning (06:00-11:59)	Phi	1638	*-0.047*	*-1.916*	*0.056*	0.033	1.349	0.178	0.026	1.036	0.300
Afternoon (12:00-17:59)	Phi	1638	0.009	0.378	0.706	-0.030	-1.207	0.227	0.018	0.721	0.471
Evening/overnight (18:00-05:59)	Phi	1638	**0.049**	**1.972**	**0.049**	-0.002	-0.072	0.943	**-0.058**	**-2.363**	**0.018**
AM peak hours (07:00-08:59)	Phi	1638	**-0.096**	**-3.902**	**0.000**	**0.056**	**2.263**	**0.024**	**0.063**	**2.575**	**0.010**
PM peak hours (16:00-17:59)	Phi	1638	**0.049**	**1.979**	**0.048**	-0.037	-1.507	0.132	-0.024	-0.958	0.338
Traffic signal status information											
Pedestrian signal status, pedestrian at conflict point											
Walk	Phi	1638	-0.036	-1.445	0.149	0.006	0.257	0.797	0.038	1.530	0.126
Flashing don't walk	Phi	1638	-0.027	-1.104	0.270	-0.007	-0.270	0.787	0.040	1.628	0.104
Steady don't walk	Phi	1638	*-0.047*	*-1.908*	*0.057*	0.041	1.643	0.101	0.018	0.737	0.461
Crossing not signalized	Phi	1638	**0.161**	**6.619**	**0.000**	*-0.048*	*-1.953*	*0.051*	**-0.152**	**-6.214**	**0.000**
Right-turn vehicle signal status, vehicle at conflict point											
Green	Phi	1638	0.040	1.623	0.105	**-0.092**	**-3.759**	**0.000**	*0.042*	*1.682*	*0.093*
Yellow	Phi	1638	0.005	0.188	0.851	-0.001	-0.048	0.962	-0.005	-0.185	0.853
Red	Phi	1638	**-0.156**	**-6.400**	**0.000**	**0.137**	**5.613**	**0.000**	**0.058**	**2.336**	**0.020**
Right turn not signalized	Phi	1638	**0.161**	**6.619**	**0.000**	*-0.048*	*-1.953*	*0.051*	**-0.152**	**-6.214**	**0.000**
Corner and intersection attributes											
Corner radius (ft)	Point-Biserial	1638	**0.173**	**7.107**	**0.000**	**-0.071**	**-2.886**	**0.004**	**-0.143**	**-5.867**	**0.000**
Crosswalk offset distance (ft) [a]	Point-Biserial	1638	*-0.045*	*-1.838*	*0.066*	0.009	0.382	0.703	*0.047*	*1.892*	*0.059*
Channelized right turn (distance not available)	Phi	1638	**0.114**	**4.646**	**0.000**	0.002	0.087	0.931	**-0.143**	**-5.840**	**0.000**
Stop bar distance (ft) [b]	Point-Biserial	1638	**-0.114**	**-4.646**	**0.000**	-0.022	-0.877	0.380	**0.162**	**6.646**	**0.000**
Channelized right turn (distance not available)	Phi	1638	**0.114**	**4.646**	**0.000**	0.002	0.087	0.931	**-0.143**	**-5.840**	**0.000**
Curb ramps (#)	Point-Biserial	1638	-0.013	-0.527	0.598	**-0.106**	**-4.316**	**0.000**	**0.120**	**4.906**	**0.000**

1	Phi	1638	0.013	0.527	0.598	**0.106**	**4.316**	**0.000**	**-0.120**	**-4.906**	**0.000**
2	Phi	1638	-0.013	-0.527	0.598	**-0.106**	**-4.316**	**0.000**	**0.120**	**4.906**	**0.000**
Curb ramp type											
Diagonal (apex)	Phi	1638	-0.034	-1.363	0.173	**0.090**	**3.652**	**0.000**	*-0.047*	*-1.899*	*0.058*
Directional	Phi	1638	**0.120**	**4.877**	**0.000**	**-0.124**	**-5.052**	**0.000**	-0.026	-1.044	0.296
Blended transition	Phi	1638	**-0.136**	**-5.563**	**0.000**	**0.049**	**1.975**	**0.048**	**0.120**	**4.896**	**0.000**
Crosswalk type											
Standard markings	Phi	1638	**0.062**	**2.530**	**0.012**	**-0.054**	**-2.200**	**0.028**	-0.024	-0.955	0.340
Continental (high-visibility) markings	Phi	1638	**-0.064**	**-2.583**	**0.010**	**0.055**	**2.234**	**0.026**	0.024	0.987	0.324
No crossing	Phi	1638	0.019	0.764	0.445	-0.012	-0.469	0.639	-0.012	-0.482	0.630
Right-turn lanes (#)	Point-Biserial	1638	**-0.157**	**-6.433**	**0.000**	**0.098**	**3.982**	**0.000**	**0.097**	**3.961**	**0.000**
0.5 (shared thru-right lane)	Phi	1638	**0.152**	**6.237**	**0.000**	**-0.059**	**-2.411**	**0.016**	**-0.129**	**-5.283**	**0.000**
1	Phi	1638	**-0.128**	**-5.223**	**0.000**	0.028	1.116	0.265	**0.131**	**5.340**	**0.000**
2	Phi	1638	**-0.067**	**-2.720**	**0.007**	**0.096**	**3.917**	**0.000**	-0.012	-0.487	0.627
Receiving lanes (#)	Point-Biserial	1638	**0.168**	**6.889**	**0.000**	**-0.053**	**-2.155**	**0.031**	**-0.155**	**-6.340**	**0.000**
0	Phi	1638	**-0.168**	**-6.889**	**0.000**	**0.053**	**2.155**	**0.031**	**0.155**	**6.340**	**0.000**
1	Phi	1638	**0.168**	**6.889**	**0.000**	**-0.053**	**-2.155**	**0.031**	**-0.155**	**-6.340**	**0.000**
Channelized right turn	Phi	1638	**0.114**	**4.646**	**0.000**	0.002	0.087	0.931	**-0.143**	**-5.840**	**0.000**
Skewed intersection	Phi	1638	**0.109**	**4.431**	**0.000**	0.023	0.935	0.350	**-0.157**	**-6.434**	**0.000**
Presence of bicycle lane	Phi	1638	**-0.077**	**-3.127**	**0.002**	**0.095**	**3.876**	**0.000**	0.001	0.053	0.958
AADP (100s)	Point-Biserial	1638	**-0.110**	**-4.500**	**0.000**	0.027	1.085	0.278	**0.110**	**4.479**	**0.000**
Natural log of AADP	Point-Biserial	1638	**-0.168**	**-6.910**	**0.000**	0.028	1.140	0.254	**0.180**	**7.404**	**0.000**
AADT (1000s)	Point-Biserial	1632	*-0.044*	*-1.783*	*0.075*	**0.066**	**2.677**	**0.008**	-0.011	-0.431	0.667
Natural log of AADT	Point-Biserial	1632	-0.020	-0.806	0.420	0.007	0.290	0.772	0.018	0.710	0.478
Right turn/crossing not signalized	Phi	1638	**0.161**	**6.619**	**0.000**	*-0.048*	*-1.953*	*0.051*	**-0.152**	**-6.214**	**0.000**
On-ramp	Phi	1638	**0.149**	**6.090**	**0.000**	*-0.042*	*-1.703*	*0.089*	**-0.142**	**-5.816**	**0.000**
Off-ramp	Phi	1638	-0.016	-0.631	0.528	**0.069**	**2.806**	**0.005**	**-0.049**	**-1.977**	**0.048**
Neighborhood attributes [c]											
Population density (1,000 people per mi^2)	Point-Biserial	1632	**-0.143**	**-5.844**	**0.000**	**0.061**	**2.483**	**0.013**	**0.116**	**4.734**	**0.000**
Employment density (1,000 jobs per mi^2)	Point-Biserial	1632	**-0.063**	**-2.545**	**0.011**	**0.057**	**2.288**	**0.022**	0.022	0.887	0.375
Land use											
Residential (%)	Point-Biserial	1632	**-0.061**	**-2.475**	**0.013**	*0.046*	*1.854*	*0.064*	0.030	1.228	0.220
Commercial (%)	Point-Biserial	1632	**0.055**	**2.239**	**0.025**	**-0.103**	**-4.186**	**0.000**	0.033	1.340	0.180
Industrial (%)	Point-Biserial	1632	0.039	1.564	0.118	*0.042*	*1.694*	*0.091*	**-0.089**	**-3.611**	**0.000**
Vacant (%)	Point-Biserial	1632	**0.110**	**4.491**	**0.000**	-0.010	-0.390	0.696	**-0.127**	**-5.169**	**0.000**
Other (%)	Point-Biserial	1632	**-0.124**	**-5.043**	**0.000**	*0.041*	*1.674*	*0.094*	**0.112**	**4.561**	**0.000**
Street intersection density (# per mi^2)	Point-Biserial	1632	**0.067**	**2.723**	**0.007**	-0.022	-0.908	0.364	**-0.061**	**-2.466**	**0.014**
4-way intersections (%)	Point-Biserial	1632	**-0.156**	**-6.391**	**0.000**	*0.046*	*1.851*	*0.064*	**0.148**	**6.041**	**0.000**
Transit stops (#)	Point-Biserial	1632	**-0.149**	**-6.104**	**0.000**	0.009	0.382	0.703	**0.175**	**7.189**	**0.000**
Places of worship (#)	Point-Biserial	1632	**-0.174**	**-7.135**	**0.000**	**0.131**	**5.331**	**0.000**	**0.086**	**3.485**	**0.001**

Schools (#)	Point-Biserial	1632	**-0.132**	**-5.366**	**0.000**	0.035	1.398	0.162	**0.129**	**5.237**	**0.000**
Park (acres)	Point-Biserial	1632	**0.092**	**3.743**	**0.000**	-0.017	-0.698	0.485	**-0.097**	**-3.933**	**0.000**
Household income (median, $1,000s)	Point-Biserial	1632	**0.049**	**1.972**	**0.049**	0.021	0.839	0.401	**-0.081**	**-3.269**	**0.001**
Vehicle ownership (mean, cars/household)	Point-Biserial	1632	**0.104**	**4.205**	**0.000**	-0.028	-1.114	0.265	**-0.101**	**-4.090**	**0.000**
Household size (mean, people/household)	Point-Biserial	1632	*0.043*	*1.719*	*0.086*	**-0.052**	**-2.106**	**0.035**	-0.001	-0.050	0.960

[a] Sideways distance from the inside edge of the right-most lane to the inside edge of the second crosswalk.
[b] Forward distance from the right-turn lane stop bar to the start of the second crosswalk.
[c] These variables were measured using a quarter-mile network buffer.

4.3.6.2 Multivariate Regression Results

Table 4.33 presents results of the multilevel model for vehicle driver stopping location. The methods and means of interpretation were the same as they were for vehicle driver reaction. The research used a mixed multinomial logit model with random intercept terms, and interprets the results using RRRs in comparison to the base category of “did not stop.” Because several variables were significant in both comparison equations, the following paragraphs interpret results based on type of variable (level one variables about the conflict vs. level two variables about the location).

Several variables measured for the conflict were significant in both equations. Large vehicles were more likely to stop somewhere (before the first crosswalk or inside/between the crosswalks) than to not stop. Similarly, stopping before the first crosswalk or inside/between the crosswalks was more likely when vehicles were turning right on red and when the right-turn queue length was longer. When pedestrians were crossing at the first crosswalk, drivers were more likely to stop before the first crosswalk (than not stop). Similarly, drivers were more likely to stop before the first crosswalk (than not stop) when more pedestrians were crossing the street and less likely to stop when temperature was 50-64°F. When pedestrians were approaching the curb, drivers were more likely to stop between the two crosswalks (compared to when pedestrians were leaving the curb). During evening/overnight hours (6 PM to 6 AM), drivers were less likely to stop inside/between the crosswalks.

Compared to other outcomes, there were several design and locational variables that were significantly associated with vehicle stopping location. At corners with larger corner radii, right-turning drivers were slightly less likely to stop before the crosswalks. Instances of drivers stopping inside/between the crosswalks were less common at locations with on-ramps. Locations with more surrounding commercial land uses tended to see fewer vehicles stopping before the first crosswalk, while places with greater population density tended to see more vehicles stopping inside/between the crosswalks.

Table 4.33 Regression results for vehicle driver stopping location

Variable	*Est.*	*SE*	z	*p*	*RRR*
Before the first crosswalk (vs. Did not stop)					
Intercept (SD = 0.638)	-0.812	0.507	-1.603	0.109	--
Natural log of group size (# people)	0.211	0.130	1.623	0.105	1.235
Crosswalk: First crosswalk	0.649	0.239	2.708	0.007	1.913
Right-turn queue length (# vehicles)	0.322	0.049	6.541	<0.001	1.380
Vehicle type: Large	0.767	0.321	2.389	0.017	2.154
Temperature: 50-64°F	-0.385	0.223	-1.725	0.084	0.680
Right-turn vehicle signal status: Red	0.670	0.220	3.044	0.002	1.954
Corner radius (ft)	-0.018	0.008	-2.179	0.029	0.982
Land use: Commercial (%)	-0.020	0.009	-2.140	0.032	0.981
Inside/between the crosswalks (vs. Did not stop)					
Intercept (SD = 0.770)	-3.665	0.487	-7.525	<0.001	--
Crossing direction: Approaching curb	0.535	0.141	3.806	<0.001	1.708
Right-turn queue length (# vehicles)	0.288	0.047	6.157	<0.001	1.334
Vehicle type: Large	0.613	0.354	1.732	0.083	1.846
Time of day: Evening/overnight (18:00-05:59)	-0.469	0.218	-2.154	0.031	0.626
Right turn vehicle signal status: Red	0.976	0.178	5.468	<0.001	2.654
On-ramp	-1.526	0.765	-1.994	0.046	0.218
Population density (1,000 people per mi2)	0.226	0.077	2.929	0.003	1.254

N (level 1) = 1,633; N (level 2) = 33.

LL (model) = -1,292.6; LL (intercept only) = -1,492.0; McFadden's pseudo-R^2 = 0.134.

4.3.6.3 Summary

Table 4.34 summarizes the significant factors identified in the bivariate and multivariate analyses for vehicle driver stopping location.

Table 4.34 Summary of results for vehicle driver stopping location

*Before the first crosswalk**	*Inside/between the crosswalks**
Positive	Positive
• **Natural log of group size (# people)**	• Age: Child or teenager
• Age: Child or teenager	• **Crossing direction: Approaching curb**
• Other characteristics: Distracted	• *Pedestrian reaction: Other reaction*
• **Crosswalk: First crosswalk**	• **Right-turn queue length (# vehicles)**
• **Right-turn queue length (# vehicles)**	• *Driver reaction: Stopped or slowed*
• *Driver reaction: Stopped or slowed*	• Vehicle type: Large
• **Vehicle type: Large**	• *Conflict severity*
• *Conflict severity*	• Day of week: Weekday (Mon, Fri)
• Temperature: Less than 50°F	• Time of day: AM peak hours (07:00-08:59)
• Time of day: AM peak hours (07:00-08:59)	• **Right-turn vehicle signal status: Red**
• **Right-turn vehicle signal status: Red**	• Stop bar distance
• Curb ramp type: Blended transition	• Curb ramps: 2
• Crosswalk type: Continental markings	• Curb ramp type: Blended transition
• Right-turn lanes: 2	• Natural log of AADP
• Presence of bicycle lane	• **Population density (people per mi^2)**
• AADT	• Land use: Other (%)
• Off-ramp	• 4-way intersections (%)
• Population density (people per mi^2)	• Transit stops (#)
• Employment density (jobs per mi^2)	• Places of worship (#)
• Places of worship (#)	• Schools (#)
Negative	Negative
• Other characteristics: Carrying load	• *Pedestrian reaction: Stopped or slowed*
• *Encroachment time*	• *Encroachment time*
• *Post-ET*	• *Post-ET*
• **Temperature: 50-64°F**	• **Time of day: Evening/overnight (18:00-05:59)**
• Day of week: Weekday (Mon, Fri)	• Corner radius
• **Corner radius**	• Right-turn lanes: 0.5 (shared thru-right lane)
• Curb ramps: 2	• Receiving lanes: 1
• Curb ramp type: Directional	• Channelized right turn
• Right-turn lanes: 0.5 (shared thru-right lane)	• Skewed intersection
• Receiving lanes: 1	• Right turn/crossing not signalized
• **Land use: Commercial (%)**	• **On-ramp**
• Household size (mean, people/household)	• Off-ramp
	• Land use: Industrial (%)
	• Land use: Vacant (%)
	• Street intersection density (# per mi^2)
	• Park (acres)
	• Household income (median)
	• Vehicle ownership (mean, cars/household)

* A positive association means more likely to have this driver stopping location/behavior than "did not stop." A negative association means less likely to have this driver stopping location/behavior than "did not stop." Regular text indicates a significant factor in one analysis, either bivariate or multivariate. **Bold** text indicates a significant factor in both analyses. *Italic* text indicates a significant factor excluded from the multivariate analysis.

4.4 Summary

This chapter presented the results of the crash data analysis—including univariate/bivariate comparisons using chi-square tests, and multivariate models utilizing ZINB regression—as well as the observational data analysis—involving bivariate analyses using correlations, and multivariate multilevel models.

For the crash data analysis: pedestrian and bicycle crashes involving right-turning motor vehicles tended to be less severe than those involving left-turn and straight-ahead movements, likely due to lower speeds during right turns. Regression models for only right-turn pedestrian/bicycle crash frequencies were generally quite similar to those models for all crashes, although some associations were stronger or weaker. The model-estimated relationships between crash counts and both prohibited RTOR (pedestrian) and channelized right turns (bicycle) were still negative but stronger when looking just at right-turn crashes (although not statistically different for pedestrians).

For the observational data analysis, there were numerous findings, many of which will be discussed in the following chapter. Among the most notable findings: The most severe conflicts were those in which pedestrians had to speed up, run, or change direction to avoid a collision, while drivers also slowed or stopped to avoid the collision. Conflicts involving larger pedestrian group sizes tended to be less severe, and drivers were more likely to stop. Pedestrians crossing in the second crosswalk were at greater risk of a more severe conflict, and drivers were less likely to stop for pedestrians in the second crosswalk. Conflict severity was worse when there were more vehicles waiting to turn right. Corner and intersection geometric design factors had complex and somewhat conflicting effects, but there was some evidence relating corner radius, crosswalk offset distance, stop bar distance, and right-turn lane configurations with pedestrian-vehicle conflict outcomes of interest.

5.0 CONCLUSIONS

5.1 Summary

The objective of this research project was to understand the factors (including curb/corner radii) affecting safety at intersections involving right-turning vehicles and pedestrians/bicyclists. To achieve this objective, the research team assembled multiple datasets from a variety of sources (Chapter 3.0): pedestrian and bicycle crash data, corner and intersection characteristics, built environment and neighborhood sociodemographic characteristics, and observations of pedestrian-vehicle conflicts and behaviors. Next (Chapter 4.0), crashes were analyzed using chi-square tests and ZINB regression models, and observations were analyzed using correlations and multilevel (linear, ordered logit, binary logit, and multinomial logit) regression models. The present chapter summarizes key findings—from both the crash data analysis and the observation data analysis—and notes study limitations.

5.2 Findings

5.2.1 Factors Associated with Right-Turn Vehicle-Pedestrian Crashes

5.2.1.1 Bivariate Analysis

The bivariate analysis of crashes between pedestrians and right-turning vehicles (Section 4.2.1) involved chi-squared tests on whether right-turn crashes were significantly more or less likely to have some characteristic than pedestrian crashes with other vehicle movements (left turn, straight thru). Key findings include the following:

Right-turn pedestrian crashes tended to be less severe: 6% (vs. 14% overall) involved fatal or serious injuries, while 51% (vs. 42% overall) involved possible or no injury. This finding is likely due to the slower speeds of right-turning vehicles, since higher speed is strongly associated with more severe pedestrian injury.

Pedestrian crashes with right-turning vehicles were relatively less common during rainy weather (7% vs. 10% overall), on wet roadways (10% vs. 14% overall), and in poor light or unlighted conditions (29% vs. 41% overall). In general, these characteristics tend to decrease road user visibility. Perhaps the simpler movements, closer proximity of road users, and slower speeds involved in right turns diminish the negative effects of these characteristics on pedestrian safety.

5.2.1.2 Multivariate Analysis

For a multivariate analysis (Section 4.2.2.1), multiple ZINB models were estimated to predict pedestrian crashes for all vehicle movements and for right-turning vehicle movements. Differences in the direction or magnitude of significant factors might point towards characteristics or situations in which right-turn vehicle crashes are over-/under-represented or more/less frequent, compared to all pedestrian crashes. Key findings from the models are as follows:

No substantial differences between all and right-turn pedestrian crashes were found for associations with pedestrian volumes, motor vehicle volumes, the number of nearby bus stops, and percentage of the neighborhood population with a disability. As pedestrian volumes, vehicle volumes, bus stops, and disability percentages increase, the models predict that pedestrian crashes involving right-turning vehicles would increase at about the same rate as overall pedestrian crashes. Thus, the effect of these characteristics does not seem to change for crashes involving right-turning vehicles.

Some relationships with pedestrian crashes became weaker or were no longer significant when looking at just right-turn crashes. Intersections with more bike lanes had fewer pedestrian crashes overall, but bike lanes did not seem to affect the number of right-turn pedestrian crashes. Perhaps bike lanes provide greater separation between pedestrians and motor vehicles in general; but, for right turns, bike lanes increase the effective corner radius that vehicles travel when turning right, thus increasing vehicle speeds and negating the benefits for pedestrian safety.

Other relationships with pedestrian crashes were actually stronger when focused on right-turn crashes only. Intersections with longer crossing distances (longer crosswalks) had more pedestrian crashes overall, but this positive association was strengthened for right-turn crashes. In fact, the model coefficients imply that shortening crossings by two lanes (24 ft) might decrease all pedestrian crashes by 9-10% (90th-percentile CI: 3–16%) but right-turn pedestrian crashes by 27% (90th-percentile CI: 18–35%). In other words, shorter pedestrian crossings appear to reduce pedestrian crashes overall, and even more so for right-turn crashes.

The models also indicated that intersections where RTOR was prohibited had fewer pedestrian crashes, overall and for right-turn crashes in particular. While the difference was not statistically significant, the model coefficients were twice as large for right-turn crashes. Specifically, according to the model, prohibiting RTOR for one movement might be expected to reduce all pedestrian crashes by 36-39% (90th-percentile CI: 3–57%) but right-turn pedestrian crashes by 55% (90th-percentile CI: 4–79%). In short, there was some (albeit weak) evidence that RTOR prohibitions help pedestrian safety especially in the context of right turns, which is an intuitive finding.

5.2.2 Factors Associated with Right-Turn Vehicle-Bicycle Crashes

5.2.2.1 Bivariate Analysis

Again, chi-squared tests assessed the over- or under-representation of right-turn (vs. left-turn and straight-thru) crashes with people bicycling for various characteristics. The following are key findings of this bivariate analysis (Section 4.2.1):

Right-turn bicycle crashes tended to be slightly less severe: 5% (vs. 8% overall) involved fatal or serious injuries, while 49% (vs. 45% overall) involved possible or no injury. As described for pedestrian crashes, this difference is likely linked to slower right-turning vehicle speeds.

Bicycle crashes with right-turning vehicles were slightly less common during rainy weather (2% vs. 3% overall), in poor light or unlighted conditions (17% vs. 23% overall), and involving DUI or drowsy/distracted driving (3% vs. 5%). The same explanations for pedestrian crashes might apply. Also, right-turn vehicle-bicycle crashes were slightly more common for low-speed (< 25 mph) roadways (23% vs. 19%), which could be explained by cyclists' preferences for these roadways.

5.2.2.2 Multivariate Analysis

As was done for pedestrian crashes, a subsequent multivariate analysis (Section 4.2.2.2) involved estimating ZINB models for bicycle crashes involving all vehicle movements and just right-turning vehicles. This determined characteristics and situations for which right-turn crashes were over-/under-represented or more/less frequent. Key findings include the following:

Some relationships with bicycle crashes became weaker or were no longer significant when looking at just right-turn crashes. The positive association between population density and the number of bicycle crashes overall was no longer significant for right-turn crashes only. Notably, right-turn crash frequency was less strongly influenced by the study's proxy measure of bicycle volumes (from Strava data). Specifically, doubling the bicycle volume might increase all bicycle crashes by 17-20% (90th-percentile CI: 9–28%) but right-turn bicycle crashes by only 8-13% (90th-percentile CI: −2–22%). The authors are unsure of why bicycle volumes do not seem to affect right-turn crashes as much, but it may be related to the next result discussed.

Other relationships with bicycle crashes were actually stronger when focused on right-turn crashes only. One notable finding is that the positive association with motor vehicle volume was much stronger for right-turn crashes than for all bicycle crashes. According to the model coefficients, a doubling of the motor vehicle volume on the major roadway might increase all bicycle crashes by 44-49% (90th-percentile CI: 33–58%) but right-turn bicycle crashes by 76-77% (90th-percentile CI: 61–94%). As mentioned above, this result defies easy explanation. The results imply that (compared to all crashes) right-turn crashes are more sensitive to changes in motor vehicle volumes and less sensitive to changes in bicycle volumes. Perhaps there is something about the way in which bicycle crashes involving right-turning motor vehicles take place (i.e., rear end, overtaking, right hook), who tends to be at fault, etc., that causes this result. Or maybe right-turning drivers have more things that they need to pay attention to, so they may be less likely to notice people bicycling (and thus the "safety in numbers" effect is weaker).

For this study, another difference between the models may be relevant. The negative relationship with channelized right turns was stronger for right-turn crashes. Specifically, the presence of one channelized right turn might be expected to reduce all bicycle crashes by 19-26% (90th-percentile CI: 8–36%) but right-turn bicycle crashes by 29-34% (90th-percentile CI:

15–46%). As with the finding about pedestrian crashes and no RTOR, this result is also intuitive. Channelized right turns shift the location where a conflict between a thru-moving bicycle and right-turning vehicle takes place, changing it from a possible right-hook conflict (at the intersection) to a merging conflict (on the approach to the channelized right turn). The same shift in conflict location/type also occurs when the bike lane is positioned to the left of a dedicated right-turn lane; although, the crash analysis was unable to study the empirical impacts of bike/right-turn lane configurations.

5.2.3 Factors Associated with Right-Turn Vehicle-Pedestrian Conflicts and Behaviors

As reported in Section 4.3, the observational data analysis performed both bivariate analyses (correlations) and multivariate analyses (multilevel regression models) on several different measures of pedestrian and right-turning vehicle driver behaviors and conflicts. Rather than discuss the results about each behavior or conflict outcome separately—encroachment time and conflict severity (Section 4.3.2), pedestrian behaviors (Sections 4.3.3 and 4.3.4), vehicle driver behaviors (Sections 4.3.5 and 4.3.6)—the authors prefer to summarize results organized by type of associated factor. In this way, common findings across conflict and behavioral outcomes can be discussed in context.

5.2.3.1 Pedestrian Characteristics

The number of pedestrians traveling together (*group size*) was significantly associated with many outcomes of interest. Specifically, the larger the group size, the less severe the conflict, and the greater the encroachment time. This may be related to driver behavior: drivers tended to be more likely to slow or stop and to stop before the first crosswalk when there were more pedestrians crossing. This finding supports one explanation of the "safety in numbers" for pedestrians (Islam et al., 2022): drivers operate more cautiously when more pedestrians are present, perhaps because it is easier to see a group of pedestrians than an individual.

The *age* of pedestrians was rarely significantly associated with encroachment time, conflict severity, or pedestrian/driver behavior in the multivariate models. The only significant association was for pedestrian reaction: when a child or teen was present, pedestrians were more likely to be observed running or changing direction to avoid a collision than having no obvious reaction. This finding might reflect that younger pedestrians may be better able to run than older adults or may have less predictable walking behavior. There was also a little evidence that drivers may turn more cautiously around children/teenagers: drivers were less likely to not stop (in other words, more likely to stop) for pedestrians when a child/teen was present.

While there were some bivariate associations with pedestrian *gender*, this was not a significant factor in most of the multivariate models. Some evidence suggests that conflicts may be slightly more severe (with shorter encroachment time) for male pedestrians, while drivers may be slightly more likely to stop/slow for women. These findings may be related to gender differences in risk-taking behavior, or gender-based perceptions of pedestrian behavior among drivers (Moyano Díaz, 2002; Rosenbloom et al., 2004).

Among *other characteristics* of pedestrians (other mode use, carrying load, distracted), people bicycling in the crosswalk had the largest associations with conflicts and other behavioral outcomes. Most notably, conflicts involving a bicyclist tended to be notably more severe and have shorter (pre-, post-, and overall) encroachment time. It could be that people bicycling on the sidewalk take more risks; the study also found that people bicycling were more likely to cross away from the crosswalk. However, the authors suspect the finding about encroachment time is more about the speed at which bicycles travel. Because pedestrians usually walk slower than how fast bicyclists ride, people bicycling can clear the lane or intersection faster than people walking. In other words, if drivers wait to turn until the lane is clear of crosswalk users, crossings with bicyclists will have shorter encroachment time simply because bicyclists are traveling faster than pedestrians. The same reasoning might explain why people skateboarding or using a scooter also had shorter post-encroachment times. For other crosswalk users, drivers may be giving them more time because these pedestrians may appear to be more vulnerable or need more time to cross. This might explain why people pushing strollers or in wheelchairs experienced lower severity conflicts, and why drivers were more likely to stop or slow down for these pedestrians. Alternatively, pedestrian behavior may also be at play: the positive association between carrying load and post-encroachment time may be because people carrying a load may walk more slowly or drivers give them more leeway before turning.

The *crosswalk* that pedestrians were using (first, second) seemed to have a significant association with conflict outcomes and pedestrian/driver behaviors. When pedestrians were using the first crosswalk, the encroachment time was longer (the conflict was less severe) and drivers were more likely to stop before the first crosswalk and less likely to swerve or speed up. This makes intuitive sense: pedestrians in the first crosswalk are usually crossing on a protected pedestrian movement (when right-turning drivers have a red indication), so drivers are more likely to stop and wait longer, or give more time before/after pedestrians when turning right. (See also the discussion below on traffic signal status.) Conversely, the results suggest that pedestrians crossing in the second crosswalk are at greater risk of collision, since encroachment time is shorter, conflict severity is higher, and drivers are less likely to stop. This could be because drivers usually see a green indication when the parallel crosswalk has a walk indication, or because some pedestrians are facing away from (and may not notice) the conflicting right-turning motor vehicles. (Also, see next paragraph.) The study did observe that pedestrians were more likely to cross away from the crosswalk when crossing the first street; this finding may simply be because more pedestrians were visible in this direction due to the camera views.

Related findings show how pedestrians' *crossing direction* (leaving curb, approaching curb) also seemed to affect conflict outcomes and road user behaviors. When pedestrians were approaching the curb (rather than leaving it), they were less likely to stop or slow and more likely to speed up/run/change direction, while drivers were more likely to stop or slow, and drivers were also more likely to stop inside or between the crosswalks and speed up/swerve. Notably, conflicts while approaching the curb tended to be less severe overall; however, there were some important differences, specifically: pedestrians approaching the curb had longer pre-encroachment times but shorter post-encroachment times. Approaching the curb means pedestrians are getting closer to the right-turn conflict points while also being able to see vehicles turning right. From a pedestrian's point of view, they are better able to see drivers' behaviors and react (or not) accordingly: If drivers are yielding, pedestrians may not react, whereas some pedestrians may speed up to get out of the way of a waiting vehicle. From a driver's point of view, they may be uncertain about the walking speed of any pedestrians, so they appear to be less willing to accept the same gap time to cross before a pedestrian as opposed to afterwards. Also, when passing after a pedestrian who is approaching the curb, the driver may be willing to turn sooner once the pedestrian has cleared the intersection. Finally, regarding the finding about driver stopping location: It could be that drivers waiting to turn right may be more likely to block the crosswalk because they do not see any pedestrians waiting on the corner and they can't see any pedestrians crossing until they pull into the crosswalk.

5.2.3.2 Driver and Vehicle Characteristics

The *right-turn queue length* was strongly linked to several measures of conflicts and pedestrian/driver behaviors. When there were more vehicles waiting to turn right, the overall encroachment time was shorter and the conflict severity was higher. Also, under these conditions, pedestrians were less likely to stop or slow but more likely to speed up, run, or change direction to avoid a conflict; while drivers were more likely to stop or slow than have no reaction and more likely to stop either before or between the crosswalks. The results suggest that having more vehicles waiting to turn right appears to be more dangerous for pedestrians. Why might this be? It could be that drivers are more impatient to turn right, either because they have been waiting longer or (due to peer pressure) they do not want to hold up the vehicles waiting behind them (Ackaah & Aidoo, 2020). As a result, they accept smaller gaps around pedestrians. Or perhaps the line of vehicles ahead makes it harder for drivers to see (or less likely to look for) pedestrians waiting or crossing. If drivers suddenly notice pedestrians only when their vehicle gets to the intersection, that might explain why drivers are more likely to (perhaps suddenly) stop or slow and why pedestrians might react by (again suddenly) running or changing direction to avoid a collision. On the other hand, there were two contrary findings: Pedestrians were less likely to cross away from the crosswalk with more right-turning vehicles, which makes sense since there would be fewer gaps when crossing midblock. Pre-encroachment time was actually longer with more queued right-turning vehicles. While this opposite finding is difficult to interpret, it could be that when the right-turn queue length is longer, most conflicts involve vehicles turning after pedestrians (shorter post-encroachment time), and the fewer pre-encroachments that do occur may be less severe.

Although this study collected data on the type of vehicle that was turning right, *vehicle type* was not significantly associated with most pedestrian or driver behaviors. Instead, it was related to encroachment time and conflict severity. Notably, conflicts involving larger vehicles (semi-trucks, delivery trucks, vehicles pulling trailers, and buses) were less severe and tended to have longer (overall and pre-) encroachment times. Drivers of large vehicles were also more likely to stop before or between the crosswalks (than not stop). These findings could relate to the fact that many of these would be professional drivers, who presumably undergo more training and may be more attentive to pedestrians. Also, larger vehicles are more visible to pedestrians, could provide greater visibility for drivers, usually require a wider turning radius, and may be turning more slowly, which might allow more time to react to pedestrians, thus increasing encroachment time and reducing conflict severity (Kumar et al., 2019).

5.2.3.3 Weather and Time Information

Weather, as recorded from the videos, was not significantly associated with encroachment time, conflict severity, pedestrian crossing location, or driver stopping location. When it was or had been raining, both pedestrians and drivers were slightly less likely to have no reaction and more likely to stop or slow down (although this was not significant in the pedestrian multivariate models). For *precipitation* measured by a weather model, when it was raining during that hour, the encroachment time was longer and conflicts were less severe. It could be that, under rainy conditions, all road users are more aware of the potential for reduced traction and visibility and thus cross and turn more cautiously (Ghadirzadeh et al., 2022). This is an example of risk compensation behavior (Wilde, 1982).

Temperature at the time of the conflict (as measured from weather models) also appeared to be linked to several road user behaviors and conflict outcomes, although not necessarily in consistent ways. Some of the clearer findings are summarized and discussed here. First, warmer temperatures appeared to increase conflict severity and decrease post-encroachment time (although not significantly in the multivariate models). Second, pedestrians and drivers were both less likely to have some other reaction (sped up, ran, or changed direction for pedestrians; sped up or swerved for drivers) as the temperature increased. Third, drivers were somewhat more likely to stop before the first crosswalk when the temperature was cold (less than 50°F). While an explanation of these findings is somewhat unclear, it could be that people are more active in warmer weather, more pedestrians are present at such times, and both pedestrians and drivers may be likely to undertake more risky behaviors. It is important to note that temperature may also be somewhat linked to which signals were studied at different times of year, which could confound some of these findings.

A few behaviors appeared to be significantly correlated with *day of week* and *time of day*. Specifically, on Mondays and Fridays, post-encroachment time was longer, drivers were more likely to stop or slow, and drivers were less likely to stop before the first crosswalk but more likely to stop inside/between the crosswalks. During morning or AM peak hours, drivers were more likely to stop before or between the crosswalks, and have some other reaction. Encroachment time was longer and conflicts were less severe during PM peak hours. In the evening and overnight hours (6pm to 6am), post-encroachment time was longer and drivers were more likely to stop or slow, less likely to have some other reaction, and less likely to stop between the crosswalks. These temporal factors could be capturing several different other factors that were not included in the models, including: variations in traffic volumes, differences in lighting conditions, driver impatience or alertness, etc. For instance, motor vehicle (and pedestrian) traffic tends to be busiest during the PM peak, so right-turning drivers may be more alert for potential conflicts, they may have to drive more slowly due to traffic congestion, or they may not experience gaps in traffic that would put them in more conflict with pedestrians. As another example, post-encroachment time may be longer at night because drivers may be modifying their behavior to be more cautious (risk compensation) to account for reduced visibility and lighting conditions.

5.2.3.4 Traffic Signal Status Information

As expected, conflict outcomes and driver/pedestrian behaviors were associated with the traffic signal statuses when pedestrians and vehicles were at the conflict point. Considering *pedestrian signal status,* crossing on steady don’t walk was linked to more dangerous behaviors and outcomes. Specifically, conflicts were more severe (encroachment time was shorter), pedestrians were more likely to slow down or stop (also speed up, run, or change direction), and drivers were more likely to speed up or swerve when pedestrians were crossing on steady don’t walk. This likely reflects the fact that drivers do not expect to see pedestrians crossing at this time (and so take evasive action to avoid a collision), while pedestrians know they should not be crossing at this time (and so stop/slow to yield to right-turning vehicles). Pedestrians were also more likely to speed up when faced with a flashing don’t walk symbol, a behavior possibly meant to show potentially impatient right-turning drivers that they are trying to give them time to turn. Relatedly, pedestrians were more likely to cross away from the crosswalk when the indication was steady don't walk, perhaps because they did not want to wait for the walk sign.

Findings regarding relationships with *right-turn vehicle signal status* are also intuitive. When drivers see a red light when turning right, conflicts with pedestrians tend to be less severe and involve longer encroachment (and pre-/post-encroachment) times. Drivers are also more likely to stop overall, either before the first crosswalk or inside/between the crosswalks, when the traffic signal shows red. These findings make sense, since drivers are expected to stop and yield to pedestrians and oncoming traffic before proceeding to turn right on red.

5.2.3.5 Conflict Information and Pedestrian/Driver Behaviors

Understanding the relationships among measures of conflicts and pedestrian/driver behaviors—encroachment time, conflict severity, pedestrian reaction, pedestrian crossing location, vehicle driver reaction, and vehicle driver stopping location—also sheds light on how right-turn traffic affects pedestrian safety. Since these were all outcomes of interest, they were not included in each other's models, so findings are solely from the bivariate analyses.

Notably, *pedestrian reactions*, *driver reactions*, *encroachment time*, and *conflict severity* were all linked with one another. Three specific findings stand out:

- No obvious pedestrian reaction and no obvious driver reaction were more likely to be observed simultaneously. These events tended to result in the least severe conflicts, with longer encroachment time. This makes sense, because if road users give each other more space/time, they can more easily navigate the potential conflict without many noticeable last-minute changes in behavior.

- The next common combination was when pedestrians slowed down or stopped, drivers were more likely to speed up or swerve. These conflicts tended to be somewhat more severe, with shorter encroachment times, especially pre-encroachment. This result also makes sense, since pre-encroachment means the driver passed before the pedestrian, and the reactions imply that pedestrians were deferring or yielding to vehicle drivers.

- The final relevant finding was that some other pedestrian reaction (sped up, ran, changed direction) and drivers slowing down or stopping were more likely to happen during the same event. Also, these conflicts tended to be the most severe, with the shortest encroachment time, especially post-encroachment time (vehicle after pedestrian). These situations seem to suggest that pedestrians are having to take evasive action to get out of the way of approaching vehicles. It also makes sense that this situation is more dangerous than pre-encroachment (vehicle before pedestrian), since pedestrians are nearly being hit by right-turning vehicles.

Altogether, these findings also start to suggest the degree to which each road user's behavior contributes to the overall severity of a conflict, as measured by (pre-/post-) encroachment time. When vehicle drivers were turning right before the pedestrian(s) (pre-encroachment), no driver behavior (reaction or stopping location) was significantly associated with pre-encroachment time, but all pedestrian reactions were. In these situations, the driver decision is already made, and the only way to change the conflict outcome (severity) is for the pedestrian to react in some way (waiting, stopping, or slowing down). In contrast, when vehicle drivers were turning right after the pedestrian(s) (post-encroachment), most driver behaviors (reaction or stopping location) and most pedestrian reactions were both significantly associated with post-encroachment time. In these situations (which tend to be more severe and dangerous, since there is the potential for a vulnerable pedestrian to be hit by a turning vehicle), both road users can do something to reduce the severity of the conflict and the chances of a collision. While pedestrians may speed up, run, or change direction to avoid a collision, the driver's behavior arguably plays a larger role (correlations in Table 4.15 were stronger) by slowing down and/or fully stopping (or not).

None of these factors were significantly associated with *pedestrian crossing location*. Some were associated with *vehicle driver stopping location*, as expected. When drivers stopped before the first crosswalk or inside/between the two crosswalks, the (overall and post-) encroachment time was shorter and the conflict severity was greater. Also, this stopping behavior was also positively associated with drivers slowing down or stopping. These results are intuitive: stopping somewhere is a type of driver reaction, and as mentioned above, stopping or slowing is linked to more severe pedestrian conflicts.

5.2.3.6 Corner and Intersection Attributes

Several characteristics describing the design of the corner and the intersection were significantly associated with encroachment time, conflict severity, and pedestrian/driver behaviors. However, given the small level two sample size (relatively few study locations) and the potential for correlations among these design features, the research team expresses greater confidence in the results from the multivariate models that control for other relationships. Therefore, the following discussions of key findings focus on regression model results.

Curb or corner radius was a central theme of this research, with the study intending to measure its linkages with vehicle-pedestrian conflicts and behaviors. However, corner radius was not significantly associated with either encroachment time or conflict severity in the multivariate analysis; although, it was positively associated with (overall and post-) encroachment time in the bivariate analyses, potentially implying less severe conflicts. As corner radii increased, pedestrians were more likely to slow down or stop in reaction to the conflict (only in the bivariate analysis). They were also more likely to cross away from the crosswalk. In places with larger corner radii, drivers were more likely to have no reaction to the conflict than to slow, stop, speed up, or swerve (only in the bivariate analysis). In the stop location multivariate model, drivers were less likely to stop before the first crosswalk; the bivariate analysis also suggested drivers were less likely to stop inside/between the crosswalks and more likely to not stop at all at locations with larger corner radii.

What do these findings about *corner radii* suggest for pedestrian safety? The authors interpret the findings as a mixture of positive and negative implications. On the one hand, intersections with larger radii tended to have longer (less severe) post-encroachment times, and it has already been discussed that no driver reaction was generally linked with less severe conflicts. It could be that corners with larger radii have a greater separation between the two crosswalks, giving drivers more time to notice and adjust their behavior to avoid pedestrians crossing in the second crosswalk. Indeed, corner radius was positively correlated with crosswalk offset distance. (This explanation is explained in more detail in the following paragraph.) On the other hand, several of these findings imply that having a larger curb/corner radius tends towards behaviors with potentially negative consequences for pedestrian safety. Corners with larger radii might require more out-of-direction travel for pedestrians to use the crosswalk, which might explain the higher share of pedestrians crossing away from the crosswalk. Also, the tendency of drivers to have no reaction or not stop (and decreased chances of stopping before the first crosswalk) might reflect how larger corner radii encourage faster turning speeds and less yielding to pedestrians. Notice that pedestrians were more likely to stop/slow at larger radius crossings, implying they feel a need to yield to right-turning vehicles in what could feel like an automobile-dominant environment. Using a smaller corner radius might discourage some of this behavior that rewards assertive drivers over pedestrians.

Results for two other measures of corner geometry might also inform an understanding of impacts on pedestrian safety. *Crosswalk offset distance*—the horizontal distance a vehicle travels when turning right, between the inside edge of the right lane and the closest edge of the second crosswalk—was linked to measures of conflict severity. Specifically, corners with longer crosswalk offset distances had conflicts that were less severe and with longer post-encroachment time. These correlations and associations with encroachment time were stronger for crosswalk offset distance than for corner radius. Since these two geometry variables were positively correlated with each other, this means that the findings for corner radius described in the previous paragraph could, instead, be mostly explained by the effect of crosswalk offset distance. *Stop bar distance*—the forward distance a vehicle travels when turning right, between the stop bar and the closest edge of the second crosswalk—was not a significant factor in any multivariate model. But, in the bivariate analysis, both measures of corner geometry were associated with more pedestrians and drivers having no reaction, and more drivers stopping inside or between the two crosswalks. These findings seem potentially counterintuitive, since a longer distance (forward or to the side) could imply more time for right-turning vehicles to accelerate and cause more severe conflicts or pedestrian safety issues. On the other hand, at intersections with longer crosswalk offset and stop bar distances, there is also more distance (and thus time) for pedestrians and drivers to see each other and avoid any last-minute reactions to prevent a collision. The authors suspect the second explanation is dominating the findings. In other words, when the second crosswalk is farther from the right-turn lane (larger crosswalk offset distance), right-turning drivers may have more time to direct their attention (and react) to any pedestrians who may be using the second crosswalk.

Generally, the number and type of *curb ramps* were not significantly linked to the outcomes of interest in the multivariate models, even if there were some significant associations in the bivariate analyses. A few highlights from those results: For corners with two (and/or directional) curb ramps (one leading straight into each crosswalk), drivers were less likely to stop before the first crosswalk and more likely to stop between the crosswalks. There may be a few potential explanations for this finding. First, the two crosswalks are usually separated from each other, so it may be easier for drivers to see which crosswalk a waiting pedestrian is using, and thus pull forward if they are using the second crosswalk. Second, with more distance between the two curb ramps (places where pedestrians usually enter the roadway), there is often more space for vehicles to wait in between the crosswalks for a pedestrian using the second crosswalk. In short, directional/two curb ramps might encourage right-turning drivers to pull forward while they wait for a pedestrian in the second crosswalk to clear. In contrast, curb ramps that were blended transitions were more likely to see drivers stop either before or between the crosswalks (than not stop). These kinds of curb transitions tend to be installed in high-activity pedestrian areas like downtowns, which might affect driver expectation about the presence of pedestrians.

Crosswalk type seemed to influence some pedestrian and driver behaviors, but again only in the bivariate (not the multivariate) analysis. Specifically, when pedestrians were crossing in crosswalks with continental (high-visibility) markings, the conflict tended to be less severe, pedestrians were more likely to speed up, run, or change direction to avoid a collision, and drivers were more likely to stop before the first crosswalk. Since these types of crosswalks are installed near schools in Utah, perhaps this finding has something to do with the kinds of pedestrians using them: 48% of conflicts at continental crosswalks involved children or teens, compared to 12% of conflicts at other types of crosswalks. Recall how children and teenage pedestrians were also more likely to have these "other" reactions to a conflict. Another potential explanation is that the greater visibility of the crosswalk encouraged drivers to stop before entering the intersection.

Several other right-turn and intersection geometric design features were significantly associated with pedestrian or driver behaviors. When there were two *right-turn lanes*, pedestrians were more likely to slow down or stop to avoid a conflict, and when there was a *receiving lane*, drivers were less likely to slow down or stop to avoid a conflict. At channelized right turns, pedestrians were more likely to have some other reaction (speed up, run, or change direction). Also, when the right turn was leading to an *on-ramp*, drivers were less likely to stop inside or between the crosswalks (and more likely to not stop).

Altogether, these findings imply conditions that suggest some potential pedestrian safety issues. They suggest an auto-centric intersection design—dual right-turn lanes, receiving/acceleration lanes, channelized right turns, and on-ramps—that encourages drivers to not stop when turning right, and also suggest that pedestrians need to take more responsibility to avoid conflicts, even if/when pedestrians have the right-of-way. With two right-turn lanes, there may be visibility issues with drivers not being able to see pedestrians. Another possible explanation is that some of these kinds of crossings had only one crosswalk to cross, so there was no way for drivers to have stopped "between" the crosswalks (although they could have stopped "inside" it).

One other finding is of note: Pedestrians were more likely to cross away from the crosswalk when at a crossing where the *right turn and crossing was not signalized* (yield only). Often, these were also channelized right turns or on-ramps, and perhaps the out-of-direction travel they required discouraged pedestrians from crossing within the crosswalk. Other factors (off-ramp, skewed intersection, and presence of a bicycle lane) did not have significant associations with these behaviors in the multivariate models; although, some off-ramps studied had two right-turn lanes or were channelized.

In one driver behavior model, an indicator of traffic exposure was significant. At intersections with higher daily *motor vehicle traffic volumes*, vehicles were more likely to slow down or stop as a reaction to the conflict. In these locations, perhaps drivers have to or expect to stop for opposing traffic, so they may be primed to stop for pedestrians, too. Average daily *pedestrian volumes* were not a significant factor in any model. Returning to the "safety in numbers" phenomenon mentioned earlier, note the safety benefits of larger pedestrian group sizes and the lack of safety benefits of average pedestrian volumes. This implies that this pedestrian safety phenomenon, from a driver's perspective, may be more likely to be caused by seeing pedestrians rather than expecting pedestrians at an intersection. Conversely, the safety benefits of more pedestrians may go away at times where few pedestrians are present.

5.2.3.7 Neighborhood Attributes

Additionally, a few land use, built environment, and sociodemographic characteristics of the surrounding neighborhood were also significantly associated with the study's conflict and behavioral outcomes. As was done for corner and intersection attributes above, this section also focuses mostly on key findings from the multivariate models. Specifically, several variables were not significant in any regression model, including: employment density, most land use types, street intersection density, percentage of 4-way intersections, transit stops, places of worship, schools, parks, and vehicle ownership.

One consistent finding was regarding *household size*. Signals in neighborhoods with larger household sizes tended to see conflicts that were less severe (longer encroachment time) than locations in neighborhoods with fewer people per household. At least one other study has found a similar result (Su et al., 2021). One explanation is that in such places, there tends to be more family walking (involving multiple pedestrians). Earlier findings highlighted how conflicts involving larger groups of pedestrians were also less severe.

There were a few other significant neighborhood attributes, although the authors are unsure exactly how to interpret these findings. First, in areas with higher median *household incomes*, it was slightly more likely that pedestrians reacted to the conflict by slowing down or stopping. Income is correlated with vehicle ownership, so these areas could see more driving and so pedestrians may expect to have to yield more frequently (although, vehicle ownership was not a significant factor itself). Second, drivers were more likely to stop before the first crosswalk at signals in *non-commercial land use* areas. Perhaps non-commercial areas are less busy for drivers, so they don't feel a pressure to expedite traffic flow by not stopping before the first crosswalk. Third, for intersections in neighborhoods with greater *population density*, drivers were more likely to stop inside or between the crosswalks. Perhaps pedestrians are more common (and expected) in higher-density places, which might explain driver stopping behavior.

5.2.4 Factors Associated with Right-Turn Vehicle-Bicycle Conflicts and Behaviors

As mentioned in Section 3.3.3, there were insufficient observations of bicycle events and vehicle-bicycle conflicts in order to conduct an analysis of factors associated with right-turn bicycle conflict outcomes and other driver or bicyclist behaviors. This is one of the limitations that will be discussed in the next section.

5.3 Limitations and Challenges

There were several challenges faced by this study that might limit some of the findings and recommendations from the research. Regarding the crash data, the analysis utilized robust analytical methods (ZINB models), but more intersection geometric design attributes could have been collected and considered. Unfortunately, it was not feasible to calculate corner attributes like corner radius, crosswalk offset distance, stop bar distance, and right-turn lane configurations for all 1,500+ signalized intersections in Utah. Furthermore, limitations on crash data micro-scale location information precluded the research team from identifying the specific location (which corner and crosswalk) where each right-turn pedestrian/bicycle crash occurred. Also, the analysis used crash data aggregated over a 10-year period (2010–2019), but other characteristics for just a single point in time. A common limitation in crash analysis, it should be noted that some crashes may have occurred when the (exposure, transportation, land use, built environment, and/or sociodemographic) characteristics were slightly or even substantially different.

Regarding the observational data analysis, the biggest limitation was the data collection method itself: manually collected data from videos are potentially subject to human errors and biases. These issues were minimized by using a standardized data collection form, training the data collectors (undergraduate students) beforehand, validating the collected data afterwards (with both manual and automatic checks/flags), and correcting any errors that were discovered. However, some biases and errors may remain, especially for variables that were more subjective or tedious to collect. For example, pedestrians' ages and genders may have been inaccurately or inconsistently recorded, due to the challenging quality of the videos, the difficulty of determining these characteristics by observation alone (people can present themselves in different ways), and any differences in how data collectors may have interpreted cues for age and gender (e.g., clothing, hair, walking speed). Similarly, there may have been some differences in how data collectors interpreted and recorded specific pedestrian and driver behaviors, including the degree to which there was "no obvious reaction" (vs. stopped, slowed, sped up, etc.) as well as any speed threshold for vehicles to be recorded as stopping (vs. "did not stop"). Given the importance of time differences in the definition of conflict severity, timestamps were checked for illogical values, but some errors may still remain. Removing the human element and using computer vision software to automatically extract road user trajectories, locations, and timestamps might improve the quality and reliability of the observational data collection. However, such a system still might not be perfect and may need help interpreting certain reactions and road user characteristics.

As previously mentioned, another major limitation of this study was that the video data collection was unable to obtain enough instances of bicycle-vehicle conflicts to perform a robust observational data analysis. Therefore, the observational portion of the study focused instead on crosswalk users, which did include some people riding a bicycle. Of course, bicycle conflicts with right-turning vehicles may look very different when someone is riding on the sidewalk versus when someone is cycling in a bike lane, shoulder, or general-purpose travel lane. Because of this, the research team recommends that future work specifically investigate bicycle conflicts with right-turning vehicles to gain insights about this important topic.

Some other research limitations result from the study design itself. As noted in the literature reviews (Chapter 2.0), there has been relatively little research on right-turn vehicle conflicts with people walking and bicycling, and most studies have not investigated the role of locational or geometric design factors like corner radius. The present study observational data collection helped to fill this gap by studying more locations (34 right turns/corners at signals) and observing more pedestrian-vehicle conflicts (1,640) than in most previous work. Although locations were specifically selected to cover a wide range of corner, intersection, and neighborhood attributes affecting conflict outcomes and behaviors, more variation in certain categories or levels of potential explanatory variables could have helped to make the study results more generalizable to other locations. For example, none of the locations in the final dataset had curb extensions or prohibited RTOR. Also, no observational data was collected on weekends, and videos were mostly recorded during the fall and early summer, so the study may not completely reflect the impacts of different weekdays or seasons on pedestrian-vehicle conflicts and other pedestrian and driver behaviors.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

This research project explored factors affecting crash frequencies, conflict severities, and other road user behaviors involving right-turning vehicles and people walking and bicycling. To improve pedestrian/bicycle safety at intersections and reduce conflicts with right-turning vehicles, based on the findings from this research (Section 5.2), the research team offers several implications and potential recommendations. Since these recommendations focus on improving bicycle/pedestrian safety, UDOT and partner agencies should consider them in relation to other potential factors, including cost and any potential operational impacts that may arise. These recommendations are organized into design, operations, and other strategies, as well as future work.

6.1.1 Design Strategies

Use smaller curb/corner radii: Conceptually, smaller radius corners offer many benefits for pedestrian safety: they encourage slower right-turning speeds, shorten the crossing distance, help to better align ramps and crosswalks with desired walking paths, and increase space allocated to pedestrians. For instance, NACTO's Urban Street Design Guide (2013) recommends corner radii no more than 15 ft and turning speeds no higher than 15 mph in urban areas. Although results from the observational analysis were mixed (between positive, negative, and no associations), there was some evidence that pedestrians do not feel as comfortable or safe at larger-radius corners. Specifically, drivers were less likely to stop before or between the crosswalks, pedestrians were more likely to stop/slow to avoid a conflict, and pedestrians were more likely to cross away from the crosswalk. Smaller radius corners might make pedestrians more visible to right-turning drivers and encourage more driver yielding. While smaller curb radii can introduce challenges for large vehicles turning right, various strategies—placing the stop-bar farther from the intersection, using mountable truck aprons, etc.—can accommodate large vehicles while controlling the turning speed of smaller vehicles. There was a little evidence that conflicts at larger-radius corners tended to be slightly less severe. However, as already mentioned, this finding was likely explained by the fact that corners with larger radii tended to also have longer crosswalk offset distances, a geometric design factor that appears to have a stronger effect on reducing conflict severity.

Consider tradeoffs among the type and placement of curb ramps and crosswalks: In addition to corner radius, the number and placement of curb ramps (and their corresponding crosswalks) on the corner affect both pedestrian and driver behaviors and conflict outcomes. In the observational analysis, corners with more crosswalk offset distance (sideways separation) and stop bar distance (forward separation) between the right-turning vehicle and the second crosswalk saw less severe conflicts, fewer pedestrian or driver reactions, and more drivers stopping between the crosswalks. Also, when there were two/directional curb ramps, drivers were less likely to stop before the first crosswalk and more likely to stop between the crosswalks. This highlights some potential tradeoffs of using (two) directional curb ramps and having more separation between right-turning drivers and pedestrians. On the one hand, directional ramps might help drivers know which direction pedestrians are waiting to cross, and more spacing might give more time for right-turning drivers to notice and stop for pedestrians (in the second crosswalk). On the other hand, this situation might make it harder for drivers to notice waiting pedestrians, encourage drivers to creep up and block the first crosswalk when waiting to turn right, and require more out-of-direction travel for pedestrians if the approaching streets have curb-tight sidewalks. While two/directional curb ramps offer some benefits, they may not be appropriate in all situations.

Discourage automobile-centric right-turn lane configurations: Several right-turn lane characteristics appeared to imply potential pedestrian safety issues in the observational analysis: two right-turn lanes (pedestrians more likely to stop/slow), a receiving lane (drivers less likely to stop/slow), a channelized right turn (pedestrians more likely to speed up/run/change direction), and an on-ramp (drivers more likely to not stop). These auto-centric design characteristics seem to encourage drivers to not stop when turning right, which might endanger pedestrians even when crossing with the right-of-way. Pedestrians appear to recognize the danger of these intersections: they were more likely to cross away from the crosswalk when the crossing was not signalized (yield only, often at channelized right turns or on-/off-ramps). Avoiding these auto-centric right-turn lane configurations whenever possible might improve pedestrian safety, although impacts to traffic flow and signal operations should also be considered.

Configure bike lanes and dedicated right-turn lanes to avoid "right-hook" conflicts: The crash analysis found that intersections with channelized right turns had fewer bicycle crashes than otherwise expected. The research team believes this could be because channelized right turns shift the conflict type and location, from a right hook at the intersection to a merge upstream from the intersection. In light of the prior recommendation against channelized right turns on pedestrian safety grounds, one possible recommendation for bicycle safety is to also shift the type and location of conflicts with right-turning vehicles, through lane configurations. Specifically, if both bike lanes and dedicated right-turn lanes are present at an intersection (and unless the bicycle and right-turn movements are controlled by separate signal phases), the right-turn lane should be on the right side of the bike lane (unless they are in a shared lane), and right-turning traffic should be directed to yield to bicycles and cross the bike lane prior to the intersection. This lane configuration avoids right-hook conflicts and likely offers a similar degree of benefit for people bicycling while avoiding the negatives of channelized right turns for people walking. The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009) and the NACTO Urban Bikeway Design Guide (2014) and supplemental guidance (2019) offer several examples of these kinds of bicycle and right-turn lane configurations.

Shorten pedestrian crossing distances: As has been found in other research in Utah (Singleton et al., 2022), intersections with longer crossing distances had more pedestrian crashes; but this study found that the association was stronger for right-turn crashes than for all crashes. In other words, shorter crossing distances are even more important for avoiding pedestrian crashes with right-turning vehicles.

Keep using high-visibility crosswalk markings: In the observational analysis, conflicts in crosswalks with continental (high-visibility) markings tended to be less severe and drivers were more likely to stop before the first crosswalk. It could be that the greater visibility of the crosswalk encourages drivers to stop and yield to pedestrians for longer. This seems to be a benefit of the high-visibility crosswalk markings.

6.1.2 Operational Strategies

Prohibit RTOR in more locations: The crash analysis found that intersections where RTOR was prohibited had fewer pedestrian crashes, and the benefit—55% reduction (90thpercentile CI: 4-79%)—was stronger for right turns than for all crashes. The observational analysis revealed some undesirable driver behaviors that might be mitigated by prohibiting RTOR. When pedestrians were approaching the curb, drivers were more likely to stop inside/between the crosswalks; when pedestrians were leaving the curb, conflicts were more severe. The research team observed many instances of drivers (while on red) pulling forward and blocking the first crosswalk while waiting for a gap to turn right on red. Not only does this behavior block a crosswalk, but drivers may be looking in the opposite direction of any pedestrians trying to cross (in the first crosswalk). Also, when drivers in this situation turn right at the end of red/start of green, they may not notice any pedestrians leaving the curb in the second crosswalk. Prohibiting RTOR removes the expectation that drivers try to turn right on red, thus reducing these potentially dangerous conflicts with pedestrians. Of course, implementing no RTOR might have negative operational impacts on the intersection in terms of reduced right-turn vehicle throughput and longer right-turn queue lengths; it may shift the timing/location of conflicts to the vehicle green phase and the second crosswalk (when/where conflicts were more severe); and some/many drivers may not comply with the turning restriction.

If prohibiting RTOR is not possible or has significant adverse operational effects, there could be other strategies for improving pedestrian safety by managing right-turn vehicle driver behavior. Signs—such as "Stop Here on Red" (R10-6) or "Turning Vehicles Yield to Pedestrians" (R10-15)—could help encourage drivers to stop before the first crosswalk (when facing a red indication) and look for and yield to pedestrians crossing in either crosswalk. Another option might be to acknowledge this behavior (pulling forward to look for a gap in traffic) among drivers seeking to turn right on red, and design the intersection such that drivers do not need to block the crosswalk in order to look left. This could be implemented by putting the stop bar for the through lanes one-half-to-one-full car's length back from the stop bar for the right-turn lane. That way, when right-turning vehicles pull up to the stop bar, there should be an unobstructed view to the left, and they wouldn't need to encroach into the first crosswalk.

Interestingly, other findings from the observational analysis suggest some negative impacts from a potential side effect of no RTOR. Specifically, when queue lengths were longer, conflicts were more severe, perhaps due to driver impatience, peer pressure (to clear the queue), or lack of visibility (vehicles in front blocking views of the signal and pedestrians). One potential strategy in this situation—where there are higher right-turning volumes—is to prohibit RTOR only during certain times, such as when the pedestrian phases are not on steady don't walk, when pedestrians activate the push-button, or at times of day when pedestrians are common. Also, providing a green right-turn arrow and right-turn overlap phase (if possible) could help to clear queues before pedestrians attempt to cross.

Use leading pedestrian intervals (LPIs) in more locations: In the observational analysis, some concerning behaviors might be mitigated through the use of LPIs. Specifically, pedestrians crossing in the second crosswalk and when vehicles faced a green signal were at greater risk of collision, since encroachment time was shorter, conflict severity was higher, and drivers were less likely to stop. LPIs give pedestrians in the second crosswalk a head start before the right-turning vehicle sees the green indication, thus increasing pedestrian visibility and driver yielding. The combined use of no RTOR with an LPI is often recommended, since the LPI could help mitigate some disadvantages of prohibited RTOR such as increases in the right-turn queue length and the number of conflicts in the second crosswalk during the green indication.

6.1.3 Other Strategies

Encourage more walking and increase pedestrian volumes: The crash analysis identified a clear "safety in numbers" effect for pedestrians—the pedestrian crash rate goes down with increasing pedestrian volumes—that was of roughly the same magnitude for right-turn crashes and all crashes. Then, the observational analysis offered key insights into the relative strength of two possible driver behavioral explanations for the "safety in numbers" effect: seeing more pedestrians, or expecting more pedestrians. Specifically, the former explanation was supported, while the latter explanation was not supported. Conflicts were less severe when there were larger group sizes of pedestrians crossing; but there was no effect of AADP on conflict severity or pedestrian/driver behaviors. This suggests that drivers seem to change their behavior (more likely to stop, and to stop before the first crosswalk) when they see more pedestrians or larger group sizes. Therefore, strategies to activate the street and encourage more walking throughout the day seem likely to offer safety benefits to those pedestrians, at the time when they are present. Conversely, these safety benefits may diminish at times when few other pedestrians are present.

Educate drivers about their responsibilities for ensuring pedestrian safety: Drivers have a greater responsibility than pedestrians for ensuring safe road user outcomes (because of differential risks and power, as will be explained), so there is a need to focus more on driver education. Fundamentally, the outcome is almost always worse when a vehicle collides with a pedestrian (often injury, sometimes severe injury or even death) than if a pedestrian collides with a vehicle (maybe minor property damage), due to the differential impacts of speed and mass. Thus, in the observational analysis, post-encroachments (vehicle after pedestrian) are more critical. In the analysis of post-encroachment time, both pedestrian and driver behaviors had significant associations, but the effects (correlations) were stronger for driver reactions. In other words, while the pedestrian might speed up, run, or change direction to avoid a collision, whether or not the driver slows down or fully stops plays a larger role in the outcome of the conflict. This suggests that the driver holds more power in this situation, and thus should have a greater responsibility for avoiding a collision. This recommendation could affect driver education programs as well as public safety messages and marketing campaigns.

6.1.4 Future Work

A limitation of this research was the inability to conduct an observational analysis on bicycle conflicts with right-turning vehicles due to too few observations. This suggests that future research should look specifically at bicycle-vehicle conflicts. To be successful, this proposed effort will likely need to record more hours of video and focus on locations with much higher bicycle volumes than could be studied in the present research project. Additionally, a different data collection form will have to be developed, since the nature of conflicts involving people bicycling in the street is likely different from the nature of conflicts among pedestrians (and other users) in the crosswalk. Some differences might include: more variety of places where people bicycle (bike lane, travel lane, shoulder, etc.), more potential conflict locations, different kinds of conflicts (including merges, cycling wrong-way), etc.

Another study limitation was the manual transcription of data from videos, which was potentially subject to various errors and biases. The use of new technologies like computer vision, LiDAR, and artificial intelligence might be able to reduce these issues through automated data collection. There may even be ways to install sensors that continuously track road users' movements, interactions, and conflicts, and send alerts to transportation agency managers if there are too many near misses at a given intersection.

6.2 Implementation Plan

Implementation of these recommendations could follow a variety of potential paths. The research team offered several potential design and operational recommendations, including: using smaller corner radii, discouraging auto-centric right-turn situations (dual right-turn lanes, channelized right turns, receiving lanes), shortening crossing distances, prohibiting RTOR, and using LPI. While these strategies appear likely to offer some safety benefits for people walking and bicycling, there may be other considerations that affect whether and where these treatments should or could be implemented. UDOT Traffic & Safety Division staff should consider the applicability of these design and operational strategies, including their costs and any tradeoffs with intersection operations and other factors. If there is concern that the pedestrian/bicycle safety benefits may not outweigh other costs or disadvantages, these treatments could be tested first in a handful of situations (in more detail than could be accomplished in this research project), and their impacts on safety, operations, etc. could be quantified for a cost-benefit assessment.

Other recommendations may involve different parties and actions to implement. Any changes to the driver education process or public safety messaging would require coordination with the Utah Department of Public Safety (DPS). Efforts to encourage walking and increase pedestrian volumes could be multifaceted, but would certainly require street design and land use planning, and involve coordination with both local municipal governments and regional metropolitan planning organizations. To implement a follow-up study focusing just on an observational analysis of bicycle conflicts with right-turn vehicles, a problem statement could be written (by UDOT staff or the authors of this report) and submitted through the annual UDOT research prioritization process. Finally, UDOT staff and research partners should continue to track developments in automated conflict analysis technologies to see if and when the accuracy improves and the costs decrease enough to make a larger-scale study and deployment feasible.

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