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Exploring the Determinants of Vulnerable Road Users' Crash Severity in State Roads

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Exploring the Determinants of Vulnerable Road Users' Crash Severity in State Roads

by

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A thesis submitted in partial fulfillment of the
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ABSTRACT

Pedestrians and bicyclists are the most vulnerable road users and suffer the most severe consequences when crashes take place. An extensive literature is available for crash severity in terms of driver safety, but fewer studies have explored non-motorized users' crash severity. Furthermore, most research efforts have examined pedestrian and bicyclist crash severity in urban areas. This study focuses on state roads (mostly outside major urban areas) and aims to identify contributing risk factors of fatal and severe crashes involving pedestrians and bicyclists in state roads. Two ordinal regression models were developed (one for pedestrian and the other for bicyclist crashes) to examine crash severity risk factors. Additional models were developed to investigate road and traffic characteristics that could increase the likelihood of fatal crashes. In the model for pedestrian crash severity risk factors such as age, vehicle type and movement, light conditions, road classification, traffic control device, posted speed limit, location of the pedestrian and wet road surface during clear weather conditions are statistically significant. The bicyclist crash severity model indicates that age, crash location, vehicle movement and alcohol intoxication during dark conditions are statistically significant. In terms of road characteristics and traffic conditions, the models suggested risk factors such as arterials, light conditions, posted speed limit, roadways, and high heavy vehicle volume, increased the odds of a crash being fatal.

The results seem to suggest that besides improvements in roadway characteristics, additional countermeasures to reduce crash severity for vulnerable users should include

separation of vulnerable users from traffic, educational campaigns, more strict control of

alcohol intoxicated drivers, and protection strategies of senior pedestrians.

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1   INTRODUCTION

There is a growing interest in increasing non-motorized transportation in the state of

Oregon as a strategy to improve public health, air quality, and to reduce traffic

congestion. With an expected increase of 30% in the total population by 2040, the state of

Oregon expects to continue its growth in walking and biking (Oregon Department of

Transportation, 2016). As residents in Oregon choose non-motorized modes, safe

walking and biking facilities become a priority.

At the national level, 41% of trips under three miles are made by walking or bicycle (U.S.

Department of Transportation, 2015), unfortunately there have been an increase in

fatalities and serious injuries for bicyclists and pedestrians (U.S. Department of

Transportation, 2015).

Pedestrians and bicyclists are among the most vulnerable users on the road and in

crashes with vehicles they tend to suffer the most severe consequences due to their lack

of protection. Risk factors associated to crash severity for pedestrians and bicyclists have

been understudied in suburban and rural roads, making it difficult for Department of

Transportation agencies (DOT) to implement countermeasures and policies to improve

safety for vulnerable road users.

This study aims to identify contributing risk factors of fatal and severe crashes involving

pedestrians and bicyclists in Oregon DOT (ODOT) roads. Identification of these factors

will provide ODOT with the ability to implement appropriate countermeasures to reduce

crash severity for pedestrians and bicyclists.

This research used pedestrian and bicyclist crash data for the years 2007 to 2014

collected from the Oregon Statewide Crash Data System. Additional information on the

ODOT's highway network, traffic conditions and road characteristics was gathered from the Oregon Department of Transportation's TransGIS database.

The remainder of the paper is structured as follows. First, we discuss the main objectives of this study and the extent of the research. Second, we show a literature review of risk factors and crash severity for pedestrian and bicyclists. Then, a description of the data sources used on this study is presented. In section 5 we present a descriptive analysis of risk factors for severity, and its relationship with different land uses. This section is followed by an exposure analysis, intended to uncover crash severity patterns by controlling by VMT and land use. Section 7 presents a brief overview of the statistical model used in this research. Then, in section 8 we present the data analysis performed, split by single variable models and pooled modes (using all the variables, and then only road and traffic risk factors). Finally, we discuss the findings and then we close with limitations and conclusions.

2   RESEARCH OBJECTIVES

TABLE 1 outlines the research questions this thesis addresses and the different

methodologies used to explore them.

TABLE 1: Research questions

RESEARCH QUESTION	METHODOLOGIES
What are the main risk factors associated to pedestrian and bicyclist crash severity?	Literature review Descriptive analysis
How crash severity levels are affected by exposure of pedestrians and bicyclists?	Descriptive analysis Exposure analysis
How location, environmental, crash, demographic traffic, and road characteristics increase or decrease severity levels for vulnerable users in state roads?	Exposure analysis Descriptive analysis Ordinal logistic regression (single variable models) Ordinal logistic regression (pooled models)
What are the main risk factors associated with severity levels for vulnerable users in state roads?	Sensitivity analysis (single variable models) Sensitivity analysis (pooled models)
What are the main risk factors associated to road and traffic characteristics?	Ordinal logistic regression (road and traffic char. models) Sensitivity analysis (road and traffic char. models)

3   LITERATURE REVIEW

Although there is extensive research in crash severity in terms of driver safety, studies on non-motorized users is more limited. Researchers who have studied vulnerable users identified several main risk factors that contribute to severity. These factors were classified into six major categories: location characteristics, environmental conditions, crash, demographic characteristics, road, and traffic conditions. This section reviews different risk factors that several researchers have identified. Furthermore, we mentioned some of the methodologies they have used as a reference for the present study.

3.1   Location characteristics

Zahabi et al. (2011) developed several models to determine the effects of road design, build environment, speed limits, and other factors on crash severity with pedestrians and cyclists involved. Data on crashes, land use (50 to 400 meters from the crash location), and road characteristics were collected for the city of Montreal. The authors found that after including land use variables in the model, the overall power of the explanatory variables increased. Pedestrian crashes that occurred near a park tended to be more severe than crashes at other locations, while pedestrian crashes that occurred near a school tended to be less severe. This finding can be attributed to the safety measures that were taken near schools.

Opposite results were found by Kim et al (2007). For bicyclist crashes, the findings suggested that areas with a school increased the probability of incapacitating injury; however, it decreases the likelihood for other severity levels (Kim, Kim, G., & Porello, 2007).

Abdul-Aziz et al. (2013) found that land use designated as industrial is associated with less severe and fatal pedestrian crashes. This finding is not surprising if we consider the low levels of pedestrian activity in these zones. On the other hand, the authors found a significant effect of commercial neighborhoods in crash severity.

Islam and Hossain (2015) explored the influence of different risk factors in severity of crashes involving non-motorized users. The authors employed a mixed-logit model approach. Severity was defined used the KABCO scale, but adding C and O in one category itself. A total of 2,442 and 789 observations for pedestrian and bicycle crashes, respectively, were analyzed. The findings suggested that occurrence of crashes in residential areas tended to increase the probability of a severe injury for both pedestrians and bicyclists. Commercial land use was also statistically significant; however, for bicyclist crashes, it had an opposite direction, crashes at commercial areas tended to be less severe and fatal than in other areas.

TABLE 2 summarizes the studies that found relationships between pedestrian and bicyclist severity levels and vulnerable user's characteristics. The arrows show the direction of the relationship between the independent variables and pedestrian severity. When an upward pointing arrow symbol (↑) is used, the probability for the crash to be fatal or severe increases due to the variable studied. When a downward pointing arrow symbol (↓) is used, the probability for the crash to be fatal or severe decreases. When the symbol is a dash (-), the study did not find a statistical difference.

TABLE 2: Summary of location characteristics review

PEDESTRIAN STUDIES				
Author (year)	**Transit access**	**Commercial land use**	**Park presence**	**School presence**
Clifton et al. (2009)	↓			
Zahabi et al. (2011)	↑	↑	↑	↓
Seyed et al. (2011)				↓
Abdul-Aziz et al. (2013)		↑		
Islam and Hossain (2015)		↑		
BICYCLIST STUDIES				
Zahabi et al. (2011)	-	-	-	-
Islam and Hossain (2015)		↓		
Kim et al. (2007)				↑

3.2   Environmental conditions

As expected, lighting conditions were associated with crash severity. Good lighting conditions resulted in less severe pedestrian injuries (Zheng, 2014). Similar findings were found in New York (Abdul-Aziz, Ukkusuri, & Hasan, 2013). Chen et al. (2016) compared severity risk factors for crashes sustained by pedestrians in facing-traffic and back-to-traffic. A binary logit mode was used to evaluate the outcome of the injury, where the injury was located (e.g. head), and if the road was built or not built. The findings of this study suggested that pedestrian crashes during dark conditions and during morning peak hours were more likely to result in an injury. For bicyclist crashes the trend was similar, better lighting conditions improved visibility, which reduced the likelihood of a severe and fatal crash (Allen-Munley, Daniel, & Dhar, 2004).

Several studies have demonstrated that inclement weather conditions, such as rain, snow and fog, were strongly associated with crash severity levels. Li et al. (2016) explored the impact of pedestrian and driver characteristics on crash severity under

different weather conditions. Crash data from Great Britain was used for this analysis. A

total of 14,174 crashes were assessed. The authors used nonparametric methods

(classification and regression tree) to develop a model of crash severity. Under fine

weather conditions, high-posted speed limits, older pedestrians, and poor light conditions,

the likelihood of a severe crash increased. Under inclement weather conditions, only

posted speed limit and older pedestrians were found to be predictors of severe crashes.

Inclement weather conditions were significantly associated with bicyclist injury

severity as well (Kim, Kim, G., & Porello, 2007). Similar to lighting conditions variables,

the authors suggested that weather was a confounding effect for other unobservable

variables, such as visibility and bicycle brake failures.

In terms of the day of the week, the study conducted by Kim et al. (2007) revealed

that bicyclists were more likely to be injured during the weekend than on weekdays.

Additionally, for crashes occurring on weekday peak hours, the severity levels tended to

be higher as well.

TABLE 3: Summary of environmental conditions review

PEDESTRIAN STUDIES				
Author (year)	**Inclement weather conditions**	**Night time/ poor lighting conditions**	**Peak hours**	**Weekend days**
Tay et al. (2011)	↑	↑	↑	
Zheng (2014)		↑		
Zhang et al. (2014)		↑		↑
Jang et al. (2013)	↑			↑
Haleem et al. (2015)	↑	↑		
Chen et al. (2016)		↑	↑	
Eluru et al. (2008)		↑		
Li et al. (2016)		↑		
Islam and Hossain (2015)	↑	↑		
Abdul-Aziz et al. (2013)		↑		
McIntyre (2016)		↑		
Zahabi et al. (2001)		↑		

TABLE 3: Summary of environmental conditions review, continued

BICYCLIST STUDIES				
Author (year)	Inclement weather conditions	Night time/ poor lighting conditions	Peak hours	Weekend days
Kim et al. (2007)	↑	↑	↑	↑
Islam and Hossain (2015)	↑	↑		
Allen-Munley et al.(2004)		↑		
McIntyre (2016)	↓			
Eluru et al. (2008)		↑		

3.3   Crash characteristics

There was a consensus between the different studies in terms of crash severity and type

of vehicles. A crash that involved a pedestrian (or a bicyclist) and a heavy vehicle was

more likely to be fatal or severe than a crash with a lighter vehicle. Zheng (2014) also

revealed that heavy vehicles had a higher crash rate than light vehicles, which increased

the overall risk for pedestrians. Zahabi (2011) found that vehicle size was positively

associated with pedestrian and bicyclist severity; however, the coefficient was only

statistically significant for pedestrian crashes. On the other hand, Kim et al. (2007),

Eluru et al. (2008), and Allen-Munley et al. (2004) found that heavy trucks increased the

probability of severe and fatal crashes compared to other types of vehicles. Eluru et al.

(2008) explained that non-motorist crashes with heavy vehicles tended to be fatal or

severe due to higher bumper heights and impact areas.

Multiple studies have also explored the impact of alcohol on crash severity;

however, most of these studies did not consider pedestrians and bicyclists exclusively.

Kim et al. (1995) found that the odds of a head-on or rollover collision were much greater

in the presence of alcohol or drugs. Additionally, young people were less likely to crash under alcohol effects than old people were.

Eluru et al. (2008) developed a mixed generalized ordered response logit to explore severity in crashes involving pedestrians and bicyclists. The authors found that pedestrians and bicyclists who were hit by an alcohol-intoxicated driver were more prone to be severely injured. Similarly, Kim et al. (2008) found that intoxicated drivers increased the probability of fatal injury by 17% and incapacitating injury by 24%. Lee and Abdel-Aty (2003) explored the interaction between lighting conditions and impaired drivers and found that people who were driving under alcohol effects in dark conditions tended to be involved in more severe crashes than people driving during dark conditions with street lighting are.

TABLE 4: Summary of crash characteristics review

PEDESTRIAN STUDIES		
Author (year)	**Size of the vehicle**	**Alcohol intoxication**
Lee and Abdel-Aty (2003)	↑	↑
Tay et al. (2011)	↑	
Zheng (2014)	↑	
Seyed et al. (2011)	↑	
Tarko and Azam (2011)	↑	
Haleem et al. (2015)	↑	
Eluru et al. (2008)	↑	↑
Allen-Munley et al. (2004)	↑	
Eluru et al. (2008)	↑	
Matsui and Oikawa (2016)	↑	
Zahabi et al. (2011)	↑	
Sasidharan et al. (2015)	↑	
Kim et al. (1995)		↑

TABLE 4: Summary of crash characteristics review, continued

BICYCLIST STUDIES		
Author (year)	**Size of the vehicle**	**Alcohol intoxication**
Zahabi et al. (2011)	-	
Kim et al. (2007)	↑	↑
Allen-Munley et al.(2004)	↑	
Eluru et al. (2008)	↑	↑

3.4 Demographic characteristics

Two variables were used for pedestrian characteristics, age and gender. Most of the studies classified age into different categories, defining elder pedestrian as people over the age of 65.

Tay et al. (2011) used a multinomial logit model to estimate the likelihood of a pedestrian being involved in a fatal, severe and non-severe crash. The authors chose this approach because it allowed them to model an unordered response and a non-monotonic effect of the independent variables on the dependent variable. A 2006 database from the South Korean Police agency was used for this purpose. The findings suggested that elder pedestrians had a greater likelihood of being involved in a fatal and severe crash than younger pedestrians. Kim et al. (2008) studied police reported crash data between 1997 and 2000 to investigate the relationship of age in the severity of the crash. The authors found that as the people get older, the probability of fatal or severe injuries after a crash increased. Similarly, Zheng (2014) showed that elder pedestrians are at a higher risk of a severe crash than younger pedestrians. These findings were attributed to the fact that walking speed, visibility reaction time, and body resistance tend to be lower for this demographic group. Kim et al. (2007) explored the factors that contributed to bicyclist

severity levels due to a crash with a motorized vehicle. A total of 2.937 bicyclist crashes from the North Carolina police report database (1997 to 2002) were used. Bicyclists with an age of 55 and over had a greater likelihood of being involved in a fatal or injury crash than younger bicyclists.

Zhao et al. (2014), a team of engineers and medical experts, collected crash data (2006) in the city of Beijing and Northern China. Only 121 crashes were studied. The study controlled for impact speed, which was estimated from the vehicle's breaking distance before the collision. Additional to the data regarding the crash, the researchers included injured body region, treatment type after the crash and surviving time. Severity was measured based on the Abbreviated Injury Scale 2005, which goes from AIS 1 (minor injury) to AIS 6 (currently untreatable). After controlling severity for the pedestrian's body impact location, the authors did not find a difference in severity levels between male and female pedestrians. Sze and Wong (2007) evaluated injury risk factors of pedestrian fatalities in Hong Kong. This study measured the associations between the injury level of pedestrian causalities and all possible contributory factors such as gender, crash characteristics, location, crash time, traffic characteristics, road environment, speed limit, road type, traffic conditions and junction controls. Furthermore, the authors included a variable to control for the temporal variation of road infrastructure and vehicle technology improvements. The findings suggested that being a male increased the chances of a fatal or severe crash. Islam and Hossain (2015) found similar results, bicyclist and pedestrian males tended to be involved in more severe and fatal crashes as well. On the other hand, it is interesting to notice that driver age had an opposite effect on

the severity of the crash (not shown in (TABLE 5). Senior drivers tended to be more

cautious than young drivers, which resulted in less fatal crashes (Zheng, 2014).

TABLE 5: Summary of demographic characteristics review

PEDESTRIAN STUDIES				
Author (year)	Young pedestrians (<15)	Older pedestrians (>65)	Male pedestrian	Alcohol effects
Wazana et al. (2000)	↑			
Tay et al. (2011)		↑	↓	
Zhao et al. (2014)			-	
Kim et al. (2008)		↑		↑
Zheng (2014)		↑		
Zhang et al. (2014)			-	
Haleem et al. (2015)		↑		
Islam and Hossain (2015)		↑		
Eluru et al. (2008)		↑	↑	↑
McIntyre (2016)	↑	↑		
Li et al. (2016)		↑		
Sze and Wong (2007)	↓	↑	↓	
Abdul-Aziz et al. (2013)		↑	-	
Islam and Hossain (2015)		↑	↑	
McIntyre (2016)		↑		
Lee and Abdel-Aty (2003)				↑
Kim et al. (1995)				↑
BICYCLIST STUDIES				
Kim et al. (2007)		↑		
Islam and Hossain (2015)		↑	↑	
McIntyre (2016)	↓			
Eluru et al. (2008)		↑		↑

3.5   Traffic conditions

The impact of traffic volume and speed was also statistically associated with non-

motorized crashes and severity. Zheng (2014) suggested that as speed increased, the

severity of the crash increased as well. The study revealed that severity increases more rapidly if the impact speed goes from medium speed (25-50 mph) to high speed (>50 mph) rather than from low speed (<25 mph) to medium speed.

Kim et al. (2007) found that the likelihood of bicyclist fatalities and severe crashes increased with increases in the speed before the impact. As the impact increased beyond 20 mph, the probability of a severe or fatal crash increased substantially (Kim, Kim, G., & Porello, 2007).

In terms of traffic volume, Halem et al. (2015) found that an increase of AADT at signalized intersections significantly increased the probability of severe injuries.

Allen-Munley et al. (2004) developed an urban bicycle route safety rating model based on crash severity and risk factors. The authors developed a new injury index created from detailed New Jersey police crash reports, for the period 1997 to 2000. An ordinal logistic model was used to estimate the strength of the predictors on severity levels. The findings suggested that as AADT increased, severity decreased. This result is explained by another potential underlying effect, speed. When traffic volumes are high, the overall traffic speed is low, resulting in less severe crashes.

TABLE 6: Summary of traffic conditions review

PEDESTRIAN STUDIES		
Author (year)	**Traffic volume**	**Speed**
Zhao et al. (2014)		↑
Zheng (2014)	↑	↑
Halem et al. (2015)	↑	
Christie (1995)	↑	
Oh et al. (2005)		↑
Haleem et al. (2015)	↑	
Allen-Munley et al. (2004)	↑	
Li et al. (2016)		↑
Aziz et al. (2013)	↑	

TABLE 6: Summary of traffic conditions review, continued

BICYCLIST STUDIES		
Author (year)	**Traffic volume**	**Speed**
Kim et al. (2007)		↑
Allen-Munley et al. (2004)	↓	

3.6   Road characteristics

- **Number of lanes**

Zheng (2014) used crash data (4,126 observations) from the Florida DOT to understand how different road and traffic characteristics were useful to predict crash severity. The authors used an ordered probit model to assess their hypothesis. Severity was defined according to the KABCO scale. The authors found that when a crash occurred in a four lane or six lane road, it was more likely to be severe or fatal than one occurring in a two lane road.

Abdul-Aziz et al. (2013) found that the number of lanes was a statistical significant predictor for severity level of crashes involving vehicles and pedestrians as well. Crashes on single lane roads in New York neighborhoods were less severe than crashes on multilane roads.

- **Road width**

Allen-Munley et al. (2004) found that wider streets resulted in more severe bicyclist crashes. This road typology was associated with higher operating vehicle speeds, which can cause dangerous interactions with the bicyclists.

- **Posted speed limit**

Eluru et al. (2008) developed an ordered logit model to understand the effect of explanatory variables on severity levels for non-motorized transportation (pedestrians and

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bicyclists). Furthermore, an elasticity study was conducted to evaluate impact of the predictors on the probability of each level of severity. Data was collected from the general estimates system obtained from the National Highway Traffic Safety Administration. The authors classified speed limit as a set of dummy variables (<25 mph, 25-50 mph, >50 mph) to understand its effect on non-motorized crash severity. Crashes tended to be more severe at roads with high posted speed limits. Zahabi et al. (2011) found that posted speed limit was not a statistically significant variable to explain bicyclist crash severity. The authors explained that drivers did not follow posted speed limits, making road geometry a better predictor. McIntyre (2016) also found that posted speed limit was only significant to predict pedestrian crash severity but not bicyclist crash severity. Pedestrian crashes that occurred on roads with a posted speed limit above 25 mph tended to be more severe and fatal than on roads with a lower speed limit.

- **Road classification**

Findings suggested that pedestrian and bicyclist severity levels increased with arterials and freeways designated roads. Crashes at arterials were more dangerous than crashes at local roads (Zahabi, Strauss, & Miranda-Moreno, 2011). On another study, the authors found that bicyclists riding on roadways designated for high AADT and speeds (such as highways), were more likely to be severely injured if a crash occurred (Allen-Munley, Daniel, & Dhar, 2004).

McIntyre (2016) explored the pedestrian and bicyclist severity determinants in San Francisco. Built environment variables such as crosswalks and bicycle facilities were considered in the analysis. Severity was classified into four categories: complaint of pain, other visible injury, severe and fatal. The study used a logistic regression model to

determine the likelihood of a bicyclist or pedestrian severity level. The findings

suggested that crashes on major roads (highways) tended to be more severe than on other

roads.

- **Road surface**

Abdul-Aziz et al. (2013) used pedestrian crash data collected from New York City (2002-

2006). A total of 4,666 observations were considered. The study classified severity in

three categories: fatal, severe injury and property damage and injury. For a few

neighborhoods in New York, a wet surface was strongly associated with severe crashes

(for the rest of the neighborhoods the findings were not significant). On the other hand,

Halem et al. (2015) found that dry surfaces increased the likelihood of severe and fatal

crashes possibly due to the increase on speeding and risky maneuvers.

- **Rural location**

Even if there were more crashes in urban areas, crashes in cities are less likely to be fatal

or severe than in rural areas. This finding can be attributed to the low speed limits

(Abdul-Aziz, Ukkusuri, & Hasan, 2013).

- **Intersections**

Zahabi et al. found that pedestrian crashes at intersections were less severe than crashes

at other sections of the roads. The finding was attributed to the low vehicle speeds at

these locations. Islam and Hossain (2015) also found that crashes at intersections were

found to increase the probability of non-injury crashes, for both pedestrians and

bicyclists. The authors explained that users on the road were more cautious before

making a decision.

- **Signalized intersections**

Abdul-Aziz et al. (2013) suggested that crashes are less likely to be fatal at unsignalized intersections since drivers and pedestrians were more cautious while crossing. Correspondingly, Zahabi et al. (2011) found that crashes at signalized intersections tended to be more dangerous for bicyclists due to the high number of conflicts with drivers. Sze and Wong (2007) found similar results.

- **Crosswalk**

Haleem et al. (2015) assessed pedestrian crash severity levels at signalized and non-signalized locations. The authors analyzed a total of 4,923 pedestrian crashes in state roads in Florida. Data was verified and completed based on police reports and sketches. Severity was defined based on the KABCO scale. The findings suggested that standard crosswalks at unsignalized intersections were associated with 1.36% reduction in pedestrian severe injuries (Haleem, Alluri, & Gan, 2015). On the other hand, Sze and Wong (2007) findings suggested that crashes that occurred at a crosswalk or within 15m of it led to higher risk of mortality and severe injury compared to pedestrians walking on the sidewalk. This result was intuitive, even if pedestrians were somehow protected in crosswalks; they interacted with vehicles, increasing the risk of a crash. Similarly, Tay et al. (2011) found that crosswalks were conflict points of pedestrians and vehicle interactions, resulting in a higher probability (compared to other road segments) of pedestrians getting severely injured.

TABLE 7: Summary of road characteristics review

	PEDESTRIAN STUDIES								
Author (year)	Major road classification	Presence of a crosswalk	Rural location	Road width	Number of lanes	Wet road surface	Posted speed limit	Intersection location	Signalized intersection
Tay et al. (2011)	↑	↑	↑	↑				↑	
Zheng (2014)					↑				
Clifton et al. (2007)		↓							
Seyed et al. (2011)	↑							↓	
Torbic et al. (2010)									↑
Tarko and Azam (2011)			↑				↑		
Haleem et al. (2015)		↓				-			
Li et al. (2016)							↑		
Eluru et al. (2008)							↑		↑
Sze and Wong (2007)		↑					↑		↑
Beck et al. (2016)	↑								

TABLE 7: Summary of road characteristics review, continued

	Major road classification	Presence of a crosswalk	Rural location	Road width	Number of lanes	Wet road surface	Posted speed limit	Intersection location	Signalized intersection
PEDESTRIAN STUDIES									
Author (year)									
Islam and Hossain (2015)	↑		↑					↓	
McIntyre (2016)	↑	↓					↑		
Sasidharan et al. (2015)	↑	↓					↑		
Zahabi et al. (2011)	↑							↓	
Abdul-Aziz et al. (2013)			↑		↑	↑	↑		↑
BICYCLIST STUDIES									
Zahabi et al. (2011)	↑	↑					-	↑	↑
Islam and Hossain (2015)	↑		↑					↓	
Eluru et al. (2008)							↑		
McIntyre (2016)	↑						-		
Allen-Munley et al. (2004)	↑			↑					

3.7 Studies in Oregon

The ODOT Pedestrian and Bicycle Safety Implementation Plan *(Kittelson & Associates, Inc. 2014)* was developed to identify the most unsafe locations along corridors in Oregon with the highest potential for reducing frequency and severity of pedestrian and bicycle crashes.

Pedestrian and Bicyclist crash data (frequency and severity) for the period 2007 to 2011 were collected. Data on pedestrian volume was not available for the state of Oregon, so vehicle traffic volume was used as a surrogate of pedestrian exposure to traffic. This section presents the main findings of the ODOT Pedestrian and Bicycle Safety Implementation Plan.

The results from this report reinforced the findings from the literature review. Pedestrian, bicyclist, and driver behavior characteristics, along with road and crosswalk features, had a strong association with pedestrian crash frequency. The authors revealed that time of the year, lighting conditions, midblock crossing, driver behavior, and alcohol / drug involvement were the main factors associated with pedestrians crashes. For bicyclist crashes, the authors found that most of the crashes occurred at intersections, caused by drivers turning right.

TABLE 8: ODOT Pedestrian and Bicycle Safety Implementation Plan findings

	PEDESTRIAN	BICYCLIST
Individual characteristics	• The majority of impaired cases (by alcohol or drug involvement) involved an impaired pedestrian rather than an impaired driver. • The most common reported pedestrian error was jaywalking. • At intersections, the most frequent crash cause involved vehicles going straight and jaywalking.	• Not available in the report
Temporal characteristics	• The number of reported pedestrian crashes (from the ODOT Crash Analysis Reporting unit) increased between October and March. • Poor lighting conditions (with and without streetlights) was a factor in pedestrian crash frequency and severity.	• Not available in the report
Road characteristics	• 80% of crashes in urban areas occurred in dark conditions. • At controlled intersections, left-turn crashes were more frequent because drivers failed to yield to pedestrians. However, the severity of "left hook" crashes is known to be less severe than collisions with pedestrians when the car is travelling straight. Controlled intersections with permitted or protected/permitted left-turn phases were found to be a potential crash risk factor for pedestrians. • In rural areas, a low percentage of crashes involving vehicles making right turns and failing to yield to pedestrians were severe at both controlled and uncontrolled intersections. • In urban areas, the majority of crashes occurred on arterials or collectors. Additionally, the majority of severe crashes occurred on roadways with four lanes. • In urban areas, 45% of crashes occurred in locations with speed limits of 45 mph or higher. • Most of the crashes in rural areas (80%) occurred on roadways with speed limits above 45 mph. • The majority of crashes occurred in urban areas (for highways across Oregon, the proportion was 80%) (FIGURE 1 a)	• Most of the crashes in Oregon Highways and the Portland Metro Area occurred at intersections. • In Oregon Highways, 63% of the crashes occurred on non-signalized intersections, while only 57% occurred at these locations in Portland intersections. • Half of severe crashes at signalized intersections occurred less than 100' from a transit stop • Risk factors found from crash pattern analysis were driveway density, undivided 4-lane roadways, lack of bicycle facilities, presence of a traffic signal, AADT and posted speed limit. • Almost 90% of the crashes occurred at urban areas.

TABLE 8: ODOT Pedestrian and Bicycle Safety Implementation Plan findings, continued

	PEDESTRIAN	BICYCLIST
Crosswalk characteristics	• The majority of pedestrian crashes that occurred away from intersections involved pedestrians attempting to cross at midblock locations and drivers failing to yield. • The proportion of crashes that occurred in locations without sidewalks is 45% and 80% in urban and rural areas, respectively. • In the Portland Metro Area, the majority of the crashes occurred at intersections (61%). At highways across Oregon, the proportion was the same for intersections and segments. Crashes were more frequent at controlled intersections (62%) in the Portland Metro Area compared to uncontrolled intersections. Along highways across Oregon, the proportion was higher at uncontrolled intersections (52%). FIGURE 2 (a)	• Not Applicable
Crash characteristics	• In most of the severe crashes, the driver was going straight and failed to yield to the pedestrian	• Most common crashes at signalized intersections included right-hook and angle crashes • Most of the crashes at 2 lane roadways included a bicyclist going straight and a driver turning right.

The next figures (FIGURE 1 and FIGURE 2) show the distribution of pedestrian and

bicyclist crashes in Oregon Highways and the Portland Metro Area. These figures are

adapted based on the information available in the Kittelson & Associates report (2014).

In FIGURE 1, observations are grouped by urban and rural areas. In FIGURE 2,

observations are grouped by intersection and segments.

Pedestrian crashes in Oregon
Total: 3505

Oregon Highways
Total: 1710
Fatal and severe: 433

Portland Metro Area
Total: 1795
Fatal and severe: 319

Urban
Total: 1368
Fatal and severe: 306

Urban
Total: 1794
Fatal and severe: 319

Rural
Total: 338
Fatal and severe: 125

Rural
Total: 1
Fatal and severe: 0

Bicyclist crashes in Oregon
Total: 4124

Oregon Highways
Total: 2030
Fatal and severe: 191

Portland Metro Area
Total: 2094
Fatal and severe: 172

Urban
Total: 1794
Fatal and severe: 143

Urban
Total: 2091
Fatal and severe: 172

Rural
Total: 236
Fatal and severe: 45

Rural
Total: 3
Fatal and severe: 0

(a)   **(b)**

FIGURE 1: (a) Pedestrian and (b) Bicyclist crashes by location. This figure is adapted from Kittelson & Associates, Inc. (2014)

For pedestrian and bicyclist crashes the distribution is similar. Most of the crashes occurred in urban areas, where most of the fatal and severe crashes are located as well. FIGURE 2 also highlights that there are almost 700 more bicyclist crashes than pedestrian crashes. The authors mentioned that one of the key problems in Oregon was the lack of bicycle infrastructure in some high vehicle speed corridors.
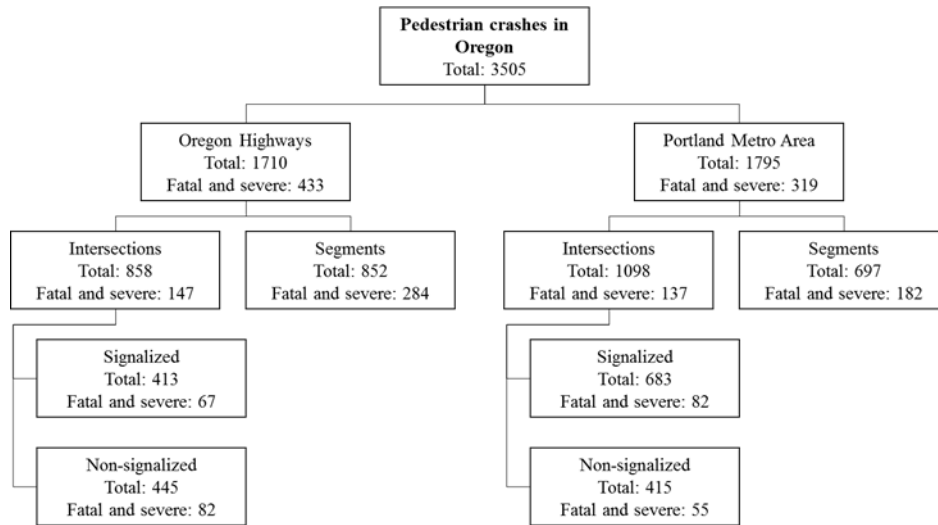
(a)
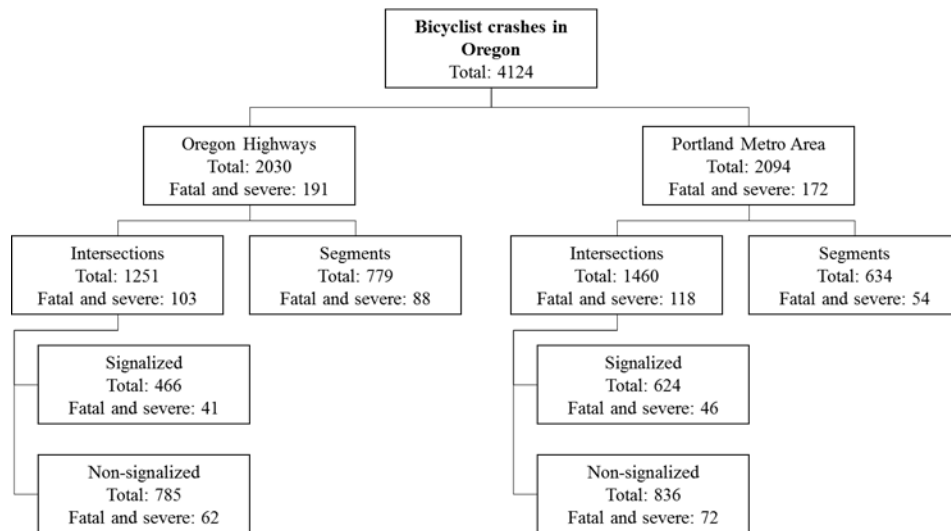
(b)

FIGURE 2: (a)Pedestrian and (b)Bicyclist crashes by road characteristics and intersection type. This figure is adapted from Kittelson & Associates, Inc. (2014)

Additionally, most of the crashes occurred on intersections. In The Portland Metro Area, most of the pedestrian crashes occurred at signalized intersections while most of bicyclist crashes occurred at non-signalized intersections.

3.8   Summary

Substantial research efforts have been made on analyzing crash severity when a pedestrian and/or bicyclist are involved. The findings of this review have helped us to start answering some of the research objective of this study: what are the main risk factors associated to pedestrian and bicyclist crash severity, and how are these levels affected by exposure. The review suggested that variables linked to the participant (driver, pedestrian, and bicyclist), road characteristics, environmental conditions, location characteristics, traffic conditions and crash characteristics are linked to severity. What is novel of approaching traffic safety in terms of severity and not crash frequency, is the fact that improvements and countermeasures can be implemented to protect vulnerable users and control for the randomness of some crash events.

Most of the studies reviewed (12 out of 12 for pedestrians, and 3 out of 4 for bicyclists) suggested that elder non-motorized travelers had a higher risk of being involved in a severe or fatal crash. These findings can be attributed to the fact that walking speed, visibility reaction time, and body resistance tended to be lower for this demographic group.

For gender, the trend was not as clear. Different studies (7) found contradictory results. The review of the literature did not conclude that men or women were involved in more severe or fatal crashes than the other gender. These findings were also different

than the ones found in studies that analyze crash rates, where male pedestrians had a higher likelihood of being involved in a crash than female pedestrians.

In terms of road characteristics, the literature review suggested that a major roads (7 out of 7 studies), rural areas (4 out of 4 studies), an increase in road width (2 out of 2 studies) and number of lanes (2 out of 7 studies), and posted speed limit (7 out of 7 studies), increased the likelihood of severe or fatal pedestrian crashes. For bicyclists, the trend was similar, with the only difference in posted speed limit. Only 1 study out of 3 found a statistical relationship with posted speed limit.

Another interesting result was found in studies that analyzed crashes at intersections. Most of the studies (3 out of 4) found that the likelihood of a severe or fatal pedestrian crash at intersections was lower than that for segments. Furthermore, when the intersection was signalized, the probability of a severe or fatal crash increased (4 out of 4 studies).

Environmental conditions were found to be significant predictors of severity, for both pedestrians and bicyclists. Inclement weather, poor light time conditions (or nighttime), peak hours, and weekend days increased the likelihood of severe and fatal crashes.

In terms of exposure, we reviewed studies that explored land uses as a surrogate of pedestrian and bicyclist exposure. Researchers used land use to examine if areas with high pedestrian and bicyclist activity resulted in more severe crashes than other land use typologies. Commercial land use and big generators of pedestrian volumes were found to increase the probability of severe crashes for pedestrians. Furthermore, some studies found that land use designated as industrial is associated with less severe and fatal pedestrian crashes due to the low levels of pedestrian activity in these zones. Two studies

found that when a school is present near the crash event, the likelihood of severe or fatal crash decreases. Schools tended to have better traffic management to reduce speeds, which protects vulnerable users.

The literature review revealed that as traffic volume and speed increase, the probability of a severe or fatal crash with a non-motorized participant increased. One study found that bicyclists were safer (in terms of severity) with higher volumes since speed tended to decrease under this condition. Moreover, 15 out of 15 studies have reported that an increase in vehicle size and weight increase the probability of a severe or fatal crash with a pedestrian or bicyclist involved.

A few studies have assessed the factors that may contribute to bicyclist crash severity. Finally, all of the studies reviewed showed that when a crash is caused by an alcohol intoxicated driver, the likelihood of a fatal or severe crash increased.

We also identified a gap in the literature in terms of the relationship between pedestrian and bicyclist crash severity. Countermeasures that were proposed to only one non-motorized travel mode may have a negative effect on likelihood of severity for the other mode.

TABLE 9: Literature review summary

VARIABLE	DESCRIPTION	CATEGORY	Increase (↑) or decrease (↓) of fatal or severe crash likelihood
Gender	There is no statistically significant difference between women and men in terms of crash severity	Female	-
		Male	-
Age	The likelihood of being involved in crash with severity level K or A is higher for seniors and children	Children	↑
		Adult	
		Senior	↑

TABLE 9: Literature review summary, continued

VARIABLE	DESCRIPTION	CATEGORY	Increase (↑) or decrease (↓) of fatal or severe crash likelihood
Posted Speed Limit	As posted speed limit increases, crash severity increases		↑
Streetlight condition	No street lighting increases the likelihood of a fatal or severe injured crash.	Present	-
		Not present	↑
Road surface	Wet road surface increases the likelihood of a fatal or severe injured crash.	Wet	↑
		Dry	-
Road Width	As road width increases, crash severity increases		↑
Crosswalk	The presence of a crosswalk decreases the likelihood of a fatal or severe injured crash.	Present	-
		Not present	↑
Intersection	Controlled intersections tend to have less fatal or severe crashes than uncontrolled intersections	Controlled	-
		Uncontrolled	↑
Road classification	Principal arterials tend to have more fatal or severe crashes than other functional classes	Arterial	↑
		Collector	-
		Local	-
Number of lanes	As the number of lanes increase, crash severity increases		↑
Weather	Clear day conditions tend to have less fatal and severe crashes than other weather conditions (e.g. rain, snow, fog)	Clear day	-
		Rainy day	↑
		Snowy day	↑
Light conditions	Dark conditions increase the likelihood of a fatal or severe crash.	Dark	↑
Time of the day	Crashes that occurred at peak hours are more likely to result in a fatality or severe injured output.	Peak hour	↑
Transit access	There is no statistically significant difference between roads with and without transit access (stop/station) in terms of crash severity		↑
Land use	Industrial land uses tend to have more fatal or severe crashes	Residential	-
		Commercial	-
		Industrial	↑
Employment density	High employment density areas tend to have less fatal or severe crashes		↑
Traffic Volume	As traffic volume increases, crash severity increases		↑

TABLE 9: Literature review summary, continued

VARIABLE	DESCRIPTION	CATEGORY	Increase (↑) or decrease (↓) of fatal or severe crash likelihood
Vehicle size	Fatal and severe crashes tend to occur when a heavy vehicle is involved in the crash		↑
Alcohol intoxication	Crashes caused by an alcohol intoxicated driver increased the odds of fatal or severe crashes		↑

4 DATA SOURCES

Pedestrian and bicyclist crash data for the years 2007 to 2014 was collected from the Oregon Statewide Crash Data System. The database consisted of fatal, bodily injury and damage to personal property (more than $1,500) traffic crashes. Crashes included those that occurred on city streets, county roads, and state highways. Only crashes that involved at least one motorized vehicle are reported in the database (e.g. the database does not contain information related to pedestrian-bicycle crashes or bicycle-bicycle crashes).

The database contained a total of 13,309 crashes, where 6,162 involved pedestrians and 7,147 involved people riding a bicycle. Information related to the crash event, the characteristics of the vehicle, and participants involved was available in the database. Information on the crash event is collected by a police officer if this involved a fatality or severe injury. In Oregon, drivers also must file an accident and insurance report form with the DMV if there was a fatality or severe injury, or if the damage to the vehicle was over $1,500, or the damage to any other participant's property was over $1,500. A significant number of crashes were underreported because not all the crashes met the thresholds to be reported, or the participants of the crash chose to not report. Studies (Washington, Haque, Oh, & Lee, 2014) (Yamamoto, Hashiji, & Shankar, 2008) have found that on average, around 50% of the property only damage crashes were reported in different cities. FIGURE 3 shows the path/process on how the crash event information is recorded in the Oregon Statewide Crash Data System.
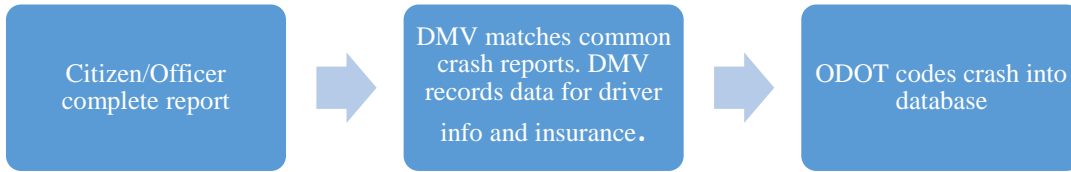
FIGURE 3: Crash event processing

Finally, the database reported crash severity based on the five point KABCO scale.

Severity level for each participant was recorded. At the crash level, severity was reported

based on the most severe injury (e.g. if a crash involved two participants, one with A and

the other with B injury, the crash severity is reported as A)

TABLE 10: KABCO severity scale

KABCO SCALE		DESCRIPTION
K	Fatal	Fatality information includes crashes that result in the death of a driver or a non-motorist within 30 days of the crash.
A	Incapacitated	Injury of the participant prevents him/her from walking, driving or normally continuing the activities he or she was capable of performing before the injury occurred.
B	Visible Injury	Injury to the participant which is evident to observers at the scene of the crash (e.g. bruises, cuts, lacerations, etc.)
C	Complaint of Pain	Participant claimed being injured, however the injury is not evident to observers (e.g. momentary unconsciousness, complaint of pain, nausea, etc.)
O	None	There was no bodily harm to the participant.

Additional information on the Oregon State Highway System was collected from the

Oregon Department of Transportation's TransGIS database. The database contained

georeferenced information of the roadway characteristics (e.g. pavement condition,

number of lanes, lane width, AADT, road classification), safety (state and non-state

crashes), and other themes (e.g. drainage, freight routes, rail network, public transit, road

network, STIP projects, environmental protection, etc.)

To account for the land use characteristics, we used the neighborhood concepts defined by Currans et al. (2015). For the Oregon census blocks, the researchers categorized different land uses into a set of six neighborhood concepts (A to F). These concepts were defined based on activity density (number of residents and jobs per acre of unprotected land), employment entropy (distribution of retail, office, industrial, services, and entertainment jobs), and intersection density (the number of intersections in the road network per square miles). The classification scheme transitioned from dense, urban environments, A or B, towards rural, less dense environments, F. Crashes in ODOT's facilities only occurred in concepts D, E and F. For a better illustration of these concepts, FIGURE shows images representing the different neighborhood concepts.

TABLE 11 describes the land use characteristics used to define the different neighborhood concepts.

FIGURE 4: Neighborhood Concept Types, adapted from *Currans et al. (2015)*

FIGURE 4: Neighborhood Concept Types, adapted from *Currans et al. (2015), continued*

TABLE 11: Neighborhood concept characteristics

NEIGHBORHOOD CONCEPT TYPE	ACTIVITY DENSITY (RESIDENTS AND JOBS PER ACRE)	EMPLOYMENT ENTROPY (UNITLESS)	INTERSECTION DENSITY (INTERSECTIONS PER SQUARE MILE)
A-B	667	0.75	489
C	245	0.75	189
D	39	0.76	141
E	20	0.67	73
F	19	0.19	71

As shown in TABLE 11, Neighborhoods with a concept of A and B have a higher

activity density and intersection density than the other concepts, while concept F,

represents a more suburban area, with low activity and intersection density and,

employment entropy. For Oregon, only four of the six neighborhood concepts exist, C, D,

E and F.
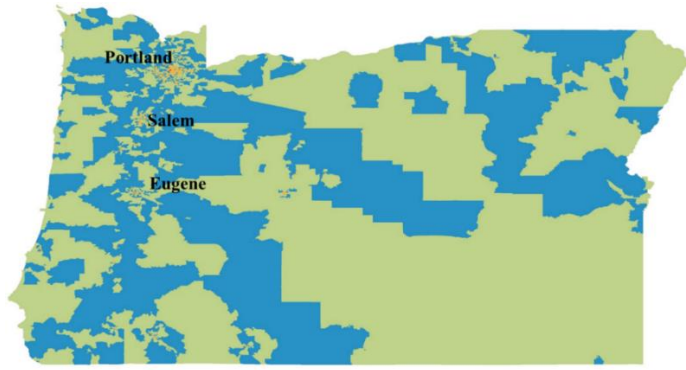
(a)
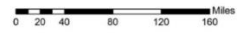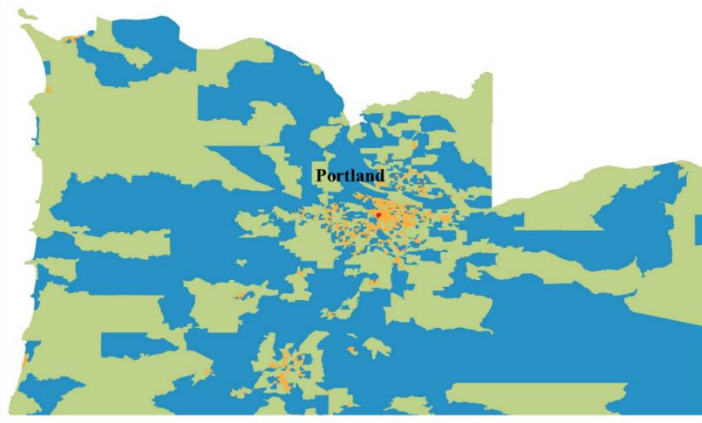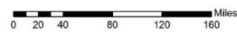
(b)

FIGURE 5: Oregon Neighborhood Concept, (a) State of Oregon, (b) Portland Metro Area

5   DESCRIPTIVE ANALYSIS

This descriptive analysis is intended to present the data and uncover patterns in terms of risk factors for crash severity and neighborhood concepts. This first approximation to the data includes all the crashes that occurred in Oregon. Section 6 and 7 will only focus on crashes that occurred in the Oregon Highway System. Crash data from the Oregon Statewide Crash Data System was grouped by intersection and segment based on the traffic control device information available at the crash level. Crashes at driveways, curves, and bridge structures were not taken into account due to the few observations available. Crash information is presented as the number of crashes reported. Furthermore, crashes were grouped by neighborhood concept (Currans, Gherke, & Clifton, 2015) to account for the differences in built environment in the likelihood of a crash occurrence.

5.1   General Trends

A total of 3,629 pedestrian crashes occurred at intersections from 2007 to 2011. Additionally, 1,822 pedestrian crashes occurred on road segments. The majority of the crashes occurred in neighborhood concept D, followed by E, F and C. As seen in Figure 5, the urban metropolitan areas in Oregon were mainly defined as concept D and E, which explains why fewer pedestrian crashes occurred in concept C (188 pedestrian crashes).

In terms of crash severity, the findings suggested that injury level B had the largest number of crashes at intersections and segments. For areas with neighborhood concept C, there has been an increase of these crashes during the last decade.

By comparing crashes at segments and intersections across the years, one result stood out. There were more fatal (K) and incapacitated (A) crashes on road segments than at intersections. On segments of the road, vehicles tended to drive faster.

TABLE 12: Statewide pedestrian crashes by neighborhood concepts and year

Year	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	0	14	4	7	0	0	0	0	0	0
2008	0	21	6	15	0	0	8	11	0	0
2009	0	0	19	4	0	0	15	11	0	0
2010	0	14	16	16	0	0	31	11	0	0
2011	0	0	15	19	0	100	8	22	0	0
2012	0	21	12	22	0	0	15	22	0	0
2013	100	7	11	10	100	0	0	11	0	0
2014	0	21	17	6	0	0	23	11	0	0
Total	1	14	81	68	1	1	13	9	0	0

Year	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	7	9	9	8	19	15	15	11	13	0
2008	19	11	9	10	6	9	14	10	16	20
2009	11	11	11	9	19	9	8	10	13	20
2010	4	8	14	14	0	11	17	16	12	0
2011	6	15	13	16	6	17	11	12	16	20
2012	17	14	12	15	13	13	15	15	14	0
2013	15	14	15	13	25	15	13	13	9	20
2014	22	19	18	15	13	11	7	13	8	20
Total	54	173	852	638	16	46	111	298	160	5

TABLE 12: Statewide pedestrian crashes by neighborhood concepts and year, continued

Year	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	17	10	9	5	6	10	13	11	10	10
2008	8	11	9	7	0	14	13	9	13	10
2009	8	9	10	11	25	7	15	12	19	20
2010	10	16	12	11	6	20	11	13	11	10
2011	17	15	14	13	6	9	16	14	14	30
2012	19	12	17	17	6	16	12	16	12	0
2013	6	15	14	17	38	13	10	15	8	20
2014	15	12	16	18	13	12	10	10	12	0
Total	48	146	588	471	16	117	148	345	193	10

Year	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	25	17	10	3	0	14	22	11	10	0
2008	0	4	4	10	14	14	12	10	12	0
2009	0	13	8	8	14	11	12	8	12	0
2010	19	9	11	19	0	19	11	11	9	0
2011	6	11	13	15	14	9	14	15	16	0
2012	13	13	22	17	29	7	14	15	10	50
2013	25	9	17	12	14	12	9	15	12	0
2014	13	23	14	15	14	14	6	15	18	50
Total	16	53	230	156	7	57	65	175	67	2

In terms of bicyclists, there were 4,702 crashes that occurred in intersections, and 864 that occurred in road segments. Most of the crashes resulted in injury B as well. Furthermore, there has been an increase of injury A and B crashes on roads located in neighborhood concept D and E over the period studied.

The number of fatal crashes at intersections and on road segments has been similar, but for the rest of the severity levels, intersections have carried the majority of the crashes. This finding contrasted with the pedestrian findings, where most of the fatal and severe crashes were at segments.

TABLE 13: Statewide bicyclist crashes by neighborhood concepts and year

Year	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	0	36	10	9	0	0	20	14	0	0
2008	0	18	7	18	0	0	0	7	0	0
2009	0	9	16	11	0	0	40	14	0	0
2010	0	9	12	14	50	0	20	14	0	0
2011	50	9	13	14	25	0	0	7	67	0
2012	50	9	17	5	0	0	0	14	0	50
2013	0	9	16	11	25	0	20	7	0	0
2014	0	0	10	18	0	0	0	21	33	50
Total	2	11	94	44	4	0	5	14	3	2

Year	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	30	13	8	9	14	0	16	10	10	0
2008	20	20	11	11	10	0	9	15	14	8
2009	10	10	11	12	16	43	22	9	15	17
2010	10	8	15	12	12	0	6	11	18	17
2011	10	12	13	13	11	14	6	14	10	8
2012	0	16	14	16	7	14	9	17	13	17
2013	10	10	14	13	21	14	9	11	9	17
2014	0	12	15	14	14	14	22	15	11	17
Total	10	145	1288	721	94	7	32	186	92	12

Year	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	21	12	9	7	6	29	19	12	8	27
2008	29	15	10	11	10	0	13	10	10	0
2009	0	13	11	12	15	7	3	13	16	27
2010	7	6	14	13	6	7	13	11	6	7
2011	21	15	14	13	9	29	10	8	13	0
2012	14	11	16	16	18	21	13	17	12	7
2013	0	18	13	13	15	0	10	16	16	13
2014	7	11	13	15	21	7	19	13	19	20
Total	14	131	937	502	67	14	31	190	83	15

TABLE 13: Statewide bicyclist crashes by neighborhood concepts and year, continued

Year	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
2007	17	8	7	6	0	33	0	11	13	0
2008	0	8	10	9	6	17	7	3	0	50
2009	0	8	12	13	6	17	20	15	6	0
2010	17	6	16	16	18	17	7	9	10	0
2011	17	17	15	12	18	17	27	12	29	0
2012	0	17	15	15	29	0	20	15	23	0
2013	17	17	13	11	18	0	7	19	10	50
2014	17	19	13	18	6	0	13	17	10	0
Total	6	36	379	198	17	6	15	124	31	2

5.2 Pedestrian and bicyclist characteristics

Two variables were assessed for pedestrian and bicyclist characteristics: age and gender.

For pedestrians, the findings suggested that most of the severity level K and A crashes

involved a pedestrian older than 45 years old (for neighborhood concept E, 60% of the

fatal crashes involved a pedestrian older than 55). This finding is similar to the findings

from the literature review: as people get older, the likelihood of a fatal and severe crash

increased due to the reduction in visibility, reaction time, and body resistance. Another

vulnerable population, pedestrians younger than 12 years old, were found to made up to

9% of the fatal crashes and 13% of the severity level A crashes for the different

neighborhood concepts.

TABLE 14: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and vulnerable user age.

Age	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	0	7	10	14	100	0	0	0	11	0
12-18	0	0	2	0	0	0	0	0	0	0
18-24	100	33	12	13	0	0	0	23	33	0
25-34	0	13	16	26	0	0	0	23	22	0
35-44	0	20	13	14	0	0	0	15	22	0
45-54	0	7	16	16	0	0	0	15	11	0
55-64	0	7	21	16	0	0	100	15	0	0
65-74	0	0	8	0	0	0	0	8	0	0
75+	0	13	1	1	0	0	0	0	0	0
Total	2	15	86	70	1	0	1	13	9	0

Age	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	3	13	10	12	31	4	14	17	18	40
12-18	1	13	10	9	6	0	0	0	0	0
18-24	10	9	16	15	31	4	13	12	8	20
25-34	9	13	17	16	25	18	9	14	17	0
35-44	13	12	10	15	6	4	15	14	16	20
45-54	16	16	13	15	0	16	13	12	11	0
55-64	15	11	12	10	0	26	16	14	15	20
65-74	16	8	7	5	0	18	13	9	8	0
75+	15	5	4	2	0	4	5	5	7	0
Total	67	184	890	661	16	50	116	334	169	5

TABLE 14: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and vulnerable user age, continued

Age	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	9	11	13	10	31	3	9	17	14	20
12-18	4	18	19	13	6	2	10	13	17	10
18-24	13	14	14	16	13	13	17	18	14	10
25-34	11	11	13	17	19	11	13	12	16	20
35-44	11	12	9	14	6	14	11	10	10	0
45-54	11	14	11	13	19	22	20	13	13	40
55-64	14	7	11	9	0	19	13	11	10	0
65-74	16	6	6	5	0	4	3	4	6	0
75+	13	7	4	3	6	11	5	4	3	0
NA	9	11	13	10	31	3	9	17	14	20
Total	56	152	616	487	16	123	152	357	200	10

Age	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	7	13	9	14	16	3	12	23	21	0
12-18	0	13	18	14	11	2	13	20	9	0
18-24	7	13	17	16	11	13	16	18	24	50
25-34	7	19	14	16	5	18	13	12	16	0
35-44	7	8	12	10	21	23	13	9	10	0
45-54	13	12	12	11	16	15	20	11	10	0
55-64	27	10	11	12	21	11	7	3	4	0
65-74	20	6	6	5	0	5	5	3	1	0
75+	13	6	2	2	0	11	1	1	4	50
NA	7	13	9	14	16	3	12	23	21	0
Total	15	52	226	173	19	62	76	184	70	2

Different results were found for bicyclists. Crashes that occurred in neighborhood D were fatal or severity level A when there was a bicyclist younger than 34. For neighborhood E, most of the fatal crashes involved bicyclists over 45, while most of the severe crashes (level A and B) involved bicyclists younger than 24. Some of the literature review

suggested that younger people who bike accepted more risk than older bikers, which

resulted in higher exposure and likelihood of being involved in a fatal or severe crash.

TABLE 15: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and vulnerable user age.

Age	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
0-12	0	0	12	14	100	0	0	14	0	50
12-18	0	0	2	7	0	0	0	0	0	0
18-24	50	9	24	23	0	0	0	7	33	50
25-34	50	27	34	34	0	0	80	64	33	0
35-44	0	27	14	9	0	0	0	14	0	0
45-54	0	18	7	9	0	0	20	0	33	0
55-64	0	18	5	2	0	0	0	0	0	0
65-74	0	0	2	2	0	0	0	0	0	0
75+	0	0	0	0	0	0	0	0	0	0
Total	2	11	95	44	4	0	5	14	3	2

Age	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
0-12	0	5	12	12	45	0	9	21	16	58
12-18	20	9	9	9	10	0	9	10	6	8
18-24	30	25	22	21	11	0	16	17	24	8
25-34	30	20	24	22	16	43	22	19	30	0
35-44	20	18	13	16	8	14	19	16	11	0
45-54	0	12	12	13	5	14	6	11	10	25
55-64	0	7	6	4	4	14	9	5	3	0
65-74	0	3	2	2	0	0	6	1	0	0
75+	0	2	1	1	0	14	3	0	0	0
Total	10	146	1304	725	99	7	32	189	93	12

TABLE 15: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and vulnerable user age, continued

Age	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	0	9	13	14	33	0	16	21	11	27
12-18	13	10	15	11	12	7	19	14	10	20
18-24	7	20	20	18	20	0	13	12	14	20
25-34	0	14	17	18	13	7	6	20	23	13
35-44	20	11	12	13	6	29	16	10	13	7
45-54	27	18	11	16	7	14	19	11	14	13
55-64	7	11	7	7	7	14	6	7	11	0
65-74	20	4	3	3	1	21	6	4	1	0
75+	7	4	1	0	0	7	0	2	2	0
NA	0	9	13	14	33	0	16	21	11	27
Total	15	131	950	505	69	14	32	191	83	15

Age	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
0-12	0	11	15	17	53	17	7	24	16	0
12-18	20	17	13	10	11	0	13	15	6	0
18-24	0	17	17	15	11	0	20	16	19	50
25-34	0	11	16	15	0	17	7	12	10	0
35-44	0	14	14	19	11	17	0	5	19	50
45-54	20	14	15	13	16	50	33	12	16	0
55-64	40	14	6	10	0	0	7	10	10	0
65-74	20	0	3	3	0	0	13	5	3	0
75+	0	3	1	0	0	0	0	2	0	0
NA	0	11	15	17	53	17	7	24	16	0
Total	5	36	385	199	19	6	15	129	31	2

In terms of gender, it was found that men were involved in more fatal and severe crashes than women were. This result was consistent for intersections and segments, and the different neighborhood concepts. Based on the literature review, there was no consensus on this topic, since studies found contradictory results or non-significant findings.

Although there was a trend in terms of gender in this descriptive analysis, more

exploration is needed to determine the role of gender.

TABLE 16: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and vulnerable user gender.

| Gender | Neighborhood Concept C | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Male	0	53	58	44	0	0	62	78	0	0
Female	100	47	41	55	0	100	38	22	0	0
Unknown	0	0	1	1	100	0	0	0	0	0
Total	2	15	83	73	1	1	13	9	0	0

| Gender | Neighborhood Concept D | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Male	60	58	52	51	63	62	66	58	63	0
Female	40	42	48	48	31	38	34	41	36	80
Unknown	0	0	0	1	6	0	0	1	1	20
Total	67	184	890	661	16	50	116	334	169	5

| Gender | Neighborhood Concept E | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Male	71	59	52	49	69	72	73	61	65	30
Female	29	41	48	51	25	28	27	38	34	70
Unknown	0	0	0	1	6	0	0	1	2	0
Total	56	152	616	487	16	123	152	357	200	10

| Gender | Neighborhood Concept E | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Male	67	62	56	48	58	74	63	67	61	50
Female	33	38	43	50	42	26	37	32	36	50
Unknown	0	0	0	2	0	0	0	1	3	0
Total	15	52	226	173	19	62	76	184	70	2

Similar results were found for bicyclists. For all the severity levels and neighborhood concepts, there were more crashes for men than women. Furthermore, similar proportions of crashes between men and women were found in neighborhood concepts C and F; however, there are not too many observations in these land use typologies.

TABLE 17: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and vulnerable user gender.

Gender	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Male	50	73	68	68	50	0	80	79	67	50
Female	50	27	31	32	50	0	20	21	33	50
Unknown	0	0	1	0	0	0	0	0	0	0
Total	2	11	95	44	4	0	5	14	3	2

Gender	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Male	80	73	70	68	76	86	66	71	71	75
Female	20	27	29	31	16	14	34	27	29	8
Unknown	0	0	0	1	8	0	0	2	0	17
Total	10	146	1304	725	99	7	32	189	93	12

Gender	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Male	80	79	75	74	81	86	78	85	84	93
Female	20	21	25	26	14	14	19	14	16	7
Unknown	0	0	0	0	4	0	3	1	0	0
Total	15	131	950	505	69	14	32	191	83	15

TABLE 17: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and vulnerable user gender, continued

| Gender | Neighborhood Concept F | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Male	60	78	77	76	58	83	87	77	77	100
Female	40	22	22	23	16	17	13	23	13	0
Unknown	0	0	0	1	26	0	0	0	10	0
Total	5	36	385	199	19	6	15	129	31	2

5.3   Road characteristics

For road characteristics, we explored the key variables found in the literature review: road classification, posted speed limit, number of lanes, road surface, and type of intersection. Width was also found to be statistically significant in most of the studies; however, information was not available in the crash database. Width is assessed in the exposure analysis.

In terms of road classification, the descriptive analysis suggested that most of the pedestrian crashes occurred on arterials (principal and minor). This result was consistent for all neighborhood concepts regardless the severity level. Furthermore, most of the fatal crashes occurred on principal arterials, and were mainly located in neighborhood concepts D and E.   Finally, most of the fatal and severe crashes occurred on principal and minor arterials. These crash observations were higher than for intersections connecting roads with the same classifications. For the other severity levels (B, C, O), intersections had more crashes.

TABLE 18: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and road classification.

Road Classification	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interstate/ Freeway	0	0	1	0	0	0	0	0	0	0
Principal Arterial	0	43	17	13	0	0	100	69	22	0
Minor Arterial	100	43	54	51	0	0	0	8	33	0
Rural collector	0	0	0	0	0	0	0	0	0	0
Urban collector	0	14	23	35	100	0	0	23	33	0
Local	0	0	4	0	0	0	0	0	11	0
Total	1	14	81	68	1	0	1	13	9	0

Road Classification	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interstate/ Freeway	4	1	1	1	6	11	2	2	1	0
Principal Arterial	59	49	38	42	38	57	49	33	33	40
Minor Arterial	28	28	33	31	19	15	26	28	21	0
Rural collector	0	0	0	0	0	0	0	0	0	0
Urban collector	9	17	20	16	25	11	19	20	26	20
Local	0	6	9	10	13	7	5	17	19	40
Total	54	173	852	638	16	46	111	298	160	5

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TABLE 18: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and road classification, continued

Road Classifi-cation	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interst/ Freeway	4	1	1	1	6	15	4	3	4	10
Principal Arterial	54	49	40	44	38	56	44	37	33	40
Minor Arterial	21	32	27	25	31	12	24	22	23	10
Rural collector	4	1	3	2	0	4	2	5	5	0
Urban collector	10	11	21	17	13	7	16	17	17	20
Local	6	8	9	10	13	6	10	17	19	20
Total	48	146	588	471	16	117	148	345	193	10

Road Classification	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interstate/ Freeway	0	0	0	0	0	12	5	7	9	0
Principal Arterial	44	28	37	38	29	26	34	23	27	0
Minor Arterial	31	38	33	35	29	28	20	27	24	0
Rural collector	19	2	3	2	0	16	8	9	4	0
Urban collector	6	21	17	17	29	12	18	15	15	0
Local	0	11	10	8	14	5	15	18	21	100
Total	16	53	230	156	7	57	65	175	67	2

In terms of bicyclist crashes, the results differed by the different neighborhood concepts. In neighborhood concept C, fatal crashes and crashes with injury level A occurred mainly on intersections with a collector leg. For segments, these crashes were mainly located on minor arterials. For concept D, most of the crashes occurred on arterials, with a majority of fatal crashes occurring on principal arterials and the majority of non-fatal crashes on

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minor arterials (for both intersections and segments). On the other hand, most of the crashes in neighborhood concept E occurred on principal arterials, regardless of the severity level. Furthermore, for concept F, the findings suggested that most of the crashes occurred on rural collectors (80%).

As expected, most of the crashes occurred on arterials; however, minor arterials were revealed to be a significant problem since a substantial number of fatal and severe crashes occurred there.

TABLE 19: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and road classification.

Road Classification	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interstate/ Freeway	0	0	0	0	0	0	0	0	0	0
Principal Arterial	0	18	21	25	0	0	0	29	0	50
Minor Arterial	50	36	40	41	75	0	100	43	33	0
Rural collector	0	0	0	0	0	0	0	0	0	0
Urban collector	50	45	35	32	25	0	0	29	33	50
Local	0	0	3	2	0	0	0	0	33	0
Total	2	11	94	44	4	0	5	14	3	2

TABLE 19: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and road classification, continued

Road Classification	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
Interstate/ Freeway	0	2	1	1	1	14	3	0	0	0
Principal Arterial	33	32	30	32	29	57	16	26	25	33
Minor Arterial	22	34	31	32	32	0	38	33	33	33
Rural collector	0	0	0	0	0	0	0	0	0	0
Urban collector	33	20	22	20	20	29	31	24	23	17
Local	11	11	16	15	18	0	13	17	20	17
Total	9	145	1288	721	98	7	32	186	92	12

Road Classification	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
Interstate/ Freeway	0	1	2	1	4	7	0	1	0	0
Principal Arterial	64	31	34	38	42	50	35	33	35	13
Minor Arterial	21	34	31	31	24	36	35	23	20	27
Rural collector	7	3	2	1	0	7	13	8	7	7
Urban collector	7	18	19	16	16	0	10	16	17	27
Local	0	13	12	12	13	0	6	19	20	27
Total	14	131	937	502	67	14	31	190	83	15

TABLE 19: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and road classification, continued

Road Classification	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Interstate/ Freeway	0	0	1	2	0	0	0	0	0	0
Principal Arterial	20	31	25	29	29	17	7	19	29	50
Minor Arterial	0	31	37	33	35	67	47	24	29	50
Rural collector	80	6	4	2	0	17	7	15	6	0
Urban collector	0	25	21	21	29	0	20	23	23	0
Local	0	8	12	13	6	0	20	19	13	0
Total	5	36	379	198	17	6	15	124	31	2

In terms of posted speed limit, the database contained a substantial number of crashes without this information. Using the data available, we found that fatal pedestrian crashes tended to occur when the major road has a posted speed limit between 35 to 50 mph. For non-fatal crashes, the majority of them occurred on roads with posted speed limits between 20 to 35 mph. This result was consistent across the neighborhood concepts. For segments, the distribution was different. Most of the crashes occurred on roads with a posted speed limit above 35 mph, regardless of severity level. For neighborhood concept E and C, non-severe crashes occurred on roads with a lower posted speed limit.

TABLE 20: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and posted speed limit.

Posted Speed Limit PSL (mph)	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	0	50	63	69	100	0	0	69	78	0
<20	0	7	1	0	0	0	0	0	0	0
20-35	100	29	31	10	0	0	100	15	22	0
35-50	0	7	0	9	0	0	0	8	0	0
50 -65	0	7	5	12	0	0	0	8	0	0
> 65	0	0	0	0	0	0	0	0	0	0
Total	1	14	81	68	1	0	1	13	9	0

PSL (mph)	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	17	41	44	56	69	9	40	49	54	100
<20	2	3	4	2	6	0	1	1	1	0
20-35	30	29	30	23	19	15	19	25	18	0
35-50	50	23	20	16	6	65	37	23	23	0
50 -65	2	3	2	4	0	9	4	1	4	0
> 65	0	0	0	0	0	2	0	0	0	0
Total	54	173	852	638	16	46	111	298	160	5

PSL (mph)	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	19	37	39	41	50	15	29	36	39	50
<20	2	1	1	1	0	1	1	1	2	0
20-35	23	25	31	29	19	9	18	23	27	20
35-50	50	34	28	26	31	46	39	31	22	20
50 -65	6	3	1	3	0	23	13	8	8	10
> 65	0	0	0	0	0	6	1	2	2	0
Total	48	146	588	471	16	117	148	345	193	10

TABLE 20: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and posted speed limit, continued

PSL (mph)	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	13	30	39	42	57	19	23	39	39	0
<20	6	4	2	3	0	2	0	3	1	100
20-35	19	32	28	27	29	4	20	18	16	0
35-50	50	28	28	24	0	33	28	21	27	0
50 -65	13	6	3	5	14	33	28	16	12	0
> 65	0	0	0	0	0	9	2	4	4	0
Total	16	53	230	156	7	57	65	175	67	2

In terms of bicyclists, there were more fatal crashes at segments and intersections with posted speed limits between 35 to 50 mph. However, for concept E, this value was higher on roads with higher posted speed limits (above 50 mph). As in the pedestrian crash descriptive analysis, bicyclist crashes tended to increase as the posted speed limit increased until it reached 50 mph. After this threshold, the number of crashes became insignificant since bicycle volumes were low in these facilities (low exposure).

TABLE 21: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and posted speed limit.

PSL (mph)	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	0	91	69	82	75	0	100	71	100	0
<20	0	0	6	2	0	0	0	0	0	50
20-35	50	0	15	14	0	0	0	21	0	0
35-50	50	9	3	0	25	0	0	0	0	0
50 -65	0	0	6	2	0	0	0	7	0	50
> 65	0	0	0	0	0	0	0	0	0	0
Total	2	11	94	44	4	0	5	14	3	2

TABLE 21: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and posted speed limit, continued

PSL (mph)	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	11	52	57	60	77	29	41	55	57	92
<20	0	2	2	1	3	0	3	1	3	0
20-35	44	26	23	22	10	14	19	20	20	0
35-50	44	18	15	14	8	43	34	17	17	0
50 -65	0	2	3	3	2	14	3	6	3	8
> 65	0	0	0	0	0	0	0	0	0	0
Total	9	145	1288	721	98	7	32	186	92	12

PSL (mph)	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	14	35	44	47	72	14	35	41	39	60
<20	0	2	1	2	6	0	6	2	0	7
20-35	21	26	24	21	7	0	16	22	31	27
35-50	64	30	28	28	15	36	29	28	22	0
50 -65	0	7	3	2	0	43	13	8	8	7
> 65	0	0	0	0	0	7	0	0	0	0
Total	14	131	937	502	67	14	31	190	83	15

PSL (mph)	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
NA	40	28	45	48	76	33	40	44	48	50
<20	0	3	1	2	6	0	0	2	0	0
20-35	20	25	26	23	0	17	13	15	10	0
35-50	0	36	23	22	12	33	27	21	26	0
50 -65	40	6	5	5	6	17	20	18	16	50
> 65	0	3	0	0	0	0	0	0	0	0
Total	5	36	379	198	17	6	15	124	31	2

Number of lanes was assessed only for segments. Most of the fatal pedestrian crashes occurred on roads with 4 lanes. For neighborhood concept F, 2-lane roads had the highest number of crashes. This can be explained by the fact that these types of roads are mainly

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located in rural areas. Furthermore, most of the crashes that resulted in injury level, A, B, C and O, were located on 2-lane roads.

TABLE 22: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and number of lanes

Number of lanes	Neighborhood Concept C (%)				
	K	A	B	C	O
0	0	0	0	0	0
1	0	0	0	0	0
2	0	100	31	33	0
3	0	0	8	22	0
4	0	0	38	33	0
5	0	0	15	0	0
6	0	0	8	11	0
7	0	0	0	0	0
8	0	0	0	0	0
Total	0	1	13	9	0

Number of lanes	Neighborhood Concept D (%)				
	K	A	B	C	O
0	0	0	0	0	0
1	0	1	0	0	0
2	27	40	49	58	60
3	4	4	5	4	0
4	60	54	42	32	40
5	4	2	3	6	0
6	4	0	1	0	0
7	0	0	0	0	0
8	0	0	0	0	0
Total	45	111	298	159	5

TABLE 22: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and number of lanes, continued

Number of lanes	Neighborhood Concept E (%)				
	K	**A**	**B**	**C**	**O**
0	0	1	0	0	0
1	0	0	0	1	0
2	44	51	60	69	50
3	3	1	3	2	20
4	45	43	33	21	20
5	4	3	2	4	0
6	3	1	1	2	10
7	0	0	0	1	0
8	0	0	0	1	0
Total	117	148	345	193	10

Number of lanes	Neighborhood Concept F (%)				
	K	**A**	**B**	**C**	**O**
0	0	0	0	0	0
1	0	0	1	0	0
2	54	74	72	66	100
3	2	0	2	1	0
4	39	20	22	27	0
5	0	3	2	1	0
6	5	3	2	4	0
7	0	0	0	0	0
8	0	0	0	0	0
Total	57	65	175	67	2

Most of the bicyclist crashes occurred on segments with two lanes, regardless the severity level. This finding was consistent for the different neighborhood concepts but concept D. In this land use typology, fatal crashes were mainly located at intersections with a 4-lane road.

TABLE 23: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and number of lanes.

Number of lanes	Neighborhood Concept C (%)				
	K	A	B	C	O
0	0	0	0	0	0
1	0	0	0	33	0
2	0	60	36	33	50
3	0	40	36	0	50
4	0	0	29	33	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	100	100	100	100
Total	0	5	14	3	2

Number of lanes	Neighborhood Concept D (%)				
	K	A	B	C	O
0	0	0	1	0	0
1	0	0	0	0	0
2	29	69	60	62	29
3	0	0	8	9	0
4	43	25	31	27	43
5	14	3	1	2	14
6	14	3	0	0	14
7	0	0	0	0	0
8	0	0	1	0	0
Total	7	32	186	92	2

TABLE 23: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and number of lanes, continued

Number of lanes	Neighborhood Concept E (%)				
	K	A	B	C	O
0	0	0	0	0	0
1	0	0	1	0	0
2	64	77	62	69	64
3	7	6	5	1	7
4	21	16	25	28	21
5	7	0	6	2	7
6	0	0	1	0	0
7	0	0	1	0	0
8	0	0	0	0	0
Total	14	31	190	83	15

Number of lanes	Neighborhood Concept F (%)				
	K	A	B	C	O
0	0	0	0	0	0
1	0	0	2	3	0
2	83	80	77	74	50
3	0	0	5	10	0
4	17	20	15	13	50
5	0	0	2	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
Total	6	15	124	31	2

In terms of road surface, there was not a substantial difference between the different severity levels and neighborhood concepts. Most of the pedestrian crashes occurred during dry conditions. Furthermore, the second most important road surface category was wet, regardless of the severity level.

TABLE 24: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and road surface

Road surface	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	1	4	0	0	0	0	0	0
Dry	100	86	59	50	100	0	100	85	44	0
Wet	0	14	40	44	0	0	0	15	44	0
Other	0	0	0	1	0	0	0	0	11	0
Total	1	14	81	68	1	0	1	13	9	0

Road surface	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	6	1	1	1	13	2	0	0	2	0
Dry	70	73	68	60	56	72	75	74	69	80
Wet	24	25	30	38	31	26	23	25	29	20
Other	0	1	1	1	0	0	2	0	0	0
Total	54	173	852	638	16	46	111	298	160	5

Road surface	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	1	1	2	13	9	1	1	1	0
Dry	67	63	71	62	69	60	70	70	71	100
Wet	31	32	26	35	19	32	28	27	25	0
Other	2	4	1	2	0	0	2	2	3	0
Total	48	146	588	471	16	117	148	345	193	10

Road surface	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	0	2	0	4	3	1	3	0
Dry	81	62	69	62	43	67	78	73	73	50
Wet	19	36	29	34	57	28	17	21	15	0
Other	0	2	2	2	0	2	2	6	9	50
Total	16	53	230	156	7	57	65	175	67	2

Similar results were found for bicyclist crashes. Most of the observations were

concentrated on dry road surfaces, regardless of the severity level.

TABLE 25: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and road surface

Road surface	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	1	2	0	0	20	0	0	0
Dry	50	100	79	80	75	0	40	79	100	50
Wet	50	0	20	18	25	0	40	21	0	50
Other	0	0	0	0	0	0	0	0	0	0
Total	2	11	94	44	4	0	5	14	3	2

Road surface	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	1	2	7	14	0	2	1	0
Dry	100	82	85	76	72	71	88	89	80	83
Wet	0	18	13	21	20	0	13	9	18	17
Other	0	0	0	0	0	14	0	0	0	0
Total	9	145	1288	721	98	7	32	186	92	12

Road surface	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	14	1	0	2	4	0	0	1	2	7
Dry	64	84	87	77	81	71	94	92	87	87
Wet	21	15	12	21	15	29	6	7	11	7
Other	14	1	0	2	4	0	0	1	2	7
Total	14	131	937	502	67	14	31	190	83	15

TABLE 25: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and road surface, continued

Road surface	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	1	3	6	0	7	3	3	0
Dry	100	94	86	84	71	83	87	87	65	100
Wet	0	6	13	14	24	17	7	10	32	0
Other	0	0	0	0	0	0	0	0	0	0
Total	5	36	379	198	17	6	15	124	31	2

5.4   Environmental conditions

For environmental conditions, the literature review found that weather, time of the day, day of the week, and light conditions were good predictors for crash severity. Most of the crashes occurred on clear days, followed by rainy days. This result was similar across the different neighborhood concepts and severity levels. This finding can be the result of less pedestrian volumes in rainy and cloudy weather conditions, which results in less exposure.

TABLE 26: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and weather conditions

Weather	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	2	3	0	0	0	0	0	0
Clear	0	71	58	49	100	0	100	54	33	0
Cloudy	0	14	12	7	0	0	0	31	11	0
Rain	0	14	26	40	0	0	0	15	44	0
Others	0	0	2	3	0	0	0	0	0	0
Total	1	14	81	68	1	0	1	13	9	0

TABLE 26: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and weather conditions, contiuned

| Weather | Neighborhood Concept D | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	4	2	1	1	13	2	0	2	2	0
Clear	52	58	57	53	56	43	51	63	56	60
Cloudy	28	21	16	14	0	35	26	16	18	0
Rain	15	18	23	30	31	15	19	18	21	20
Others	2	1	2	2	0	4	4	1	3	20
Total	54	173	852	638	16	46	111	299	164	5

| Weather | Neighborhood Concept E | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	0	1	1	2	13	8	1	1	1	0
Clear	56	45	62	49	44	38	53	57	63	90
Cloudy	21	23	16	18	25	37	24	22	17	10
Rain	21	29	19	27	13	16	20	17	18	0
Others	2	3	3	3	6	2	1	3	2	0
Total	48	146	586	471	16	117	147	345	193	10

| Weather | Neighborhood Concept F | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	13	6	6	8	0	4	2	1	4	0
Clear	31	45	51	44	29	53	69	61	66	50
Cloudy	38	17	21	19	29	16	12	16	19	0
Rain	19	25	20	24	43	25	17	16	9	0
Others	0	8	2	4	0	4	0	6	1	50
Total	16	53	230	156	7	57	65	175	67	2

Very similar results were found for bicyclist crashes. After clear days, cloudy conditions had the second highest number of crashes regardless of the severity level. Number of crashes during rainy conditions was also low, which is expected due to the low bicyclist volume under rain events.

TABLE 27: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and weather conditions

| Weather | Neighborhood Concept C | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	2	2	0	20	0	0	0	0
Clear	50	100	71	73	75	40	64	67	100	0
Cloudy	0	0	11	11	0	20	14	33	0	0
Rain	50	0	15	14	25	20	14	0	0	0
Others	0	0	1	0	0	0	7	0	0	0
Total	2	11	94	44	4	5	14	3	2	0

| Weather | Neighborhood Concept D | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	0	1	1	2	7	14	0	2	1	0
Clear	56	72	77	67	76	29	81	80	76	75
Cloudy	44	12	12	16	4	57	9	12	10	8
Rain	0	14	9	14	13	0	9	6	12	17
Others	0	1	0	1	0	0	0	0	1	0
Total	9	145	1288	721	98	7	32	186	92	12

| Weather | Neighborhood Concept E | | | | | | | | | |
| | Intersection (%) | | | | | Segment (%) | | | | |
	K	A	B	C	O	K	A	B	C	O
Unknown	14	2	1	1	3	0	0	2	2	7
Clear	50	76	76	68	79	50	81	79	80	73
Cloudy	21	15	15	15	10	43	13	13	10	20
Rain	14	8	8	14	7	7	6	5	8	0
Others	0	0	1	1	0	0	0	1	0	0
Total	14	131	937	502	67	14	31	190	83	15

Weather	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	3	1	3	6	0	0	3	3	0
Clear	60	81	75	71	76	83	93	75	48	100
Cloudy	40	8	13	16	6	0	7	16	26	0
Rain	0	6	11	10	12	0	0	4	19	0
Others	0	3	1	1	0	17	0	2	3	0
Total	5	36	379	198	17	6	15	124	31	2

At intersections, the majority of crashes occurred during daylight conditions. Furthermore, the descriptive analysis revealed that fatal crashes for concept E occurred mainly under dark environments with street light. For segments of the road, most of the fatal crashes (injury level A was substantial as well) occurred under dark conditions with no streetlight (except for concept D, where the highest number of fatal crashes occurred on dark conditions with streetlight).

TABLE 28: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and light conditions

Light conditions	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	0	0	0	0	0	0	0	0
Daylight	0	100	67	68	100	0	0	31	44	0
Darkness-with street light	50	0	23	23	0	0	100	62	44	0
Darkness-no street light	0	0	2	2	0	0	0	0	11	0
Dawn	0	0	3	7	0	0	0	0	0	0
Dusk	50	0	4	0	0	0	0	8	0	0
Total	2	11	94	44	4	0	1	13	9	0

TABLE 28: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and light conditions, continued

Light conditions	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
Unknown	2	0	0	0	6	0	0	0	0	0
Daylight	44	49	58	55	75	20	34	49	56	60
Darkness-with street light	43	33	30	30	19	57	40	35	28	40
Darkness-no street light	11	6	5	6	0	17	15	7	9	0
Dawn	0	5	2	3	0	0	3	2	1	0
Dusk	0	8	5	5	0	7	8	6	7	0
Total	54	173	852	638	16	46	111	298	160	5

Light conditions	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
Unknown	0	0	0	0	0	2	0	0	0	0
Daylight	33	49	64	54	63	16	39	53	51	70
Darkness-with street light	46	28	22	28	19	24	21	19	23	10
Darkness-no street light	15	12	5	9	19	50	27	19	20	0
Dawn	2	5	3	3	0	1	1	1	1	0
Dusk	4	7	5	5	0	7	11	7	5	20
Total	48	146	588	471	16	117	148	345	193	10

TABLE 28: Statewide pedestrian crashes (2007-2014) by severity level, neighborhood concept and light conditions, continued

Light conditions	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	0	1	0	0	2	0	0	0
Daylight	44	53	60	52	71	16	42	55	43	100
Darkness-with street light	31	21	25	28	29	16	14	12	27	0
Darkness-no street light	25	19	8	8	0	56	32	22	22	0
Dawn	0	4	2	7	0	5	6	4	1	0
Dusk	0	4	5	3	0	7	5	6	6	0
Total	16	53	230	156	7	57	65	175	67	2

For bicyclist crashes, the trend was not as visible as for pedestrian crashes. Most of the crashes occurred during daylight conditions regardless the severity level. Nonetheless, it was followed by dark conditions with no street light. There was less bicyclist activity during the night since the commuting time is over and bicycle recreational activities did not tend to occur at night.

TABLE 29: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and light conditions

Light conditions	Neighborhood Concept C									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	0	0	0	0	0	0	0	0
Daylight	0	100	67	68	100	0	40	79	67	50
Darkness-with street light	50	0	23	23	0	0	40	21	33	50
Darkness-no street light	0	0	2	2	0	0	0	0	0	0
Dawn	0	0	3	7	0	0	0	0	0	0
Dusk	50	0	4	0	0	0	20	0	0	0
Total	2	11	94	44	4	0	5	14	3	2

Light conditions	Neighborhood Concept D									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	2	0	0	0	6	0	0	0	0	0
Daylight	44	49	58	55	75	20	34	49	56	60
Darkness-with street light	43	33	30	30	19	57	40	35	28	40
Darkness-no street light	11	6	5	6	0	17	15	7	9	0
Dawn	0	5	2	3	0	0	3	2	1	0
Dusk	0	8	5	5	0	7	8	6	7	0
Total	54	173	852	638	16	46	111	298	160	5

TABLE 29: Statewide bicyclist crashes (2007-2014) by severity level, neighborhood concept and light conditions, continued

Light conditions	Neighborhood Concept E									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	0	0	0	0	0	0	0	0	0
Daylight	64	82	81	76	78	57	90	80	81	87
Darkness-with street light	21	11	9	11	12	7	0	10	5	7
Darkness-no street light	0	5	2	4	0	29	6	5	6	0
Dawn	14	0	3	4	6	0	3	1	4	7
Dusk	0	3	5	5	4	7	0	4	5	0
Total	14	131	937	502	67	14	31	190	83	15

Light conditions	Neighborhood Concept F									
	Intersection (%)					Segment (%)				
	K	A	B	C	O	K	A	B	C	O
Unknown	0	2	0	1	0	0	0	0	0	0
Daylight	83	75	79	74	75	67	73	77	68	50
Darkness-with street light	0	14	10	13	0	0	0	7	6	50
Darkness-no street light	17	6	3	4	13	33	13	6	16	0
Dawn	0	2	3	3	6	0	0	3	3	0
Dusk	0	2	5	5	6	0	13	6	6	0
Total	6	64	366	183	16	6	15	124	31	2

5.5   Summary

This initial effort to examine the data helped us exploring risk factors associated to crash severity in state roads, and provided us with a preliminary understanding of how severity levels were affected by exposure. The descriptive analysis suggested that age plays an

important role in crash severity. In terms of road characteristics, arterials, 4 lane roads (2 lane roads for bicyclist crashes), and high-posted speed limit roads were potential risk factors for pedestrian and bicyclist crash severity. In terms of exposure, we started to explore neighborhood concepts as a surrogate of pedestrian and bicyclist activity levels and exposure. We found that most of the crashes occurred on concept E and F, or suburban and rural.

6 EXPOSURE ANALYSIS

One of the most challenging tasks in safety research is the analysis of crash rates but accounting for exposure. Since detailed pedestrian and bicyclist volumes are typically not available, it is necessary to account for exposure utilizing indirect methods. We have tried to control for exposure in this chapter by analyzing the impact of (VMT) and pedestrian and bicyclist volumes (by using a neighborhood concepts as a surrogate). The analysis was limited to the Oregon State Network (TransGIS database) only because it did include complete records for AADT, posted speed limit, the number of lanes, road classification and road width.

TABLE 30: Pedestrian and bicyclist crashes in Oregon

	PEDESTRIAN CRASHES IN OREGON	PEDESTRIAN CRASHES IN OREGON STATE HIGHWAYS (only at segments and intersections)	BICYCLIST CRASHES IN OREGON	BICYCIST CRASHES IN OREGON STATE HIGHWAYS (only at segments and intersections)
Total crashes	6,162	1,840	7,147	1,584
Crashes at intersections	3,629	1,088	4,702	1,045
Crashes at segments	1,822	561	864	169
Others	711	191	1481	370

The following analysis considered the percentage of crashes that took place in the Oregon State Highway Network. Crashes were categorized by posted speed limit, number of lanes, road width, and road classification. Exposure was controlled by estimating the proportion of the Oregon State Highway Network VMT (using pedestrian crashes per 10,000 AADT and highway length).

The following tables show the ratio of the percentage of crashes to the percentage of the Oregon State Highway Network length by category (e.g. AADT range). This methodology was borrowed from a research developed by the author and adviser to study pedestrian crash frequency in uncontrolled marked crosswalks (Figliozzi, Unnikrishnan, Kothuri, Caviedes, & Soto, 2017).

To control for exposure, we estimated a VMT ratio (controlled for VMT). For segments, exposure was estimated as the segment's VMT. For intersections, exposure was estimated as the VMT of the segments that cross at the junction. For any ratio that is higher than 1, the findings suggested that there was a high concentration of pedestrian or bicyclist crashes under this condition.

To a better understanding of the next tables, some values are accompanied by *, **, or defined as NA: if the percentage of crashes or the percentage of the highway network is less than 2%, the ratio is NA. If the percentage of crashes *or* the percentage of the highway network is higher than 2% and lower than 5%, the ratio value is accompanied by *. If the percentage of crashes *and* the percentage of the highway network are higher than 2% and lower than 5%, the ratio value is accompanied by **.

Equations used for the estimation of the ratio after controlling for exposure:

$$f_{ijk} = \cfrac{1}{\cfrac{10,000}{AADT_{ijk}} \; x \; l_{ijk}}$$

Factor for segment k in sub-category j and in category i.

(equation 1)

$$\forall i \in I$$
$$\forall j \in J$$
$$\forall k \in K$$

$AADT_{ij}$

AADT of segment k in sub-category j and in category i.

$i \in I$

Category analyzed (e.g. AADT)

$j \in J$

Sub-category analyzed (e.g. ADDT between 0 and 1,000)

$k \in K$

Length segment from the Oregon Highway State Network

l_{ijk}

Length (miles) of segment k in sub-category j and in category i.

$$VMT \; ratio_{ijk} = \cfrac{\cfrac{\sum_k n_{ijk}}{\sum_i \sum_j \sum_k n_{ijk}}}{\cfrac{\sum_j \sum_k f_{ijk}}{\sum_i \sum_j \sum_k f_{ijk}}}$$

Risk ratio for sub-category j and category i

(equation 2)

$n_{ij}k$

Number of pedestrian crashes in segment k for sub-category j and category i.

$$\forall i \in I$$
$$\forall j \in J$$
$$\forall k \in K$$

6.1 Posted speed limit

In terms of pedestrian crashes, TABLE 31 reveals the ratio by posted speed limit. After controlling by VMT, the findings suggested that there was a high concentration of pedestrian and bicyclist crashes in roads with a posted speed limit between 20 and 35 mph (ratio higher than 1). The risk ratio tended to decrease as speed limit increased, which can be due to the few number of observations on roads with those characteristics. Furthermore, the analysis suggested that the highest ratios were severity B, C, and O.

TABLE 31: Pedestrian crash frequency and posted speed limit exposure ratio

POSTED SPEED LIMIT (mph)	K	A	B	C	O
< 20	NA	NA	NA	NA	NA
20-35	11.06 *	11.75*	13.26*	13.02*	11.28*
35-50	3.59	4.15	3.66	3.87	3.78
50-65	0.34	0.21	0.20	0.18	0.24
> 65	NA	NA	NA	NA	NA

TABLE 32: Bicyclist crash frequency and posted speed limit exposure ratio

POSTED SPEED LIMIT (mph)	K	A	B	C	O
< 20	NA	NA	NA	NA	NA
20-35	8.95*	8.24*	11.39*	10.92*	7.49*
35-50	5.50	6.64	6.26	6.16	7.58
50-65	0.51	0.35	0.29	0.33	0.27
> 65	NA	NA	NA	NA	NA

Furthermore, the findings suggested that even if roads with a posted speed limit between 50 to 65 mph represented 62% of the Oregon Highway System, most of the pedestrian and bicyclist crashes occurred on roads with a posted speed limit between 20 to 35 mph.

TABLE 33: Proportion of road segment by posted speed limit

POSTED SPEED LIMIT	% TOTAL
<20	0.0%
20-35	2.6%
35-50	9.3%
50-65	61.8%
>65	26.4%
TOTAL (mi)	8116.11

6.2 Number of Lanes

The findings suggested that the concentration of crashes tended to increase as the number

of road lanes increased. Furthermore, most of the crashes observed occurred on 4-lane

roads, and the majority tended to be severity level K and A. For bicyclist crashes, there

was not a trend for the most serious crashes. TABLE 34 reveals that most of the fatal

crashes occurred on roads with two lanes. For the rest of the severity levels, crashes were

concentrated in 4-lane roads. Furthermore, there was a drop in the risk ratio for roads

with three lanes. These roads normally have two traffic lanes and one turning lane,

sometimes with a median included, which provides a refugee island for pedestrians and

bicyclists, resulting in less crashes.

TABLE 34: Pedestrian crash frequency and number of lanes exposure ratio

No LANES	K	A	B	C	O
1	NA	NA	0.29*	0.43*	NA
2	0.69	0.62	0.66	0.60	0.69
3	0.37	0.27	0.41	0.56	0.86
4	3.54	3.96	3.39	3.24	1.71
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA

TABLE 35: Bicyclist crash frequency and number of lanes exposure ratio

No LANES	K	A	B	C	O
1	NA	NA	0.13	0.11*	0.17
2	2.79	2.14	1.82	1.70	1.31
3	1.09	0.35	0.59	0.41	0.56
4	1.96	3.15	3.03	3.31	3.72
5	NA	NA	0.47*	0.50*	0.32*
6	NA	0.99**	NA	0.63**	NA

In is interesting to notice that there was a concentration of pedestrian and bicyclist crashes in 4 lane roads; however, they only make up 6% of the highway system. On the other hand, 2 lane roads represent 81% of the network, but pedestrian risk ratios are under 1. Bicyclist risk ratios are higher than 1 at these locations, but are lower that ratios for 4 lane roads.

TABLE 36: Proportion of road segment by number of lanes

NUMBER OF LANES	% TOTAL
1	6.5%
2	80.9%
3	6.6%
4	5.9%
5	0.1%
6	0.0%
TOTAL (mi)	8930.46

6.3   Width

Similar to the number of lanes category, we studied road width to explore a trend in the risk ratio by the size of the road. It was found that risk ratios tended to increase as road width increased. TABLE 37 suggests that 40-50 width roads had the highest ratio for pedestrian and bicyclist crashes. In terms of only bicyclist risk ratios, it is also important

to notice the high concentration of crashes in roads between 20 to 30 ft. While
pedestrians were safer in narrow roads, bicyclists were found to be at risk of fatal and
incapacitated injury crashes. Finally, 30-40 ft. roads were found to have a lower risk
ratio, which is explained by the fact that this size is commonly found in 3 lane roads.

TABLE 37: Pedestrian crash frequency and width exposure ratio

WIDTH (ft.)	K	A	B	C	O
0-10	NA	NA	NA	NA	NA
10-20	NA	NA	0.28*	0.36*	NA
20 - 30	0.65	0.52	0.55	0.51	0.58
30 - 40	0.44	0.42	0.56	0.69	0.83
40 - 50	3.12	3.49	3.10	3.01	2.30
50 - 60	NA	NA	NA	NA	NA
60 - 70	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA

TABLE 38: Bicyclist crash frequency and width exposure ratio

WIDTH (ft.)	K	A	B	C	O
0-10	NA	NA	NA	NA	NA
10-20	NA	0.13*	0.29	0.27*	0.38
20 - 30	3.78	2.30	1.84	1.75	1.63
30 - 40	0.90	0.69	1.00	0.78	0.61
40 - 50	4.74	6.41	6.31	6.82	7.27
50 - 60	NA	2.11*	2.71*	2.94*	3.52*
60 - 70	NA	0.85**	0.86**	0.74**	0.57**
> 80	NA	0.93**	NA	NA	NA

In terms of the Oregon highway network, we found that 80% of the road has a 20 to 30 ft.
width. This explained why there was a substantial concentration of bicyclist crashes at
these roads. On the other hand, most pf the pedestrian crashes occurred on 40 – 50 ft.,
roads, which only represent 6% of the network.

TABLE 39: Proportion of road segment by road width

ROAD WIDTH (ft.)	%TOTAL
0-10	0.0%
10-20	6.6%
20 - 30	79.7%
30 - 40	7.3%
40 - 50	5.6%
50 - 60	0.6%
60 - 70	0.2%
> 80	0.0%
TOTAL (mi)	8930.50

6.4 Road classification

Finally, the road classification was assessed to uncover crash patterns in Oregon. While

for most of the road classification categories the data was unreliable (after controlling for

VMT), results showed that most of the pedestrian and bicyclist crashes occurred in

principal and minor arterials. For pedestrian crashes, the trend revealed that risk ratios

were higher for fatal and severe crashes (level A) in principal arterials than any other

category. For bicyclist crashes, the risk ratio was similar across the different severity

levels; nonetheless, there is an increase of fatal and severe risk ratios in minor arterials.

TABLE 40: Pedestrian crash frequency and road classification exposure ratio

ROAD CLASSIFICATION	K	A	B	C	O
Interstate	0.18	0.09	0.11	0.10	0.31
Principal Arterial	2.60	2.60	2.53	2.61	1.90
Minor Arterial	1.42	1.71	1.68	1.48	0.85
Major collector	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA

TABLE 41: Bicyclist crash frequency and road classification exposure ratio

ROAD CLASSIFICATION	K	A	B	C	O
Interstate	0.11*	0.09*	0.08*	0.07*	0.17
Principal Arterial	3.96	3.85	3.89	3.93	4.16
Minor Arterial	1.09	1.05	0.97	0.82	0.70
Major collector	0.28*	0.22*	0.13*	0.14*	NA
Minor collector	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA

In terms of the highway network, we observed that most of the crashes occurred on principal arterials since they represent 40% of the network. Interstate and freeways also have a high percentage of segments in the network; however, the concentration of crashes is lower since pedestrians and bicyclists are not allowed to travel there.

TABLE 42: Proportion of road segment by road classification

ROAD CLASSIFICATION	%TOTAL
Interstate/Freeway	19.6%
Principal Arterial	38.9%
Minor Arterial	23.0%
Rural collector	15.9%
Urban collector	0.8%
Local	1.8%
TOTAL (mi)	8926.82

6.5   Neighborhood Concepts

This section discusses the concentration of crashes by neighborhood concepts. Most of the pedestrian and bicyclist crashes that occurred on the Oregon State Highway were located in areas D, E and F. This analysis was performed to control for pedestrian and bicyclist activity (exposure), since the neighborhood concepts account for population density and employment entropy. Additionally, we considered crashes at intersections

versus segments to have a better understanding of crash severity. Overall, the findings

suggested that most of the fatal and severe crashes occurred on concepts E and F, which

are mainly suburban and rural areas. After controlling by VMT, these areas revealed high

risk ratios for levels K and A, which can be explained by the high speed vehicles and lack

of control devices. Furthermore, similar to the findings in section 3 and 4, the findings

suggested that for pedestrians, most of the crashes were concentrated in segments, while

for bicyclists, crashes were mainly at intersections. Table 43 shows a summary of the

main findings. For more detail on risk ratio, please refer to the referenced tables.

TABLE 43: Crash frequency and neighborhood concept exposure ratio summary

VAR.	TYPE OF CRASH	NEIGH. CON. D	NEIGH. CON. E	NEIGH. CON. F	REF. TABLE
PSL	PED.	Crashes were concentrated in 35-50 mph speed limit roads. At intersections, highest risk ratios occurred in 20-35 mph roads. At segments, most dangerous roads had a 35-50 mph speed limit.	Crashes were concentrated in 20-35 mph speed limit roads. Intersections with 35-50 mph posted speed limits had the highest risk ratios.	The majority of the observations occurred on 35-50 mph roads. While at intersections most of the crashes were PDO, in segments were fatal or severe.	TABLE 61 TABLE 62 TABLE 63
	BICYCLIST	Most of the crashes occurred on roads with a speed limit between 20 to 50 mph. Risk ratios were found to be higher for segments than for intersections.	Crashes were concentrated on 20 to 35 mph limit roads. Crashes tended to be fatal and severe for segments and intersections.	Crashes were concentrated on 20 to 35 mph limit roads. While at intersections most of the crashes were PDO, in segments were fatal or severe.	TABLE 73 TABLE 74 TABLE 75

TABLE 43: Crash frequency and neighborhood concept exposure ratio summary, continued

VAR.	TYPE OF CRASH	NEIGH. CON. D	NEIGH. CON. E	NEIGH. CON. F	REF. TABLE
WIDTH	PED.	Risk ratio increased as road width increased. Most of the crashes were concentrated on 50-60 road segments, and most of them were fatal or severe.	Risk ratio increased as road width increased. Risk ratios remained constant between segments and intersections.	Risk ratio increased as road width increased. 45-50 ft. roads had the highest risk ratios. At intersections, the highest risk ratio was for level O, while for segments it was level K.	TABLE 64 TABLE 65 TABLE 66
	BIC.	Risk ratio increased as road width increased. At intersections, most of the severe crashes were concentrated in 50-60 ft. roads. For the segment case, high-risk ratios occurred in 40 to 50 ft. roads.	Risk ratio increased as road width increased. Similar trends for intersections and segments. Most of the crashes occurred on 40 to 50 ft. roads.	Risk ratio increased as road width increased. Most of the crashes occurred on 40 to 50 ft. roads. Intersections had more PDO crashes than segments.	TABLE 76 TABLE 77 TABLE 78
NUMBER OF LANES	PED.	Risk ratio increased as number of lanes increased. Highest risk ratios occurred in 4 lane roads. Furthermore, segments were more dangerous than intersections.	Risk ratio increased as number of lanes increased. Most of the crashes were concentrated at intersections with 4 lanes.	Risk ratio increased as number of lanes increased. Similar to the other concepts, highest risk ratios were on 4 lane roads. At intersections, the highest risk ratio was for level O, while for segments it was level K.	TABLE 67 TABLE 68 TABLE 69

TABLE 43: Crash frequency and neighborhood concept exposure ratio summary, continued

VAR.	TYPE OF CRASH	NEIGH. CON. D	NEIGH. CON. E	NEIGH. CON. F	REF. TABLE
NUMBER OF LANES	BIC.	Risk ratio increased as number of lanes increased. Four lane roads had the highest risk ratios.	Risk ratio increased as number of lanes increased. Four lane roads had the highest risk ratios. There were more fatal crashes at intersections than in segments.	Risk ratio increased as number of lanes increased. Most of the crashes occurred on four lane roads, specifically at intersections.	TABLE 79 TABLE 80 TABLE 81
ROAD CLASS.	PED.	Most of the crashes occurred on principal and minor arterials. The trend of risk ratios was similar between intersections and segments.	Most of the crashes occurred on principal and minor arterials. The trend of risk ratios was similar between intersections and segments.	Most of the crashes occurred on principal and minor arterials. Segments had higher risk rations than intersections.	TABLE 70 TABLE 71 TABLE 72
	BIC.	Most of the crashes occurred on principal and minor arterials. Intersections had higher concentrations of crashes than segments.	Most of the crashes occurred on principal and minor arterials. Most of the fatal crashes occurred on segments.	Most of the crashes occurred on principal and minor arterials. Intersections had higher concentrations of crashes than segments.	TABLE 82 TABLE 83 TABLE 84

Risk ratios were higher in rural areas (concepts E and F), which can be explained by the

high percentage of segments that go through these land uses.

TABLE 44: Proportion of road segment by neighborhood concepts

NEIGH. CONCEPT	%TOTAL
D	3.0%
E	60.4%
F	36.6%
TOTAL (mi)	8116.11

6.6   Summary

This section presented the findings of a crash analysis after trying to account for exposure based on VMT and land use (neighborhood concepts). These results reinforced some of the findings of the literature review and provided a preliminary indication of the potential variables that increased severity levels. Furthermore, in terms of the research questions, we found that exposure allowed us to identify how road characteristics affect crash severity, even after controlling for traffic exposure (VMT) and vulnerable user activity (land use=neighborhood concepts).

TABLE 45: Exposure analysis summary

TYPE	VARIABLE	FINDINGS	
		PEDESTRIAN CRASHES	BICYCLIST CRASHES
ROAD CHARACTERISTICS	POSTED SPEED LIMIT	The highest risk ratio was for roads with a posted speed limit between 20 to 35 mph.	The highest risk ratio was for roads with a posted speed limit between 20 to 35 mph.
	NUMBER OF LANES	Fatal crashes were concentrated in 4 lane roads. Severity increased as number of lanes increased.	Fatal and severe crashes were concentrated in 2 lane roads. Severity increased as number of lanes increased.
	WIDTH	Road widths between 40 and 50 ft. had the highest risk ratio. Severity increased as road width increased.	Road widths between 40 and 50 ft. had the highest risk ratio. Severity increased as road width increased; however, most of the crashes were level O.
	ROAD CLASSIFICATION	Most of the crashes were concentrated in arterials.	Most of the crashes were concentrated in arterials. Risk ratios for fatal and severe crashes were higher than for pedestrian crashes.
LAND USE	NEIGHBORHOOD CONCEPTS	Most of the crashes were concentrated in concepts E and F. There were more fatal and severe crashes for segments than for intersections.	Similar to pedestrians, crashes were concentrated in suburban and rural areas. More crashes occurred at intersections.

7   DATA ANALYSIS AND RESULTS

After identifying potential risk factors and trends in the descriptive and exposure analysis, the next chapters are going to be focused on statistical methodologies to predict pedestrian and bicyclist crash severity in terms of risk factors. The database contained a total of 13,309 crashes, where 6,162 involved pedestrians and 7,147 involved people riding a bicycle. Since this study was targeted to ODOT's facilities, only crashes that fell in the ODOT highway network were analyzed in this section (1,649 pedestrian crashes and 1,214 bicyclist crashes). Furthermore, we dropped observations that were not useful in this study (i.e. crashes at interstates), resulting in 1,535 pedestrian crashes and 1,000 bicyclist observations.

Most of the studies reviewed have explored crashes using methodologies that took into consideration the categorical and ordinal nature of severity. Based on these examples and the crash severity modelling review by Savolainen et al. (2011), an ordinal regression methodology was chosen. The ordinal regression is a statistical tool to predict an ordinal dependent variable (e.g. severity level) in terms of other independent variables. The parameters estimated in the model represent the log of the odds that an event occurs. For example, the odds that a fatal crash occurs is the ratio of the probability of a fatal crash to the probability of a non-fatal crash. The ordinal logistic regression model results presented in this section were estimated with the use of the R package ordinal (Christensen, n.d.) and MASS (Ripley, et al., n.d.).

The variables explored in the models are summarized in TABLE 46: 11% of pedestrian crashes were reported as fatal, while 16% incapacitated injury. For bicyclist crashes, only 2% were fatal, while 7% were reported as incapacitated injury. While some

risk factors such as age and posted speed limit (for pedestrian crashes) showed an

increase in severity as the variable increased, most of the factors did not show a pattern.

It should be noted that for the estimation of the models, some non-significant levels were

used as part of the base group.

TABLE 46: Distribution (%) of risk factors for different severity levels

CATEGORY	VARIABLE	n PED. CRASHES	n BIC. CRASHES	PED. CRASHES (%)					BIC. CRASHES (%)				
				K	A	B	C	O	K	A	B	C	O
Location charac.	Location												
	Segment	1039	867	5.3	13.1	46.1	34.8	0.7	1.0	6.1	57.7	31.9	3.2
	Intersection	496	133	20.0	21.4	36.3	21.8	0.6	7.5	12.8	57.1	21.1	1.5
	Land Use												
	Concept C	602	372	6.0	14.6	45.8	33.1	0.5	0.8	6.7	60.2	29.6	2.7
	Concept D	724	487	12.4	16.9	40.1	29.8	0.8	2.9	7.4	55.0	30.8	3.9
	Concept F	209	141	13.4	15.3	44.5	26.3	0.5	1.4	6.4	59.6	31.9	0.7
Environmental charac.	Season												
	Summer	284	361	9.9	14.8	46.8	27.8	0.7	1.1	6.4	60.7	28.3	3.6
	Fall	270	210	11.9	15.6	46.7	25.2	0.7	3.3	6.7	56.7	30.5	2.9
	Winter	662	203	11.2	14.5	38.4	35.3	0.6	2.0	10.3	51.2	34.0	2.5
	Spring	319	226	6.3	19.4	45.8	27.9	0.6	1.8	5.3	59.3	31.0	2.7
	Day of the week												
	Monday	137	77	14.6	15.3	46.7	23.4	0.0	2.6	5.2	62.3	26.0	3.9
	Tuesday	247	167	10.9	17.8	39.3	31.6	0.4	0.0	9.6	53.9	33.5	3.0
	Wednesday	219	162	6.4	16.4	42.0	34.7	0.5	1.9	5.6	58.0	32.7	1.9
	Thursday	235	164	9.8	11.9	45.1	32.3	0.9	1.8	4.3	58.5	28.7	6.7
	Friday	225	161	8.4	17.3	45.8	28.4	0.0	1.9	9.3	59.0	29.2	0.6
	Saturday	284	145	9.2	13.0	45.4	31.3	1.1	1.4	5.5	60.7	31.0	1.4
	Sunday	188	124	13.3	19.7	36.2	29.3	1.6	4.8	8.9	52.4	29.8	4.0

TABLE 46: Distribution (%) of risk factors for different severity levels, continued

Time of the day											
Morning peak hour (6-9 am)	162	139	7.4	11.1	48.1	33.3	0.0	0.7	7.9	57.6	33.1	0.7
Evening peak hour (4-7 pm)	537	308	9.7	15.6	42.6	31.1	0.9	1.3	8.1	60.4	28.2	1.9
Rest of the day	836	553	10.8	16.7	42.1	29.8	0.6	2.5	6.1	56.1	31.1	4.2
Weather											
Clear day	856	749	9.9	13.8	45.0	30.5	0.8	1.5	7.2	58.9	29.8	2.7
Bad conditions (i.e. rain)	679	251	10.2	18.3	40.4	30.8	0.4	3.2	6.4	53.8	32.7	4.0
Light conditions											
Daylight	775	786	5.0	12.9	47.6	33.5	0.9	1.9	6.5	59.2	29.3	3.2
Darkness with street light	410	113	10.5	16.8	40.2	32.0	0.5	1.8	9.7	54.9	30.1	3.5
Darkness no street light	228	42	27.6	22.4	29.4	20.2	0.4	4.8	11.9	54.8	28.6	0.0
Twilight	122	59	7.4	18.0	47.5	27.0	0.0	0.0	5.1	44.1	49.2	1.7

Crash charac.

Pedestrian/Bicyclist location during the crash											
Crosswalk	1042	423	5.2	13.2	45.8	35.1	0.7	0.9	5.7	58.2	33.1	2.1
Roadway	452	541	21.9	21.9	36.5	19.0	0.7	2.8	7.9	57.7	27.9	3.7
Midblock	41	0	2.4	12.2	41.5	43.9	0.0	NA	NA	NA	NA	NA
Bike lane	0	36	NA	NA	NA	NA	NA	0.0	8.3	50.0	38.9	2.8
Alcohol intoxication											
Yes	1292	961	7.1	14.0	44.6	33.5	0.8	1.9	6.5	57.9	30.7	3.1
No	243	39	25.5	25.1	34.2	15.2	0.0	2.6	20.5	51.3	25.6	0.0

TABLE 46: Distribution (%) of risk factors for different severity levels, continued

	Motor vehicle movement												
	Straight	893	393	14.7	21.4	40.1	23.1	0.8	4.6	11.2	57.0	23.7	3.6
	Turning	642	607	3.6	7.9	46.9	41.1	0.5	0.2	4.3	58.0	34.9	2.6
	Vehicle type												
	Passenger vehicle	1496	989	9.6	15.8	43.0	30.9	0.7	1.6	7.0	57.9	30.4	3.0
	Truck and buses	39	11	28.2	15.4	38.5	17.9	0.0	27.3	9.1	27.3	36.4	0.0
Demographic charac.	Age												
	<=54	1188	856	7.6	15.8	43.4	32.3	0.8	1.3	6.3	56.8	32.2	3.4
	55-74	273	127	14.3	15.4	42.5	27.8	0.0	3.9	8.7	65.4	21.3	0.8
	>74	74	17	33.8	16.2	36.5	13.5	0.0	17.6	29.4	41.2	11.8	0.0
	Gender												
	Male	909	754	12.3	16.6	40.5	30.1	0.4	2.0	6.8	57.4	30.6	3.2
	Female	626	246	6.7	14.5	46.5	31.3	1.0	1.6	7.7	58.1	30.1	2.4
Traffic conditions	AADT												
	0-5,000	88	70	9.1	17.0	46.6	27.3	0.0	5.7	11.4	57.1	25.7	0.0
	5,000-20,000	830	536	11.6	15.2	42.8	29.6	0.8	1.5	6.3	59.3	30.4	2.4
	20,000-50,000	613	388	8.0	16.3	42.6	32.6	0.5	1.8	7.2	55.2	31.4	4.4
	>50,000	4	6	25.0	25.0	50.0	0.0	0.0	0.0	0.0	66.7	33.3	0.0
	AADT (only trucks)												
	0-1,500	1107	716	10.6	14.8	41.8	32.2	0.6	1.8	7.3	59.8	28.5	2.7
	1,500-5,000	418	271	8.9	18.2	45.7	26.6	0.7	2.2	6.3	51.7	35.8	4.1
	5,000-7,500	9	8	0.0	22.2	44.4	33.3	0.0	0.0	12.5	62.5	25.0	0.0
	>7,500	1	5	0.0	0.0	100.0	0.0	0.0	0.0	0.0	60.0	40. 0	0.0

TABLE 46: Distribution (%) of risk factors for different severity levels, continued

Road charac.

Number of lanes												
1	26	40	0.0	3.8	53.8	42.3	0.0	0.0	2.5	60.0	37.5	0.0
2	513	341	10.1	15.0	44.2	29.6	1.0	2.9	8.8	57.8	28.4	2.1
3	139	86	5.8	11.5	39.6	41.7	1.4	2.3	3.5	67.4	20.9	5.8
4	812	500	11.2	17.7	42.2	28.6	0.2	1.4	6.8	54.8	33.4	3.6
5	36	24	5.6	5.6	52.8	33.3	2.8	0.0	0.0	70.8	29.2	0.0
6	9	13	11.1	22.2	11.1	55.6	0.0	0.0	15.4	46.2	38.5	0.0
Width												
0-10												
10-20	24	38	0.0	4.2	58.3	37.5	0.0	0.0	2.6	57.9	39.5	0.0
20-30	420	285	11.7	15.0	42.9	29.3	1.2	3.5	9.1	56.1	28.8	2.5
30-40	192	114	5.2	12.5	42.2	39.6	0.5	0.0	6.1	68.4	23.7	1.8
40-50	680	448	10.9	17.5	42.2	29.0	0.4	2.0	6.5	55.1	32.6	3.8
50-60	175	84	10.9	16.6	45.1	27.4	0.0	0.0	6.0	58.3	31.0	4.8
60-70	36	26	5.6	11.1	47.2	33.3	2.8	0.0	3.8	73.1	23.1	0.0
>70	8	5	0.0	25.0	12.5	62.5	0.0	0.0	20.0	20.0	60.0	0.0
Road classification												
Arterials	1438	913	10.6	15.9	42.6	30.5	0.5	0.0	0.0	0.0	0.0	0.0
Collectors	53	44	1.9	13.2	56.6	24.5	3.8	38.6	145.5	1204.5	625.0	61.4
Local streets	44	43	0.0	15.9	38.6	43.2	2.3	4.7	7.0	58.1	30.2	2.3
Road surface												
Dry	1075	862	10.2	16.5	44.1	28.5	0.7	2.0	7.1	59.4	28.8	2.8
Wet	460	138	9.6	14.1	40.2	35.7	0.4	1.4	6.5	46.4	41.3	4.3

TABLE 46: Distribution (%) of risk factors for different severity levels, continued

Traffic control device												
Other devices	1492	992	10.2	15.9	42.2	31.0	0.7	0.0	0.0	87.5	12.5	0.0
Pedestrian signal	43	8	4.7	11.6	67.4	16.3	0.0	1.9	7.1	57.4	30.6	3.0
Posted speed limit												
<=20	55	26	1.8	5.5	50.9	38.2	3.6	0.0	0.0	69.2	30.8	0.0
20-35	1032	616	6.5	14.6	44.7	33.7	0.5	1.0	5.4	60.4	29.7	3.6
35-50	316	239	19.6	18.4	38.0	23.4	0.6	2.9	10.0	54.0	30.5	2.5
50-65	131	114	18.3	22.1	38.2	20.6	0.8	5.3	10.5	47.4	35.1	1.8
>=65	1	5	0.0	100.0	0.0	0.0	0.0	0.0	20.0	60.0	20.0	0.0

NA=Not applicable

7.1 Single variable models

As a preliminary exploratory analysis, we conducted an ordinal regression model to explore KABCO levels by each independent variable. The next sections present the results in terms of odds.

7.1.1 Location characteristics

In terms of the location of the crash, the findings suggested that the odds of fatal crashes were higher in segments than at intersections. This is true for pedestrian and bicyclist crashes. Furthermore, TABLE 47 reveals that pedestrian and bicyclist crashes that occurred in suburban and rural areas (concept E and F), tended to increase the odds of a fatal outcome. For bicyclist crashes, we did not find a statistical difference in concept F and E, versus concept D.

TABLE 47: Single variable model – location characteristics (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	Location	Intersection	Segment	2.62	2.15	3.21	0.00
	Land Use	Concept D	Concept E	1.28	1.05	1.57	0.01
			Concept F	1.46	1.10	1.93	0.00
Bic.	Location	Intersection	Segment	2.06	1.47	2.89	0.00
	Land Use	Concept D	Concept E	1.09	0.85	1.38	0.51
			Concept F	1.07	0.75	1.51	0.72

7.1.2 Environmental conditions

The findings did not suggest significant differences in terms of season. In terms of day of the week and vulnerable user crashes, the findings did not suggest a statistical

relationship with severity. On the other hand, time of the day showed some significant differences. Pedestrian crashes during morning peak hours tended to be less severe than crashes that occurred during non-peak hours. The high traffic volumes in peak hour resulted in vehicles traveling at lower speeds, which ended up reducing severity when a crash occurred.

Considering weather conditions, the results showed that cloudy days increased the severity of crashes. On the other hand, rainy days decreased it at a significant level (for both pedestrian and bicyclist crashes); however, the finding is non-significant. This last finding suggested that drivers may tend to travel at lower speeds when it is raining, which results in less severe crashes.

Finally, the results for light conditions only showed a significant association for pedestrian crashes. Crashes that occurred during dark light conditions tended to be more severe.

TABLE 48: Single variable model – environmental conditions (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	Season	Summer	Fall	1.01	0.76	1.38	0.93
			Winter	0.78	0.61	1.01	0.06
			Spring	0.90	0.67	1.20	0.48
	Day of the week	Sunday	Monday	1.10	0.73	1.65	0.64
			Tuesday	0.83	0.58	1.18	0.30
			Wednesday	0.72	0.51	1.04	0.08
			Thursday	0.75	0.53	1.07	0.11
			Friday	0.91	0.63	1.30	0.59
			Saturday	0.76	0.53	1.06	0.10

TABLE 48: Single variable model – environmental conditions (odd ratios), continued

	Time of the day	Rest of the day	Morning peak hour (6-9 a.m.)	0.74	0.56	0.99	0.04
			Evening peak hour (4-7 p.m.)	0.96	0.78	1.18	0.71
	Weather cond.	Clear day	Cloudy	1.44	1.14	1.84	0.00
			Rain	0.82	0.65	1.03	0.09
	Light cond.	Daylight	Darkness with street lights	1.33	1.06	1.65	0.01
			Darkness with no street light	3.05	2.30	4.05	0.00
			Dawn twilight	1.33	0.73	2.42	0.50
			Dusk twilight	1.63	1.09	2.45	0.01
Bic.	Season	Summer	Fall	0.98	0.71	1.33	0.87
			Winter	0.96	0.70	1.31	0.78
			Spring	0.92	0.68	1.24	0.58
	Day of the week	Sunday	Monday	0.93	0.56	1.59	0.78
			Tuesday	0.79	0.52	1.26	0.31
			Wednesday	0.77	0.50	1.49	0.24
			Thursday	0.82	0.54	1.27	0.39
			Friday	0.97	0.63	1.49	0.89
			Saturday	0.85	0.55	1.32	0.48
	Time of the day	Rest of the day	Morning peak hour (6-9 a.m.)	1.23	0.88	1.72	0.23
			Evening peak hour (4-7 p.m.)	1.16	0.91	1.49	0.24
	Weather cond.	Clear day	Cloudy	1.06	0.77	1.45	0.71
			Rain	0.66	0.44	0.98	0.04

TABLE 48: Single variable model – environmental conditions (odd ratios), continued

Light cond.	Daylight	Darkness with street lights	0.93	0.65	1.34	0.70
		Darkness with no street light	1.41	0.78	2.56	0.25
		Dawn twilight	0.50	0.22	1.14	0.09
		Dusk twilight	0.76	0.45	1.30	0.32

7.1.3 Crash characteristics

Four variables were considered for crash characteristics: location during the crash, alcohol intoxication, vehicle movement, and vehicle type.

The findings suggested that pedestrian crashes that were outside the crosswalk tended to be more severe than crashes that occurred in the crosswalk. In terms of alcohol intoxication, the results are intuitive as well. Pedestrian and bicyclist crashes caused by an impaired driver tended to increase the odds of a severe crash.

In terms of vehicles movements, crashes caused by a vehicle moving straight had higher odds to be fatal than crashes caused by vehicles turning. These results were significant for the pedestrian and bicyclist models. Furthermore, heavy vehicles (i.e. trucks and buses) tended to increase the odds of fatal pedestrian and bicyclist crashes.

TABLE 49: Single variable model – crash characteristics (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	Loc. during the crash	crosswalk	At intersection-outside crosswalk	1.90	1.22	2.95	0.00
			At intersection-in roadway	1.71	1.17	2.51	0.01
			Not at intersection-in roadway	3.72	2.98	4.65	0.00
			On shoulder	2.00	1.19	3.35	0.01
			Beyond shoulder, but within traffic way	2.03	1.03	3.98	0.04
			On sidewalk	1.26	0.50	3.19	0.60
			Outside traffic boundaries	1.66	0.74	3.76	0.20
			Inside midblock crossing	0.69	0.31	1.51	0.40
	Alcohol Intox.	No	Yes	4.37	3.38	5.65	0.00
	Vehicle mov.	Straight	Turning right	0.30	0.24	0.39	0.00
			Turning left	0.34	0.27	0.42	0.00
			Stopped in traffic	0.58	0.24	1.41	0.20
			Parked properly	0.34	0.18	0.62	0.00
	Vehicle type	Passenger vehicle	Trucks and buses	2.85	1.70	4.79	0.00

Bic.	Loc. during the crash	crosswalk	At intersection-outside crosswalk	1.14	0.86	1.51	0.36
			At intersection-in roadway	0.79	0.54	1.14	0.21
			Not at intersection-in roadway	1.92	1.23	2.98	0.00
			On shoulder	7.53	3.32	17.0	0.00
			Beyond shoulder, but within traffic way	0.97	0.41	2.33	0.95
			In bike path or parking lane	0.90	0.43	1.89	0.79
			In bike lane	0.53	0.18	1.51	0.23
	Alcohol Intox.	No	Yes	2.92	1.65	5.16	0.00
	Vehicle mov.	Straight	Turning right	0.47	0.37	0.61	0.00
			Turning left	0.49	0.35	0.67	0.00
			Stopped in traffic	0.25	0.13	0.48	0.00
	Vehicle type	Passenger vehicle	Trucks and buses	3.28	1.12	9.63	0.03

7.1.4 Demographic characteristics

In the event of a crash, (>55) older pedestrians and bicyclists tended to have a higher

probability of getting involved in a fatal crash (p-value < 0.05). In terms of gender, the

findings suggested that male pedestrians had higher odds of being in a fatal crash than

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women at a significant level. For the bicyclist model there was not a statistically

significant difference.

TABLE 50: Single variable model – demographic characteristics (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	Age	0-14	15-24	1.17	0.87	1.58	0.30
			25-34	1.25	0.89	1.74	0.20
			35-44	1.22	0.86	1.72	0.30
			45-54	1.77	1.28	2.46	0.00
			55-64	1.56	1.09	2.23	0.02
			65-74	1.90	1.25	2.87	0.00
			75-84	3.59	2.10	6.16	0.00
			>84	3.70	1.57	8.69	0.00
	Gender	Male	Female	0.78	0.65	0.93	0.01
Bic.	Age	0-14	15-24	1.32	0.93	1.88	0.12
			25-34	1.45	0.99	2.10	0.05
			35-44	1.27	0.85	1.90	0.25
			45-54	1.38	0.94	2.03	0.10
			55-64	2.11	1.31	3.39	0.00
			65-74	2.99	1.60	5.60	0.00
			75-84	10.11	3.72	27.4	0.00
			>84	33.85	1.62	707.	0.02
	Gender	Female	Male	1.03	0.80	1.34	0.81

7.1.5 Traffic conditions

AADT was the only variable available to assess traffic conditions. The results suggested

that only AADT for trucks was significant for pedestrian crashes. As truck AADT

increased, the odds of a fatal crash increased as well. This result is associated with heavy

vehicles, which can cause fatal or severe injuries even if travelling at slow speeds.

In terms of the bicyclist model, the results revealed that AADT decreased the

severity of the crashes. Since in this case this variable includes all kind of vehicles, the

results make sense. High volumes resulted in less vehicles traveling at higher speeds.

TABLE 51: Single variable model – traffic conditions (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	Traf. cond.	NA	AADT	0.99	0.91	1.09	0.93
			log (AADT)	0.95	0.83	1.09	0.47
		NA	AADT(only truck)	1.00	0.99	1.00	0.12
			log (AADT truck)	1.18	1.04	1.34	0.01
Bic.	Traf. cond.	NA	AADT	0.88	0.79	0.98	0.02
			log (AADT)	0.82	0.71	0.94	0.00
		NA	AADT(only truck)	1.00	1.00	1.00	0.60
			log (AADT truck)	0.86	0.75	0.98	0.29

7.1.6   Road characteristics

To assess road characteristics we considered number of lanes, width, road classification,

road surface, traffic control device and posted speed limit.

Nor number of lanes or road width showed a significant difference for pedestrian and

bicyclist crashes. Nonetheless, in terms of road classification (which can be a surrogate

for number of lanes), the results revealed that crashes that occurred on arterials were

more severe than pedestrian crashes on local streets.

In terms of road surface, the findings suggested that wet road surfaces decreased

severity levels compared to dry surfaces. This results is counterintuitive and may be

produced by its correlation with weather conditions, which is assessed in section 7.2. In

terms of traffic control device, we compared pedestrian crashes based on special

pedestrian signal to other devices. Results are not significant; however, they showed that

the presence of traffic control devices (e.g. medians, traffic signal, or RRFB increased the severity of the crashes. For bicyclist crashes, we compared the presence of control versus no control, but the results are not statistically significant. Finally, pedestrian crash severity increased as posted speed limit increased at a significant level.

TABLE 52: Single variable model – road characteristics (odd ratios)

	VAR.	BASE GROUP	LEVEL	MEAN	95% C.I.		P-VALUE
Ped.	# of lanes	NA	# of lanes	1.07	0.98	1.17	0.15
	Width	NA	Width (ft.)	1.00	0.99	1.01	0.26
	Road class.	Principal Arterials	Minor arterial	1.05	0.80	1.37	0.72
			Rural collector	1.20	0.55	2.64	0.64
			Urban collector	0.78	0.43	1.42	0.42
			Local	0.51	0.29	0.89	0.01
	Road surface	Dry	Wet	0.77	0.63	0.95	0.01
			Snow	0.39	0.14	1.13	0.08
	Traffic control device	Others	Special pedestrian signal	1.17	0.70	1.97	0.55
	PSL	NA	(mph)	1.04	1.03	1.05	0.00
			(mph²)	1.00	1.00	1.00	0.00

TABLE 52: Single variable model – road characteristics (odd ratios), continued

Bic.	# of lanes	NA	# of lanes	0.91	0.82	1.01	0.07
	Width	NA	Width (ft.)	0.99	0.98	1.00	0.12
	Road class.	Principal Arterials	Minor arterial	1.17	0.86	1.61	0.32
			Rural collector	1.23	0.51	2.96	0.64
			Urban collector	0.89	0.46	1.73	0.74
			Local	0.74	0.43	1.27	0.28
	Road surface	Dry	Wet	0.63	0.45	0.85	0.00
	Traffic control device	Others	Traffic control device	1.00	0.63	1.16	1.00
	PSL	NA	(mph)	1.01	0.99	1.02	0.31
			(mph²)	1.00	1.00	1.00	0.36

7.2 Pooled models

Pooled models, i.e. with several variables by category (TABLE 55), were used to identify the key risk factors of crash severity. The final models were selected by using the backwards stepwise method based on the Akaike Information Criterion AIC (a forward stepwise was also used, but the final variables were the same). Once the key risk factors were identified, we dropped the ones that were not significant and included them in the base group category. A   Additionally, we did not include the observations of interstate and freeways, since pedestrians and bicyclists are not allowed to be in these facilities. Furthermore, we interacted factors that were correlated for a better model estimation and interpretation. Finally, we tested for the proportional odds assumption to assess the models. For the pedestrian model, we found that posted speed limit and AADT

(only truck) did not pass the test. We classified the speed variable into two categories, <50 mph and ≥ 50mph. For AADT (only truck) we created two categories using the 25% percentile of the variable distribution as the cut-point (TABLE 53) to differentiate between low and high heavy vehicle volume. By doing this, the proportional odds test was met. Final models are shown in TABLE 55 (for more detail see (TABLE 85). Parameters are in log odds units. Additionally, odd ratios were estimated for a better interpretation of the results (FIGURE 6).

TABLE 53: AADT only trucks cut-points

AADT only trucks (cut-points)	Observations
≤670	390
>670	1145

For the pedestrian model, the findings suggested that age, followed by alcohol intoxication, had the biggest impact on crash severity prediction. In a crash event, older pedestrians were at a higher risk than young pedestrians (p-value<0.001). The odds of a fatal (K) crash involving a person older than 74 versus the other severity levels combined, were 4.91 times that of young pedestrians (p-value<0.001) given that all the other variables in the model remain constant. For pedestrians between 55 and 74, the odds were 1.64 greater. If a crash involves an alcohol intoxicated driver, the odds of a fatal (K) crash versus the other severity levels combined were 2.48 times that of sober drivers, ceteris paribus (p-value<0.001).

In terms of environmental conditions, only light condition was included in the model due to its statistical significant level. We separated darkness with no streetlight from the other lighting conditions. The findings suggested that if a crash occurs in dark

conditions with no streetlights, the odds of a fatal (K) crash versus the other severity levels combined were 1.95 times that of other lighting conditions (p-value<0.001).

Crash characteristics were also significant predictors of severity. The odds of a fatal crash where a truck (or bus) was involved were 2.48 times that of passenger vehicles (p-value<0.001). Furthermore, the odds of a fatal crash where a vehicle was turning were 0.49 times that of a vehicle travelling straight (p-value<0.001). Vehicles turning tend to decrease their speed, which result in less severe crashes.

Considering road characteristics, we found that local streets, special pedestrian traffic control device and posted speed limits were statistically significant. The odds of a fatal crash in a local street were half that of a crash in arterials (p-value<0.05). High-posted speed limits tended to increase crash severity as well. The odds of a fatal (K) crash versus the other severity levels combined in a ≥ 50 mph road were 1.60 times that of <50 mph roads.

In terms of traffic conditions, the findings suggested that AADT for trucks was a statistically significant predictor for crash severity. The odds of a fatal crash in a road with an AADT (only trucks) higher than 670 heavy vehicles were 1.36 times that of a road with an AADT below 670 heavy vehicles.

Traffic control device indicates the predominant control present at the crash location. If more than one control was present, the crash recorder chose the device that was more related to the crash. We explored different devices and found that the presence of traffic control devices (i.e. Rectangular Rapid Flash Beacon-RRFB, median, traffic signal) was significant in the pooled model. The findings suggested that the odds of a crash where a control device was present, was 2.07 times that of other control devices.

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This result must be taken with caution because it must be the result of poor data quality (incorrect coding). Special pedestrian signals such as RRFBs have been found to reduce crash frequency (Monsere, Figliozzi, Kothuri, Razmpa, & Hazel, 2016). Monsere et al. (2016) identified a trend in the reduction of severity of pedestrian crashes after the installation of several crosswalk treatments (RRFB, flashing amber, high visibility and standard parallel crossings); a shift from level K and A, to B and C.

We found several potential explanations for our finding. First, the installation of these devices may increase the pedestrian volume, increasing crash frequency. Furthermore, these special signals are normally installed at locations with high crash frequency, which can reduce crash frequency but may not have an impact on severity when a crash occurs. Finally, pedestrians may feel more confident that incoming traffic would yield to pedestrians if for example an RRFB has been activated or a median is present. Another reason for the significance of this variable was also found on how this factor is recorded in the crash database. At the time of filling out the crash report, there are not enough instructions on what is a special pedestrian signal, which may cause errors in the report.

Finally, an interaction variable between weather and road surface conditions was added due to the correlation between the two variables (i.e. wet road conditions and rainy day). The odds of a fatal crash on a wet road during a clear day were 1.54 that of other weather and road surface conditions.

Location, vehicle movement, age, alcohol intoxication, AADT, and light conditions were significant in the crash model for bicyclists. The AADT did not meet the proportion odds assumption, for this reason we transformed this variable into categorical.

Tot try to capture roads with low and high volume, we used the 25% percentile of the

AADT distribution as the cut-point (10,000 vehicles). See TABLE 54 for more detail.

Doing this allowed us to meet the assumption.

TABLE 54: AADT cut-points

AADT only trucks (cut-points)	Observations
≤10,000	222
>10,000	778

The odds of a fatal crash in a roadway segment versus the other severity levels

combined were 1.77 times that of a crash at an intersection. For crash characteristics the

results were similar to the pedestrian model, vehicles turning tended to be less severe

than crashes with vehicles going straight (odds of 0.66, p-value<0.01).

In terms of age, The odds of a fatal (K) crash involving a person older than 74

versus the other severity levels combined, were 9.29 times that of young pedestrians (p-

value<0.001) given that all the other variables in the model remain constant. For

pedestrians between 55 and 74, the odds were 1.91 greater.

The result for AADT was intuitive, more cars were found to decrease the

likelihood of a crash being fatal. High volumes may result in a high crash frequency but

less fatal and severe crashes since vehicles are not travelling fast. The odds of a fatal

crash in a road with an AADT above 10,000 vehicles per day were 0.74 that of roads

below 10,000 vehicles.

Alcohol intoxication was only significant at the 0.1 level, for this reason we

explored this variable in terms of others, such as light conditions. Lee and Abdel-Aty

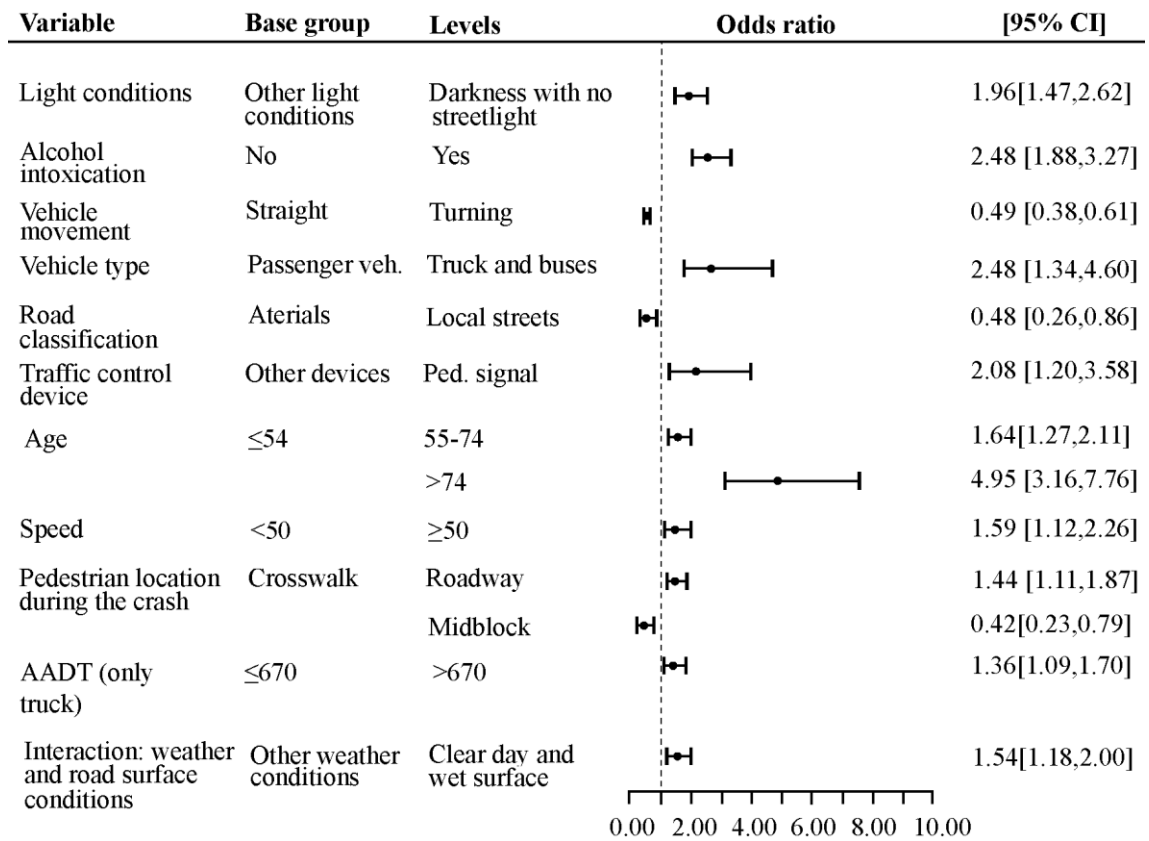(2003) explored the interaction between lighting conditions and impaired drivers and

found that people who were driving under alcohol effects in dark conditions, tended to be involved in more severe crashes than people driving during other lighting conditions. We found similar evidence. The odds of fatal crashes involving an alcohol-intoxicated driver and during dark conditions were 3.81 times that of crashes where the driver was sober or the driver was intoxicated but not driving at night.

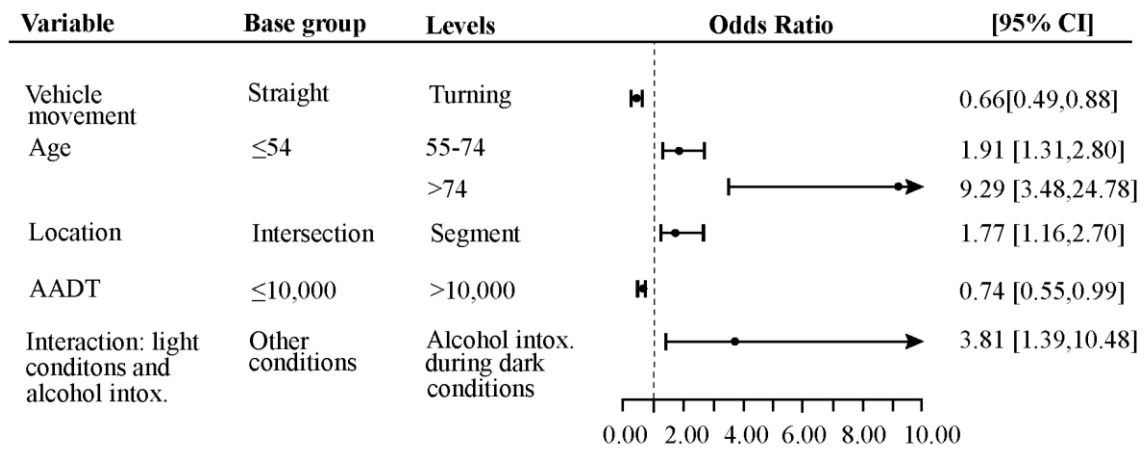**TABLE 55: Ordinal regression model. Crash severity for pedestrians and bicyclists**

VARIABLE	BASE GROUP	LEVEL	PED. PARAM.		BIC. PARAM.	
Light conditions	Other lighting conditions	Darkness no street light	0.67	***	NA	
Alcohol intoxication	No	Yes	0.91	***	NA	
Vehicle movement	Straight	Turning	-0.72	***	-0.41	**
Vehicle type	Passenger vehicle	Truck and buses	0.91	**	NA	
Road classification	Arterials	Local streets	-0.74	*	NA	
Traffic control Device	Other devices	Special pedestrian signal	0.73	**	NA	
Age	≤ 54	55-74	0.50	***	0.65	***
		>74	1.60	***	2.23	***
Posted speed limit	<50 mph	≥ 50 mph	0.46	*	NA	
Location	Intersection	Segment	NA		0.57	**
Ped. /Bic. location during the crash	Crosswalk	Roadway	0.36	**	NA	
		Midblock	-0.86	**	NA	
AADT (only truck)	<670	670-1100	0.31	**		
AADT	≤ 10,000	>10,000	NA		-0.31	*

TABLE 55: Ordinal regression model. Crash severity for pedestrians and bicyclists, continued

VARIABLE	BASE GROUP	LEVEL	PED. PARAM.		BIC. PARAM.	
Interaction weather and road surface conditions	Other weather and road surface conditions	Wet road surface and clear day	0.43	**	NA	
Interaction light conditions and alcohol intoxication	Other light and alcohol intoxication conditions	Alcohol intoxication during dark conditions	NA		1.34	**
	Threshold coefficients					
		O | C	-4.80	***	-3.85	***
		C | B	-0.42	***	-1.02	***
		B | A	1.73	***	2.18	***
		A | K	3.07	***	3.88	***

*	$0.01 \leq$ p-value < 0.05	Log. Lik.	-1800.98	-1011.39
**	$0.001 \leq$ p-value < 0.01	AIC	3635.96	2042.78
***	$0 \leq$ p-value < 0.001			
NA	not applicable			

Variable	Base group	Levels	Odds ratio	[95% CI]
Light conditions	Other light conditions	Darkness with no streetlight		1.96[1.47,2.62]
Alcohol intoxication	No	Yes		2.48 [1.88,3.27]
Vehicle movement	Straight	Turning		0.49 [0.38,0.61]
Vehicle type	Passenger veh.	Truck and buses		2.48 [1.34,4.60]
Road classification	Aterials	Local streets		0.48 [0.26,0.86]
Traffic control device	Other devices	Ped. signal		2.08 [1.20,3.58]
Age	≤54	55-74		1.64[1.27,2.11]
		>74		4.95 [3.16,7.76]
Speed	<50	≥50		1.59 [1.12,2.26]
Pedestrian location during the crash	Crosswalk	Roadway		1.44 [1.11,1.87]
		Midblock		0.42[0.23,0.79]
AADT (only truck)	≤670	>670		1.36[1.09,1.70]
Interaction: weather and road surface conditions	Other weather conditions	Clear day and wet surface		1.54[1.18,2.00]

0.00 2.00 4.00 6.00 8.00 10.00

(a)

Variable	Base group	Levels	Odds Ratio	[95% CI]
Vehicle movement	Straight	Turning		0.66[0.49,0.88]
Age	≤54	55-74		1.91 [1.31,2.80]
		>74		9.29 [3.48,24.78]
Location	Intersection	Segment		1.77 [1.16,2.70]
AADT	≤10,000	>10,000		0.74 [0.55,0.99]
Interaction: light conditons and alcohol intox.	Other conditions	Alcohol intox. during dark conditions		3.81 [1.39,10.48]

0.00 2.00 4.00 6.00 8.00 10.00

(b)

FIGURE 6 Odd ratios for (a) Pedestrian and (b) Bicyclist models

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Finally, we explored which risk factors had the biggest predictive power in the final model. By removing each variable at a time (ceteris paribus), we obtained the difference in log likelihood between the full model and the model with one variable removed. Then, we ranked the variables from the highest log likelihood difference to the lowest (TABLE 56)**.**

TABLE 56: Predictive power rank

	PEDESTRIAN MODEL		BICYCLIST MODEL	
RANK	**VARIABLE**	**Log Likelihood difference**	**VARIABLE**	**Log Likelihood difference**
1	Age	29.17	Age	14.02
2	Alcohol intoxication	20.98	Vehicle movement	3.91
3	Vehicle movement	18.22	Location	3.53
4	Light conditions	10.39	Interaction light conditions and alcohol intoxication	3.19
5	Pedestrian/Bicyclist location during the crash	8.81	AADT	2.07
6	Interaction weather and road surface conditions	5.15		
7	Vehicle type	4.16		
8	AADT(only truck)	3.91		
9	Traffic control device	3.38		
10	Posted speed limit	3.30		
11	Road classification	3.14		

Overall, for both models age was the strongest risk factor. For the pedestrian model, the most important risk factors after age were related to cash characteristics (alcohol intoxication, and vehicle movement). Light conditions also had a strong predictive power for crash severity. In terms of the bicyclist model, vehicle movement was the second strongest variable; however, the log likelihood difference is one third of the difference of age.

7.3   Road characteristics and traffic conditions models

Exploring location, environmental, crash, demographic, traffic and road characteristics

was useful to identify risk factors of crash severity. Nonetheless, it is the interest of

DOTs to know risk factors related to road and traffic characteristics, since the agencies

will have more room to implement countermeasures and policies to reduce fatalities. This

section focuses only on road and traffic characteristics were used to identify risk factors.

Similar to the methodology used in section 7.2, we estimated ordinal regression models

for pedestrian and bicyclist crashes. We selected the variables by using a backwards

stepwise method based on AIC. Results are shown in TABLE 57 (for more detail see

TABLE 86). Additionally, for a better interpretation, odd ratios are shown in FIGURE 7.

For the pedestrian model, results are similar to TABLE 55, with the difference

that now location of the crash (intersection vs segment) and AADT (only for trucks) are

significant. Risk factors that were repeated from the pooled models (TABLE 55) kept the

same direction with severity level (sign) and similar coefficients.

We found strong evidence that the odds of a crash of being fatal at an intersection

of being fatal were 0.71 times that of a crash that occurred in a segment of the road. In

other words, if a crash occurred in a segment of the road, it had a higher probability of

being fatal.

Furthermore, we found that volume of trucks had a positive relationship on the

likelihood of fatal crashes. In terms of AADT for trucks, the findings suggested that high

AADTs increased the likelihood of fatal crashes (p-value<0.05). The odds of a crash

being fatal in a roadway with and AADT (only trucks) above 670 were 1.47 that of a

roadway with an AADT below 670 vehicles. This result was consistent with the previous findings, where a crash that involved a heavy vehicle had a greater chance of being fatal. In terms of the bicycle model, we found that only location (intersection vs segment) and AADT are significant risk factors to explain severity. Location was found in the pooled models (TABLE 55) and it maintained the same sign in this model (in relation to the standard deviation).

The odds of a fatal crash in a roadway segment versus the other severity levels combined were 2.03 times that of a crash at an intersection (p-value<0.01). In terms of AADT, the findings suggested that crashes being fatal are less likely to happen in low volume roads than high volume roads. The odds of a crash being fatal in a roadway with an AADT below 10,000 were 0.72 times that of roadways with AADT above 10,000.

TABLE 57: Ordinal regression model. Road and traffic characteristics

VARIABLE	BASE GROUP	LEVEL	PED. PARAM.		BIC. PARAM.	
Light conditions	Other lighting conditions	Darkness no street light	0.88	***	NA	
Road class.	Arterials	Local streets	-0.76	*	NA	
PSL	<50 mph	≥ 50 mph	0.47	**	NA	
Location	Intersection	Segment	0.71	***	0.86	***
AADT (only truck)	≤670	>670	0.39	***	NA	
AADT	≤ 10,000	>10,000	NA		-0.33	*
	Threshold coefficients					
		O | C	-4.50	***	-3.66	***
		C | B	-0.21	***	-0.85	***
		B | A	1.76	***	2.22	***
		A | K	2.99	***	3.86	***

*	0.01 ≤ p-value < 0.05	Log. Lik.	-1890.68	-1033.67
**	0.001 ≤ p-value < 0.01	AIC	3799.36	2079.34
***	0 ≤ p-value < 0.001			
NA	not applicable			

Variable	Base group	Levels	Odds ratio	[95% CI]
Light conditions	Other light conditions	Darkness with no streetlight		2.40 [1.80,3.19]
Road classification	Aterials	Local streets		0.47 [0.26,0.84]
Speed	<50	≥50		1.60 [1.13,2.25]
Location	Intersection	Segment		2.04 [1.64,2.53]
AADT (only truck)	≤670	>670		1.47 [1.18,1.82]

0.00 2.00 4.00 6.00 8.00 10.00

(a)

Variable	Base group	Levels	Odds Ratio	[95% CI]
Location	Intersection	Segment		2.36 [1.60,3.46]
AADT	≤10,000	>10,000		0.72 [0.54,0.96]

0.00 2.00 4.00 6.00 8.00 10.00

(b)

FIGURE 7 Odd ratios for (a) Pedestrian and (b) Bicyclist models (only road and traffic characteristics)

Similarly to TABLE 56, we explored which risk factors had the biggest predictive power in the final model. TABLE 58 shows road and traffic risk factors ranked by predictive power. Most of the risk factors kept the same order found in TABLE 56. The only difference was found in location of the pedestrian crash, which was not significant in the pooled model.

For both pedestrian and bicyclist models, the location factor was the strongest variable, followed by light conditions and truck AADT (in the pedestrian model), and AADT (in the bicyclist model).

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TABLE 58: Predictive power rank (road and traffic characteristics)

	PEDESTRIAN MODEL		BICYCLIST MODEL	
RANK	**VARIABLE**	**Log Likelihood difference**	**VARIABLE**	**Log Likelihood difference**
1	Location	21.35	Location	9.94
2	Light conditions	18.30	AADT	2.46
3	AADT(only truck)	6.24		
4	Posted speed limit	3.60		
5	Road classification	3.38		

8   DISCUSSION

The results mostly agreed with the literature review. Risk factors associated with high vehicle speeds, visibility, vehicle size, alcohol intoxication, and age of the pedestrian/bicyclist explained crash severity level at a significant level.

From the exposure analysis, we focused only on road characteristics and neighborhood concepts. This analysis was advantageous since it allowed us to identify patterns by controlling for exposure. Overall, the results suggested that as number of lanes and road width increased, pedestrian and bicyclist crash severity tended to increase. High concentration of crashes was found in four lane roads, 40-50 ft. roads, and roads with a posted speed limit between 20 to 25 mph. In terms of neighborhood concepts, the findings suggested that high risk ratios were concentrated in suburban areas (concept E and F). Additionally, most of the fatal crashes in these land uses occurred on segments as opposed to intersections.

The exploration of the variables through the single variable models showed some potential risk factors for crash severity. In the pedestrian model, neighborhood concepts E and F, related to suburban and rural areas respectively, were found to increase severity levels. Nonetheless, we did not find evidence in the pooled or only road and traffic characteristics models suggesting that land use (neighborhood concepts) was related to crash severity. Driver, road and traffic characteristics were found to have a significant stronger association with severity than land use.

Moreover, a look to traffic conditions through the single variable models revealed that truck AADT yielded statistically significant associations with severity. As truck volume increased, the probability of a fatal crash increased. Similar results were found in

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(Kashani & Besharati, 2016). Other risk factors that had a statistically positive association with crash severity were number of lanes and road width.

For the bicyclist single variable models, results indicated that AADT (for all vehicles) decreased crash severity. This result is consistent with the literature (2004), where we found that even if AADT increased crash frequency, the severity was found to be lower perhaps due to vehicles travelling at a lower speed. Furthermore, it was found that heavy vehicles (trucks and buses) were associated with severe and fatal crashes.

In terms of the pooled models (TABLE 55) and the only road and traffic factors models (TABLE 57), the impact of the risk factors are better understood if they are applied to specific examples. TABLE 59 shows crash severity predictions for different scenarios. For the pedestrian model, we considered the base line to be the safest scenario (young pedestrian, good light conditions, crash occurred at an intersection, driver was sober, passenger vehicle turning, posted speed limit under 50 mph, local street, dry road surface, low truck volume, and no traffic control device). The probability for a fatal or incapacitated crash under these conditions is only 3.9%. For the rest of the scenarios, we estimated probabilities based on the worst level of each risk factor, as shown below.

1. Worst case scenario (scenario where all the worst risk factor levels occurred.)

2. Pedestrian older than 74

3. Driver was alcohol intoxicated

4. Truck or bus involved in the crash

5. Crash occurred on an arterial

6. Special pedestrian signal present

7. Vehicle was moving straight

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8. Dark conditions and no street light

9. Posted speed limit over 50 mph

10. Wet road surface and clear day

11. The pedestrian was walking on the roadway (as opposed to using a crosswalk)

12. AADT (only trucks) above 670 vehicles

TABLE 59 reveals the change (%) between each scenario and the base line. For example, in the worst-case scenario, the likelihood that the crash will be fatal or incapacitated injury will increase by 95.1%. Overall, the findings suggested that any change on any of the risk factor levels, increased the probability of severity levels K, A and B. In terms of the most important risk factors, the likelihood of a fatal or incapacitated injury crash increased as pedestrians are older than 74 (+12.9%), the driver was alcohol intoxicated (+5.3%)., or a truck or bus was involved in the crash (+5.3%),

The second part of the sensitivity analysis only considered the bicycle model. In this case, the base line (safest case) was the scenario where a crash occurred at an intersection, the vehicle was turning, the driver was sober under good lighting conditions, high AADT (lower vehicle speeds), and the bicyclist was younger than 55. In this scenario, the probability of being in a fatal or incapacitated injury crash is 5.3%. Five different scenarios were estimated:

1. Worst case scenario (scenario where all the worst risk factor levels occurred.)

2. Pedestrian older than 74

3. Driver was alcohol intoxicated and driving during dark conditions

4. Crash occurred on the roadway as opposed to an intersection

5. Vehicle was moving straight

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6. Low AADT (below 10,000)

As with the pedestrian model results, any change in the risk factors increases the
likelihood of fatal and incapacitated injury crashes. If a bicyclist gets into a crash under
the worst-scenario conditions, the probability of a K+A crash increases by almost 82.5%.
Age and an intoxicated driver at night have the strongest effect on crash severity
outcomes.

TABLE 59: Impact of risk factors on severity level

	PED. MODEL	LEVEL	K+A (%)	B (%)	C (%)	O (%)
	Base line (%)		**3.9**	**22.1**	**70.6**	**3.4**
Change (%)	Worst case scenario		95.1	-21.3	-70.5	-3.4
	Age	>74	12.9	24.5	-34.6	-2.7
	Alcohol intoxication	Yes	5.3	15.3	-18.6	-2.0
	Vehicle type	Passenger vehicle	5.3	15.2	-18.5	-2.0
	Road classification	Arterials	4.0	12.5	-14.8	-1.8
	Device	Pedestrian signal	3.9	12.2	-14.4	-1.7
	Vehicle movement	Straight	3.8	12.1	-14.3	-1.7
	Light conditions	Darkness no street light	3.5	11.2	-13.1	-1.6
	Speed	>=50 mph	2.2	7.7	-8.7	-1.3
	Wet road surface and clear day		2.0	7.1	-8.0	-1.2
	Pedestrian location during the crash	Roadway	1.6	5.9	-6.5	-1.0
	AADT (only trucks)	>670	1.3	4.7	-5.2	-0.9

TABLE 59: Impact of risk factors on severity level, continued

	BIC. MODEL	LEVEL	K+A (%)	B (%)	C (%)	O (%)
	Base line (%)		**5.3**	**52.3**	**38.3**	**4.2**
Change (%)	Worst case scenario		82.5	-40.5	-37.8	-4.1
	Age	>74	28.8	6.4	-31.4	-3.7
	Alcohol intoxication during dark conditions		12.2	14.1	-23.2	-3.0
	Location	Segment	3.7	9.4	-11.3	-1.8
	Vehicle movement	Straight	2.5	7.1	-8.2	-1.4
	AADT	<10,000	1.8	5.5	-6.2	-1.1

A similar analysis was developed for the models with only road and traffic characteristics (TABLE 60). For pedestrian crashes, the most important risk factors are light conditions and road classification. Or bicyclist crashes is location (segment vs intersection). Providing better lighting conditions at night and separating pedestrian and bicyclist movement in segments of the road and arterials are key strategies DOTs can implement to reduce fatalities.

TABLE 60: Impact of road and traffic risk factors on severity level

	PED. MODEL	LEVEL	K+A (%)	B (%)	C (%)	O (%)
Change (%)	**Base line (%)**		**7.4%**	**29.2%**	**61.1%**	**2.3%**
	Worst case scenario		58.9%	-2.1%	-54.6%	-2.2%
	Light conditions	Darkness no street light	8.7%	12.8%	-20.1%	-1.3%
	Road classification	Arterials	7.2%	11.4%	-17.4%	-1.2%
	Location	Segment	6.6%	10.8%	-16.3%	-1.2%
	Speed	>=50 mph	3.9%	7.4%	-10.5%	-0.8%
	AADT (only trucks)	>670	3.1%	6.2%	-8.6%	-0.7%
	BIC. MODEL	LEVEL	K+A (%)	B (%)	C (%)	O (%)
Change (%)	**Base line (%)**		**7.2%**	**55.5%**	**33.8%**	**3.5%**
	Worst case scenario		13.2%	8.8%	-19.6%	-2.4%
	Location	Segment	8.3%	8.9%	-15.2%	-2.0%
	AADT	<10,000	2.6%	4.8%	-6.4%	-1.0%

9   POLICY IMPLICATIONS

The State of Oregon has adopted the Oregon Transportation Safety Action Plan to bring the number of fatal and severe crashes down to zero. The state and several cities across the world have committed to improve traffic safety, coordination between different stakeholders, and use of quantitative tools to make better decisions that will protect vulnerable users. These strategies will inform decision makers on prioritizing projects, programs and policies to fund, which will have the greatest benefit toward achieving the vision of zero fatalities and injuries (Oregon Department of Transportation, 2016).

This study is an important step toward informing risk factors that can be addressed to improve traffic safety in the State of Oregon. Findings of this research effort suggested that fatal and severe crashes were more common on roads that provide a good environment for high speed vehicles. We found evidence that variables such as arterials, wide roads, and high posted speed limits, increased the likelihood of fatal and severe crashes. When it comes to countermeasures related to infrastructure, working in road characteristics to reduce vehicle speed (i.e. narrow roads, local streets, low posted speed limits), have a potential to minimize fatalities and severe crashes.

Furthermore, the results of this research support policies and actions to separate vulnerable user transportation modes (walking and biking) from motorized modes. The literature suggests that vulnerable users prefer lower-stress roads to move, especially found when pedestrians and/or bicycles do not share the same space with drivers (Pucher, Dill, & Handy, 2010). Separating heavy vehicles and high speed roads from vulnerable users can substantially bring down the number of fatal and severe crashes. Furthermore, providing separation for bicycles and pedestrians can help the state to promote more

desirable environments for these transportation modes. Further work is needed to assess different separation alternatives that consider infrastructure cost.

Additionally, results of this study provided important insights to reduce crash severity for vulnerable users in state roads. Interventions and policies should focus in suburban and rural areas, targeting roads with geometric characteristics that allow high traffic speeds (i.e. wide roads with high number of lanes). Furthermore, educational programs and training classes should take place to teach drivers how to interact with vulnerable users. Special emphasis should be given to heavy vehicle drivers, which present the highest risk for both pedestrians and bicyclists.
Additionally, improving street lighting and making crosswalks and sidewalks more visible can have a positive impact on reduction of fatal and severe crashes. Furthermore, more strict controls and penalties should take place to reduce alcohol intoxicated drivers, especially when light conditions are poor.

This study also showed that elder pedestrians and bicyclists are at high risk if a crash occurs. Strategies to protect these users in recreational bike lanes and roads, and provision of accessible facilities and infrastructure can facilitate the movement of these users. Moreover, traffic engineers should design better traffic signals to accommodate the different walking speeds of senior pedestrians when crossing the road.

10 LIMITATIONS

We advise the reader to be mindful of the focus and limitations of the study. This research concentrated on crashes that occurred on ODOT's facilities, which are mainly located in suburban and rural areas. Limiting crashes to state facilities reduced variability in some variables, such as posted speed limit, number of lanes, and road width (TABLE 33, TABLE 36, and TABLE 39).

A crash is included in the database if it involved a motorized vehicle, and if at least there was property damage over $1,500. A crash that only involved two bicyclists, for example, is not included in the database. Additionally, a crash where a vehicle hit a pedestrian, but it did not cause an injury or property damage over the threshold, is not reported. These characteristics on how a crash is reported caused a bias on the data, resulting in more observations of fatal and severe injury crashes. This problem was evident for pedestrian crashes, where almost zero crashes were property only damage (severity level O). On top of this, researchers (Lord & Mannering, 2010) have found that some crashes are not reported because the participants prefer to avoid the police or dealing with insurance issues.

We run the models dropping level O observations and we found the same risk factors and coefficients (by using the stepwise technique). The crash models were better to understand how risk factors increased the likelihood of going from level B or C, to level K or A.

In terms of bicyclist crashes, there were more severity level O observations, likely to be product of the cost of the bicycle involved in the crash. When we dropped the

severity level O observations, we found that AADT was not significant in the resulting model anymore.

Estimation of crash risk under various road characteristics is key to reduce the frequency of fatal and severe crashes. Nonetheless, assessing crash risk of vulnerable users has been a challenge among traffic safety researchers, since accurate information is not available. Since the probability of a crash occurring depends on measures of exposure, the lack of pedestrian and bicyclist volumes result in a loss of accuracy in estimating crash risks. We tried to control for exposure by using a crash risk ratio. This ratio considered VMT and percentage of pedestrian and bicyclist crashes (under several road conditions) as a measure of exposure; however, we acknowledge the importance of having data that can better reflect the actual exposure of vulnerable users. Furthermore, having vulnerable user exposure data can provide a better understanding of the relationship (if any) between crash frequency and crash severity.

This study also found that special pedestrian signals increased the likelihood of a crash being fatal. This finding can be related to the explanations highlighted in section 7.2; however, it may be also a problem with how this variable was reported in the database. The presence of a special pedestrian sign can be reported at locations where these treatments were not implemented, product of the lack of familiarity of people involved in the crash when reporting the crash. We explored the locations of the pedestrian crashes with special pedestrian signals reported and found that in most of them there was an RRFB or a median; however, there were some observations where there were also traffic signals.

Furthermore, these special treatments are implemented in places where there are safety concerns (high crash frequency). The special pedestrian signs are useful to reduce number of crashes but may not fully solve severity issues when a crash occurs. For example (Monsere, Figliozzi, Kothuri, Razmpa, & Hazel, 2016) found that crashes caused by no yielding were reduced at a significant level after RRFB installation; however, even if there was a reduction in fatal crashes, the change was small. Further research is needed to better understand this variable, for example, studies considering before and after special pedestrian sign implementation can be useful to quantify changes in severity levels over time.

Finally, we recommend for future research to assess how different bike facility designs (e.g. bike lane vs shared roadway) have an impact on crash severity. Our descriptive analysis showed that crashes in bike lanes tended to be level O (property only damage) rather than fatal or severe; however, the variable was not significant in the models.

11   CONCLUSION

DOTs have an interest in increasing non-motorized transportation in the short and long term as a strategy to improve public health, air quality, and reduce traffic congestion. This interest has motivated researchers to explore what are the main strategies and policies that yield the maximum net benefit in terms of ridership and safety.

The goal of this study was to identify risk factors of crash severity for pedestrians and bicyclists in the Oregon Highway Network System, which is mainly located in suburban and rural areas. The findings of this observational study provide decision makers and planners the ability and information to improve safety conditions for both pedestrian and bicyclists in non- urban areas.

Risk factors such as age, vehicle type and movement, light conditions, road classification, traffic control device, posted speed limit, location of the pedestrian and wet road surfaces during clear weather conditions, were found to play an important role in the model for pedestrian crashes. For the bicyclist model, the findings suggested that age, crash location, vehicle movement and alcohol intoxication during dark conditions are statistically significant.

Models using only road and traffic characteristics were developed to provide more specific and tangible risk factors for DOTs to reduce fatal and severe crashes. Factors such as lack of streetlight at night, arterials, posted speed limit over 50 mph, high only truck volumes, and low traffic volumes (which result in higher speeds), were found to increase the likelihood of severe crashes.

Since most of the risk factors found in this study were associated with infrastructure that promotes high speed traffic, treatments to control how fast drivers are going are a feasible

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approach to protect vulnerable users. Similarly, policies and strategies to separate

vulnerable users (walking and biking) from motorized modes are potential actions to

reduce the fatal and severe crashes.

Targeting educational campaigns in rural areas may be key to preventing fatal and

severe crashes related to vulnerable users. Training classes for heavy vehicle drivers in

regards of pedestrians and bicyclists can help reduce crash severity as well. More strict

policies and control should take place to reduce alcohol intoxicated drivers, especially

when light conditions are poor. Moreover, more safe strategies should be implemented in

recreational corridors and roads where seniors tend to walk or bike, since they were

found to be the group with the highest risk if a crash occurs.

A direct application of this research is to map some of the risk factors to identify

potential severity hot spots in the state network. This map can be included in future

updates of the   Oregon Bicycle and Pedestrian Plan.

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APPENDICES

Appendix A: risk ratio by neighborhood concept

Crash data from the Oregon Statewide Crash Data System was grouped by intersection and segment based on the traffic control device information available at the crash level. If a crash occurred at any type of intersection (controlled and uncontrolled), it was grouped in the uncontrolled category. If the crash was reported in a segment, then it was grouped in the segment category. Crashes at driveways, curves, bridges structures were not taken into account due to the few observations available. Crash information is presented as the number of crashes reported. Furthermore, crashes were grouped by neighborhood concept (Currans, Gherke, & Clifton, 2015) to account for the differences in built environment in the likelihood of a crash occurrence.

A. Pedestrian exposure analysis by neighborhood concept

TABLE 61: Pedestrian Risk ratio. Posted Speed limit by neighborhood concept D

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	4.29	4.51	4.46	4.62	7.73	NA	1.25	2.76	3.73	NA
35-50	2.26	2.31	2.15	2.31	0.79	3.30	3.32	2.76	2.60	NA
50-65	0.15	0.10	0.17	0.09	0.31	0.17	0.10	0.11	0.08	NA
> 65	NA	NA	NA	NA	NA	2.60 *	NA	NA	NA	NA

TABLE 62: Pedestrian Risk ratio. Posted Speed limit by neighborhood concept E

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	8.77 *	10.37 *	14.16 *	13.76 *	NA	2.25 *	1.77 **	7.05 *	8.84 *	7.31 *
35-50	4.62	4.63	3.85	3.81	5.77	4.00	4.31	4.56	3.26	2.89
50-65	0.24	0.15	0.11	0.18	0.41	0.66	0.59	0.29	0.43	0.81
> 65	NA	NA	0.08 *	NA	NA	0.18	0.19	0.10 *	0.28	NA

TABLE 63: Pedestrian Risk ratio. Posted Speed limit by neighborhood concept F

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
35-50	8.18	6.55	8.66	6.55	13.09	3.98	6.86	4.36	5.82	NA
50-65	0.50	0.71	0.18	0.27	NA	1.29	0.76	0.91	0.77	NA
> 65	0.30	NA	NA	0.06 *	NA	0.11 *	0.12 *	0.20	0.14	NA

TABLE 64: Pedestrian Risk ratio. Road width by neighborhood concept D

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	NA	0.30 *	0.21 *	NA	NA	NA	NA	NA	NA
20 - 30	0.94	0.55	0.83	0.83	1.98	0.55	0.32	0.53	0.26	NA
30 - 40	0.25	0.35	0.41	0.47	0.53	0.44	0.34	0.33	0.14	NA
40 - 50	2.52	2.85	2.49	2.18	1.18	2.29	3.23	3.26	3.87	NA
50 - 60	7.75 *	8.14 *	4.35 *	4.31 *	NA	11.30 *	7.88 *	4.36 *	7.50 *	NA
60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 65: Pedestrian Risk ratio. Road width by neighborhood concept E

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	NA	0.40 *	0.43 *	NA	NA	NA	NA	NA	NA
20 - 30	0.43	0.43	0.39	0.41	0.71	0.77	0.66	0.74	0.81	NA
30 - 40	0.87	0.49	0.69	0.83	NA	0.42	0.26 *	0.43	0.79	2.18
40 - 50	2.85	3.29	2.89	2.95	2.59	2.89	3.14	2.33	2.09	1.30
50 - 60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 66: Pedestrian Risk ratio. Road width by neighborhood concept F

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	NA	NA	1.25	NA	NA	NA	NA	NA	NA
20 - 30	0.84	0.60	0.47	0.61	NA	0.47	0.80	0.80	0.53	NA
30 - 40	NA	0.63	0.54	0.90	NA	1.19	0.65 *	1.43	2.28	NA
40 - 50	3.98	3.79	5.39	3.13	10.61	9.42 *	6.88 *	5.01 *	9.36 *	NA
50 - 60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 67: Pedestrian Risk ratio. Road width by neighborhood concept F, continued

60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 67: Pedestrian Risk ratio. Number of lanes by neighborhood concept D

#OF LANES	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
1	NA	NA	0.33 *	0.22 *	NA	NA	NA	NA	NA	NA
2	1.23	0.86	1.04	1.20	1.94	0.54	0.73	0.87	0.26	NA
3	NA	0.23	0.25	0.25	0.56	0.46	NA	0.10 *	0.15	NA
4	3.24	3.32	2.66	2.37	1.05	3.49	3.88	3.37	4.41	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 68: Pedestrian Risk ratio. Number of lanes by neighborhood concept E

#OF LANES	INTERSECTION					SEGMENT				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
1	NA	NA	0.39 *	0.55 *	NA	NA	NA	NA	0.40 *	NA
2	0.49	0.47	0.56	0.43	0.70	0.79	0.71	0.77	0.85	0.35
3	0.68	0.50	0.62	0.85	NA	0.43	NA	0.40	0.55	2.25
4	3.19	3.76	3.12	3.17	2.46	2.83	3.47	2.80	2.18	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 69: Pedestrian Risk ratio. Number of lanes by neighborhood concept F

#OF LANES	INTERSECTION					SEGMENT				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
1	NA	NA	NA	1.22	NA	NA	NA	NA	NA	NA
2	0.84	0.60	0.54	0.69	NA	0.66	1.20	1.12	0.84	NA
3	NA	0.64	0.41	0.82	NA	0.39	0.21 *	0.47	1.00	NA
4	4.85	4.16	5.52	3.09	9.70	4.64	2.31	2.22	2.70	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 70: Pedestrian Risk ratio. Road classification by neighborhood concept D

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
Interstate	0.11	0.06 *	0.06 *	0.04 *	0.28	0.23	NA	0.10	NA	NA
Principal Arterial	3.71	3.43	3.26	3.41	3.38	3.52	3.81	3.32	3.33	3.33
Minor Arterial	0.92 **	2.66 *	2.76 *	2.33 *	NA	NA	0.74 **	2.87 *	3.02 *	3.02 *
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 71: Pedestrian Risk ratio. Road classification by neighborhood concept E

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
Interstate	0.14	0.05 *	0.13	0.12	0.34	0.19	0.14	0.09	0.22	0.34
Principal Arterial	2.45	2.29	2.34	2.39	1.84	2.45	2.12	2.37	2.12	1.23
Minor Arterial	1.16	2.17	1.14	1.39	NA	1.34	2.34	2.04	1.64	2.91
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 72: Pedestrian Risk ratio. Road classification by neighborhood concept F

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
Interstate	0.21	0.24	0.13	0.08 *	NA	0.22	0.16	0.24	0.28	NA
Principal Arterial	1.82	2.60	2.75	2.82	NA	2.06	2.78	1.75	2.23	NA
Minor Arterial	2.71	0.78	1.34	1.23	NA	2.83	1.55	2.94	2.41	NA
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

B. Bicyclist exposure analysis by neighborhood concept

TABLE 73: Bicyclist Risk ratio. Posted Speed limit by neighborhood concept D

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	NA	2.66	3.99	3.99	4.02	4.29	8.58	2.93	2.58	NA
35-50	3.96	2.46	2.04	1.99	2.23	1.32	NA	2.52	2.77	3.96
50-65	NA	0.27	0.27	0.29	0.19	0.51	0.51	0.21	0.15	NA
> 65	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 74: Bicyclist Risk ratio. Posted Speed limit by neighborhood concept E

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	13.71 *	9.88 *	10.79 *	9.14 *	5.22 *	NA	NA	6.85 *	12.80 *	NA
35-50	4.51	4.10	3.99	4.14	5.50	2.71	4.33	3.91	3.25	3.61
50-65	NA	0.28	0.28	0.35	0.19	1.27	0.81	0.51	0.41	1.02
> 65	NA	0.08 *	NA	NA	NA	NA	NA	0.06 *	NA	NA

TABLE 75: Bicyclist Risk ratio. Posted Speed limit by neighborhood concept F

POSTED SPEED LIMIT	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
< 20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20-35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
35-50	NA	13.09	8.28	6.82	6.55	6.55	4.36	5.54	4.36	NA
50-65	NA	NA	0.32	0.54	0.99	0.99	1.32	0.84	1.32	1.98
> 65	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 76: Bicyclist Risk ratio. Road width by neighborhood concept D

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	0.31 *	0.51	0.41 *	NA	NA	NA	NA	NA	NA
20 - 30	3.30	0.57	0.89	0.89	0.82	NA	1.10	0.60	0.33	NA
30 - 40	NA	0.27	0.42	0.29	0.17	0.88	1.76	0.36	0.26	NA
40 - 50	NA	2.64	2.19	2.42	2.58	3.93	NA	3.48	3.53	5.89
50 - 60	NA	7.02 *	4.32 *	5.36 *	10.17 *	NA	NA	1.85 **	4.07 *	NA
60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 77: Bicyclist Risk ratio. Road width by neighborhood concept E

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	NA	0.57 *	0.70	1.22	NA	NA	NA	NA	6.40
20 - 30	0.45	0.43	0.49	0.41	0.42	1.34	1.25	0.48	0.71	NA
30 - 40	0.68	0.59	0.60	0.60	0.26 *	NA	1.09	0.57	NA	NA
40 - 50	4.05	3.51	2.85	2.93	3.40	1.62	0.65	3.11	3.24	3.24
50 - 60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 78: Bicyclist Risk ratio. Road width by neighborhood concept F

WIDTH (ft.)	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
0-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10-20	NA	NA	0.62 *	0.29 *	NA	NA	NA	0.53 *	2.29	NA
20 - 30	1.68	0.67	0.48	0.49	0.56	1.68	1.68	0.71	0.84	1.68
30 - 40	NA	NA	0.53	0.46	NA	NA	NA	0.68	NA	NA
40 - 50	NA	6.37	4.91	5.53	7.07	NA	NA	4.08	3.54	NA
50 - 60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 78: Bicyclist Risk ratio. Road width by neighborhood concept F, continued

60 - 70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
> 80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 79: Bicyclist Risk ratio. Number of lanes by neighborhood concept D

#OF LANES	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
1	NA	0.26 *	0.50	0.36 *	NA	NA	NA	NA	NA	NA
2	3.23	0.78	1.19	1.05	0.81	NA	2.15	0.59	0.32	NA
3	NA	0.10 *	0.26	0.19	0.17	0.93	0.93	0.38	0.28	NA
4	NA	3.25	2.20	2.68	3.60	3.49	NA	3.33	3.67	5.24
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 80: Bicyclist Risk ratio. Number of lanes by neighborhood concept E

#OF LANES	INTERSECTION					SEGMENT				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
1	NA	NA	0.63	0.67	1.17	NA	NA	NA	NA	6.13
2	0.44	0.57	0.56	0.54	0.42	1.32	1.23	0.59	0.70	NA
3	1.41	0.15 *	0.52	0.31	0.54	0.70	1.13	0.35	NA	2.82
4	3.07	3.65	3.01	3.15	3.22	0.77	0.61	3.58	3.68	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 81: Bicyclist Risk ratio. Number of lanes by neighborhood concept F

#OF LANES	INTERSECTION					SEGMENT				
	K	**A**	**B**	**C**	**O**	**K**	**A**	**B**	**C**	**O**
1	NA	NA	0.60 *	0.28 *	NA	NA	NA	0.51 *	2.23	NA
2	1.68	0.67	0.55	0.56	0.56	1.68	1.68	0.77	0.84	1.68
3	NA	NA	0.47	0.56	NA	NA	NA	0.52	NA	NA
4	NA	5.82	4.63	4.65	6.47	NA	NA	3.73	3.23	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 82: Bicyclist Risk ratio. Road classification by neighborhood concept D

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
Interstate	NA	0.10	0.05 *	0.04 *	NA	0.47	0.47	NA	NA	NA
Principal Arterial	4.22	3.06	2.93	3.04	3.17	2.81	2.81	3.07	3.80	4.22
Minor Arterial	NA	3.16 *	4.02 *	3.38 *	5.73 *	NA	NA	3.13 *	NA	NA
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 83: Bicyclist Risk ratio. Road classification by neighborhood concept E

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
Interstate	NA	NA	0.06 *	0.05 *	0.25	NA	NA	0.04 *	NA	NA
Principal Arterial	3.06	2.47	2.32	2.24	2.19	1.91	2.14	2.55	2.45	3.06
Minor Arterial	NA	2.02	1.80	2.05	0.69 *	3.63	2.91	1.51	1.45	NA
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 84: Bicyclist Risk ratio. Road classification by neighborhood concept F

ROAD CLASSIFICATION	INTERSECTION					SEGMENT				
	K	A	B	C	O	K	A	B	C	O
Interstate	NA	NA	0.05 *	0.07 *	NA	NA	NA	NA	NA	NA
Principal Arterial	NA	2.92	2.45	2.66	3.65	1.82	0.61	2.52	2.43	3.65
Minor Arterial	10.85	2.17	1.94	0.90	NA	5.43	5.43	3.34	1.81	NA
Major collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Minor collector	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Local	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix B: Pooled Models

TABLE 85: Detailed ordinal regression model. Crash severity for pedestrians and bicyclists

VARIABLE	BASE GROUP	LEVEL	PEDESTRIAN				BICYCLIST			
			PAR.	STD ERROR	Z VALUE	P VALUE	PAR.	STD ERROR	Z VALUE	P VALUE
Light conditions	Other lighting conditions	Darkness no street light	0.67	0.15	4.55	***	NA			
Alcohol intoxication	No	Yes	0.91	0.14	6.46	***	NA			
Vehicle movement	Straight	Turning	-0.72	0.12	-6.01	***	-0.41	0.15	-2.78	**
Vehicle type	Passenger vehicle	Truck and buses	0.91	0.32	2.88	**	NA			
Road classification	Arterials	Local streets	-0.74	0.30	-2.48	*	NA			
Traffic control Device	Other devices	Special pedestrian signal	0.73	0.28	2.60	**	NA			

TABLE 85: Detailed ordinal regression model. Crash severity for pedestrians and bicyclists, continued

Age	≤ 54	55-74	0.50	0.13	3.85	***	0.65	0.19	3.36	***
		>74	1.60	0.23	6.97	***	2.23	0.50	4.45	***
Posted speed limit	<50 mph	≥ 50 mph	0.46	0.18	2.57	*	NA			
Location	Intersection	Segment	NA				0.57	0.22	2.64	**
Pedestrian/Bicyclist location during the crash	Crosswalk	Roadway	0.36	0.13	2.73	**	NA			
		Midblock	-0.86	0.32	-2.70	**	NA			
AADT (only truck)	≤ 670	> 670	0.31	0.11	2.79	**				
AADT	≤ 10,000	>10,000	NA				-0.31	0.15	-2.03	*
Interaction weather and road surface conditions	Other weather and road surface conditions	Wet road surface and clear day	0.43	0.14	3.21	**	NA			

TABLE 85: Detailed ordinal regression model. Crash severity for pedestrians and bicyclists, continued

Interaction light conditions and alcohol intoxication	Other light and alcohol intoxication conditions	Alcohol intoxication during dark conditions	NA				1.34	0.52	2.59	**
Threshold coefficients										
		O | C	-4.80	0.34	-14.12	***	-3.85	0.25	-15.56	***
		C | B	-0.42	0.13	-3.12	***	-1.02	0.17	-5.87	***
		B | A	1.73	0.14	12.24	***	2.18	0.19	11.25	***
		A | K	3.07	0.16	19.00	***	3.88	0.28	13.64	***

*	$0.01 \le$ p-value < 0.05	Log. Likelihood	-1800.98
**	$0.001 \le$ p-value < 0.01	AIC	3635.96
***	$0 \le$ p-value < 0.001		

With -1011.39 and 2042.78 for the second model.

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Appendix C: Road characteristics and traffic conditions models

TABLE 86: Detailed ordinal regression model. Road and traffic characteristics

VARIABLE	BASE GROUP	LEVEL	PEDESTRIAN				BICYCLIST			
			PAR.	STD ERROR	Z VALUE	P VALUE	PAR.	STD ERROR	Z VALUE	P VALUE
Light conditions	Other lighting conditions	Darkness no street light	0.88	0.14	3.04	***	NA			
Road classification	Arterials	Local streets	-0.76	0.29	-2.58	*	NA			
Posted speed limit	<50 mph	≥ 50 mph	0.47	0.17	2.69	**	NA			
Location	Intersection	Segment	0.71	0.11	6.50	***	0.86	0.20	4.39	**
AADT (only truck)	<670	670-1100	0.39	0.11	3.52	**				
AADT	≤ 10,000	>10,000	NA				-0.33	0.15	-2.21	*
Threshold coefficients										
		O | C	-4.50	0.33	-13.77	***	-3.66	0.22	-16.42	***
		C | B	-0.21	0.10	-2.05	***	-0.85	0.14	-6.15	***
		B | A	1.76	0.11	15.72	***	2.22	0.16	13.67	***
		A | K	2.99	0.13	22.78	***	3.86	0.26	14.82	***

TABLE 86: Detailed ordinal regression model. Road and traffic characteristics, continued

*	0.01 ≤ p-value < 0.05	Log. Likelihood	-1890.68		-1033.67
**	0.001 ≤ p-value < 0.01	AIC	3799.36		2079.34
***	0 ≤ p-value < 0.001				