COMPLIANCE AND SURROGATE SAFETY MEASURES FOR UNCONTROLLED CROSSWALK CROSSINGS IN OREGON

Final Report

PROJECT SPR 806

RESEARCH

Oregon Department of Transportation

COMPLIANCE AND SURROGATE SAFETY MEASURES FOR UNCONTROLLED CROSSWALK CROSSINGS IN OREGON

Draft Final Report

SPR 806

by

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September 2018

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-OR-RD-19-02		

4. Title and Subtitle	5. Report Date
Compliance and Surrogate Safety Measures for Uncontrolled Crosswalk Crossings in Oregon	September 2018
	6. Performing Organization Code
7. Author(s) Miguel Figliozzi, Avinash Unnikrishnan, Sirisha Kothuri, Álvaro Caviedes, David R. Soto Padín	8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Section 555 13th Street NE, Suite 1 Salem, OR 97301	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Oregon Dept. of Transportation Research Section and Federal Highway Admin. 555 13th Street NE, Suite 1 400 Seventh Street, SW Salem, OR 97301 Washington, DC 20590-0003	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This research aims to find readily observable and measurable field measures and geometric data to evaluate relative crosswalk safety performance. A literature review was conducted and crash data analysis was undertaken to determine the significant predictors for pedestrian crashes at unsignalized marked crosswalks. These factors were used to select nine sites for data collection. Video and radar equipment were used to collect pedestrian and traffic information at each of the sites. Both qualitative and quantitative analyses conducted at each site provided important insights into driver and pedestrian behavior. Ultimately, normalized entering volume (NEV) and no-stop percentage (NSP) are recommended as macro-level surrogate metrics that could be used to analyze pedestrian safety at unsignalized marked crosswalks. They are strongly associated with pedestrian-vehicle conflicts and are based on readily observable and measurable field measures and geometric data.

17. Key Words	18. Distribution Statement
Pedestrian safety, unsignalized marked crosswalk, macro surrogate measures, field data collection	Copies available from NTIS, and online at www.oregon.gov/ODOT/TD/TP_RES/

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	165	

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized Printed on recycled paper

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APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

The authors would like to thank the members of the ODOT Research Section for their sage advice and assistance in the preparation of this report. The authors also acknowledge the contributions of research assistants Alvaro Caviedes, Robert Burdalski, Santiago Espinosa, and David Soto.

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1.0 INTRODUCTION

This is the final report that addresses the research objectives and questions set out at the start of the research project SPR 806. This first chapter clearly outlines objectives, research questions, data collection constraints, and report organization.

1.1 RESEARCH OBJECTIVES

Traditionally, highway safety analysis and safety prioritization have been performed utilizing only crash data. Unfortunately, relying solely on archived crash data has several problems. The crash based approach is:

1. Reactive, fatalities and crashes must take place before any action is taken;

2. Sluggish, data access lead time is substantial, over a year or more until official crash statistics are published; and

3. Incomplete, high-risk locations are often not identified through a crash data analysis due to low rates of exposure and/or low-crash frequency.

The objective of this research is to analyze, as robustly as possible, the ability of field measurements and geometric data to predict the expected relative safety of an existing unsignalized marked crosswalk.

1.2 RESEARCH QUESTIONS

The proposed research aims to answer these questions:

1. Can field measures and geometric data be used as a reliable predictor of crosswalk safety performance?

2. Is it possible to utilize field-based surrogate safety measures as a tool to examine the need of crosswalk improvements?

1.3 FOCUS AND DATA COLLECTION CONSTRAINTS

This research focuses on unsignalized marked crosswalks at intersections. The research will attempt to produce a model or method to collect field data and estimate the relative safety of a location. Noteworthy constraints and/or necessary characteristics for the potential field-based surrogate safety measures or evaluation method include: (a) the staff data collection effort should be limited to a certain number of hours (i.e. it cannot consume full workdays), (b) the data collection effort and/or analysis method should involve no more than two or three ODOT staff members, (c) data collection should be carried out with portable equipment that can be readily deployed, and (d) data post-processing and analysis should not be arduous or involve specialized software or video analysis techniques.

1.4 REPORT ORGANIZATION

This report is organized into seven chapters. Chapter two presents a literature review. Chapter three presents a crash and exposure analysis based on Oregon pedestrian crash data on state roads. Chapter four describes the site selection process while chapter five presents an overview of traffic and pedestrian conditions at the data collection sites. Chapter six analyzes vehicle-pedestrian interaction data and compares the performance of different crosswalks. Surrogate measures are also proposed and analyzed in chapter six. The report ends with conclusions and next steps in Chapter seven. References and two appendices are also included in this report.

2.0 LITERATURE REVIEW

This chapter presents an extensive though not exhaustive literature review.

2.1 FACTORS INFLUENCING PEDESTRIAN-VEHICLE CRASHES

To predict the relative safety of existing uncontrolled marked crosswalks at unsignalized intersections, it is important to first identify factors that may affect pedestrian-vehicle interactions and pedestrian safety.

2.1.1 Pedestrian Behavior and Demographic Factors

Liu and Tung (2014) explored the effects of age on road crossing decisions. A total of 32 subjects were asked to watch videos of an approaching vehicle and indicate the last moment at which they would cross, based on their judgment about vehicle speed and position. Walking time was statistically lower for young people (6.59 seconds) than elderly people (8.46 seconds).

Arman et al. (2015) investigated pedestrian gap acceptance at an unsignalized location and a midblock crosswalk. Data were collected by video during peak and off-peak hours. For the unsignalized intersection crosswalk, there were 1,163 accepted gaps and 1,435 rejected gaps. For the midblock crosswalk scenario, there were 1,208 accepted gaps and 1,812 rejected gaps. The data analysis suggests that females tend to accept greater gap sizes or wait more before crossing than males. Young people were more willing to accept a shorter gap than seniors. The authors also found that pedestrians tended to accept larger gap sizes when they were walking in groups although the speed of pedestrians in larger groups may be lower than the speed of individual pedestrians *(O'Flaherty and Parkinson 1972).*

Yagil (2000) found evidence of higher traffic law compliance by female pedestrians. The author administered a questionnaire to 203 students (with average age of 24) at two higher education institutions in Israel. The findings suggest that men have a strong belief that walking signals are designed mostly for children and elderly populations. *Tom and Granié (2011)* also explored gender differences in pedestrian traffic law compliance before and during road crossing. Four hundred people (200 males and 200 females) were observed at four intersections (two signalized and two unsignalized) in France. Traffic and pedestrian volumes were considered. The findings suggest that during road crossings mainly at signalized intersections, females tend to pay more attention towards other pedestrians than males. Before crossing, females turned their heads toward traffic more frequently than males, showing a more cautious behavior. *Al-Shammari et al. (2009)* found that men are more likely to be involved in a pedestrian crash in Saudi Arabia.

Katz et al. (1975) explored pedestrian and driver characteristics that could influence driver decision to yield to pedestrians. Trained pedestrians were observed while crossing two real-world marked and unmarked crosswalks. Driver response was measured in terms of vehicle speed while controlling for pedestrian and traffic volume. Field observations were made to collect pedestrian behavior. A speed sensor (Rustrak Model 8 Event recorder) was used to measure vehicle speeds. A total of 480 events were analyzed. One of the key findings of the study was that female and older drivers were more likely to slow down and yield to pedestrians than other drivers.

The use of cellphones may affect gap acceptance and pedestrian waiting time. *Arman et al. (2015)* found that if the pedestrian was crossing with a child or using a cellphone, he or she tended to accept a higher gap size and longer waiting times. *Nassar and Troyer (2013)* conducted a macro-level study to explore the relationship of crashes and severity with cellphone use in the U.S. (not controlled for exposure). Data were collected from the National Electronic Injury Surveillance System database. A total of 5,482 incidents were analyzed. Results suggest that using a cellphone may reduce awareness and result in unsafe behaviors while crossing the road. *Kim et al. (2008)* collected data at 45 sites (signalized and unsignalized intersections) in the city of Honolulu to explore pedestrian safety. Two observers collected the information for one hour at each site. One observer collected pedestrian behavior information (pedestrians crossing on crosswalks and jaywalkers within 200 ft. of the crosswalk), while the other recorded data in pre-prepared forms. Independent variables were controlled for exposure (pedestrian and traffic volume). Findings suggest that the most common traffic violation was jaywalking. Most of these events occurred at unsignalized intersections.

Table 2.1 summarizes the studies that found relationships between pedestrian safety levels and socio-demographic characteristics or pedestrian walking behavior. Due to differences in the dependent variable analyzed (gap acceptance, law compliance rate, pedestrian crash frequency and severity) we use a term called "pedestrian safety level" to aggregate these safety measures into one concept. The arrows represent the direction of the relationship between the independent variables and pedestrian safety. When an upward pointing arrow symbol (↑) is used, the variable improves pedestrian safety. When a downward pointing arrow symbol (↓) is used, the corresponding variable decreases pedestrian safety levels. Some cells do not have symbols when the variable was not explored in the corresponding paper.

2.1.2 Land Use Types

At a broader level, researchers have also studied pedestrian safety by analyzing aggregated socio-economic and land use data for large areas (such as census tract, block group and traffic analysis zone). These studies have explored these relationships by using aggregated data for large areas and did not control for exposure (e.g. pedestrian or traffic volume).

Land use areas designated for high levels of population and employment density are likely to have more pedestrian crashes *(Kim et al. 2006)*. There is also a proportional relationship between senior and children population concentration and frequency of crashes in urban areas *(Abdel-Aty et al. 2013)*.

By studying the relationship between pedestrian crashes and census geography levels, researchers have been able to study variables such as race and income. In terms of race, places with high proportions of minority groups and residents living below the poverty line are likely to have more pedestrian crashes as well *(Wier et al. 2009)*. *Lee et al.* (2015) found that areas with high proportions of African Americans and Hispanics communities are more likely to have more pedestrian crashes. The frequency of pedestrian crashes also tends to be higher at areas with high proportions of residents without vehicles.

Table 2.1: Pedestrian Safety and Demographic Data Summary

AUTHOR	PEDESTRIAN SAFETY LEVEL					
	Female gender	Pedestrian was using a cellphone before (or while) crossing	Pedestrian crossing with a child	Age (binary)		Pedestrian group size
				Young	Old	
Arman et al. (2015)	↑	inconclusive	↑	↓	↑	↑
Liu & Tung (2014)	↑			↓	↓	
Yannis et al. (2013)	↓					
Nassar and Troyer (2013)	↑	↓			↑	
Tom and Granié (2011)	↑					
Sarkar et al. (2011)				↓	↓	
Zhuang and Wu (2011)					↑	
Kim et al. (2008)	↑					
Garder (2004)	↑					
Yagil (2000)	↑			↑	↑	
Katz et al. (1975)	↑				↑	↑

Abdel-Aty et al. (2013) conducted a study in Florida to explore the effect of zonal variation (traffic analysis zone, block group, census tract) on traffic safety. Crash data were collected from two counties for 2005 and 2006. A total of 87,718 crashes were studied. Exposure was taken into account by using VMT and traffic at the zone level. The authors found that pedestrian crash frequency was strongly associated with commuting to work rates by transit and walking (the higher these rates, higher the pedestrian crash frequency). Race was also found to be a significant factor; areas with high proportion of minority groups tend to have more pedestrian crashes.

Kim et al. (2006) explored the relationship between traffic safety and urban development in the city of Honolulu. The data collected was aggregated at a grid level (0.1 sq. mile). Population, number of jobs, number of parks, and commercial areas were statistically associated with more pedestrian crashes.

Wier et al. (2009) collected data on pedestrian crashes and environment for 176 census tracts in San Francisco. Exposure was considered by using traffic volume counts at the track level. A total of 4,039 pedestrian crashes were analyzed for the period 2001 to 2005. Results show that the frequency of pedestrian crashes is greater in areas with high concentrations of commercial land use, and high levels of resident and employee population. Household income was also found to be significant, areas with more people living below the poverty line experience more pedestrian crashes.

Wang et al. (2016) investigated the relationship between pedestrian crashes and road characteristics. Pedestrian crash data were collected for 263 traffic analysis zones (TAZ) in the city of Shanghai. The findings suggest that an increase in major arterial road length and road density is associated with an increase in pedestrian crashes. Low levels of intersection spacing were found to be associated with more pedestrian crashes. Table 2.2 summarizes studies that found relationships between pedestrian safety levels and land use or socio-demographic characteristics.

Table 2.2: Pedestrian Safety and Land Use Summary

AUTHOR	**PEDESTRIAN SAFETY LEVEL**					
	Commercial land use (binary)	**Minority group density**	**Income level**	**Population**	**Employment density**	**Proportion of residents that commute by transit or by walking**
Wang et al. (2016)				↓		
Lee et al. (2015)		↓	↓			
Abdel-Aty et al. (2013)		↓				↓
Wier et al. (2009)	↓		↓		↓	
Kim et al. (2006)	↓			↓	↓	

2.1.3 Traffic Characteristics

Vehicle Miles Traveled (VMT), Annual Average Daily Traffic (AADT), and pedestrian volumes are positively associated with pedestrian crashes at a statistically significant level *(Abdel-Aty et al. 2013, Lee et al. 2015, and Loukatiou-Sideris et al. 2007).*

Strauss et al. (2014) explored pedestrian safety at 647 signalized and 435 unsignalized intersections in Montreal. Traffic counts were collected in 2008 and 2009 for signalized intersections and in 2012 for unsignalized intersections. Crash data were collected over a 6-year period from 2003 to 2008. The study found that pedestrian injuries are expected to increase by 5.6% and 4.16% with a 10% increase in traffic volume at signalized and unsignalized intersections, respectively.

Haleem et al. (2015) explored factors that were associated with pedestrian crash severity at signalized and unsignalized intersections. Crash data were collected from the Florida Department of Transportation crash analysis reporting system for the period between 2008 and 2010. A total of 7,030 pedestrian crashes were analyzed. Most of the pedestrian crashes at signalized intersections were found at locations with high posted speed limits and high truck volumes. At signalized intersections, young pedestrians (less than 15 years old) were more likely to be involved in these incidents. For unsignalized intersections, most of the crashes occurred at places with poor lighting conditions (involving more seniors than young pedestrians). The authors also found that the presence of crosswalks at unsignalized intersections result in a 1.35% reduction in severe injuries for pedestrians.

Garder (2004) explored the relationships among pedestrian crashes, travel speeds, traffic volumes and road design. A total of 1,598 reported crashes were analyzed from the Maine Department of Transportation database (1994-1998). Crashes were analyzed based on the characteristics and conditions of the event (weather, gender, age, vehicle type, vehicle speed, location, etc.). Pedestrian and vehicle counts were recorded at 70 crosswalks at intersections and 52 midblock crossings to estimate volumes and exposure. Findings suggest that crash severity increases as vehicle speed increases.

When the vehicle speed is low, drivers are more likely to yield to pedestrians *(Katz et al. 1975)*. Wider roads are associated with higher speeds and higher pedestrian-vehicle crash frequency *(Garder 2004)*. Various authors suggest that a reduction in vehicle speed will reduce the frequency and severity of crashes *(Liu et al. 2011)* especially for vehicle-pedestrian crashes *(Walz et al. 1983, Anderson et al. 1997).*

Yannis et al. (2013) recorded video data at a mid-block crossing to explore pedestrians' traffic gap acceptance and decision to cross. A total of 243 events were studied. The authors found that the most important variable to explain pedestrian gap acceptance is the distance between the vehicle and the pedestrian. Other authors have found that faster approaching speeds increase gap size *(Cherry et al. 2012, Hine and Russell 1993, Brewer et al. 2006)*. Illegal parking and vehicle size also increased the accepted gap size.

Several authors have explored the factors that affect driver pedestrian law compliance. *Cheng et al. (2013)* explored the relationships between traffic delay and crossing pedestrian volumes, as well as pedestrian waiting times with traffic volumes. An unsignalized crosswalk was video-recorded at peak and off-peak hours on two different days. The total sample size was 1,608 pedestrian-vehicle interactions. Pedestrian waiting time increased as a function of traffic volume. Traffic conflicts between vehicles and pedestrians were serious when vehicle speeds were higher than 56 km/h (35 mph). *Schroeder and Rouphail (2011)* found that a driver is approaching a crosswalk at high speed levels is less likely to yield. Additionally, no yield events were found when the observed deceleration rate was above 10 ft/s^2. Data were collected at two unsignalized midblock crosswalks in North Carolina (two-lane cross) with heavy pedestrian and vehicle flows. Six hours of video were recorded and 1,074 driver-pedestrian interaction events were analyzed. Potential vehicle deceleration rates and approaching speeds were found to be good predictors of yield decisions. *Figliozzi and Tipagornwong (2016)* examined traffic and trajectory factors that affect driver and pedestrian law compliance in Oregon. An unsignalized intersection with a high number of crosswalk law violations was video-recorded and a total of 684 vehicles and 531 pedestrians were observed. Findings suggest that traffic characteristics and vehicle speed profile, speed and headway increases, may be more important to explain compliance than approaching speed.

Almodfer et al. (2016) explored the influence of waiting time on traffic conflicts. Data were collected at an unsignalized marked crosswalk with bidirectional traffic near a bus stop. Two cameras were used to record the crosswalk between 10:00 am and 2:00 p.m. on a weekday. A total of 5,749 cars, 617 buses, 186 bicycles, and 1,262 pedestrians were recorded and analyzed. The findings suggest that the number of conflicts decreases as waiting time increases based on the increase in vehicle flow. On the other hand, *Zhuang and Wu (2011)* found that pedestrians preferred crossing actively rather than waiting, resulting in more traffic conflicts.

Table 2.3 summarizes the studies that found significant results to explain pedestrian safety level based on traffic conditions. Several studies agree that an increase in traffic, pedestrian volume, vehicle speed, and VMT result in more pedestrian crashes (with higher severity).

Table 2.3: Pedestrian Safety and Traffic Conditions Summary

AUTHOR	PEDESTRIAN SAFETY LEVEL (1)				
	Traffic Volume	Pedestrian Volume	Vehicle Speed	VMT	Truck Volume
Guo et al. (2016)	↓				
Almodfer et al. (2016)		↓			
Niaki et al. (2016)		↓			
Figliozzi and Tipagornwong (2016)			↓		
Haleem et al. (2015)	↓		↓		↓
Liu and Tung (2014)			↓		
Strauss et al. (2014)	↓	↓			
Cheng et al. (2013)		↓	↓		
Yannis et al. (2013)	↓				
Abdel-Aty et al. (2013)				↓	
Garder (2004)			↓		
Schroeder and Rouphail (2011)			↓		
Zegeer et al. (2001)	↓	↓			
Yagil (2000)	↓				
Katz et al. (1975)			↓		

2.1.4 Road Characteristics

Zajac and Ivan (2003) explored the effect of roadway and area features on the severity of pedestrian crashes. Crashes were collected from the Connecticut Department of Transportation database for the period 1989 to 1998. The findings suggest that roadway width is strongly

[1] Due to the difference in dependent variables (gap acceptance, compliance rate, pedestrian crash frequency and severity) analyzed in the studies, we use the term pedestrian safety level to include these safety measures in one concept.

associated with pedestrian crash severity. Similarly, *Strauss et al. (2014)* and *Almodfer et al. (2016)* found that frequency of crashes increases as the number of lanes increase. *Himanen and Kulmala (1988)* found that the most important factors that explain pedestrian-vehicle conflicts are pedestrian distance from the curb and vehicle speed.

Abdel-Aty et al. (2013) analyzed zonal variation (traffic analysis zone, block group, census tract) and traffic safety and found that pedestrian crash frequency was higher on road segments with posted speed limits higher than 35 mph. Road segments with a posted speed limit of 65 mph are associated with severe crashes. *Lee et al. (2015)* found that roads with speed limits of 55 mph or above are statistically associated with high frequency of pedestrian crashes.

Another factor that was found to affect pedestrian safety at a significant level was lighting. The frequency and severity of vehicle-pedestrian crashes can be intensified by nighttime and the lack of lighting. A driver's ability to react to a risky event deteriorates with poor lighting conditions *(Elvik 1995)*. Pedestrian visibility is reduced at night, so drivers cannot engage in evasive actions when needed *(FHWA 2002)*. Drivers often see pedestrians at night only when they are within the safe stopping sight distance *(FHWA 2002)*.

Rea et al. (2010) explored the relation between lighting and driver visibility. Lighting simulations were conducted at a virtual intersection to investigate the visibility of hazards for a driver approaching the intersection at different speeds. The authors suggest that older drivers are likely to benefit more from high illumination levels on roadways than other age groups. *Elvik (1995)* explored the literature to find evidence on the effects of public lighting on traffic safety. Thirty-seven studies from eleven countries containing 142 results were meta-analyzed; 81% of the studies reviewed found that pedestrian safety improved after a lighting installation.

Niaki et al. (2016) used a SpectroSense 2+ (SKL 925) to collect illuminance data in areas with high pedestrian and bicycle crash rates. The authors found that lighting was associated with higher pedestrian and bicycle crash rates. The authors suggest that either (1) drivers at locations with bad lighting tend to be more cautious or (2) the lighting improvements have been made on streets with higher than average number of crash rates. The study is not without its limitations, since the number of crashes reported was very low and there was lack of data on nighttime flows of pedestrians, bicycles and vehicles.

Ole (2009) analyzed crash data on Dutch roads for the period of 1987-2006 to investigate the effect of road lighting on crashes. Ole found that lighting indeed had a significant safety risk reduction effect for pedestrians and cyclists. Specifically, lighting on roads decreased the risk of pedestrian and bicycle crashes by 54% and 66% respectively. Ole also found that the safety effect of road lighting is significantly reduced in adverse weather and road surface conditions. The authors also found that the safety effect of lighting was significantly greater at rural than at urban locations.

Most studies concurred that high speed limits, poor lighting conditions, and wide roads increase the frequency of pedestrian crashes. Table 2.4 summarizes the studies significant results to explain pedestrian safety level based on road characteristics.

Table 2.4: Pedestrian Safety and Road Characteristics Summary

AUTHOR	PEDESTRIAN SAFETY LEVEL				
	Posted Speed Limit	Poor Lighting	Arterial Road	Road Width	Number of Lanes
Almodfer et al. (2016)					↓
Wang et al. (2016)				↓	↓
Niaki et al. (2016)		↑	↓		↓
Lee et al. (2015)	↓				
Haleem et al. (2015)	↓				
Strauss et al. (2014)					↓
Abdel-Aty el al. (2013)	↓				
Rea et al. (2010)		↓			
Zegeer et al. (2001)					↓
Zajac and Ivan (2003)				↓	
Elvik (1995)		↓			
Ole (2009)		↓			

2.1.5 Safety Treatments

This section focuses on unsignalized crosswalks. Several traffic control treatments and countermeasures to modify drivers' speed behavior while approaching a pedestrian crossing were found to have a significant impact on pedestrian safety. Traffic treatments, such as raised medians, traffic and pedestrian signals, curb extensions, raised islands, tighter turn radii and lighting were found to reduce crash frequency and severity significantly *(Mead et al. 2014)*. Other countermeasures like flashing red lights and raised crosswalks have been shown to increase driver (and pedestrian awareness) and increasing yield rates *(Zegeer et al. 2001)*.

Bella and Silvestri (2015) explored driver's speed behavior while approaching a zebra crossing in the presence of several countermeasures intended to improve pedestrian visibility. The following countermeasures were considered: (1) advanced yield lines, (2) removal of parking, (3) curb extensions, and (4) in-pavement warning lights. The findings suggest that the countermeasures analyzed had a significant impact on driver behavior (yielding more frequently to pedestrians).

Curb extensions had the biggest impact on driver behavior (measured by the deceleration rate). Drivers speed decreased at a longer distance from the crossing when the curb extension was present. Zebra visibility improved by using the curb extension, allowing drivers to notice the pedestrian sooner. Additionally, the distance from the pedestrian crossing where the braking phase ends, is higher when curb extensions are present than that for advance yield markings.

Gates et al. (2016) found that traffic controls on crosswalks have a significant influence on driver behavior. Drivers yield to pedestrians more frequently, if a pedestrian hybrid beacon and a rectangular rapid-flashing beacon are present at the marked crosswalk. These results are supported in a study by *Sarkar et al. (2011),* which found that pedestrian crashes were more severe at locations with no traffic light or stop control than those occurring at signalized intersections.

Ardershiri and Jeijani (2014) explored the effect of dynamic speed display signs on driver compliance, on roads with posted speed limits. Speed readings were collected upstream and downstream of the dynamic speed display sign locations, on multiple roads with varying speed limits. The before (the implementation of dynamic display signs) and after condition were considered. The authors studied three corridors with 45, 35, and 25 mph speed limits. About 110,000 speed records were collected for 10 days. Dynamic speed display signs were found to be effective in reducing speeds near the displays.

Guo et al. (2010) explored driver's responses to parallelogram-shaped pavement markings as they were approaching pedestrian crosswalks. A treatment-control study was developed. Speed data were collected at twelve unsignalized midblock crosswalks (upstream and downstream from the treatment). Six of the intersections had parallelogram-shaped pavement markings (treatment group) while the other six did not (control group). A total of 10,000 speed observations were studied. The average crash frequency for the treatment group is statistically lower than the control group; fewer drivers exceeded the speed limit at treatment locations than at control locations.

Liu et al. (2011) identified how automated speed enforcement (ASE) affects speeds on rural highways in China. Speed data were collected at seven segments of three rural highways with posted speeds of 60 km/h (~40 mph), and 80 km/h (50 mph) for three months. Speeds of 13,000 vehicles were measured. The number of speed violation events were lower at locations near the ASE than at other sections of the road. Vehicle speed reductions were between 11.7 km/h (7.3 mph) to 15.7 km/h (9.8 mph) at the ASE influence area (400 meters from the ASE location).

Shurbutt et al. (2009) explored the effects of rectangular rapid-flash beacons (RRFBs) on marked crosswalks. Three experiments were designed to evaluate if significant differences exist at RRFB-controlled crosswalks compared to uncontrolled crosswalks. In the first experiment, eight crosswalks were studied. Pedestrian behavior was recorded by field observations. For the second experiment, the authors studied a before and after RRFB implementation approach at two locations. For the third experiment, the design was similar to the first experiment but instead 22 locations were studied and the treatment control crosswalks had an advance warning rapid-flash sign. After the RRFB installation, there is an immediate yield compliance increase from baseline to the seventh day, followed by a smaller additional increase on the 30th day and then a general trend line plateau. The average proportion of yielding compliance results for the two-beacon system and four-beacon system was 81% and 88% respectively, while the baseline was 18%.

Malkhamah et al. (2005) recorded data at a Pelican crossing on a busy main road in Leeds during a 5-year period. Data on pedestrian-vehicle conflicts and vehicle deceleration were collected by field measures, video recording, and by using 'system D' loops. Pelican crossings were not found to be safer than unsignalized crossings. Table 2.5 summarizes overall findings. Most of the treatments were found to decrease vehicle speeds and improve pedestrian visibility.

Table 2.5: Pedestrian Safety and Safety Treatments Summary

AUTHOR	SAFETY TREATMENT	PEDESTRIAN VISIBILITY	COMPLIANCE RATE
Bella and Silvestri (2015)	Curb extension	↑	↑
Bella and Silvestri (2015)	Advanced yield lines		↑
Bella and Silvestri (2015)	Removal of parking restrictions	↑	
Bella and Silvestri (2015)	In-pavement warning light		↑
Guo et al. (2016)	Pavement marking (parallelogram-shaped pavement marking)		↑
Ardeshiri and Jeihani (2014)	Dynamic display sign		↑
Liu et al. (2011)	Automated speed enforcement		
Schroeder and Rouphail (2011)	in-street pedestrian crossing sign	↑	↑
Schroeder and Rouphail (2011)	Pedestrian-actuated in-roadway warning lights	↑	↑
Shurbutt et al. (2009)	Rapid flash beacon	↑	↑
Malkhamah et al. (2005)	Pelican crossing	↑	↑
Zeeger et al. (2001)	Raised median	↑	↑
Zeeger et al. (2001)	Painted median	↑	

2.2 SURROGATE MEASURES

This chapter reviews and synthesizes published literature that focuses on surrogate measures of traffic safety. Surrogate measures do not utilize crash data. Instead, other (more frequent) events are analyzed to avoid crash data analysis shortfalls linked to rarity and spatial-temporal randomness of crashes. Surrogate safety measures can be divided into four main groups: Time-to-Collision (TTC), Post-Encroachment Time (PET), Deceleration-based surrogates, and mixed methods. These are further described below.

2.2.1 Time to Collision (TTC) Group

TTC is the time that it takes two vehicles to reach a common position if they continue to follow the same trajectory without changing speeds *(Hayward 1972)*. A lower TTC indicates a higher probability of collision. If TTC is lower than a threshold of 1.5 s, the vehicles are assumed to collide *(Horst 1991)*. In most cases, TTC is calculated with the assumption that road users' trajectories cross at a right angle or are parallel. *Hayward (1972)* suggested that time to collision (TTC) can act as a surrogate for crash frequency and severity *(Chin and Quek 1997)*.

Chin and Quek (1997) showed that useful results with TTC could be obtained if conflicts are defined and measured objectively and quantitatively. They also recognized that most surrogates depend heavily on human or advanced image processing to evaluate the data. *Vogel (2003)* recommended using headways to measure vehicle proximity and TTC to evaluate safety. Some authors have indicated that TTC is not a good measure of crash severity, as a lower TTC can indicate the probability of collision but not its severity *(Kruysee 1991, Tiwari et al. 1998)*. TTCs are difficult to measure in the field but can be quantified in simulation models.

There are many variations of TTC such as time exposed TTC (TET), time integrated TTC (TIT), and Time-to-Zebra (TTZ).

2.2.1.1 Time Exposed Time-to-Collision (TET)

TET measures the length of time for which all vehicles involved in a conflict are below a minimum TTC threshold, which separates a safe vs. an unsafe event *(Minderhound and Bovy 2001)*. Calculation of TET requires position and speed of vehicles entering a specified road section over a time period, from which trajectories and TTC can be identified *(Minderhound and Bovy 2001)*.

2.2.1.2 Time Integrated Time-to-Collision (TIT)

TIT measures the difference between a threshold TTC value (TTC*) representing a time interval in which collision is unavoidable and the observed TTC. It is calculated over the period it takes a vehicle to ride over a road segment, which reflects its exposure to collision *(Minderhound and Bovy 2001). Guido et al. (2011)* suggested that TIT identifies unsafe conditions more consistently than TTC.

2.2.1.3 Time to Zebra (TTZ)

TTZ is the time it takes for a car to reach a zebra crossing when a pedestrian begins crossing. It was proposed by *Várhelyi (1996)* as a variation of TTC which considers frequency and severity of a critical situation between vehicles and pedestrians approaching a crosswalk. Like other similar surrogates, TTZ requires the researcher to define when a conflict occurs, absent automated image processing software. TTZ can also be viewed as the conflict time during which the vehicle cannot brake safely before reaching conflict area where a pedestrian is exposed.

Várhelyi (1998) used TTZ to explore driver-pedestrian interactions at a crosswalk. The author hypothesized the measure could be used to find a safe crossing condition, defined as a scenario where the vehicle slows down on the driver's initiative to brake while approaching the crosswalk. The author observed that as vehicles approached the crosswalk, they tended to maintain speeds if a pedestrian was not present or speed up if a pedestrian was present at the beginning of the crosswalk. The author presumes drivers were speeding up to avoid having to slow down to yield to pedestrians.

2.2.2 Post-Encroachment Time (PET) Group

PET is the second most used traffic conflict indicator. PET is "the time between the first road user leaving and the second arriving at a common spatial zone" *(Allen et al. 1978)*. A PET value less than the predefined threshold is considered a conflict *(Songchitruska and Tarko 2004)*. A lower PET indicates a higher probability of collision. Although PET can be objectively measured, it is difficult to distinguish between a true conflict severity and the willingness of drivers to accept the risk *(Chin and Quek 1997)*. Furthermore, *Archer (2005)* suggested that PET is useful for measuring critical events where crossing trajectories for road users are involved. Estimating PET is easier than other metrics, as it does not need speed and direction assumptions.

A limitation of PET is that drivers at a right-angle may be able to enter the common spatial zone within a threshold value and never actually collide. To overcome this, *Laureshyn et al. (2010)* defined PET as the minimum detainment (in terms of seconds) needed for the leading driver to apply to result in a collision. This approach will help to overcome the assumption of measuring PET only when vehicles are approaching at a right angle. *Pirdavani et al. (2010)* used PET to evaluate motorized traffic safety at unsignalized intersections. *Almodfer et al. (2016)* proposed a lane-based PET to overcome the limitations of PET by considering a full lane as the potential conflict zone (small LPET values indicate high severity) in an unsignalized marked crosswalk. Conflicts with a LPET lower than 1 second were considered serious conflicts. This is consistent with *Archer (2005)* who proposed a PET maximum threshold of 1.5 seconds to distinguish between severe and non-severe conflicts. Results suggests that the number of conflicts per lane increases with distance from the departure curb. The surrogate measures denominated gap time (GT) and time advantage (TA) are closely related to PET.

2.2.2.1 Gap time (GT)

GT is the time difference (measured as a single value) between the arrival times of the involved vehicles at the point of crossing, if no evasive actions are taken by either vehicle *(Glauz and Migletz 1980)*. It is measured as the time of the first vehicle passing a spatial point and the front of the second car arriving at that point *(Laureshyn et al. 2010, Vogel 2002)*. Nonetheless, measuring this surrogate value is complicated if the two vehicles do not follow the same trajectory. GT performs worse than TTC because it only considers proximity between road users (not speed or acceleration).

2.2.2.2 Time Advantage (TAdv)

TAdv is an indicator to express the situations where two vehicles would crash if they pass through the same point at the same time *(Hansson 1975)*. Some researchers have described this measure as an extension of PET. While PET has a single value for an encounter (directly measurable), TAdv calculates PET for each moment assuming the road users would continue with the same speeds and paths *(Laureshyn et al. 2010)*. Like PET, this surrogate value is difficult to measure when the vehicles are not approaching at a right angle. One of the advantages of TAdv is that low values indicate safety concerns and higher values (above 2 seconds) describe normal traffic conditions *(Laureshyn et al. 2010, Hansson 1975, Hagring 2000).*

2.2.3 Deceleration Group

This group of surrogates is based on measuring or estimating deceleration rates necessary to avoid a collision.

2.2.3.1 Deceleration rate (DR)

DR is a measure of the highest rate at which a vehicle decelerates to avoid collision in response to other vehicle erratic maneuver *(Songchitruska and Tarko 2004)*. A higher DR indicates a higher probability of collision. *Malkhamah et al. (2005)* found that there was a strong relationship between vehicle deceleration and the severity of conflict for vehicle-pedestrian conflicts and Pelican crossings. The authors considered conflicts with deceleration rates of 6.0 m/s^2 or higher to be serious.

2.2.3.2 Deceleration rate to avoid a crash (DRAC)

DRAC is defined as the difference in speeds between a following and leading vehicle divided by their collision time. The leading vehicle is responsible for the initial action, while the following vehicle is responsible for the evasive action *(Almquist et al. 1991). Archer (2005)* highlighted that this indicator considers speed and deceleration in traffic flow. He suggests that a given vehicle is in a conflict if DRAC exceeds a threshold value of 3.35 m/s^2. This surrogate indicator may fail to reflect traffic conflicts because it does not consider vehicle braking capability and traffic conditions *(Cunto and Saccomanno 2008, Guido et al. 2011)*. Deceleration Rate to avoid a rear-end crash is calculated as follows:

$$\boldsymbol{DRAC_{FV,t+1}^{REAR}} = \frac{\left(\boldsymbol{V_{FV,t}} - \boldsymbol{V_{LV,t}}\right)^{\mathbf{2}}}{(\boldsymbol{X_{LV,t}} - \boldsymbol{X_{FV,t}}) - \boldsymbol{L_{LV,t}}} \tag{2-1}$$

(2-1)

Where *t* is the time interval, *X* is the position of the vehicle, *L* is the vehicle length and *V* is the velocity of the following (FV) and leading (LV) vehicles.

2.2.3.3 Proportion of stopping distance (PSD)

PSD is the ratio of the distance remaining to the projected collision point to the minimum acceptable stopping distance *(Songchitruska and Tarko 2004, Allen et al. 1978). Guido et al. (2011)* found that this indicator tends to be more sensitive to higher risk scenarios. The formulas associated with the Proportion of Stopping Distance (PSD) are:

$$PSD = \frac{RD}{MSD}$$

(2-2)

$$MSD = \frac{V^2}{2d}$$

(2-3)

Where *PSD* is proportion of stopping distance, *RD* is the remaining distance to the point of collision, *MSD* is the minimum acceptable stopping distance, *V* is the approaching velocity and *d* is the maximum acceptable deceleration rate.

The study by *Guido et al. (2011)* compared different crash surrogate measures in an urban roundabout setting using data collected from observing videotaped vehicle interactions. A total of 134 individual vehicle trajectories were analyzed with 176 virtual detectors, spaced 1 meter apart using the Trimble GPS Pathfinder ProXRT tracking system. The study found that DRAC's validity depends on the assumed deceleration rates.

2.2.3.4 Crash Potential Index (CPI)

Cunto and Saccomanno (2008) introduced the crash potential index (CPI) as a surrogate to improve upon DRAC by including the probability that the DRAC of a vehicle is higher than its braking capacity or maximum deceleration rate. This surrogate indicator has been used to evaluate signalized intersections.

2.2.4 Mixed Surrogates

Some researchers have combined TTC and deceleration based surrogates. The following section describes these combined measures.

2.2.4.1 Pedestrian Risk Index (PRI)

Cafiso et al. (2011) proposed the Pedestrian Risk Index to evaluate the potential severity of a pedestrian-vehicle conflict (time duration and severity). The index considers the behavior of both the driver and the pedestrian. A driver approaching a pedestrian crossing the street has two options: (1) accelerate to reach the conflict area before the pedestrian or (2) stop to allow the pedestrian to cross. PRI considers TTC values and the speed of the vehicle. The approach to analyzing the conflict is based on dividing the pedestrian-vehicle conflict into three phases: (1) stopping phase, (2) conflict phase, and (3) passing phase. Each instant of the conflict phase can be expressed in three temporal values and are formulated as follows:

$$TTC_i = \frac{D_{yi\,(v)}}{V_{i\,(v)}}$$

$$TTC_{i\,(p)} = \frac{D_{xi\,(v)} - D_{xi\,(p)}}{V_p} \qquad \textbf{(2-4)}$$

$$T_{si} = T_r - \frac{V_{i\,(v)}}{2a_b} \qquad \textbf{(2-5)}$$

(2-6)

Where:

- TTC_i is the time for the vehicle *i* to reach the pedestrian crossing
- $D_{yi\,(v)}$ is the distance between the vehicle and the ped. crossing at time *i*,
- $V_{i\,(v)}$ is the vehicle speed at time *i*,
- $TTC_{i\,(p)}$ is the time for the pedestrian to reach the conflict area,
- $D_{xi\,(v)}$ is the vehicle position at time *i*,
- $D_{xi\,(p)}$ is the pedestrian position at time *i*,
- V_p is the pedestrian speed,
- T_{si} is the stopping time at instant *i*,
- T_r is the reaction time of the driver. A reaction time of 2 seconds was chosen by *Cafiso et al.* (2011).

If the stopping time is less than the time for the vehicle to reach the pedestrian crossing ($TTC_i > T_{si}$), then the vehicle can come to a halt before the pedestrian crossing. If the contrary is true ($TTC_i < T_{si}$), then the vehicle cannot stop before the pedestrian crossing. When it takes less time for the pedestrian to reach the conflict area than for the vehicle to reach the pedestrian crossing ($TTC_i > TTC_{i\,(p)}$), the pedestrian will be exposed to a conflict with the vehicle. When the contrary occurs ($TTC_i < TTC_{i\,(p)}$), the pedestrian is not in conflict because the car has passed the pedestrian crossing area.

A conflict occurs when $TTC_{i(p)} < TTC_i < T_{si}$. If a conflict occurs, the following formulas can be used to determine the Pedestrian Risk Index where:

$$V_{impact,i} = \sqrt{V_{i(v)}^2 - 2a_b * \left(D_{yi(v)} - V_{i(v)} * T_r\right)} \qquad \textbf{(2-7)}$$

$$PRI = \sum_{TTZ_{duration}} V_{impact,i}^2 * (T_{si} - TTC_{vi})$$

(2-8)

- $TTZ_{duration}$ is the time in the interval of $TTC_{i(p)} < TTC_i < T_{si}$
- $V_{impact,i}$ is the collision speed at instant *i*
- $V_{i(v)} * T_r$ is the distance travelled during the perception reaction time
- a_b is the braking deceleration

Cafiso et al. (2011) examined this surrogate in a crosswalk in Valencia, Spain. The findings suggest that these surrogates are useful to evaluate traffic safety at pedestrian intersections before and after improvements.

2.2.5 Pros and Cons of Surrogate Safety Measures

Allen et al. (1978) conducted one of the first studies comparing the effectiveness of surrogate measures. *Gettman and Head (2003)* compared various surrogate measures and made recommendations as to their relative ease of use for simulation experiments. *Hunter and Rodgers (2012)* evaluated surrogate measures for conducting safety analysis at rural multi-lane facilities and considered the potential drawbacks of many of the surrogates discussed in the previous section. For example, they found that collecting deceleration profiles was both an equipment and labor-intensive process. Table 2.6 summarizes key advantages and disadvantages of the surrogates discussed previously.

Table 2.6: Advantages and Disadvantages of Crash Surrogates

CRASH SURROGATES	ADVANTAGE	DISADVANTAGE
TTC (Time-to-collision)	• Manifests in virtually every driving scenario, ideal for transferability	• Users with no probability of collision will have a TTC value associated to them
TET (Time-exposed-TTC)	• Considers conflicts over a segment	• It is not useful for users not on a collision course • Fails to capture TET values below threshold values
TIT (Time-integrated-TTC)	• Identifies more unsafe conditions than TTC and TET	• It is not useful for users not on a collision course
TTZ (Time-to-zebra)	• Uniquely focused on pedestrian-vehicle conflicts at crossings	• Post-processing required if image processing not automated
PRI (Pedestrian Risk Index)	• Considers severity with TTZ	• Requires additional post-processing
PET (Post-encroachment time)	• Commonly used at intersections	• It is not useful for users not on a collision course • PET fails to identify all cases of near-crash events • Not useful on a highway segment
TAdv (Time Advantage)	• Low values indicate safety concerns and high values indicate normal conditions • Calculates PET continuously	• Not commonly used in safety research • PET equals 0 when on collision course
GT (Gap Time)	• Good for vehicles with a common trajectory	• Based on proximity, meaning it does not work well for vehicles with different trajectories
PSD (Proportion of stopping distance)	• Measures severity	• Difficult to measure • Lowest “collection desirability” (Allen et al. 1978)
DR (Deceleration Rate)	• Measures severity	• Excessive braking maneuvers can reduce reliability
DRAC (Deceleration rate to avoid crash)	• Widely used • Recognized by AASHTO	• Assumes one vehicle takes evasive action • Relatively more difficult to collect
CPI (Crash Potential Index)	• Broadly used to evaluate the road risk in safety analysis • Considers vehicle’s braking capacity	• Uses DRAC as arbitrary boundary setting • Relatively more difficult to collect
DST (Deceleration to safety time)	• Precise in pedestrian-vehicle conflicts (questionable)	• Not studied thoroughly

2.4 TRAFFIC CONFLICT STUDIES

Traffic Conflict Techniques (TCTs) are methodologies for studying traffic conflicts that usually involve on-site data collection carried out by trained observers; "A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" (Guttinger 1984). While several methodologies have been developed based on this definition, one of the best known methodologies to study traffic conflicts is the Swedish Traffic Conflict Technique (STCT). Sweden has a long tradition pioneering innovative safety studies and techniques.

Traffic conflict studies can be ideal for any of the following situations (InDev 2016):

1. Estimation of safety of sites where crash data is not sufficient.

2. Investigating the factors contributing to dangerous behavior to complement a crash analysis study.

3. A relatively expeditious evaluation method to evaluate safety improvements before-and-after conditions.

Traffic conflict studies can measure severity in either a subjective or objective manner. Subjective methods are associated with significant variability among trained observers as well as among different days (Hauer 1978).

2.4.1 Traffic Conflicts and Crash Severity

Traffic conflicts may have an associated level of severity based on how close a conflict was to becoming a crash. There is also a known relationship between the closeness of a crash occurring and the frequency of crashes. This concept was described by Hydén (1987) with the "safety pyramid" (Figure 2.1). The severity of conflicts is commonly ranked by indicators based on temporal or spatial dimensions, such as Time-to-Collision (TTC) or Proportion of Stopping Distance (PSD).

A conflict can eventually become a collision or remain a near-miss. The theoretical relationship between the outcomes of traffic interactions was proposed by Hauer and Gärder (1986) and can be defined as:

$$\boldsymbol{\lambda = \sum c_i * \pi_i}$$

(2-9)

Where ci is the expected number of conflicts and πi is the crash-to-conflict ratio for each severity category i.

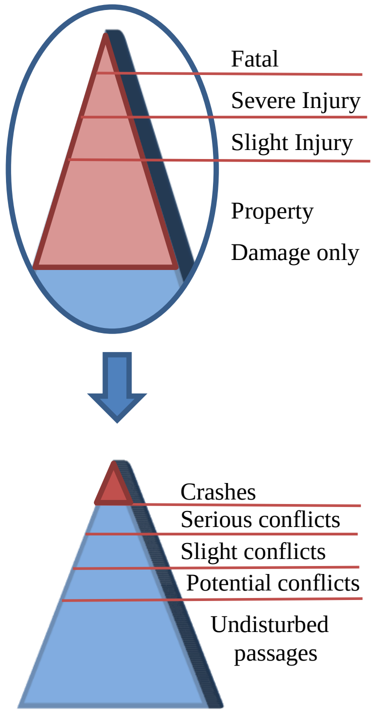

Figure 2.1: Safety pyramid based on *Hydén* (1987)

2.4.2 Swedish Traffic Conflict Technique

In the Swedish Traffic Conflict Technique (STCT) method, the severity of a conflict is quantified based on time to accident (TA) and conflicting speed (CS). TA is the time from when a road user reacts until when a collision would have occurred. CS is the speed when the road reacts to a near miss. STCT was proposed for use in traffic engineering at Lund University in Sweden in the 1970s. In the 1980s many tests were conducted to validate the method.

Hydén (1977) studied the threshold values of TA through field observations and found that less than 1.5 seconds represented serious conflicts. *Garder (1982)* explored the applicability of this method in rural environments *(InDev 2016)*. Garder proposed the following speed dependent relation to classify conflicts into serious and non-serious conflicts:

$$\boldsymbol{TA = \frac{1.5V}{16.7e^{-0.148V}} \quad (V\ in\ m/s)} \tag{2-10}$$

Figure 2.2 shows the curve of the aforementioned speed dependent relation with a safety margin of 0.5 seconds.

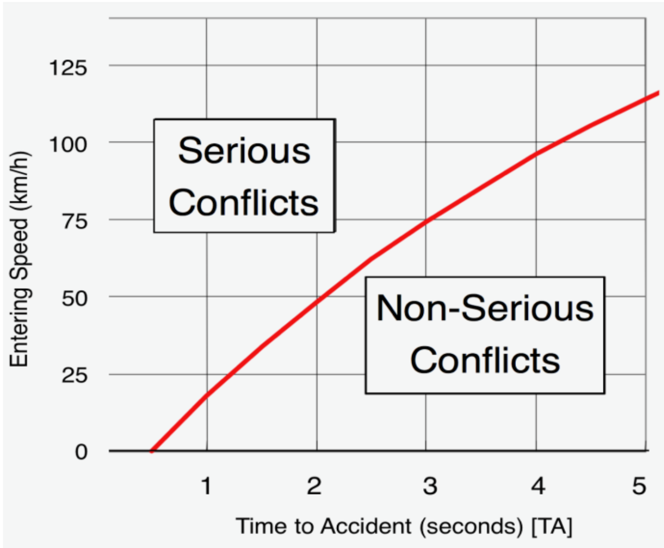

Figure 2.2: Speed dependent relationship dividing serious and non-serious conflicts (adopted from *InDev* (2016))

Hydén and Várhelyi (2000) used the Swedish Traffic Conflict Technique to evaluate the long-term safety effects of roundabouts. The authors used these variables to compute the severity level using Figure 2.3.

This method employed 30-hour observation periods per intersection and was conducted by trained observers on site. It was found that while the number of conflicts between vehicles increased, those involving pedestrians and bicyclists decreased. The results confirmed the exponential relationship between the reduction in mean speed and the reduction in the number of predicted injury crashes *(Hydén and Várhelyi 2000)*.

Overall, the STCT is useful for academic research where volunteers can be recruited as trained observers, but may not be practical as a procedure to use to evaluate roadways on a regular basis.

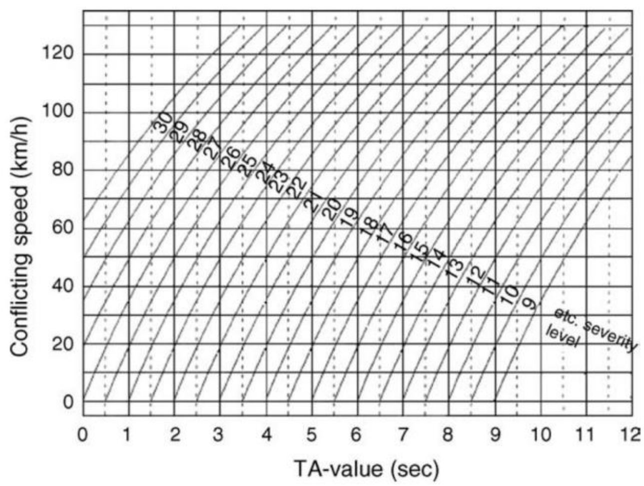

Figure 2.3: **Graphs used to determine severity level with STCT (Source: *InDev (2016)*)**

2.4.3 Traffic Conflicts and Crash Rates

The reviewed literature indicates that exposure has an influence on traffic conflict frequency. Exposure refers to the frequency of traffic events that create a risk of crashes (Carroll 1973). For example, a measure of exposure for motorized vehicle crashes is vehicle miles traveled or AADT. At a zonal level, Hauer (1982) suggested using the number of crossings as a measure of pedestrian exposure. Nilsson (1978) defined pedestrian exposure as the square root of the product of the volume of pedestrians per hour and the number of motor vehicles per hour that may experience a traffic conflict.

Sayed and Zein (1999) used the traffic conflict technique and data collected from 94 conflict studies (52 signalized and 42 unsignalized intersections) to develop predictive models, relating the volume of traffic to the frequency of motorized traffic conflicts, at signalized and unsignalized intersections in urban and suburban settings. The researchers used a subjective severity rating scale commonly applied in traffic conflict techniques, whereby the severity of observed conflicts are rated from 1 to 6. The regression models indicated the average hourly conflict (AHC) and average hourly severe conflict rate (AHC4+) correlated with the traffic volumes observed at the intersections under study. AHC refers to the total number of observed conflicts at an intersection divided by the number of observation hours. AHC4+ refers to the total number of severe conflicts observed (conflicts with a total severity score of four or greater) divided by the number of observation hours. At unsignalized intersections, the models developed were the following:

$$\boldsymbol{AHC = -0.50 + 6.15PEV} \tag{2-11}$$

$$\boldsymbol{AHC\,4+ = -0.21 + 1.75PEV} \tag{2-12}$$

Where *PEV* is the square root of the product of entering vehicles.

Sayed and Zein (1999) found that these models explained for 69% and 65% of the variation in *AHC* and *AHC4+*, respectively.

Guo et al. *(2010)* recorded high-resolution naturalistic driving method data for crashes and near-crashes. A near crash event was identified using a combination of vehicle kinematic measures and visual evaluation of the severity of the events. A crash was measured as a combination of all the conditions necessary for a crash to happen. The authors found a positive relationship between crashes and near crashes, with no significant difference between the causal factors of such events.

Wu and Jovanis (2012) proposed a methodology to relate surrogates to crashes, as the likelihood that a surrogate event evolves to a crash, taking into consideration non-observable variables. A non–crash event is "any circumstance that requires a rapid evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive maneuver is defined as a steering, braking, accelerating or any combination of control inputs that approaches the limit of the vehicle capabilities" *(Klauer et al. 2006)*. In their study, the findings revealed that driving on the wet surface or high acceleration rate events (greater than 0.7 g) are more likely to result in a crash. This approach was also followed by Svensson *(1998)*. He suggested that a statistical association between conflict and crash should include cases of non-zero likelihood of a crash, otherwise, the crash probability may be underestimated.

El-Basyouny and Sayed (2013) developed a negative binomial regression model that included the exposure, area (urban, rural) and presence of right-turn lanes. Urban area was associated with an increase in crashes and presence of right-turn lanes was associated with a decrease in traffic conflicts. The following is the final negative binomial safety performance function:

$$\boldsymbol{ln(\theta_i) = ln(\alpha_0) + 0.711\,ln(PEV) + 0.656(Area) - 0.318(RT_2)} \tag{2-13}$$

where θ_i is the expected number of average hourly conflicts, α_0 is the intercept, PEV is the square root of the product of entering volumes, area refers to if the context is urban and RT is the presence of a right-turn lane in the minor approach. Figure 2.4 visualizes a right-turn lane on the minor approach.

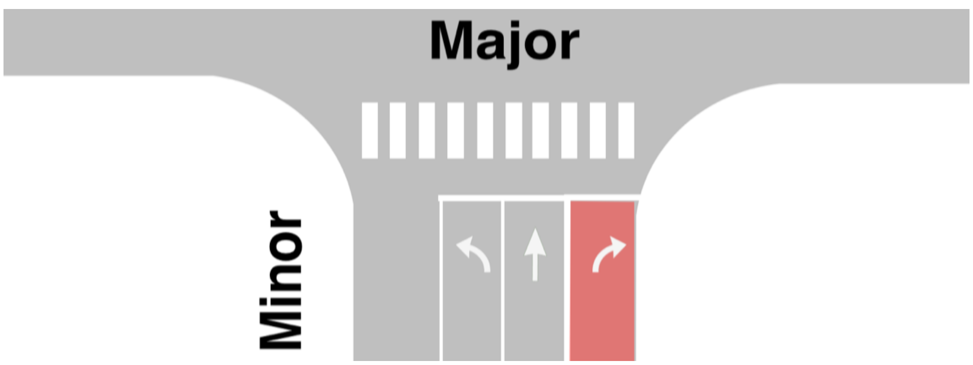

Figure 2.4: Example of presence of right-turn lane on the minor approach

Zhao et al. (2011) analyzed the conflicts at signalized intersections with permissive right turn on red. They found that vehicle flow, pedestrian flow and right-turn radius affect the number of conflicts. Severe conflicts (defined as when both vehicle and pedestrian stop within 0.5 meters of each other) were observed when pedestrian flows and vehicular flows were lowest, while more conflicts in general were observed with increases in pedestrian and vehicular flows.

While many traffic conflict studies have been conducted at controlled locations, few studies were found on traffic conflicts at uncontrolled locations. *Bowman and Vecellio (1994)* investigated pedestrian conflicts at raised median, two-way left turn lanes (TWLTL) and undivided arterials in built-up areas and found no statistical difference between conflict rates observed at urban and suburban locations. More research is needed on the factors that influence traffic conflicts at uncontrolled locations.

Other studies have not found a strong relationship between traffic conflicts and crashes *(Tarko 2012)*. *Tiwari et.al. (1999)* compared crashes and conflicts for non-motorized vehicles and motorized vehicles at 14 mid-block locations in Delhi, India. Correlation coefficients for traffic conflicts and crashes for interactions between motorized vehicles and non-motorized vehicles were low. The authors acknowledged the correlations coefficient were low because the crash surrogates used in the study were not suitable for the driving behavior in Delhi. *Glennon et.al. (1977)* and *Williams (1981)* were not able to find a relationship between crashes and conflicts. This was attributed to the lack of a standard operational definition for traffic conflict concept.

Hauer and Garder (1986) suggested that traffic conflicts should be used to evaluate levels of safety rather than being used to predict crashes or evaluate surrogates.

2.5 PEDESTRIAN SAFETY INDICES

This section reviews studies that assess safety at pedestrian facilities (segments and intersections) based on variables that can be readily measured in the field. Although the variables can be mostly measured in field visits, the estimation of these models (especially regression models) require data/observation from many sites (control and baseline locations) or the recruitment of numerous volunteers that can evaluate videos or photographs of distinct pedestrian facilities.

2.5.1 Point System Approach

The point system rates pedestrian facilities to assess the overall pedestrian safety. Different variables are considered in this estimation, contributing differently to the final pedestrian score. Additionally, this tool is accessible to non-technical personnel, who can follow a guideline or a check list while evaluating a facility. The point system can be adjusted for different contexts, however, there is no rigorous method to estimate the weight of the indicators which may result in biased results.

Dixon (1996) evaluated the Gainesville pedestrian level of service (PLOS) by testing it on five arterials and one collector highway with mixed results. Table 2.8shows the variables used for the estimation of PLOS. *Asadi-Shekari et al. (2013)* reviewed a total of 17 studies to explore indicators and variables that are effective to promote pedestrian mobility. The authors found that most of PLOS models treated pedestrians as vehicles. For example, The Highway Capacity Manual (HCM) considers volume and speed to calculate PLOS, however, different authors have criticized this methodology because it does not include the walking environment *(Asadi-Shekari et al. 2015, Singh and Jain 2011)* or characteristics of disabled pedestrians, seniors and children *(Asadi-Shekari et al. (2013). Asadi-Shekari et al. (2015)* proposed the Pedestrian Safety Index (PSI), a point system capable of comparing existing conditions to a standard. A total of 24 factors (slower traffic speed, buffer and barriers, fewer traffic lanes, shorter crossing distance, mid-block crossing, landscape and trees, footpath pavement, crosswalk, pedestrian refuge and median, corner island, sidewalk on both sides, advance stop bar, driveway, lighting, signing, bollard, slope, lift, curb ramp, tactile pavement, warning, ramp, grade and signal) were identified from 20 guidelines reviewed by the authors.

Sarkar (2002) developed two methods to estimate PLOS based on perceived pedestrian comfort (physical and psychological). The authors reviewed 30 studies to identify the physical and psychological factors that affect pedestrian mobility. *Miller et al. (2000)* developed a 3D visualization tool to validate and calibrate PLOS in suburban areas. The road and crosswalk characteristics that were evaluated include presence of: medians, signalized intersections, blinking pedestrian crossing signals, raised or colored crosswalks, lighting conditions, handicapped access ramps and speed limit. A total of 56 volunteers were asked to rate different pedestrian facilities from A to E. The facilities were ranked based on animations and illustrations generated by the 3D visualization model.

One of the main drawbacks of the point system approach is the arbitrariness on how to assign weights to each term of the model. Table 2.8 presents the studies reviewed and the different variables used to develop the models. Because some variables were more important (based on their weights) than others while estimating pedestrian safety (PSI or PLOS), Table 2.7 reveals the importance rank. A variable with a rank of 1 means that it was the most important term in the model (e.g. sidewalk width was the most important term in Sarkar's study). Importance rank was color coded for better understanding:

Table 2.7. Importance Rank and Reference Color

IMPORTANCE RANK	
1 (most important)	
2	
3	
4	
5-17	

Some studies gave the same weight to all the variables *(Sarkar 2002),* while others had different weights for different variables *(Asadi-Shekari et al. 2015).*

2.5.2 Regression Approach

The regression approach is a tool used by researchers to estimate the statistical association between characteristics of the pedestrian facility and pedestrian safety (e.g. measured by pedestrian crash frequency). The outcome of this method is a formula that can be used by practitioners and non-technical stuff to assess a pedestrian facility. One of the main disadvantages of this methodology is its potential lack of replicability and transferability.

1000 Friends of Oregon (1993) examined the relationship between travel behavior and land use patterns. As a part of the project, the authors estimated the Pedestrian Environment Factor (PEF), which is an indicator of street pedestrian friendliness. Travel behavior data were collected from an interview survey. Four variables were found to increase the PEF index: ease of street crossings, sidewalk continuity, local street characteristics (grid vs. cul-de-sac) and topography. Ease of street crossings was measured at key intersections, collecting crosswalk/sidewalk width, extent of signalization and traffic volumes.

Landis et al. (2001) placed people in different roadway types (collectors, arterial and local streets) and conditions (traffic volumes between 200 to 18,400 AADT; vehicle speed between 25 to 125 km/h) to evaluate their response and opinions on their perception of pedestrian safety and comfort. A total of 75 people rated the facilities on scale of A to F resulting in 1,250 observations. The findings suggest that the lateral separation between vehicle and pedestrian facilities, traffic volume and speed are significant predictors of perceived pedestrian level of service. *The Florida Department of Transportation (FDOT)* (2009) followed the *Landis et al. (2001)* methodology to develop a PLOS model. A total of 1,315 real-time observations in Pensacola were analyzed to estimate the model. The authors only examined the statistically significant terms found by *Landis et al. (2001)*: existence of a sidewalk, lateral separation of pedestrians from motorized vehicles, traffic volumes and vehicle speeds.

Table 2.8: Key Studies on Pedestrian Safety Index from the Point System Approach

MODEL TERMS	ASADI-SHEKARI ET AL. (2015) *% PSI(²)*	SARKAR (2002) *PLOS*	DIXON (1996) *PLOS*	MILLER ET AL. (2000) *PLOS*
Buffer and barriers (min width for curb is 0.15 m and min height 0.10-0.15 m)	1		1	
Presence of sidewalk on both sides and	1			
Sidewalk width	1	1	1	
Presence of trees (Trees should be at least 7.6 m far from intersection)	2		3	
Traffic speed (arterials =60-80 km/h. Locals = 40-50 km/h)	3		4	1
Slope (<2%)	4			
Midblock crossing (not farther apart than 60-90 m. min width = 3 m)	5			
Footpath pavement condition	5			
Pedestrian refuge (min width = 1.8 m. min length = 6 m) and median (min width = 1.8 m. max height = 0.22 m)	5		2	
Presence of lighting	6		3	1
Curb ramp (min top landing = 1.2 x 1.2 m. max slope = 2%)	6			2
Crossing distance	7			
Signal (delay of 40 sec or less. Audible signal)	8		2	2
Presence of signing	9			
Driveway (3.6 m < width < 7.5 m)	10		2	
Marked crosswalk (min with = 3 m. desirable width = 5 m)				1
Presence of bollards				
Traffic lanes (arterial = up to 6 lanes. Local = 2 lanes)				
Presence of tactile pavement (warning)				
Presence of corner island				
Ramp (min width = 1.2 m. Max slope = 8.3%)				1
Presence of advance stop bar			2	
Presence of tactile pavement (guiding)				
Presence of lifts at bridges				
Presence of shelter		1		
Attractive pedestrian destinations (e.g. presence of restaurants, parks and seating)		1		1

[2] PSI % was measured on a scale from 0% to 100%. A pedestrian facility with a score of 100% was rated as A.

Zegeer et al. (2006) developed a pedestrian safety index value for intersections only. The authors gathered data on intersection characteristics and pedestrian safety (frequency of crashes) to estimate their association, which was used to produce the pedestrian index. Additionally, a panel of experts rated the facilities based on their perceived degree of safety. A total of 68 intersections (42 of them were signal controlled) were selected in Miami, Philadelphia and San Jose for the analysis. The findings suggest that commercial area was a significant factor in the pedestrian safety index. Factors that provide pedestrian priority, such as stop and signal controlled crossing were also significant. Additionally, high speeds and volumes were found to affect negatively the pedestrian index.

Petritsch et al. (2006) included traffic volumes to control for exposure in their PLOS model. Approximately 100 subjects walked through different pedestrian facilities (3 miles long, including segments and intersections) while the researcher's collected real-time responses. The participants carried a scorecard during the walk, where they could score a facility from A to E, with A being the best score. The subjects walked through different land uses, road configurations (two, three, or four lane roadways), traffic volumes and crossed intersections (some with medians) up to six lanes. The authors studied proximity to travel lanes, perceived conflicts at intersections, perceived threat exposure when crossing and delay at intersections. Only crossing width and traffic volume were good predictors for PLOS score perceived by the subjects.

The *NCHRP (2008)* conducted a study to develop a multimodal level of service. The authors identified key factors that influence pedestrian levels of service and then evaluated them to estimate a new PLOS model. A total of 145 people watched between 26 and 35 video clips of typical urban streets and intersections. Then the participants were asked to rate the facility on a scale from A to F, being A defined as the best score. The authors developed a PLOS model based on two models, one PLOS for segments and another for intersections. Table 2.9 includes the findings for the PLOS intersection model.

Statistically significant variables and their coefficients for the different models reviewed are presented in Table 2.9. Three of the four models estimated PLOS from traffic conditions and characteristics of the road. PLOS rates ranges from A to F, being A the highest rank. The authors quantified this scale to a scale from 1 to 6 (Table 2.10) for modeling purposes. The traffic volume variable was based on the average traffic during a 15 minute period for the studies by *Landis et al. (2001), FDOT (2009), and Petritsch et al. (2006).*

Table 2.9: Key Studies on Pedestrian Safety Index Based on the Regression Approach

MODEL VARIABLES	ZEGEER ET AL. (2006) *PSI([3])*	LANDIS ET AL. (2001) *PLOS*	FDOT (2009) *PLOS*	NCHRP (2008) *PLOS*	PETRITSCH ET AL. (2006) PLOS
Signal controlled crossing (1=yes)	-1.821				
Stop sign-controlled crossing (1=yes)	-1.83				
Number of through lanes on street being crossed	0.368			0.681	
Traffic speed (mph)	0.368	0.0005	0.0004	0.00013([4])	
Traffic volume (ADT)	0.018	0.253	0.0091		0.008
Predominant land use on surrounding area (commercial =1)	0.221				
Presence of a sidewalk and lateral separation elements ([5])		-1.2021	-1.2276		
Total width of crossing at conflict locations (feet/mi)					0.001
Sum of the number of right-turn-on-red vehicles and the number of motorists making a permitted left turn in a 15-minute period				0.00569	
Pedestrian delay (sec)				0.0401	

[3] Pedestrian Safety Index was measured on a scale of 1 to 6. A rating of one was given if the subjects felt very comfortable walking
[4] Product of speed and the traffic in the outside through lane of the street being crossed
[5] Width of outside lane (feet), width of shoulder or bike lane (feet), on-street parking effect coefficient (=0.20), percent of segment with on-street parking, buffer area barrier coefficient (=5.37 for trees spaced 20 feet on center), buffer width (feet), width of the sidewalk (feet)

Table 2.10: Pedestrian Level of Service (PLOS) categories

PEDESTRIAN LEVEL OF SERVICE	MODEL SCORE
A	<= 1.5
B	> 1.5 and <= 2.5
C	> 2.5 and <= 3.5
D	> 3.5 and <= 4.5
E	> 4.5 and <= 5.5
F	> 5.5

2.6 SUMMARY AND DISCUSSION

The extensive literature review indicates that variables related to (1) pedestrian behavior and socio-demographic characteristics, (2) land use types, (3) traffic characteristics, (4) road characteristics, and (5) safety treatments are strongly linked to pedestrian safety.

For the purposes of this research project, the reviewed surrogate measures present useful insights but cannot be readily estimated during a quick site visit and/or without major staff and post-processing support (requiring specialized software or video analysis techniques). To satisfy ODOT requirements existing surrogates will have to be streamlined and simplified. The most promising surrogates are based on a simplified estimation of conflict rates. Surrogates that are mostly based on detailed analysis of each interaction or using time to collision or post-encroachment times are likely too complex for the purposes of this research effort. Pedestrian safety indices may be easier to apply after a field visit but it is onerous and difficult to estimate unbiased or relevant weights.

For the purposes of this research project, it is concluded traffic conflict techniques provide useful insights and may be adapted so they are readily estimated during a site visit and/or without major staff and post-processing support.

3.0 CRASH AND EXPOSURE ANALYSIS

In this chapter, Oregon pedestrian-vehicle crashes in the 2007-2014 period iss studied to identify trends or patterns. The first part of the chapter studies general trends with a focus on pedestrian crashes at controlled and uncontrolled intersections. The second part of the chapter focuses on trends that take into account exposure (at least regarding motorized traffic exposure).

3.1 PEDESTRIAN-VEHICLE CRASHES AT CONTROLLED AND UNCONTROLLED INTERSECTIONS

In the previous chapters the authors found that several researchers have linked pedestrian safety to factors such as pedestrian and driver characteristics, location, traffic conditions, road and crosswalk characteristics, and safety treatments. The key variables are shown in Table 3.1 along with a marker that shows what variables are included in the following crash data analysis. Some variables were not included in the analysis because they were not available in the crash dataset. First, descriptive statistics regarding pedestrian crash frequency, location, and temporal distributions are presented. Next, the crash data are summarized by variables listed in Table 3.1.

Table 3.1: Variables from the Literature Review Included in the Analysis

CATEGORY	VARIABLE	INCLUDED IN CRASH DATA ANALYSIS?
Pedestrian and driver characteristics	Gender	YES
	Age	YES
	Group size	- no -
	Crossing with a child	- no -
	Using a cellphone	- no -
	Income level	- no -
	Minority group	- no -
Location characteristics	Land use	YES
	Population	YES
	Employment density	YES
	Mode share	- no -
	Road density	YES
	Intersection density	YES
Traffic conditions	Traffic volume	YES
	Pedestrian volume	- no -
	Vehicle speed	- no -
	VMT	- no -
Road characteristics	Posted speed limit	YES
	Light condition	YES
	Road type	YES
	Road width	YES
	Number of road lanes	YES
Crosswalk characteristics	Intersection type	YES
	(controlled vs uncontrolled)	YES
Safety treatment	Safety treatment type	YES

Data were grouped by controlled and uncontrolled intersections based on the traffic control device information available at the crash level. If a crash occurred at a location without any control (as stated on the police report), it was grouped in the uncontrolled category. If the crash occurred at a location with any type of traffic control[6], then it was grouped in the controlled category. Crash information is presented as a percentage of the variables assessed. The percentage in each column for each table in this section adds up to 100%

Furthermore, crashes were grouped by location, urban or rural. Crashes that occurred on a road inside a Federal Urban Area Transportation Boundary (FAUB) are considered "urban". All

[6] This includes: traffic signal, flashing beacon, stop sign, slow sign, regulatory sign, yield sign, warning sign, curve sign, school crossing sign, police officer, flagman, school patrol, bridge gate-barrier, temporary barrier, no passing zone, one way street, channelization, median barrier, pilot car, special pedestrian signal, crosswalk, through green arrow or signal, left/right turn green arrow (or lane markings), wigwag or flashing lights without drop arm gate, advance warning, flashing lights with drop arm gates, supplemental overhead sign, illuminated grade crossing, metered ramps, rumble strip, left turn refuge, right turn at all times sign, emergency signs, acceleration or deceleration lanes, right turn prohibited in red after stopping, bus stop sign.

others are considered rural, even in areas with populations greater than 5,000 *(Oregon Department of Transportation 2014*). The location of the road was given by its functional classification (for more detail, go to Table 3.12).

3.1.1 General Trends

A total of 371,129 crashes occurred in the State of Oregon between 2007 and 2014, with 6,162 (1.7%) involving pedestrians but pedestrians represent approximately 15% of the fatalities (for example, in 2014 356 persons were killed in crashes and 56 were pedestrians). Of these crashes, 3,629 occurred at intersections with 3,349 crashes which occurred at controlled (92.3%) and 280 at uncontrolled intersections (7.7%). Additionally, more than 96% of the crashes at intersections occurred in urban areas. Table 3.2 shows the proportion of crashes at intersections for each year of analysis. The percentage in each row adds up to 100%.

Table 3.2: Statewide Pedestrian Crashes by Controlled/Uncontrolled Intersections and Year

YEAR	LOCATION TYPE	NUMBER OF CRASHES	CONTROLLED	UNCONTROLLED
2007	Urban	(n=284)	93.7%	6.3%
	Rural	(n=14)	92.9%	7.1%
2008	Urban	(n=308)	92.5%	7.5%
	Rural	(n=14)	85.7%	14.3%
2009	Urban	(n=358)	91.3%	8.7%
	Rural	(n=13)	46.2%	53.8%
2010	Urban	(n=451)	89.1%	10.9%
	Rural	(n=9)	88.9%	11.1%
2011	Urban	(n=477)	92.7%	7.3%
	Rural	(n=23)	87.0%	13.0%
2012	Urban	(n=541)	93.2%	6.8%
	Rural	(n=23)	91.3%	8.7%
2013	Urban	(n=503)	91.5%	8.5%
	Rural	(n=24)	91.7%	8.3%
2014	Urban	(n=571)	96.1%	3.9%
	Rural	(n=16)	75.0%	25.0%

*considering only intersections

Figure 3.1 shows the temporal distribution of pedestrian crashes by time of day and day of week across Oregon. Darker cells represent higher frequency of crashes. Majority of the crashes occurred primarily during the later afternoon to early evening hours (between 3:00 p.m. to 6:00 p.m.) on weekdays, which corresponds with the PM peak hour in many locations. The number of crashes during a portion of morning peak hour (7:00 am) was also high during weekdays. These findings can be attributed to the exposure of pedestrians to higher volumes of traffic during the peak hours.

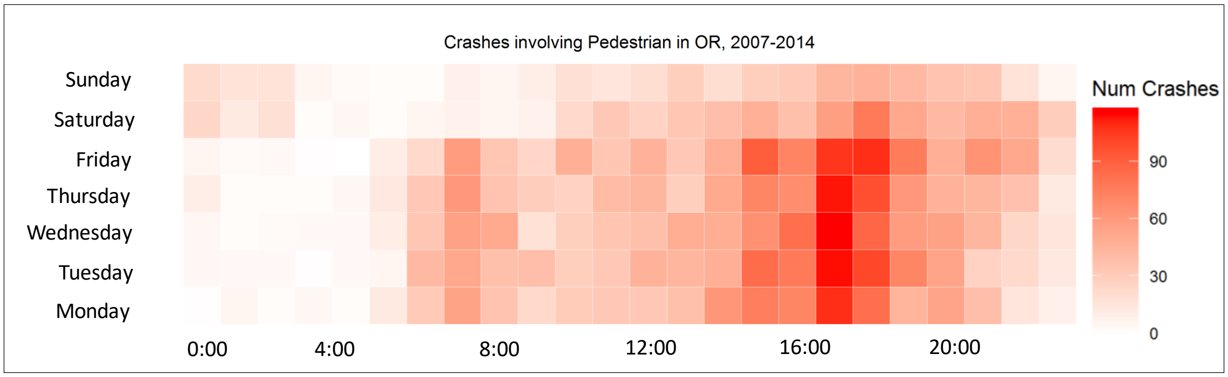

Figure 3.1: Statewide temporal distribution of pedestrian crashes

Figure 3.2 shows the number of pedestrian crashes by month and time of the day. Dark cells represent temporal events (by month and time of the day) when most of the crashes occurred. Most of the crashes occurred between the months of November and February during the evening (5:00 p.m. to 6:00 p.m.) when light availability is low. This finding is consistent with The ODOT Pedestrian and Bicycle Safety Implementation Plan *(Kittelson & Associates, Inc. 2014*) findings, where the number of pedestrian crashes increased between October and March.

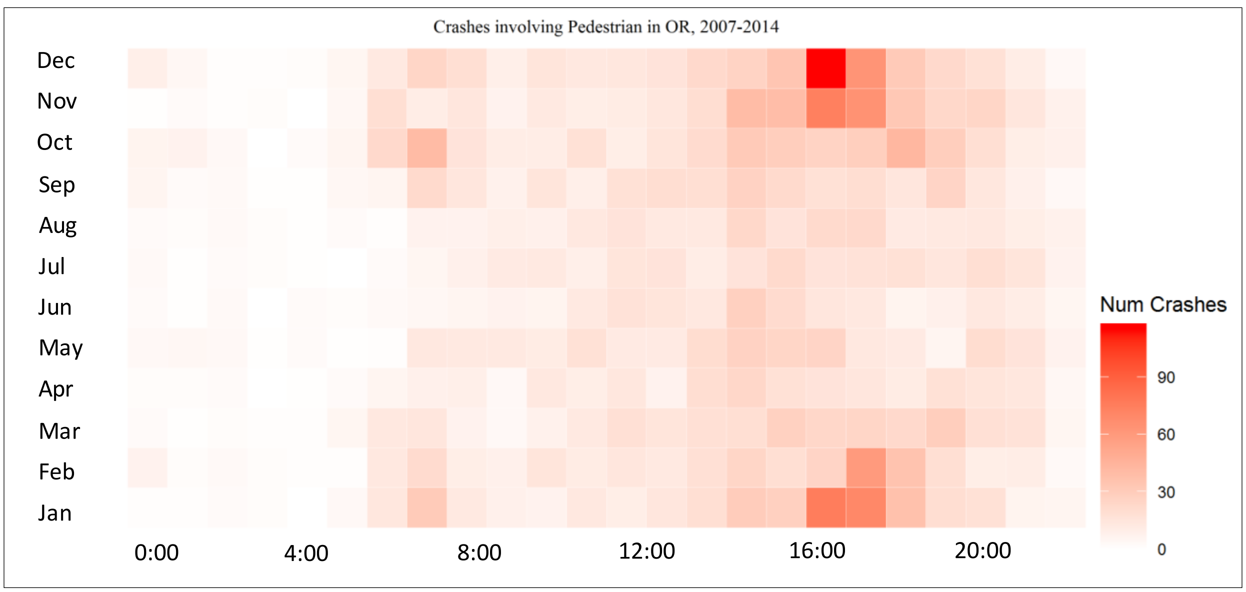

Figure 3.2: Statewide pedestrian crashes (2007-2014) by month and time of the day

Figure 3.3 shows the total pedestrian crashes and pedestrian crashes per intersection per 100 million VMT across each county in Oregon. After controlling for VMT, most of the crashes occurred in the most populated counties in Oregon (e.g. Multnomah, Washington, Clackamas, Lane and Marion). Similar trends were observed between total pedestrian crashes and those that occurred only at intersections.

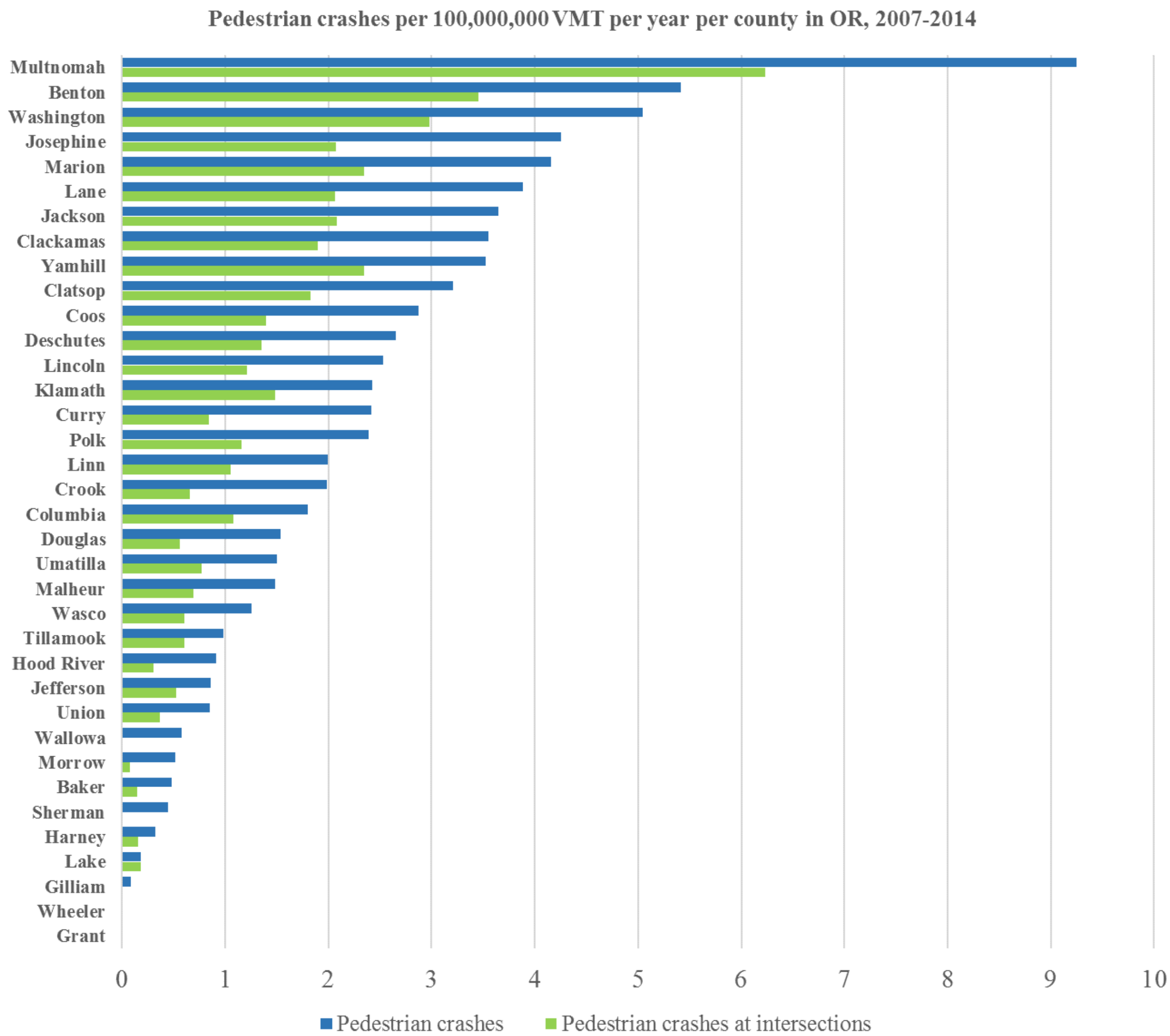

Figure 3.3: Statewide pedestrian crashes by VMT (2007-2014)

Figure 3.4 shows the pedestrian crash rate by county for the state of Oregon controlling for VMT. Figure 3.5 displays the pedestrian crash rate controlling for population density. Both figures show the top five counties with the highest pedestrian crash rates. Multnomah County displays the highest crash rate in both visualizations. Washington and Benton counties displayed elevated levels of pedestrian crashes per billion VMT. Clatsop, Sherman and Josephine counties display higher pedestrian crashes per 10,000 people.

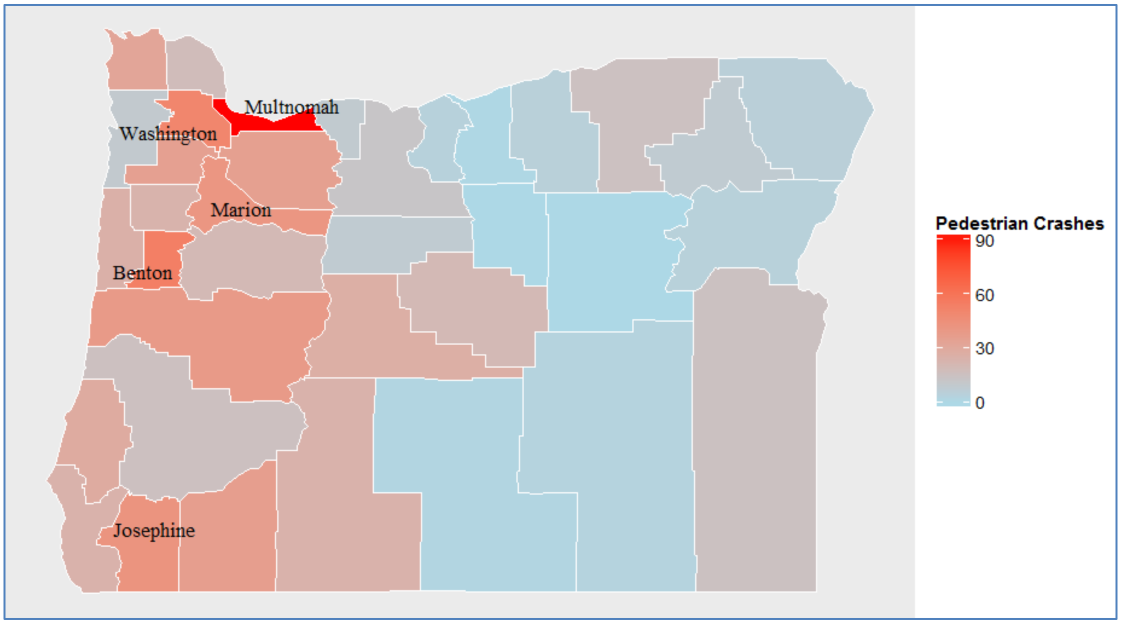

Figure 3.4: Visualization of pedestrian crashes per billion VMT by county, 2007-2014

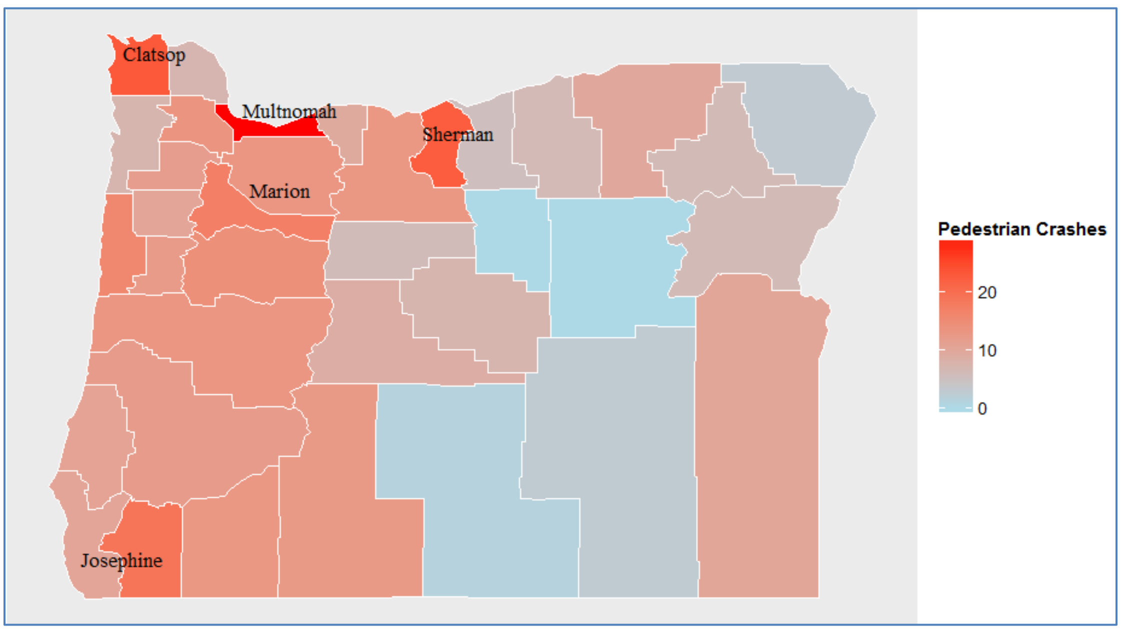

Figure 3.5: Visualization of pedestrian crashes per 10,000 population by county, 2007-2014

3.1.2 Pedestrian and Driver Characteristics

In terms of pedestrian and driver characteristics, the literature review revealed that male pedestrians, young pedestrians and pedestrians using a cellphone while (or just prior to) crossing are key factors that decrease pedestrian safety. Conversely, the presence of a child while crossing, large pedestrian group sizes, senior pedestrians and being female are factors that contribute to a reduction in the frequency of crashes (however, the crash severity outcomes for senior pedestrians is higher). The findings of the literature review suggested that gender and age are predictors for gap acceptance, compliance behavior, crash frequency, and severity. Most of the studies found that females were more cautious and more likely to comply with traffic law than males. In terms of age, studies agreed that seniors were more likely to be in a severe or fatal crash than other age cohorts. Studies that evaluated pedestrian safety in terms of compliance and gap acceptance, found that seniors were more likely to comply with the law and have longer waiting times. For more detail on the studies reviewed, go to Chapter 2.

From the ODOT Crash Analysis and Reporting database, only gender and age were available. An analysis was undertaken using these variables and pedestrian behavior was also evaluated by using the information available in the database (e.g. cause of the crash).

Table 3.3 shows the number of pedestrian crashes by gender, grouped by controlled and uncontrolled intersections. Majority of the crashes in urban and rural areas, both at controlled and uncontrolled intersections, involved males (greater than 50%). This was consistent with the findings of the literature review.

Table 3.3: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Gender

	URBAN		RURAL	
GENDER	**CONTROLLED (n=3376)**	**UNCONTROLLED (n=263)**	**CONTROLLED (n=120)**	**UNCONTROLLED (n=22)**
Male	52.6%	57.0%	51.7%	54.5%
Female	47.4%	43.0%	48.3%	45.5%
* not considering unknown category				

Table 3.4 shows the number of pedestrian crashes by age, grouped by controlled and uncontrolled intersections. In urban areas, majority of the crashes occur among pedestrians between 18 to 54 years of age (for controlled intersections). As age increases, the number of crashes tends to decrease. Additionally, the table reveals that about 30% of the crashes in urban uncontrolled intersections involved pedestrians younger than 17 years. These findings agree with the literature review; younger adults are more likely to be involved in crashes as they are willing to accept small gap sizes and waiting times. Similarly, at rural uncontrolled intersections, most of the crashes involved people younger than 17 years of age.

Pedestrian behavior was another key variable that was found in the literature review to impact safety. For example, the literature review revealed that a pedestrian crossing with a child or in a large group was more likely to accept a larger gap and comply with traffic law (using the crosswalk). While, the ODOT Crash Analysis and Reporting database did not include group size and whether or not a pedestrian was crossing with a child, it did include information about the cause of the crash (e.g. jaywalking). The database also included information for the main causes of the crashes (e.g. inattention, did not yield right of way) which were then aggregated by cause into four categories -behavior, speed, vehicle-related, and miscellaneous.

Table 3.4: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Age Group

AGE	URBAN		RURAL	
	CONTROLLED (n=3395)	**UNCONTROLLED (n=265)**	**CONTROLLED (n=122)**	**UNCONTROLLED (n=22)**
0-12	10.8%	16.6%	14.8%	22.7%
12-17	11.7%	13.6%	16.4%	40.9%
18-24	15.3%	14.3%	9.0%	4.5%
25-34	15.8%	12.1%	11.5%	0.0%
35-44	12.0%	9.8%	9.8%	4.5%
45-54	13.3%	12.1%	10.7%	13.6%
55-64	11.3%	10.2%	10.7%	9.1%
65-74	6.0%	7.2%	5.7%	4.5%
75+	3.7%	4.2%	11.5%	0.0%

Table 3.5 shows the number of pedestrian crashes by cause category, grouped by controlled and uncontrolled intersections. The findings from Table 3.5 reveal that the majority of pedestrian crashes can be attributed to behavior across both urban and rural areas as well as controlled and uncontrolled intersections.

Table 3.5: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Main Cause of the Crash

CRASH CAUSE	URBAN		RURAL	
	CONTROLLED **(n=3235)**	**UNCONTROLLED (n=258)**	**CONTROLLED (n=114)**	**UNCONTROLLED (n=22)**
N/A	0.1%	0.4%	0.9%	0.0%
Behavior	97.3%	95.7%	91.2%	90.9%
Miscellaneous	1.5%	3.5%	0.9%	9.1%
Speed	1.1%	0.4%	5.3%	0.0%
Vehicle related	0.0%	0.0%	1.8%	0.0%

Considering only pedestrian crashes where behavior was the primary cause (3,518 out of 3,629 crashes), Table 3.6 shows a more specific cause of the crashes. At controlled intersections, in both urban and rural areas, most of the crashes were caused by drivers who did not yield right-of-way, followed by pedestrians that were crossing illegally. Similar trends are observed at uncontrolled intersections. However higher proportions of crashes were attributed to pedestrians crossing illegally at uncontrolled intersections when compared to controlled intersections. This finding is consistent with The ODOT Pedestrian and Bicycle Safety Implementation Plan *(Kittelson & Associates, Inc. 2014)* findings, where the most common reported pedestrian issue was jaywalking.

Table 3.6: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Behavior Related Cause of the Crash

	URBAN		RURAL	
	CONTROLLED (n=3147)	UNCONTROLLED (n=247)	CONTROLLED (n=104)	UNCONTROLLED (n=20)
Did not yield right of way	71.5%	57.9%	65.4%	55.0%
Disregarded traffic signal	8.7%	0.0%	0.0%	0.0%
Non-motorist illegally in roadway	10.2%	26.3%	13.5%	20.0%
Non-motorist clothing not visible	2.2%	6.9%	3.8%	10.0%
Inattention	1.7%	3.2%	2.9%	5.0%
Careless driving	1.7%	2.4%	3.8%	5.0%
Other	4.0%	3.2%	10.6%	5.0%
* considering only behavior related crashes				

3.1.3 Location Characteristics

Several macro-level studies reported in the literature review report revealed that areas designated as commercial land use were more likely to have a higher pedestrian crash frequency than other land uses. Additionally, as population density and employment density increases, the frequency of crashes tends to increase as well. Finally, another study found that areas with a high density of intersections tended to have more pedestrian crashes. It is important to highlight that these studies did not control for exposure due to lack of available information. Table 3.7 shows the proportion of crashes by location for each year of analysis. Similar to the literature review, intersections seem to play an important role in the occurrence of a crash with pedestrians involved. For the period between 2007 and 2014, there were 3629 pedestrian crashes at intersections, accounting for 60% of the total crashes.

Table 3.7: Statewide Pedestrian Crashes by Location and Year

LOCATION	2007		2008		2009		2010	
	RURAL (n=64)	**URBAN (n=523)**	**RURAL (n=70)**	**URBAN (n=539)**	**RURAL (n=67)**	**URBAN (n=595)**	**RURAL (n=56)**	**URBAN (n=736)**
Intersection	21.9%	54.3%	20.0%	57.1%	19.4%	60.2%	16.1%	61.3%
Driveway	10.9%	7.3%	5.7%	6.7%	10.4%	6.6%	5.4%	7.1%
Straight roadway	50.0%	35.0%	60.0%	31.5%	53.7%	29.9%	64.3%	28.5%
Transition	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Curve	12.5%	1.7%	8.6%	1.3%	11.9%	1.8%	3.6%	1.5%
Turnout	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	1.8%	0.0%
Vertical curve	4.7%	0.8%	5.7%	2.8%	4.5%	1.2%	7.1%	1.2%
Bridge structure	0.0%	0.8%	0.0%	0.4%	0.0%	0.3%	1.8%	0.4%

LOCATION	2011		2012		2013		2014	
	RURAL (n=82)	**URBAN (n=767)**	**RURAL (n=72)**	**URBAN (n=851)**	**RURAL (n=74)**	**URBAN (n=776)**	**RURAL (n=70)**	**URBAN (n=820)**
Intersection	28.0%	62.2%	31.9%	63.6%	32.4%	64.8%	22.9%	69.6%
Driveway	9.8%	8.2%	2.8%	7.9%	2.7%	8.9%	7.1%	7.8%
Straight roadway	46.3%	27.5%	40.3%	26.6%	48.6%	24.1%	52.9%	20.9%
Transition	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
Curve	6.1%	0.9%	13.9%	0.7%	10.8%	1.2%	4.3%	0.9%
Turnout	0.0%	0.1%	1.4%	0.0%	0.0%	0.1%	0.0%	0.0%
Vertical curve	9.8%	0.8%	8.3%	0.8%	5.4%	0.4%	11.4%	0.1%
Bridge structure	0.0%	0.3%	1.4%	0.4%	0.0%	0.5%	1.4%	0.6%

Currans et al. (2015) categorized different built environments into a set of six neighborhood concepts (A-F) to capture the effects of the built environment on travel behavior. Examples of these six concepts are shown in Figure 3.6. In general, the classification scheme transitions from dense, urban environments as A or B towards rural, less dense environments as F. Based on *Currans et al. (2015),* A and B neighborhood concepts should be combined into one category due to the similarity of their built environment and difficulty in generating comparisons.

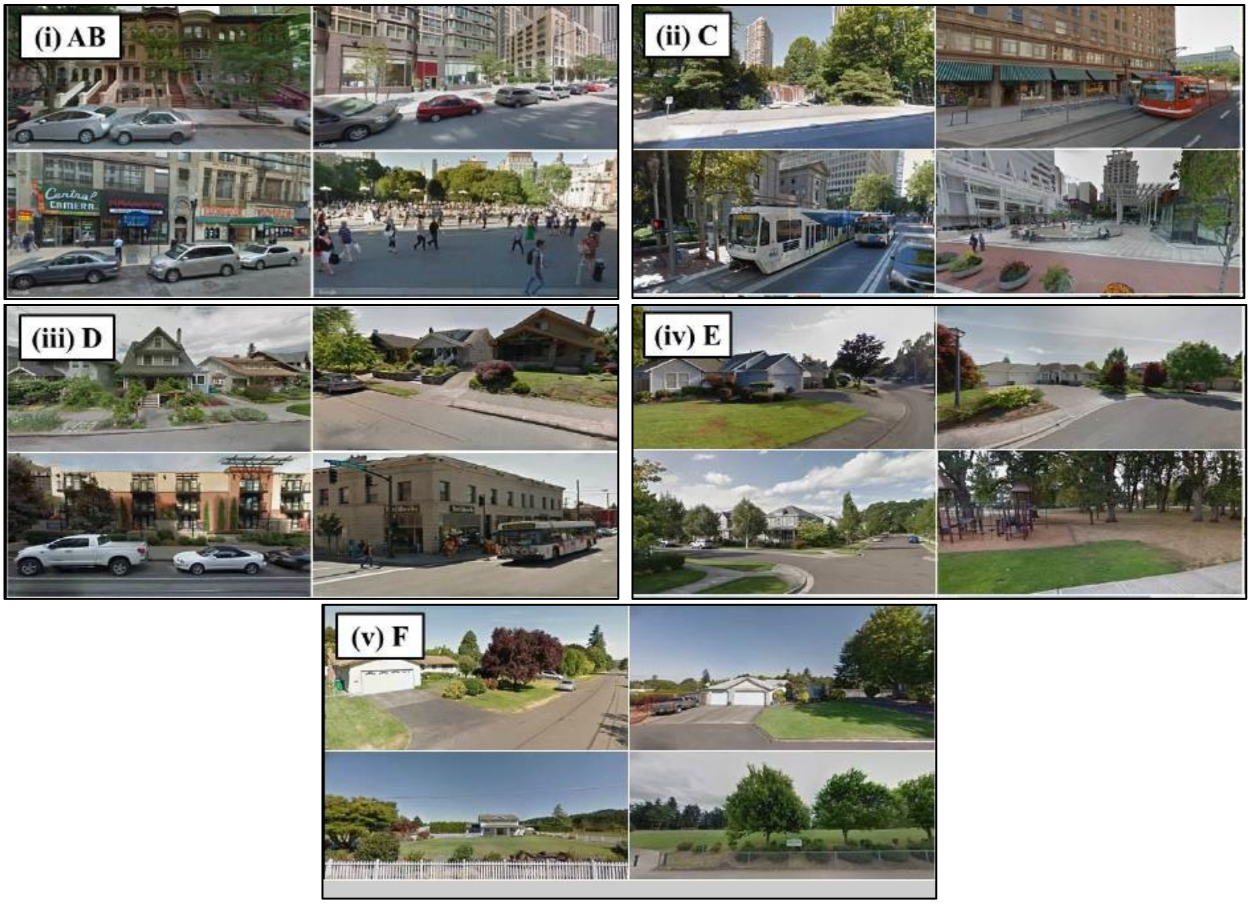

Figure 3.6: Neighborhood concept types, adapted from *Currans et al. (2015)*

These concepts were defined based on activity density, employment entropy, and intersection density. Activity density refers to the number of residents and jobs per acre of unprotected land within a census block group. Employment entropy refers to the distribution of retail, office, industrial, services, and entertainment jobs within a block group. Intersection density refers to the number of intersections in the road network per square miles within a block group.

Table 3.8. Neighborhood Concept Type 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 3.8, 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. Table 3.9 shows the number of pedestrian crashes by neighborhood concepts. In urban areas, pedestrian crashes are higher in neighborhoods with a D rating for both controlled and uncontrolled locations, presumably due to higher activity levels (suggested by the literature review as well). For rural areas, majority of the pedestrian crashes were observed in locations with E rating.

Table 3.9: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Neighborhood Concepts

NEIGHBORHOOD CONCEPT	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
	(n=3235)	(n=258)	(n=114)	(n=22)
A-B	0.0%	0.0%	0.0%	0.0%
C	5.0%	1.2%	0.0%	0.0%
D	49.3%	48.1%	7.9%	9.1%
E	33.7%	35.7%	63.2%	59.1%
F	11.9%	15.1%	28.9%	31.8%

3.1.4 Traffic Conditions

The literature review revealed that an increase in traffic and pedestrian volume, vehicle speed, and VMT, results in more pedestrian crashes with higher severity. Some studies found that traffic conflicts between vehicles and pedestrians were found to be serious when vehicle speeds were higher than 56 km/h (35 mph). Another study found that the pedestrian crash frequency was found to be higher on roads with posted speed limits above 35 mph.

As VMT and traffic volume data was not available via the ODOT Crash Analysis and Reporting database, posted speed limit (as a surrogate for speed) is used instead. Table 3.10 shows the number of pedestrian crashes by posted speed limit, grouped by controlled and uncontrolled intersections. At controlled and uncontrolled intersections, both in urban and rural areas, most of the crashes occurred at locations with posted speed limits between 20 to 35 mph. The second highest proportion of crashes occurred at locations with posted speed limits between 35 to 50 mph.

Table 3.11 shows the number of pedestrian crashes by posted speed limit, grouped by severity (fatal vs non-fatal). Higher posted speed limits resulted in increase in crash severity. Fatal crashes occurred mainly on roads with a posted speed limit of 35 to 50 mph. Non-fatal crashes occur on roads with a posted speed limit of 20 to 35 mph and these findings agreed with the literature review findings.

Table 3.10: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Posted Speed Limit

POSTED SPEED LIMIT	URBAN		RURAL	
	CONTROLLED (n=3235)	UNCONTROLLED (n=258)	CONTROLLED (n=114)	UNCONTROLLED (n=22)
NA	44.8%	46.9%	21.9%	27.3%
< 20 mph	2.2%	1.2%	1.8%	4.5%
20-35 mph	26.8%	31.4%	47.4%	36.4%
35-50 mph	23.6%	17.8%	16.7%	18.2%
50-65 mph	2.6%	2.7%	12.3%	13.6%
> 65 mph	0.0%	0.0%	0.0%	0.0%

Table 3.11: Statewide Pedestrian Crashes (2007-2014) by Posted Speed Limit and Severity

POSTED SPEED LIMIT	URBAN		RURAL	
	FATAL (n=111)	NON-FATAL (n=3348)	FATAL (n=9)	NON-FATAL (n=127)
N/A	18.0%	45.7%	11.1%	23.6%
< 20 mph	1.8%	2.1%	11.1%	1.6%
20-35 mph	27.0%	27.2%	11.1%	48.0%
35-50 mph	49.5%	22.4%	44.4%	15.0%
50-60 mph	3.6%	2.6%	22.2%	11.8%
> 65 mph	0.0%	0.0%	0.0%	0.0%

*not considering only property damage crashes

3.1.5 Road Characteristics

The findings of the literature review revealed that poor lighting conditions and arterial roads are associated with low levels of pedestrian safety. Additionally, an increase in road width, number of lanes, road density and intersection density increase the frequency of pedestrian crashes. In this section, road type, number of lanes and light conditions, plus other variables (weather and road conditions) that were available in the database were analyzed and are potentially useful to assess pedestrian safety levels at unmarked crosswalks. For more detail on the studies reviewed, see chapter 2.

Table 3.12 shows the definitions for roadway classifications that are used in the crash database (*Oregon Department of Transportation 2014)*. Arterials provide mobility and serve high traffic volumes on a continuous network with almost no direct land access. Collectors provide both mobility and land access, gathering trips from localized areas and feed them into the arterial network. Finally, the local classification refers to low traffic volume roadways that provide direct land access but are not designed to serve through traffic needs.

Table 3.12: Roadway Classification Definition

FACILITY CLASSIFICATION	URBAN	RURAL
Principal arterial	This classification focuses on two main aspects: • Mobility by serving trips through urban areas and, • Long distance trips between generators within an urban area (including interstates and freeways).	It focuses on statewide and interstate mobility. This category typically includes the Interstate system and other rural freeways that serve longer distance high-volume corridors.
Minor arterial	It focuses on mobility but serves shorter trips between traffic generators within urban areas.	It focuses on mobility but typically links smaller cities, towns and other statewide traffic generators, such as resorts (which are not served by principal arterials).
Major collector	Urban collectors focus on mobility and land access by serving both intra-urban and local trips that take travelers to arterials.	It focuses on linking county seats and communities not served by arterials; however, it has an intra-county rather than statewide emphasis.
Minor collector	Not applicable.	These collectors collect traffic from local road and smaller communities.
Local streets	It focuses on land access rather than through trips and includes all other public roads.	It focuses on land access and relatively short trips and includes all other public roads.

Table 3.13 shows the number of pedestrian crashes by road classification, grouped by controlled and uncontrolled intersections. The classifications are intended to group roads by operation (or function) in three main categories: arterials, collectors and locals. For urban roads, data for the major and minor collector road categories was not available. For rural roads, data for freeway and collector road categories was not available. In urban areas, most of the crashes were located at controlled intersections with arterials (principal and minor), consistent with findings from a prior report *(Kittelson & Associates, Inc., 2014).* For uncontrolled intersections, most of the crashes occurred along arterials as well. This is consistent with the findings of the literature review, where arterials were the most important road type associated with crash frequency.

Information regarding the number of lanes was not available for crashes that occurred at intersections; therefore, this variable was used for crashes that occurred along road segments. Table 3.14 shows the distribution of number of pedestrian crashes by the number of lanes. Most of the crashes occurred at segments with two lanes, followed by four lanes. The literature review revealed that the frequency of pedestrian crashes increases as the number of lanes to cross increases. The findings from Table 3.14 suggest that there are more crashes at roads with two lanes than wider roads. This can be explained by the fact that pedestrians feel more comfortable crossing a road with a few lanes, increasing the overall exposure for this type of road.

Table 3.13: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Road Classification

ROADWAY CLASSIFICATION	URBAN		RURAL	
	CONTROLLED (n=3235)	UNCONTROLLED (n=258)	CONTROLLED (n=114)	UNCONTROLLED (n=22)
Interstate	0.7%	0.0%	0.0%	0.0%
Principal Arterial	41.4%	27.5%	29.8%	36.4%
Minor Arterial	31.2%	34.5%	21.1%	13.6%
Major collector	-	-	35.1%	22.7%
Minor collector	-	-	2.6%	4.5%
Local	7.9%	15.1%	11.4%	22.7%
Freeway	0.3%	0.0%	-	-
Collector	18.5%	22.9%	-	-

Table 3.14: Statewide Pedestrian Crashes (2007-2014) by Number of Road Lanes

NUMBER OF LANES	URBAN (n=2114)	RURAL (n=419)
Unknown	0.7%	0.2%
1	0.4%	1.2%
2	52.8%	74.5%
3	3.8%	2.1%
4	36.8%	20.0%
5	3.5%	0.2%
6	1.8%	1.7%
7	0.1%	0.0%
8	0.0%	0.0%

Table 3.15 shows the number of pedestrian crashes by weather conditions, grouped by controlled and uncontrolled intersections. Most of the crashes occurred during clear days, followed by rain and cloudy days.

Table 3.15: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Weather Conditions

WEATHER	URBAN		RURAL	
	CONTROLLED (n=3235)	UNCONTROLLED (n=258)	CONTROLLED (n=114)	UNCONTROLLED (n=22)
Unknown	1.5%	1.2%	1.8%	0.0%
Clear	54.6%	57.0%	54.4%	36.4%
Cloudy	16.6%	19.0%	20.2%	40.9%
Rain	24.9%	20.5%	18.4%	13.6%
Sleet / freezing rain	0.1%	0.4%	0.9%	0.0%
Fog	1.5%	1.6%	2.6%	4.5%
Snow	0.6%	0.4%	1.8%	4.5%
Smoke	0.0%	0.0%	0.0%	0.0%
Ash	0.0%	0.0%	0.0%	0.0%

Table 3.16 shows the number of pedestrian crashes by light conditions, grouped by controlled and uncontrolled intersections. Most of the crashes occurred during daylight conditions, followed by darkness-with street lights and darkness without street lights. This finding is counterintuitive, since higher crash frequency is expected during dark conditions where there is no light. However, some of the papers found in the literature review revealed that drivers are more cautious at dark conditions, decreasing the likelihood of a crash.

Table 3.16: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Light Conditions

LIGHT CONDITIO N	URBAN		RURAL	
	CONTROLLED (n=3235)	UNCONTROLLE D (n=258)	CONTROLLED (n=114)	UNCONTROLLE D (n=22)
Unknown	0.2%	0.0%	0.0%	0.0%
Daylight	56.2%	47.3%	64.0%	54.5%
Darkness-with street lights	29.7%	30.2%	13.2%	18.2%
Darkness-no street lights	5.7%	13.6%	15.8%	13.6%
Dawn	3.1%	2.7%	1.8%	4.5%
Dusk	5.0%	6.2%	5.3%	9.1%

Table 3.17 shows the number of pedestrian crashes by road conditions, grouped by controlled and uncontrolled intersections. For controlled and uncontrolled intersections, in both urban and rural areas, most of the crashes occurred at dry road conditions, followed by wet conditions.

Table 3.17: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Road Conditions

ROAD SURFACE CONDITION	URBAN		RURAL	
	CONTROLLED (n=3235)	UNCONTROLLED (n=258)	CONTROLLED (n=114)	UNCONTROLLED (n=22)
Unknown	1.6%	0.4%	0.9%	0.0%
Dry	65.3%	66.7%	67.5%	63.6%
Wet	31.9%	30.6%	28.9%	27.3%
Snow	0.7%	1.6%	0.9%	4.5%
Ice	0.5%	0.8%	1.8%	4.5%

3.1.6 Crosswalk Characteristics

The literature review revealed that controlled intersections and presence of a marked crosswalk at an uncontrolled intersection are safer for pedestrians than other types of crossing. However, a few studies suggested that unmarked crossings were safer since pedestrians tend to be more cautious while crossing. For more detail on the studies reviewed, see chapter 2. This section shows some characteristics of the crosswalk that were associated with the number of crashes in Oregon.

Table 3.18 shows the location of the pedestrian at the time of the crash at intersections. At controlled intersections in urban areas, majority of the crashes occurred when the pedestrian was inside the crosswalk. At rural areas, most crashes occurred inside the crosswalk as well .It is also important to observe that a very low proportion of crashes occurred at mid-block crosswalks.

Table 3.18: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections

	URBAN (n=4016)	RURAL (n=148)
Controlled	92.61%	83.82%
Uncontrolled	7.39%	16.18%

Using the information from Table 3.19, crashes that occurred at an intersection and inside a crosswalk are selected to estimate the proportion of crashes in controlled and uncontrolled marked crosswalks. Table 3.20 shows the findings. 110 pedestrian crashes occurred in marked crosswalks at uncontrolled intersections 2007-2014.

Table 3.19: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Location of the Participant at the Time of the Crash

LOCATION OF PARTICIPANT IN CRASH	URBAN		RURAL	
	CONTROLLED (n=3396)	UNCONTROLLED (n=267)	CONTROLLED (n=123)	UNCONTROLLED (n=24)
At intersection - not in roadway	0.8%	1.5%	3.3%	8.3%
At intersection - inside crosswalk	80.1%	41.2%	55.3%	20.8%
At intersection - in roadway, outside crosswalk	7.2%	18.7%	13.0%	16.7%
At intersection - in roadway, unknown if crosswalk is available	8.9%	28.5%	16.3%	45.8%
Not at intersection - in roadway	1.0%	4.1%	2.4%	0.0%
Not at intersection - on shoulder	0.3%	0.4%	2.4%	0.0%
Not at intersection - on median	0.0%	0.0%	0.0%	0.0%
Not at intersection - beyond shoulder	0.2%	0.7%	1.6%	0.0%
Not at intersection - in bike path or parking lane	0.0%	0.4%	0.0%	0.0%
Not at intersection - on sidewalk	0.7%	2.2%	1.6%	0.0%
Outside traffic way boundaries	0.2%	0.4%	2.4%	0.0%
Not at intersection - inside mid-block crosswalk	0.0%	0.4%	0.0%	0.0%
Other - not in roadway	0.1%	0.4%	0.0%	0.0%
Unknown location	0.4%	0.4%	0.8%	0.0%

Table 3.20: Statewide Pedestrian Crashes (2007-2014) by Controlled/Uncontrolled Intersections and Marked/Unmarked Crosswalks

	URBAN		RURAL	
	CONTROLLED (n=3235)	**UNCONTROLLED (n=258)**	**CONTROLLED (n=114)**	**UNCONTROLLED (n=22)**
Marked crosswalk	80.1%	40.7%	55.3%	22.7%

Table 3.21 summarizes the overall trends with respect to pedestrian crashes 2007-2014 in Oregon. Pedestrian and driver characteristics, location characteristics, traffic conditions, road characteristics, and crosswalk characteristics are important factors that influence pedestrian safety.

Table 3.21: Overall Trends and Patterns Found in the Analysis of Pedestrian Crashes (2007-2014)

CATEGORY	VARIABLE	FINDINGS
Pedestrian and Driver Characteristics	Gender	The majority of crashes involved males.
	Age	In urban uncontrolled intersections, 30.2% of the crashes involved pedestrians younger than 17 years, followed by 26.4% of crashes involving pedestrians between 18 and 34, respectively. In rural uncontrolled intersections, 63.6% of the crashes involved pedestrians younger than 17 years.
	Cause of the crash	The majority of crashes were caused by the behavior of the driver and/or the pedestrian. Drivers not yielding right of way, in urban and rural areas, respectively, caused a 57.9% and 55% of crashes at uncontrolled intersections. The second main reason was a pedestrian illegally in a roadway.
Location characteristics	Location of the crash	In urban and rural areas, most of the pedestrian crashes occurred at intersections (~60%).
	Neighborhood concept	Most of the crashes that occurred in urban areas were located in neighborhood concepts D and E (83%). In rural areas, crashes occurred mainly in concepts E and F (90.9%).
Traffic Conditions	Posted Speed Limit	Most of the crashes in urban and rural uncontrolled intersections occurred on roads with a posted speed limit of 20-35 mph (31.4% and 36.4%, respectively).
Road Characteristics	Road classification	Most of the crashes in urban uncontrolled intersections occurred on arterials (41.4% on major and 31.2% on minor). In rural uncontrolled intersections, 36.4% of the crashes occurred in principal arterials.
	Number of lanes	In urban areas, more than half of the crashes occurred on roads with 2 lanes, followed by roads with 4 lanes. In rural areas, 74.5% of the crashes occurred on roads with 2 lanes.
	Weather conditions	In urban uncontrolled intersections, the majority of crashes occurred on clear days, followed by rainy days. In rural areas, most of the crashes occurred on cloudy days.
	Light conditions	In urban and rural uncontrolled intersections, the majority of the pedestrian crashes occurred during daylight conditions.
	Road conditions	In urban and rural uncontrolled intersections, the majority of the pedestrian crashes occurred on dry road surfaces.
Crosswalk characteristics	Location of the pedestrian at the time of the accident	In urban uncontrolled intersections, in most of the crashes, the pedestrian was inside the crosswalk. In rural uncontrolled intersections, the pedestrian was in the roadway, but it is unknown if a crosswalk was available. This category is followed by crashes with a pedestrian located inside of the crosswalk at the time of the crash.

3.2 EXPOSURE ANALYSIS

One of the thorniest tasks in safety research is the analysis of crash rates but accounting for exposure. Since detailed vehicle-pedestrian volumes or conflict rates are typically non-existing, it is necessary to account for exposure utilizing indirect measurements. We have tried to control for exposure in this chapter by analyzing the impact of traffic volumes (AADT), pedestrian volumes (utilizing a land use based measurement), month/day light conditions, and type of facility. The analysis is limited to the state network (TransGIS database) only because it does include complete records for AADT, posted speed limit, the number of lanes and road width (Figure 3.7).

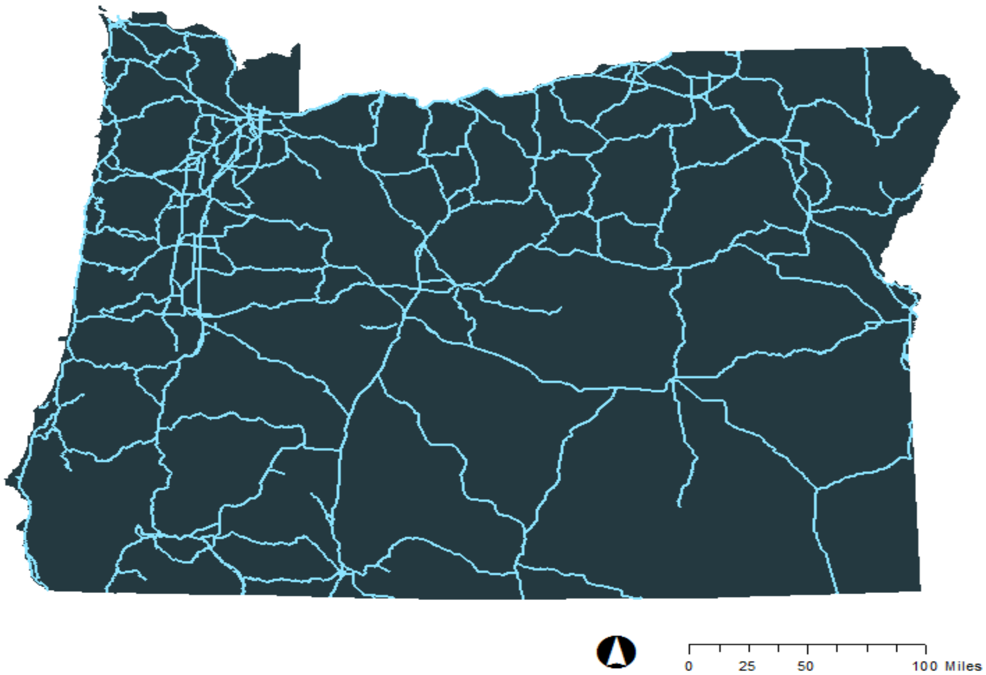

Figure 3.7: Oregon state highway network

Only pedestrian crashes that occurred on the Oregon State Highway Network were selected for exposure analysis. A threshold of 20 ft. was used for this selection. Table 3.22 shows the number of pedestrian crashes that were used for the exposure analysis after the selection. A total of 2,124 crashes were analyzed of which 60% took place at intersections (3% took place at uncontrolled intersections).

Table 3.22: Statewide Pedestrian Crashes (2007-2014)

	PEDESTRIAN CRASHES IN OREGON	PEDESTRIAN CRASHES ON OREGON STATE HIGHWAYS
Total Pedestrian crashes	6162	1840
Pedestrian crashes at intersections	3629	1088
Pedestrian crashes at uncontrolled intersections	280	58
Pedestrian crashes at uncontrolled marked intersections	110	27

The following analysis considers the percentage of pedestrian crashes that took place at controlled and uncontrolled intersections in the Oregon State Highway Network. Pedestrian crashes are categorized by AADT, posted speed limit, number of lanes, road width, and road classification. Exposure was controlled by estimating the proportion of the Oregon State Highway Network length and 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). To control for exposure, we considered length of the highway network and VMT. For section 3.2.1, a length ratio (controlled for highway length) and a VMT ratio (controlled for VMT) were estimated. For sections 3.2.2 and 3.2.3, only the length ratio was considered. For any ratio that is higher than 1, the findings suggest that there is a high concentration of pedestrian crashes for that condition.

If the percentage of crashes or the percentage of the highway network is less than 2%, the ratio is N/A. 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 **.

3.2.1 Road Characteristics

Road characteristics (AADT, posted speed limit, road width, number of lanes, and road classification), were controlled by highway network length and VMT.

Table 3.23 shows the length ratio by AADT range. For both urban and rural locations, an increasing trend in the ratio is observed, with an increasing AADT range. The findings suggest that at urban controlled intersections, most of the crashes occurred on roads with an AADT between 15,000 and 30,000 after controlling only for length. Crashes at uncontrolled intersections were mainly located on roads with a higher AADT (30,000-50,000). For rural controlled and uncontrolled intersections, the concentration of crashes was located on roads with an AADT between 10,000 and 15,000.

Table 3.23: Crash Frequency and AADT Exposure (by Length) Ratio

AADT	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	0.42*	N/A	0.21
1,001 - 2,500	N/A	0.36*	0.23*	N/A
2,501 - 5,000	0.36*	N/A	0.96	1.75
5,001 - 10,000	0.53	0.89	3.54	3.59
10,001 - 15,000	1.02	1.78	5.66*	4.31*
15,001 - 20,000	2.20	0.61	N/A	N/A
20,001 - 30,000	2.20	1.93	N/A	N/A
30,001 - 50,000	1.86	1.97	N/A	N/A
50,001 - 75,000	N/A	N/A	N/A	N/A
75,001+	N/A	N/A	N/A	N/A

Table 3.24 shows the same analysis as in the previous table, but this time controlling for AADT. For this case the ratios are closer to 1 than in the previous chapter (which is expected) but a similar trend of increasing ratios with increasing AADT still holds. Pedestrian crashes tend to increase as AADT increases at both controlled and uncontrolled intersections.

Table 3.24: Crash Frequency and AADT Exposure (by Length and AADT) Ratio

AADT	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	N/A	N/A	2.15*
1,001 - 2,500	N/A	0.84**	0.54*	N/A
2,501 - 5,000	0.48*	N/A	0.84	1.53
5,001 - 10,000	0.56	0.94	1.86	1.88
10,001 - 15,000	0.75	1.30	0.78	0.59
15,001 - 20,000	1.51	0.42	0.69*	N/A
20,001 - 30,000	2.13	1.87	1.49*	N/A
30,001 - 50,000	1.78	1.89	N/A	N/A
50,001 - 75,000	N/A	N/A	N/A	N/A
75,001+	N/A	N/A	N/A	N/A

Table 3.25 shows the ratio by posted speed limit. After controlling for length, this analysis suggests that intersections (controlled and uncontrolled) with a posted speed limit between 35 and 50 mph, have a higher ratio than any other type of intersection. This relationship is stronger in urban intersections, where the percentage of crashes and the percentage of the highway network for this posted speed limit category were higher than 5%.

Table 3.25: Crash Frequency and Posted Speed Limit Exposure (by Length) Ratio

POSTED SPEED LIMIT (MPH)	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A	N/A	N/A
20-35	1.77	1.97	N/A	N/A
35-50	2.18	2.32	7.39*	10.01*
50-65	0.25	0.06*	0.19	0.28
> 65	N/A	N/A	0.19	N/A

Table 3.26 shows the ratio by posted speed limit, controlling for AADT and length. The table reveals that in rural locations (controlled and uncontrolled intersections), most of the pedestrian crashes occurred on roads with a posted speed limit of 20 – 35 mph.

Table 3.26: Crash Frequency and Posted Speed Limit Exposure (by AADT and Length) Ratio

POSTED SPEED LIMIT (MPH)	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A	N/A	N/A
20-35	0.79	0.89	1.98	1.63
35-50	2.05	2.18	0.92	1.25
50-65	0.30	0.07*	0.62	0.95
> 65	N/A	N/A	0.25	N/A

Table 3.27 shows the ratio of the percentages of pedestrian crashes to highway network length by road width. The findings reveal that the pedestrian crashes tend to increase as the road width increases, after controlling for length. At urban intersections, the highest ratio was observed on roads with a width between 50 and 60 feet. For rural intersection, this value was between 40 and 50 ft.

Table 3.27: Crash Frequency and Road Width Exposure (by Length) Ratio

ROAD WIDTH (FT)	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A	N/A	N/A
10-20	0.24*	N/A	N/A	N/A
20 - 30	0.41	0.28	0.69	0.72
30 - 40	1.08	1.24	1.88	N/A
40 - 50	2.62	2.48	7.25*	14.72*
50 - 60	5.26*	11.75*	NA	NA
60 - 70	N/A	N/A	N/A	N/A
> 80	N/A	N/A	N/A	N/A

After controlling for AADT and length, Table 3.28 shows a similar trend of increasing ratio as road width increases. The only difference observed between these tables is the concentration of pedestrian crashes at rural intersections. The highest ratios were found on roads with widths between 30 and 40 ft. for controlled intersections, and 20 and 30 ft. for uncontrolled intersections.

Table 3.28: Crash Frequency and Road Width Exposure (by AADT and Length) Ratio

ROAD WIDTH (FT)	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A	N/A	N/A
10-20	0.16*	N/A	N/A	N/A
20 - 30	0.77	0.51	0.88	0.92
30 - 40	0.74	0.86	0.95	N/A
40 - 50	2.61	2.47	N/A	N/A
50 - 60	3.43*	7.67*	0.64	N/A
60 - 70	0.21*	N/A	N/A	N/A
> 80	N/A	N/A	N/A	N/A

Table 3.29 shows the ratio by the number of lanes, after controlling for length. At urban and rural intersections, the ratio of pedestrian crashes increases as the number of road lanes increase. Most of the pedestrian crashes occurred at intersections with 4 lanes.

Table 3.29: Crash Frequency and Number of Lanes Exposure (by Length) Ratio

NUMBER OF LANES	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
1	0.27*	N/A	N/A	N/A
2	0.51	0.53	0.80	0.81
3	0.93	1.07	0.57*	N/A
4	2.84	3.09	9.92*	11.33*
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A

Similarly, Table 3.30 reveals an increase of pedestrian crashes with an increase of road lanes after controlling for AADT and length.

Table 3.30: Crash Frequency and Road Classification Exposure (by AADT and Length) Ratio

NUMBER OF LANES	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
1	0.17*	0.15*	NA	N/A
2	0.84	0.88	0.89	0.90
3	0.74	0.85	N/A	N/A
4	2.67	2.90	2.39	2.73
5	0.27*	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A

Table 3.31 shows the ratio for roadway functional classification categories. While, for most of the road classification categories the data was unreliable (after controlling for length), the ratios were computed for a few sub-categories. The findings from Table 3.31 suggest that most of the pedestrian crashes occurred on arterials (principal for urban intersections, and minor for rural intersections).

Table 3.31: Crash Frequency and Road Classification Exposure (by Length) Ratio

FACILITY CLASSIFCATION	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
Interstate	0.10*	N/A	N/A	N/A
Principal arterial	2.02	2.09	1.21	1.51
Minor arterial	0.92	1.16	1.68	1.68
Major collector	N/A	N/A	0.61	N/A
Minor collector	N/A	N/A	N/A	N/A
Local	N/A	N/A	N/A	N/A
Freeway	N/A	N/A	N/A	N/A
Collector	N/A	N/A	N/A	N/A

After controlling for AADT and length, the findings from Table 3.32 show that the highest ratio of pedestrian crashes was observed on principal arterials for urban and rural intersections. Nonetheless, as in Table 3.31, data for most of the categories is unreliable.

Table 3.32: Crash Frequency and Road Classification Exposure (by AADT and Length) Ratio

FACILITY CLASSIFCATION	URBAN		RURAL	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
Interstate	0.12*	N/A	N/A	N/A
Principal arterial	2.31	2.39	1.54	1.92
Minor arterial	0.52	0.65	1.35	1.35
Major collector	N/A	N/A	1.05	N/A
Minor collector	N/A	N/A	N/A	N/A
Local	N/A	N/A	N/A	N/A
Freeway	N/A	N/A	N/A	N/A
Collector	N/A	N/A	N/A	N/A

3.2.2 Neighborhood Concepts

This section discusses the concentration of pedestrian crashes by neighborhood concepts and exposure. Pedestrian crashes that occurred on the Oregon State Highway Network were located only in areas with D, E and F. Exposure was considered by controlling only for highway network length. Concept D has a higher activity density, employment entropy and intersection density than concepts E and F, which represent more suburban neighborhoods (for more detail, go to Figure 3.6 and Table 3.8).

Table 3.33 reveals an increase in the ratio at controlled intersections as AADT increases (until it reaches 30,000). This trend is similar for the various neighborhood concepts; however, ratios for concept E tend to be higher than for D and F. At uncontrolled intersections, in neighborhood concepts D and E, most of the pedestrian crashes occurred on roads with an AADT between 30,000 and 50,000, while for concept F, this occurred in roads with an AADT between 20,000 and 30,000.

Table 3.33: AADT and Crash Frequency Ratio by Land Use

AADT	D		E	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	N/A	N/A	0.09*
1,001 - 2,500	N/A	1.48**	N/A	N/A
2,501 - 5,000	0.62*	N/A	0.36*	0.84
5,001 - 10,000	0.64	0.80	1.25	2.38
10,001 - 15,000	1.21	1.51	2.07	4.71
15,001 - 20,000	1.38	0.33*	8.66*	1.34**
20,001 - 30,000	1.80	1.69	5.24*	1.91*
30,001 - 50,000	1.38	2.49	11.19*	7.00*
50,001 - 75,000	N/A	N/A	N/A	N/A
75,001+	N/A	N/A	N/A	N/A

AADT	F	
	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	0.35
1,001 - 2,500	0.13*	N/A
2,501 - 5,000	0.22*	N/A
5,001 - 10,000	0.64	1.46
10,001 - 15,000	3.42	3.74
15,001 - 20,000	9.04*	3.75*
20,001 - 30,000	8.63*	11.06*
30,001 - 50,000	4.22*	N/A
50,001 - 75,000	N/A	N/A
75,001+	N/A	N/A

Table 3.34 shows the ratio by posted speed limit and land use. The analysis does not suggest an increase of pedestrian crashes with an increase of posted speed limit. For neighborhood concepts D and E, the highest ratio occurred at intersections with a posted speed limit of 20-35 mph. additionally, the ratio was almost 10 times higher at concept E than concept D, revealing a critical distribution of pedestrian crashes at these types of intersections. For concept, F the highest ratio occurred at intersections with a posted speed limit between 35 and 50 mph.

Table 3.34: Posted Speed Limit and Crash Frequency Ratio by Land Use

POSTED SPEED LIMIT (MPH)	D		E	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A	N/A	N/A
20-35	1.48	1.60	14.30*	15.87*
35-50	1.33	1.48	6.19	5.95
50-65	0.30	N/A	0.13	0.13
> 65	N/A	N/A	N/A	N/A

POSTED SPEED LIMIT (MPH)	F	
	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A
20-35	N/A	N/A
35-50	10.10	9.46
50-65	0.22	0.16
> 65	0.09*	N/A

Table 3.35 shows the ratio by road width and neighborhood concept. After controlling for highway network length, the findings suggest an increase of pedestrian crashes at intersections as the road width increases. This finding was stable for concept D, E and F. For concept E and F, the critical road width in terms of the ratio was between 40 and 50 ft. For concept D, the critical width was between 50 and 60 ft. Furthermore, uncontrolled intersections had higher ratios than controlled intersections for this road width category.

Table 3.36 reveals an increase of the ratio as the number of lanes increase, after controlling for highway network length. Additionally, for the three neighborhood concepts, most of the pedestrian crashes occurred at intersections with 4 lanes. Furthermore, the findings suggest that there were more pedestrian crashes on these intersections, if they were located at areas with neighborhood F rating.

Table 3.35: Road Width and Crash Frequency Ratio by Land Use

ROAD WIDTH (FT)	D		E	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A	N/A	N/A
10-20	0.21*	N/A	0.61**	N/A
20 - 30	0.68	0.52	0.28	0.30
30 - 40	0.71	0.43	1.99	2.79
40 - 50	1.89	1.75	8.41	7.86
50 - 60	2.54*	7.65*	N/A	N/A
60 - 70	N/A	N/A	N/A	N/A
> 80	N/A	N/A	N/A	N/A

ROAD WIDTH (FT)	F	
	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A
10-20	0.68**	N/A
20 - 30	0.39	0.40
30 - 40	2.00	1.52
40 - 50	9.98*	10.70*
50 - 60	N/A	N/A
60 - 70	N/A	N/A
> 80	N/A	N/A

Table 3.36: Number of Lanes and Crash Frequency Ratio by Land Use

NUMBER OF LANES	D		E	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
1	0.23*	N/A	0.77**	N/A
2	0.82	0.81	0.33	0.51
3	0.48	N/A	2.03	3.05
4	2.02	2.70	9.49	6.98
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A

NUMBER OF LANES	F	
	CONTROLLED	UNCONTROLLED
1	0.72**	N/A
2	0.43	0.40
3	1.75	1.60
4	10.77**	12.91*
5	N/A	N/A
6	N/A	N/A

Table 3.37 shows the ratio by road classification and neighborhood concept. The findings suggest that most of the pedestrian crashes at intersections occurred on principal arterials. For concept D, most of the pedestrian crashes at uncontrolled intersections were associated with minor arterials rather than principal arterials.

Table 3.37: Road Classification and Crash Frequency Ratio by Land Use

FACILITY CLASSIFCATION	D		E	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
Interstate	0.11*	N/A	0.18*	N/A
Principal Arterial	1.78	1.77	2.07	2.06
Minor Arterial	1.12	1.85	0.56	0.78
Major collector	N/A	N/A	N/A	N/A
Minor collector	N/A	N/A	N/A	N/A
Local	N/A	N/A	N/A	N/A
Freeway	0.26*	N/A	N/A	N/A
Collector	N/A	N/A	N/A	N/A

FACILITY CLASSIFCATION	F	
	CONTROLLED	UNCONTROLLED
Interstate	0.16*	N/A
Principal Arterial	2.10	2.35
Minor Arterial	0.49	0.48
Major collector	0.18*	N/A
Minor collector	N/A	N/A
Local	N/A	N/A
Freeway	N/A	N/A
Collector	N/A	N/A

3.2.3 Temporal Characteristics

This analysis reveals trends in ratio by temporal characteristics and exposure. Temporal characteristics were grouped by winter and time of the day (evening). The months of November, December, January and February were considered for the winter season. The rest of the months were grouped as not winter. For evening, a time period of 5 hours between 15:00 and 20:00 was analyzed. The rest of the hours of the day were grouped as not evening. The ratio was controlled for highway network length.

Table 3.38 shows the ratio by road classification, season and time of the day. Similar to the previous section, the ratio increases as AADT increases. In terms of season, there is not a clear distinction between ratio in winter and not winter months. In terms of time of the day, for uncontrolled intersections, the ratio was higher for not winter evening hours than evening winter hours (except for and AADT between 15,000 and 20,000). Furthermore, during winter, the ratio was similar for the different AADT ranges at different times of the day (evening vs not evening).

Table 3.38: AADT and Crash Frequency Ratio by Season, and Time of the Day

AADT	EVENING WINTER		EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	0.15	N/A	0.27
1,001 - 2,500	N/A	N/A	N/A	N/A
2,501 - 5,000	1.19	0.76	1.14	2.04
5,001 - 10,000	1.45	0.39	1.55	N/A
10,001 - 15,000	0.59*	N/A	0.77*	1.59
15,001 - 20,000	8.04*	7.18*	9.03*	3.23*
20,001 - 30,000	5.39*	8.66*	3.07*	N/A
30,001 - 50,000	5.30*	9.46*	6.41*	17.03*
50,001 - 75,000	N/A	N/A	N/A	N/A
75,001+	N/A	N/A	N/A	N/A

AADT	NOT EVENING WINTER		NOT EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0 - 1,000	N/A	N/A	N/A	N/A
1,001 - 2,500	0.13*	0.65	N/A	N/A
2,501 - 5,000	1.01	1.51	1.13	2.59
5,001 - 10,000	1.68	0.78	1.50	0.33*
10,001 - 15,000	0.76*	1.77	0.77*	0.76*
15,001 - 20,000	8.57*	7.18*	7.62*	6.15*
20,001 - 30,000	3.62*	N/A	4.88*	3.71*
30,001 - 50,000	5.55*	9.46*	5.94*	8.11*
50,001 - 75,000	N/A	N/A	N/A	N/A
75,001+	N/A	N/A	N/A	N/A

The highest ratio for the different temporal characteristics occurred at intersections with a posted speed limit of 20–35 mph. Table 3.39 reveals that during winter, in not evening hours the ratio is higher than during evening hours for the different posted speed limit categories. For not winter months this trend is opposite.

Table 3.40 shows the ratio by temporal characteristics and road width. The ratio tends to increase as road width increases. During evening hours, the crash ratio is higher than during not evening hours for intersections with a road width between 40 and 50 ft. In terms of season, at uncontrolled intersections, the ratio tends to be higher during not winter months (except for intersections with road width between 30 and 40 ft.).

Table 3.39:Posted Speed Limit and Crash Frequency Ratio by Season, and Time of the Day

POSTED SPEED LIMIT (MPH)	EVENING WINTER		EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A	N/A	N/A
20-35	12.65*	13.73*	16.61*	16.47*
35-50	7.11	7.67	5.69	5.75
50-65	0.10	N/A	0.14	0.17
> 65	N/A	N/A	N/A	N/A

POSTED SPEED LIMIT (MPH)	NOT EVENING WINTER		NOT EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
< 20	N/A	N/A	N/A	N/A
20-35	15.22*	22.88*	12.70*	13.73*
35-50	6.30	5.11	6.50	6.57
50-65	0.13	N/A	0.20	0.16
> 65	N/A	N/A	N/A	N/A

Table 3.40: Road Width and Crash Frequency Ratio by Season, and Time of the Day

ROAD WIDTH (FT)	EVENING WINTER		EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A	N/A	N/A
10-20	0.43**	N/A	1.10*	N/A
20 - 30	0.27	0.27	0.26	0.49
30 - 40	1.95	0.77	1.94	N/A
40 - 50	8.58	8.13	8.26	10.98
50 - 60	N/A	N/A	N/A	N/A
60 - 70	N/A	N/A	N/A	N/A
> 80	N/A	N/A	N/A	N/A

ROAD WIDTH (FT)	NOT EVENING WINTER		NOT EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
0-10	N/A	N/A	N/A	N/A
10-20	0.71**	N/A	N/A	N/A
20 - 30	0.36	0.27	0.32	0.23
30 - 40	2.05	6.16	2.04	1.98
40 - 50	7.00	6.10	7.85	6.10
50 - 60	N/A	N/A	N/A	N/A
60 - 70	N/A	N/A	N/A	N/A
> 80	N/A	N/A	N/A	N/A

Table 3.41 shows the ratio by temporal characteristics and number of lanes at the intersection. The ratio tends to increase with the number of lanes. For uncontrolled intersections with 4 lanes, the ratio is higher during winter months. For not winter months, this relationship is opposite. In terms of time of the day, the ratio is higher at evening hours than at not evening hours, especially for winter months.

Table 3.41: Number of Lanes and Crash Frequency Ratio by Season, and Time of the Day

NUMBER OF LANES	EVENING WINTER		EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
1	0.72**	N/A	1.16*	N/A
2	0.33	0.34	0.34	0.72
3	1.56	0.84	1.38	N/A
4	9.81	11.67	9.32	7.00
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A

NUMBER OF LANES	NOT EVENING WINTER		NOT EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
1	0.75**	N/A	0.46**	N/A
2	0.45	0.54	0.38	0.40
3	1.51	5.02	1.78	1.43
4	8.07	3.89	8.68	10.00
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A

Table 3.42 shows the ratio by road classification and temporal characteristics. The highest ratios were observed at intersections on principal arterials. For evening and not evening hours, the ratios are higher during winter months than not winter months. In terms of time of the day, big differences between evening and not evening hours was not observed.

Table 3.42: Road Classification and Crash Frequency Ratio by Season, and Time of the Day

FACILITY CLASSIFCATION	EVENING WINTER		EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
Interstate	0.17*	N/A	0.20*	N/A
Principal Arterial	2.19	2.18	2.08	1.83
Minor Arterial	0.40	0.73	0.54	1.32
Major collector	N/A	N/A	N/A	N/A
Minor collector	N/A	N/A	N/A	N/A
Local	N/A	N/A	N/A	N/A
Freeway	N/A	N/A	N/A	N/A
Collector	N/A	N/A	N/A	N/A

FACILITY CLASSIFCATION	NOT EVENING WINTER		NOT EVENING NOT WINTER	
	CONTROLLED	UNCONTROLLED	CONTROLLED	UNCONTROLLED
Interstate	0.16*	N/A	0.18*	N/A
Principal Arterial	2.07	2.32	2.06	2.11
Minor Arterial	0.61	0.49	0.56	0.63
Major collector	N/A	N/A	N/A	N/A
Minor collector	N/A	N/A	N/A	N/A
Local	N/A	N/A	N/A	N/A
Freeway	N/A	N/A	N/A	N/A
Collector	N/A	N/A	N/A	N/A

3.3 SUMMARY

This chapter presented the findings of the analysis of pedestrian crashes for the 2007- 2014 period in Oregon. An overall summary of the observed trends for pedestrian crashes is shown in Table 3.43. The majority of the crashes took place between November to February and during the am and pm peak hours. Further exploration of the crash data revealed that pedestrian and driver characteristics, location, traffic, road, and crosswalk characteristics are important predictors of pedestrian safety. Accounting for exposure, the results reinforces most findings found in the literature review and provides a preliminary indication of the relative weight of different variables that are important for the site selection process.

Table 3.43: Overall Trends for Pedestrian Crashes in the Oregon State Highway Network (2007-2014)

<table>
<tr><th>TYPE</th><th colspan="2">VARIABLE</th><th colspan="3">FINDINGS</th></tr>
<tr><td rowspan="6">Road variables</td><td colspan="2" rowspan="2">AADT</td><td colspan="3">Pedestrian crashes and ratios tend to increase with increases in AADT.</td></tr>
<tr><td colspan="3">For urban uncontrolled intersections, the highest ratio was on roads with an AADT between 20,000 and 50,000. For rural uncontrolled intersections, this occurred on roads with an AADT between 10,000 and 15,000.</td></tr>
<tr><td colspan="2">Posted speed limit</td><td colspan="3">For urban areas, the highest ratio was found on intersections with a posted speed limit of 35 to 50 mph. For rural areas, the highest ratio was found on intersections with a posted speed limit of 20 to 35 mph.</td></tr>
<tr><td colspan="2">Road width</td><td colspan="3">Pedestrian crashes and ratios tend to increase as road width increases. For urban uncontrolled intersections containing a road width 50 to 60 ft., there is a high ratio of pedestrian crashes. For rural uncontrolled intersections, there are not reliable observations for the identification of a critical road width.</td></tr>
<tr><td colspan="2">Number of lanes</td><td colspan="3">For urban and rural uncontrolled intersections, the highest ratio was found on intersections with 4 lanes.</td></tr>
<tr><td colspan="2">Road classification</td><td colspan="3">For urban and rural uncontrolled intersections, the highest ratio was found on principal arterials.</td></tr>
<tr><td rowspan="3">Neighbor. concept</td><td colspan="2">D</td><td colspan="3">For uncontrolled intersections, ratios for concept D remained very close to 1 for most of the variables considered. Only for intersections with a road width of 50 to 60 ft., the ratio went to almost 8.</td></tr>
<tr><td colspan="2">E</td><td colspan="3">Uncontrolled intersections with a posted speed limit of 20-35 mph in neighborhood concept E has the highest ratio for pedestrian crashes among the different neighborhood concepts.</td></tr>
<tr><td colspan="2">F</td><td colspan="3">Neighborhood concept F resulted to be the one with the highest ratios. Uncontrolled intersections had the highest ratios for AADT (20,000-30,000), width (40 – 50 ft.), number of lanes (4 lanes) and road classification (principal arterial) among the different neighborhood concepts.</td></tr>
<tr><td rowspan="11">Temporal character. (This section only shows relevant variables found from the road characteristics summary. The < / > sign shows which season ratio is higher</td><td>Variable</td><td>Time</td><td>Winter ratio</td><td>greater or less than</td><td>Not winter ratio</td></tr>
<tr><td rowspan="2">AADT (20,000-50,000)</td><td>evening</td><td></td><td><</td><td></td></tr>
<tr><td>not evening</td><td></td><td>></td><td></td></tr>
<tr><td rowspan="2">Posted speed limit (35-50 mph)</td><td>evening</td><td></td><td><</td><td></td></tr>
<tr><td>not evening.</td><td></td><td>></td><td></td></tr>
<tr><td rowspan="2">Road width (40-50 ft.)</td><td>evening</td><td></td><td><</td><td></td></tr>
<tr><td>not evening</td><td></td><td>inconclusive</td><td></td></tr>
<tr><td rowspan="2">Number of lanes (4 lanes)</td><td>evening</td><td></td><td>></td><td></td></tr>
<tr><td>not evening</td><td></td><td><</td><td></td></tr>
<tr><td rowspan="2">Road class. Principal arterial)</td><td>evening</td><td></td><td>></td><td></td></tr>
<tr><td>not evening</td><td></td><td>></td><td></td></tr>
</table>

4.0 SITE SELECTION

This chapter details the process for site selection along with description of the data collection equipment and methods. The findings of the literature review and crash data analysis tasks were used to identify road characteristics, traffic and environmental conditions associated with high risk of pedestrian crashes. A risk map was developed to identify corridors with risk factors. Using these identified risk factors and the risk map, a database was developed to identify locations at uncontrolled intersections with marked crosswalks, where pedestrian crashes occurred. This database included locations on the ODOT network as well as locations on non-state roadway facilities.

Additionally, sites with no pedestrian crashes that met the relevant criteria (high risk factors) were also included in the database to provide sites for control locations. From this database, locations on the ODOT network that met the site selection criteria were filtered and sites were selected from those locations. Figure 4.1 shows the process for the identification of sites.

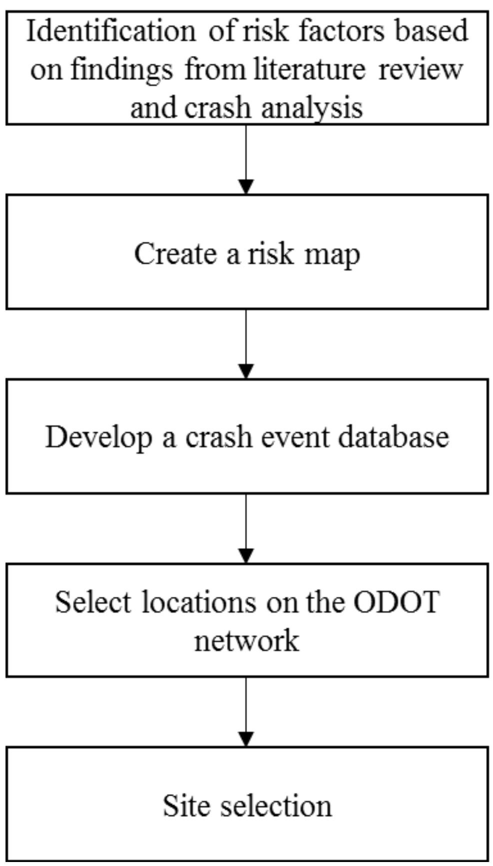

Figure 4.1: Site Selection Process Flowchart

Each of these steps that were undertaken to select sites are further described below.

4.1 IDENTIFICATION OF RISK FACTORS

Based on the results presented in the literature review and crash data analysis chapters, the research team identified various variables that were found to increase the likelihood of a pedestrian crash at an uncontrolled intersection with marked crosswalk.

In terms of road characteristics and traffic conditions, Table 4.1 summarizes the main findings. The highest risk for pedestrian crashes was found on principal arterials with four lanes, with AADT between 20,000 and 50,000 vehicles, road width between 50 – 60 ft and posted speed limits between 35 – 50 mph in urban areas. A risk ratio was computed for each category and was defined as the percentage of pedestrian crashes to the percentage of VMT for each segment studied.

Table 4.1: Summary of Findings by Facility Characteristics

FACILITY VARIABLE	FINDINGS
AADT	For urban uncontrolled intersections, the highest ratio was observed on roads with an AADT between 20,000 and 50,000. For rural uncontrolled intersections, the highest ratio was observed on roads with an AADT between 10,000 and 15,000.
Road width	For urban uncontrolled intersections, the highest ratio was observed on roads whose width varies 50 to 60 ft. For rural uncontrolled intersections, sufficient reliable observations were not available for the identification of a critical road width.
Posted speed limit	For urban areas, the highest ratio was found on roadways with a posted speed limit of 35 to 50 mph. For rural areas, the highest ratio was found on roadways with a posted speed limit of 20 to 35 mph.
Number of lanes	The highest risk ratio for pedestrian crashes was found on roadways with 4 lanes.
Road functional class	For urban and rural uncontrolled intersections, the highest ratio of pedestrian crashes was found on principal arterials.

4.2 RISK MAP

Using the risk factors identified in Table 4.1, a risk map was developed. Road characteristics such as number of lanes, road width, functional class, posted speed limit and traffic conditions such as AADT were ranked using risk scores from 1 to 5, with 1 being low risk and 5 being high risk. The risk scores were computed using risk ratios based on the exposure crash analysis. Table 4.2 shows the risk score associated with the road and traffic characteristics.

In terms of AADT, the findings from the literature review and crash data analysis revealed that as AADT increases, the frequency of crashes also increases. Thus, the risk score reflects this trend by assigning higher risk scores to roadways with higher AADTs. At urban uncontrolled intersections, most of the crashes occurred on roads with an AADT between 30,000 and 50,000 after controlling only for length. For rural uncontrolled intersections, the highest concentration of crashes was located on roads with an AADT between 10,000 and 15,000. Therefore, road segments with AADT higher than 10,000 were assigned the highest risk score (4 or 5), as shown in Table 4.2.

Similarly, previous findings suggest that as road width increases, the ratio of crashes (to VMT) increases as well. The highest ratio for uncontrolled intersections was found for roads with a width between 50 to 60 ft. Roadways with a posted speed limit between 35 and 50 mph, have a higher risk ratio than roadways with other speed limits. Additionally, as the posted speed limit increases, the ratio of pedestrian crashes also increases and is reflected in the risk score of Table 4.2.

At urban and rural intersections, the ratio of pedestrian crashes increases as the number of road lanes increase. Most of the pedestrian crashes occurred at intersections with 4 lanes. Table 4.2 shows the risk score associated with number of lanes. Most of the pedestrian crashes also occurred on arterials (principal for urban intersections, and minor for rural intersections). These type of facilities were given a risk score of 5, followed by collectors and local roads. Table 4.2 shows the risk score associated with functional class.

Table 4.2: Risk Score Associated with Road and Traffic Characteristics

ROAD AND TRAFFIC CHARACTERISTICS	CATEGORIES	RISK SCORE
AADT	0-2,500	1
	2,500-5,000	2
	5,000-10,000	3
	10,000-20,000	4
	>20,000	5
ROAD WIDTH (ft.)	0-10	1
	10-20	2
	20-30	3
	30-50	4
	>50	5
POSTED SPEED LIMIT (mph)	< 20	1
	20	2
	25	3
	30	4
	≥35	5
NUMBER OF LANES	1	2
	2	3
	3	4
	> 3	5
FUNCTIONAL CLASS	Local road	1
	Collector	3
	Arterial	5

Five risk maps accounting for each risk factor were developed for the ODOT highway network. These maps were merged into a single map using the average risk scores to account for the risk of the different variables. Segments in red represent the highest risk, whereas those in pink represent the lowest risk. Figure 4.2 shows the risk map that was developed for the ODOT highway network. Figure 4.3 shows the zoomed in map for Portland metropolitan area. For the city of Portland, the corridors identified as high risk are similar to those identified in the *Kittelson & Associates (2014)* report: Powell Blvd., 82nd Ave, Lombard St. and Macadam Ave.

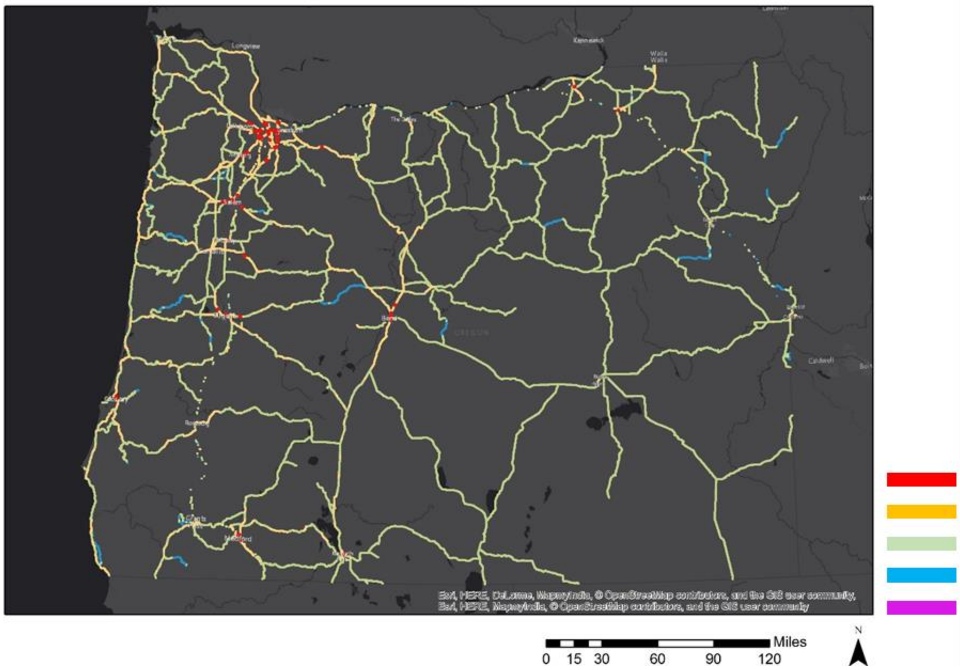

Figure 4.2: Risk map of the ODOT highway network

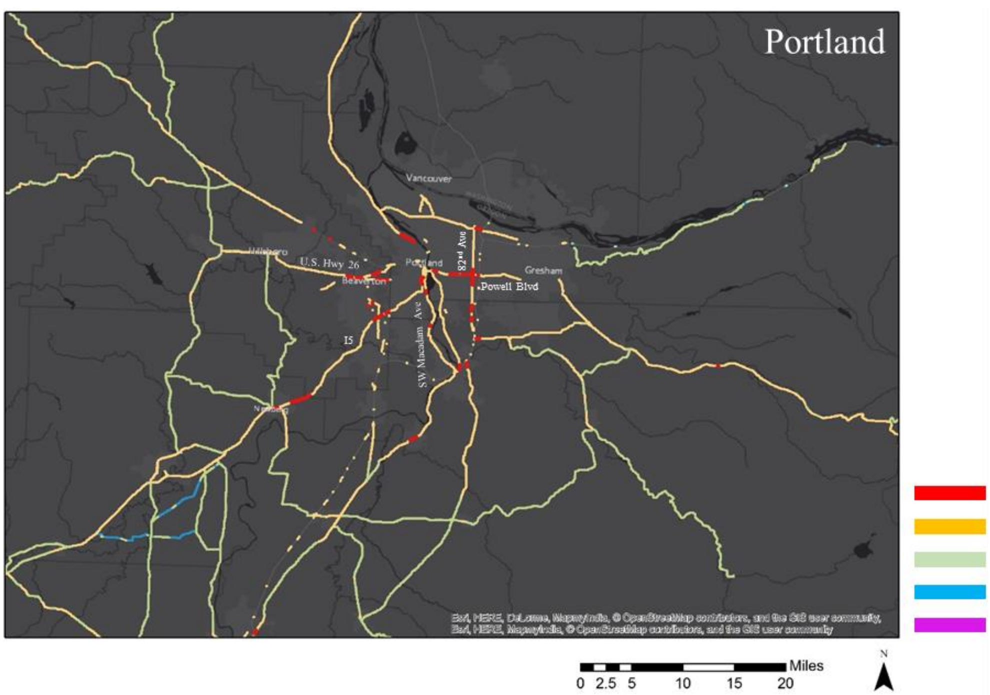

Figure 4.3: Risk map for Portland, OR

4.3 SELECTION OF LOCATIONS WITH CRASH OCCURENCE

Using the risk map, the next step was to select locations within this network for different risk levels. The objective of identifying sites with varying risk levels was to allow for comparison of characteristics between the sites, so that the contributory causes of pedestrian crashes could be identified. Locations where pedestrian crashes occurred were identified and categorized with respect to the severity of crashes, and prioritized in the selection process.

For severity levels, the five point KABCO scale was used as shown in Table 4.3. At the crash level, severity is reported based on the most severe injury (e.g. if a crash involved two participants, one with level A and the other with level B injury, the crash severity is reported as A). Additionally severity level for each participant was also recorded in the crash database.

Table 4.3: KABCO Severity Scale Description

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.

A total of 180 pedestrian crashes at uncontrolled intersections with marked crosswalks occurred in Oregon from 2007 to 2014. Only 58 (32%) of those crashes occurred on the ODOT highway network. Most of these crashes were categorized as level B (visible injury). Due to the few observations available for KABCO levels K, A, C and O, the crashes were aggregated in two categories: K+A, and C+O. Additionally, there were a few crashes that occurred on segments with a risk level 1, 2 or 3. These levels were aggregated as well. Table 4.4 shows the distribution of pedestrian crashes at uncontrolled intersections by risk level and severity.

Table 4.4: Distribution of Pedestrian Crash Events at Uncontrolled Intersections by Risk Level and Severity

RISK LEVEL	DESCRIPTION	K+ A	B	C+O	TOTAL
[1,3)	Low	3 (27%)	13 (43%)	4 (24%)	20
[3,4)	Medium	3 (27%)	9 (30%)	9 (52%)	21
[4,5]	High	5 (46%)	8 (27%)	4 (24%)	17
Total		11 (100%)	30 (100%)	17 (100%)	58

4.4 CRASH EVENT DATABASE

A database of crash events was constructed by identifying the locations associated with 266 crashes involving pedestrians at uncontrolled intersections as documented in the crash data analysis. A number of important variables were identified for each crash location as listed in Table 4.5. The information was gathered using a combination of Google Maps Street View and Oregon Department of Transportation TransGIS platform. The presence of pedestrian traffic generators was not collected because of the lack of data for locations outside of the Portland Metro region.

Table 4.5: Data Collection Elements Collected at Each Location

VARIABLE	DESCRIPTION
Marked status at the event of the crash	Crosswalk marking status at the time of crash
Current marked status	Current crosswalk marking status
Crash ID	Crash ID from the crash database
Date	Date of crash
Year	Year when crash occurred
Severity	Severity of the crash based on the KABCO scale
State Highway Number	ODOT State Highway Number (if applicable)
Name of route and intersecting route	Main and cross streets where the crash occurred
City / Town	City and town where the crash occurred
Latitude / Longitude	Latitude and Longitude of the crash location
Link	Link to Google StreetView
Crash Severity	Severity of the crash based on the KABCO scale
Posted Speed	Posted speed limit of the facility where the crash occurred
Number of lanes	Number of lanes on facility where the crash occurred
Traffic flow configuration	Configuration of flow i.e. one-way vs. two-way
Presence of sidewalks	Sidewalk presence at the crash location (1 if Y, 0 if N)
Presence of bike lanes	Bike lane presence at the crash location (1 if Y, 0 if N)
Presence of on-street parking	Presence of on-street parking at the crash location
Traffic Volumes (AADT)	AADT of the facility where the crash occurred
Land Use	Land use category based on the neighborhood concept by Currans et al.
Risk Level	Risk level for ODOT network based on geometric, traffic flow and land use characteristics
Crosswalk marking type	Transverse, continental, ladder, other
Lighting conditions	Lighting conditions at the location of crash

Table 4.6 shows the distribution of crash events based on land use, crosswalk type, risk and severity in the database. Pedestrian crashes on marked crosswalks at uncontrolled intersections were not observed on sites with neighborhood concept C. The majority (82%) of observations were on facilities within neighborhood classes D and E. 68% of the pedestrian crash events at uncontrolled intersections occurred where marked crosswalks were not present. Of the crash events at marked crosswalks, more crashes occurred at crosswalks with transverse and continental crossings. Most pedestrian crashes occurred at sites where risk information was not available. This is because risk was only computed for locations that were on ODOT State highway facilities. Of the crash events, where risk information was available, crash events occurred almost evenly at sites with risk levels of 3, 4, and 5. The majority (96%) of observations were crashes that resulted in injury (96%). Fatal crashes accounted for 3% of the crashes in the database.

Table 4.6: Distribution of Neighborhood Concepts in the Crash Events Database

FACTORS	CATEGORIES	TOTAL	% TOTAL
NEIGHBORHOOD CONCEPT	D	121	45%
	E	99	37%
	F	44	17%
	Not available	2	1%
CROSSWALK TYPE	None	181	68%
	Transverse	40	15%
	Continental	30	11%
	Ladder	15	6%
RISK	2-3	1	0%
	3-4	19	7%
	4-5	18	7%
	5	14	5%
	Not available	214	80%
SEVERITY	Fatal	8	3%
	Injury	256	96%
	Property Damage Only	2	1%

4.5 CORRIDOR SELECTION

The events in the crash database were used to identify corridors where crashes were observed. Corridors were selected based on the availability of a representative sample of sites with a similar distribution of land use and risk level observed in the crash event database. Of the 266 pedestrian crashes at uncontrolled locations, 80% occurred on non-state roads. A set of criteria was developed to identify select corridors for the data collection process. Based on the objectives of this study, priority was given to selecting locations on ODOT facilities in the data collection strategy. Additional considerations for selecting sites included proximity to PSU (within 1 hour of driving time) and presence of a marked crosswalk (22 sites). Table 4.7 shows the selected corridors in the Oregon State Highway Network using the crash event database. Additional corridors (Wa Na Pa St., Willamette Drive, and Proctor/Pioneer Boulevard) that were not present in the crash event database but were considered to be suitable locations for potential sites were also added as shown in Table 4.7.

Table 4.7: State Highway Corridors Selected from Crash Events Database near Portland, OR

CORRIDOR	CITY	MARKED CROSSWALKS AT UNCONTROLLED INTERSECTIONS
SE Powell Blvd	Portland	10
W / E Powell Blvd	Gresham	2
SE 82nd Ave	Portland	0
NE Sandy Blvd	Portland	0
Hillsboro-Silverton Hwy NE / Mount Hood Ave	Woodburn	5
Pacific Hwy 99W	Newberg	10
SE McLoughlin Boulevard	Portland	1
Cascade Avenue	Hood River	7
Clackamas Highway	Estacada	0
Wa Na Pa Street	Cascade Locks	4
Willamette Drive	Portland - Oregon City	3
Proctor / Pioneer Boulevard	Sandy	3

Along these selected corridors, location characteristics were collected for sites with marked crosswalks at uncontrolled locations. These characteristics are shown in Table 4.8 and include latitude, longitude, presence of median refuge, streetlights, types of signs, advance stop bar, curb extensions if available. Other characteristics include traffic flow, number of lanes, land use, AADT, risk, and pedestrian activity level.

Table 4.8: Location Characteristics for Potential Sites

VARIABLE	DESCRIPTION
Site	Name of site
Major Approach	Name of major approach on which the crosswalk is located
Minor Approach	Name of minor approach on which the crosswalk is located
Link	Link to Google Maps with the site location
Latitude	Latitude of the site
Longitude	Longitude of the site
Driving time	Driving time from PSU
Traffic Flow	One-way vs. two-way
Crossing length	Width of the roadway at the crosswalk location
Median refuge	None, TWLTL, Island
Width of Refuge Island	If present, width of the refuge island
Streetlight location	Whether streetlight was above, away or absent from the crosswalk
Type of Signs	Type of signs if present
Type of signs per approach direction	Number of signs per approach direction
Advance stop bar	If present, distance from crosswalk to advance stop bar
Presence of curb extension	Y/N
Speed Limit	Posted speed limit of the facility on which the crosswalk is located
Number of Lanes	Number of lanes on the facility on which the crosswalk is located
Land Use	Land use classification
AADT	AADT of the facility on which the crosswalk is located
Risk	Risk level
Pedestrian activity level	Based on visible pedestrians in Google Street View, low – if no pedestrians are present, medium – if 1-2 pedestrians are present, high – if more than 3 pedestrians are present.

4.6 SITE SELECTION

Final sites were selected after consulting with the TAC and considering the following criteria.

- Presence on a facility on the ODOT state network
- Marked unsignalized crosswalk
- Prioritize sites that lack pedestrian safety enhancements
- Include sites with varying pedestrian activity levels
- Occurrence of pedestrian crashes along the corridor
- Equal distribution of sites by neighborhood concept
- Equal distribution of sites by level of risk based on roadway features
- Diversity of sites
- Presence of poles for locating equipment
- Presence of sidewalks
- Lack of visual obstruction

Table 4.9 shows the main characteristics of the nine sites that were selected for the data collection. The posted speed limit at these sites varied between 25 – 40 mph, while the number of lanes varied 2 – 4. Both one-way and two-way locations were included and two sites also had raised medians.

Table 4.9: Sites for Data Collection

Sites	Land Use	Speed Limit [mph]	One-Way Two-Way	Median	Pedestrian Island	Number of lanes
SE Powell Blvd and 28th Pl. *	Urban	35	Two-Way	Two-Way Left Turn Lane	Yes/No*	4
SE Powell Blvd and SE 36th Ave	Urban	35	Two-Way	Two-Way Left Turn Lane	No	4
SE Powell Blvd and SE 75th Ave	Urban	35	Two-Way	Raised	Yes	4
W. Powell Blvd. and SW. Duniway Ave.	Suburban	40	Two-Way	Raised	Yes	3
Wa Na Pa St. and SW. Oneonta St.	Rural	30	Two-Way	N/A	No	2
Wa Na Pa St. and SW. Regulator St.	Rural	30	Two-Way	N/A	No	2
Pioneer Blvd. and Beers Ave.	Rural	25	One-Way	N/A	No	2
Pioneer Blvd. and Shelley Ave.	Rural	25	One-Way	N/A	No	2
E. Hancock St. and N. Edwards St.	Suburban	25	One-Way	N/A	No	3

*Changed before and after removing marked crosswalk

4.7 DATA COLLECTION AND EQUIPMENT

The equipment and methods used for data collection and processing are described in this section.

4.7.1 Equipment

Two types of equipment were used for the data collection – video cameras and a radar recorder. The video recording was captured in 720p60 Wide Angle (1280 by 720 pixels at 60 frames per second) format using two GoPro Hero 4 Silver cameras. These cameras have a built-in Wi-Fi and a touch screen. These wireless capacities allow the cameras to connect to a smartphone through the GoPro Connect app, enabling adjustment to the angle of capture. Two cameras were used to capture interactions from both eastbound and westbound directions. An external battery (re-fuel by Digipower) was attached to record videos for 6 hours as shown in Figure 4.4. The battery extends the runtime of the GoPro Hero 4, allowing for more than six hours of continuous use.

Figure 4.4: Video recording equipment used for data collection

To collect traffic data, Jamar Black Cat radar recorder was used. The Black Cat Recorder detects position of vehicles, allowing the radar to record two lanes of bidirectional traffic or traffic travelling in the same direction (two lanes). The recorder has the ability to record speed per vehicle, traffic volume, gap size, and vehicle classification (based on the length of the vehicle). Additionally it displays the data in real time. Data can be accessed by connecting a cable to the device or remotely by Bluetooth or IP address. Figure 4.5 (a) shows the JAMAR radar recorder during setup and calibration process and Figure 4.5 (b) shows the device in use.

Figure 4.5: Equipment setup including (a) JAMAR radar recorder during setup (b) JAMAR radar recorder in use

4.7.1.1 Time Synchronization

During the data collection phase, the research team ensured that a picture with the time on the respective device (camera, radar) and the time on an app (Alarm Clock HD) were taken, so that syncing can be performed later. **Figure 4.6** shows a picture of the time stamp on the phone that was used to sync with the camera time. **Figure 4.7** shows the picture of the JAMAR software time stamp and the time on the phone app. The same app was used for all the devices. The video and radar times and the real times from the app were obtained for each site. The difference between the time shown on each device and the time on the app was the adjustment factor. This factor was individually determined for each device per site and the corrected adjusted time for each device was obtained.

Figure 4.6: Camera time sync

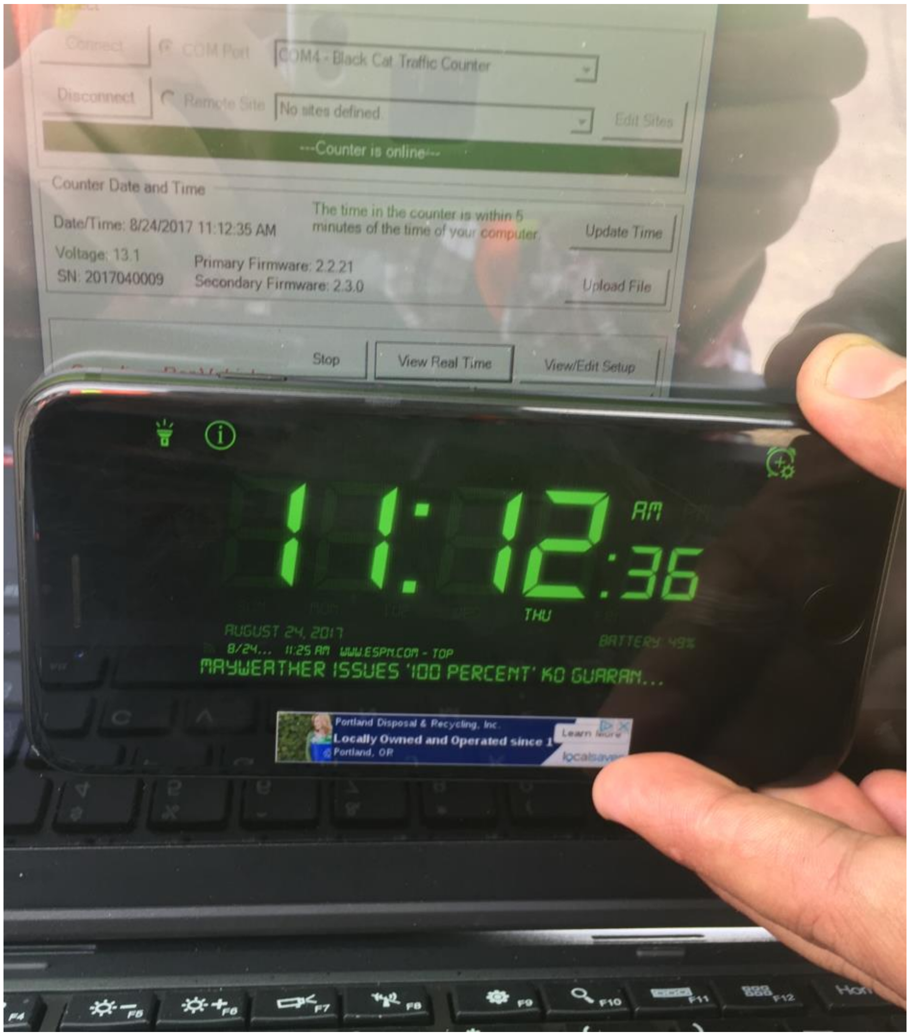

Figure 4.7: Radar time sync

4.7.1.2 Temporary Markings

Temporary transverse markings were laid down near the crosswalk to determine a) the distances where the drivers stopped to yield to the pedestrians and (b) the location where pedestrians crossed (either within the crosswalk, 5ft away from the crosswalk or beyond). These markings were laid down at 5 ft., 15 ft., and 30 ft. both upstream and downstream of the crosswalk location.

4.7.2 Video Processing

After ensuring the time sync and calculation of the real adjusted time, the next step was to process the video data. Members of the research team watched video from each site and recorded the following metrics for each pedestrian event. A pedestrian event was defined as the time between when the pedestrian(s) approached the curb and waits, signaling an intent to cross and the time when they reach the other curb (at the end of the crosswalk).

Events – A pedestrian crossing was classified as an event which included either a single pedestrian or a group of pedestrians crossing at the same time. Jaywalking pedestrians were counted but their interactions with vehicles were not analyzed.

Interactions – Events analyzed at the lane level. There are two basic types of interactions

- Null: If no vehicle is present when the pedestrian is crossing, then type "N" interaction is recorded

- Otherwise, if vehicles are present then a "Valid" interaction is recorded

If vehicles are present then a "Valid" interaction is recorded. The test to determine the presence of a vehicle is that the vehicle(s) that interact with the pedestrian can stop within the Stopping Sight Distance (SSD).

The "Valid" interactions were classified as follows (one interaction per present vehicle):

- A - Driver stops before the advance stop bar (a stop bar was present in all locations)
- B - Driver stops between 15ft from the crosswalk and the stop bar
- C - Driver stops between 0 and 15ft from the crosswalk
- D - Driver slows down but does not stop
- E - Driver does not slow down
- F - Driver takes an evasive action (braking, swerving, lane changing)

Dangerous Interaction – This is a subjective measure to quantify interactions perceived as dangerous by the observer.

Jaywalking – Jaywalking in this study was defined when a pedestrian crossed the roadway a location located more than 5 ft from the crosswalk. If a pedestrian jaywalked, no other information pertaining to their crossing was collected.

Time Pedestrian Arrives at the Curb - This is the time when the pedestrian arrives at the curb, prior to beginning to cross.

Time Pedestrian starts to walk - This is the time when the pedestrian starts to cross from the curb.

Time Pedestrian Finishes Crossing - Time when the pedestrian reached the opposite curb.

Pedestrian Waiting Time – This metric is defined as the difference between pedestrian start to walk time and pedestrian arrival time.

Pedestrian Group Size – The group size of crossing pedestrians was also noted for each event.

Congested Event - Whether or not the pedestrian crossing event occurred during congested traffic conditions.

4.7.3 Radar Data Processing

Once the radar data was downloaded from the device and synced with respect to time, it was further processed and the following metrics were extracted for each location utilizing 15-minute intervals.

Speeds – average speed of all the vehicles passing as well as 85^{th}, 90^{th}, 95^{th} percentiles and maximum speeds.

Vehicle Count – The number of vehicles passing the radar device.

Speeding Vehicles – The number of vehicles traveling above the speed limit.

Average Gap – The time in seconds between consecutive vehicles.

4.7.4 Safe Stopping Distance (SSD)

To determine if a vehicle was present and there was a valid interaction the SSD was estimated at each location. The speed limit was utilized in the SSD calculation unless there was severe congestion. If congestion was severe, the 85^{th} speed of the corresponding 15-minute interval was utilized in the SSD calculation. The total stopping time (TST) as defined by the Institute of Transportation Engineers (ITE) for traffic signals (ITE, 1999) is:

$$\boldsymbol{t_s = t_r + t_b = t_r + \frac{v}{(2a + 2Gg)}} \qquad \textbf{(4-1)}$$

Where

t_s= Total time to stop (s or seconds) or TST

v= Vehicle speed (ft. /s)

t_r= Reaction time (s or seconds)

t_b= Breaking time (s or seconds)

a= Deceleration rate (ft. /s^2)

G= Roadway grade (percent)

g= Gravity acceleration (ft. /s^2)

The operational reaction time of an average driver in an urban area is assumed to be 1 second and maximum deceleration rate is assumed to be 10 ft. /s^2 or 6.8 mph. The safe stopping distance (SSD) d_s is obtained multiplying, t_s and v, time and speed. For a speed of 25 miles per hour (40.2 km/h) a vehicle SSD is 104 feet (31.7 m); for a speed of 30 miles per hour (48.3 km/h) a vehicle SSD is 141 feet (42.9 m). Note that in this study G = 0 and with the 1 second reaction time the SSD can be calculated as $d_s = v + \frac{v^2}{20}$ $[ft]$ if the speed is measured in ft/s.

4.8 SUMMARY

This chapter outlined the site selection process as well as equipment and the main definitions and methods used in the data collection and processing steps. The following chapter presents data results and analysis.

5.0 INITIAL DATA ANALYSIS

This chapter presents a physical description of the sites chosen for the data collection and general description of traffic conditions and pedestrian behavior at each data collection site. Graphs describing traffic conditions (speed vs. flow and flow vs. gap) utilize 15 minute intervals (each dot is a data pair obtained averaging traffic conditions in a 15 minute interval).

5.1 SE POWELL BLVD. AND SE 28TH PL. (BEFORE)

Figure 5.1 shows a view of the crosswalk looking westbound. At this location, SE Powell Blvd. is a two-way arterial with two travel lanes in each direction and a speed limit of 35 mph. On the north and south ends of the crosswalk, food establishments were present, although the establishment on the south end was not functional. The width of the crosswalk was 52 ft. A bus stop was present on the south side, adjacent to the east bound lanes. The pilot test data collection was conducted at this location on Friday, May 26th, 2017 between 1 PM and 7 PM.

Figure 5.1: SE Powell Blvd. and SE 28th Pl.

Figure 5.2 shows the position of the data collection equipment with respect to the crosswalk. Two cameras were used to record the pedestrian-motor vehicle interactions and were placed on poles at a height of approximately 20 ft. from the ground. One radar device was used to capture the traffic characteristics of the eastbound lanes only.

Figure 5.2: Location of equipment at SE. Powell Blvd. and SE. 28th Pl.

5.1.1 Qualitative Analysis

One hundred and sixty seven pedestrians were observed crossing at this location during the hours of data collection. A number of dangerous incidents were observed at this location. Instances of sudden braking and rolling stops were also observed. The video recordings showed that a number of drivers started accelerating as soon as the pedestrian is out of their lane, close to exiting their lane, which could lead to dangerous situations especially if the pedestrians stutters, falls down, or stops suddenly.

5.1.2 Traffic Characteristics

The JAMAR radar device was used to record the volume, speed and gap of vehicles as they were approaching the crosswalk. This data was processed for each location. Figure 5.3 shows the plots of mean speed, 85th percentile speed, maximum speed vs. flow and flow vs. average gap for this location. While the mean speed and the 85th percentile speeds at this location were below the posted speed limit of 35 mph, the maximum speeds were above the speed limit. The plot of flow vs. average gap show that as the gap increases flow decreases as expected.

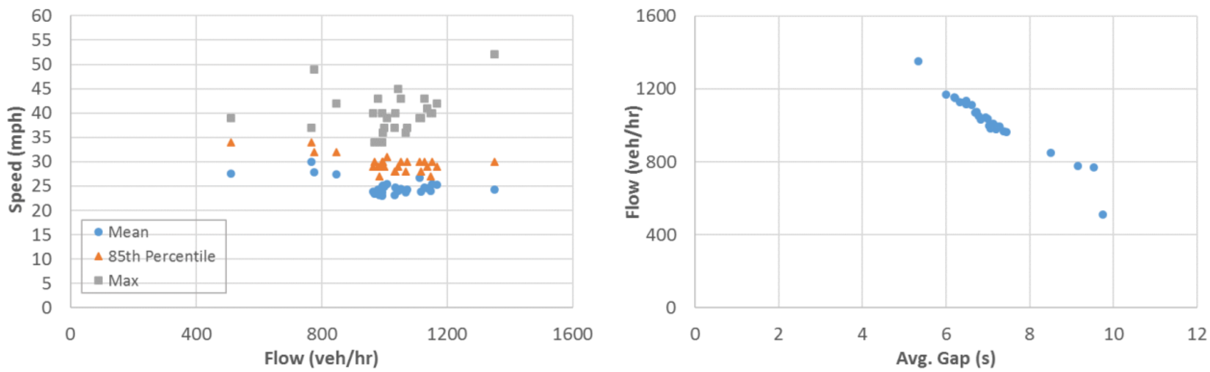

Figure 5.3: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 28th Pl. Eastbound (before)

5.2 SE POWELL BLVD. AND SE 28TH PL. (AFTER)

After the initial data collection, the crosswalk markings at this location were removed. New crosswalk markings and a new traffic signal was installed at the intersection of SE Powell Blvd and SE 28th Ave, which is located 300 ft. away. Figure 5.4 shows the location after the removal of crosswalk markings, pedestrian island, and warning signs. The research team wanted to re-collect data at this location to understand the impacts of the crosswalk removal. Hence, the second set of data collection at this location was conducted on August 10th, 2017. The equipment was set up in the same locations that were used previously (see Figure 5.2). Data was collected for approximately 6.5 hours at this location.

Figure 5.4: SE. Powell Blvd. and SE. 28th Pl (after removal of crosswalk markings).

5.2.1 Qualitative Analysis

After the crosswalk markings were removed, the video recordings showed that people continued to cross at this location, although the count decreased. Yielding rates were observed to decline significantly when compared to the before condition and long pedestrian delays were observed. Multiple situations were observed where the drivers in the lane closest to the curb were observed to yield to the pedestrian, however the drivers in the other lanes did not yield, resulting in long pedestrian delays. A common incident was observed where the pedestrians waited in the spot where the median island was previously located, however a higher rate of drivers did not yield to the pedestrians.

5.2.2 Traffic Characteristics

Figure 5.5 and Figure 5.6 show the plots of speed vs. flow and flow vs. average gap for the eastbound and westbound directions respectively after the crosswalk markings were removed. The maximum speeds observed in the westbound were well above the posted speed limit of 35 mph indicating that some vehicles were speeding. The plot of flow vs. average gap for both directions shows expected trends.

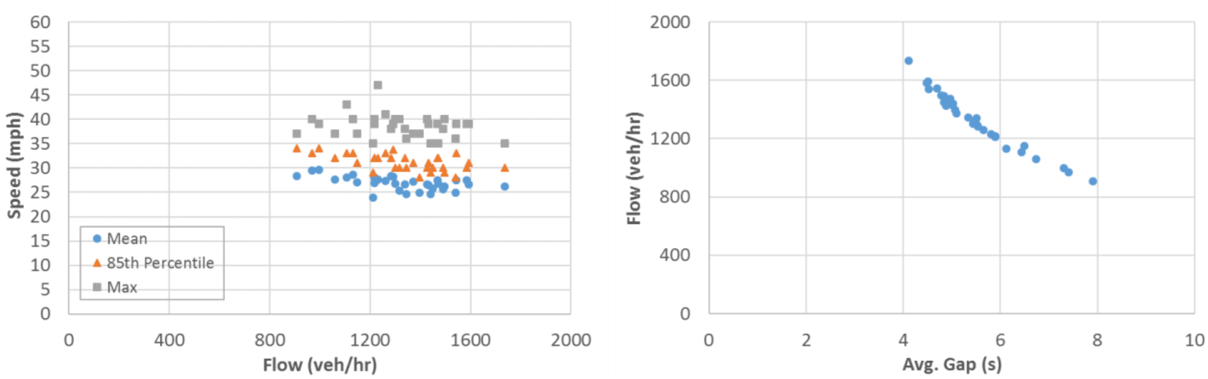

Figure 5.5: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 28th Pl. Eastbound (after)

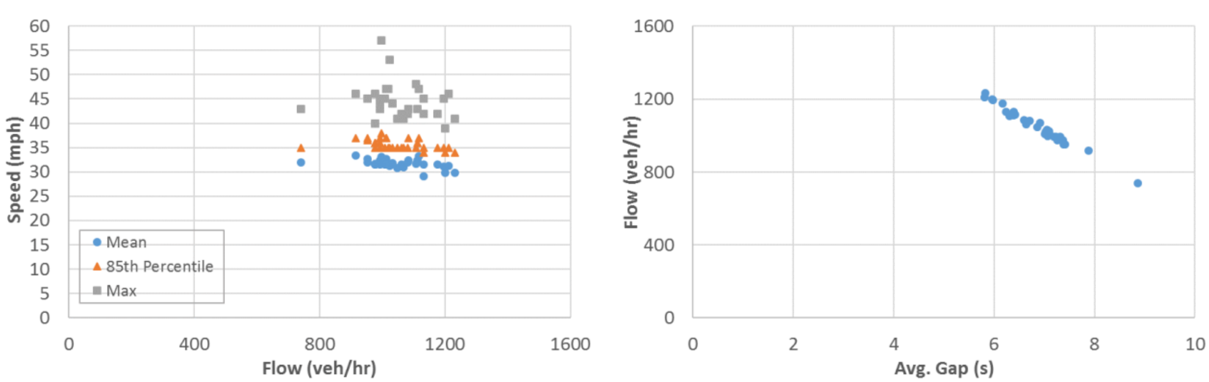

Figure 5.6: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 28th Pl. Westbound (after)

5.3 SE POWELL BLVD. AND SE 36TH AVE

The crosswalk at SE Powell Blvd. and SE 36th Ave. is located in SE Portland, OR. At this location, SE Powell Blvd. is a two-way arterial with two travel lanes in each direction with a two-way left turn lane and a speed limit of 35 mph. A coffee store and businesses are located on the north and south ends of the crosswalk respectively. The width of the eastbound and westbound crosswalks is 26 ft. (each) approximately. A pedestrian island was not present but there is a raised median near the crosswalk offers some protection for pedestrians crossing in two stages. Figure 5.7 shows the location of the crosswalk of SE Powell Blvd. The data collection at this location was conducted on July 13th, 2017. Figure 5.8 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 6.5 hours.

Figure 5.7: SE Powell Blvd. and SE 36th Ave

Figure 5.8: Location of data collection equipment at SE Powell Blvd. and SE 36th Ave.

5.3.1 Qualitative Analysis

At this location, many long platoons of vehicles were observed not yielding to the pedestrians, which resulted in large pedestrian delays. This intersection also had a large presence of cyclists compared to other study sites. There is a bus stop at this location, and observations showed that while the bus stopped to drop off/pick up passengers in the right lane, the drivers in the left lane still kept going, even though pedestrians indicated their intent to cross, leading to potentially unsafe situations. Congested conditions were observed during the peak periods at this location.

5.3.2 Traffic Characteristics

Figure 5.9 and Figure 5.10 show the plots of speed vs. flow and flow vs. average gap at this location for the east and westbound directions. The speed vs. flow plot for the eastbound direction shows some observations with lower mean, 85th percentile and maximum speeds compared to the westbound direction indicating congested conditions. Hourly flows in the eastbound direction are also lower compared to the westbound direction. The plots for flow vs. average gap show expected trends. Congested conditions were observed during the peak periods at this location.

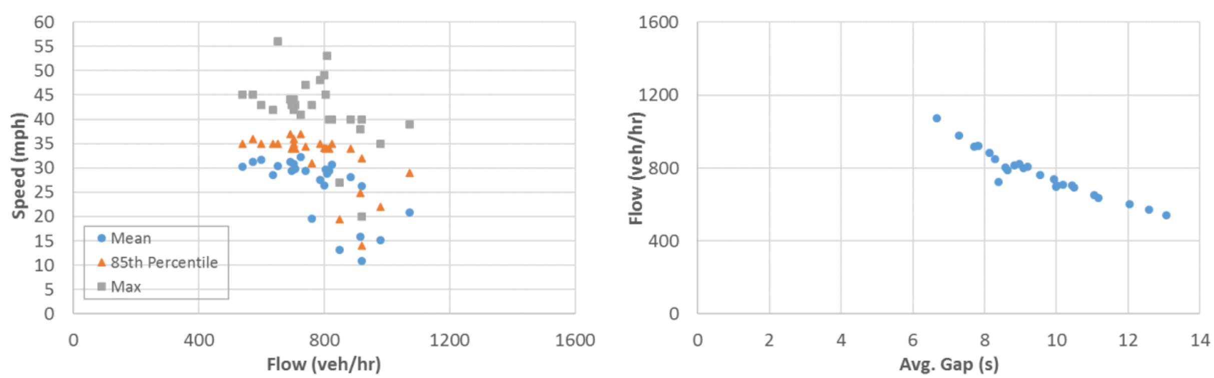

Figure 5.9: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 36th St. Eastbound

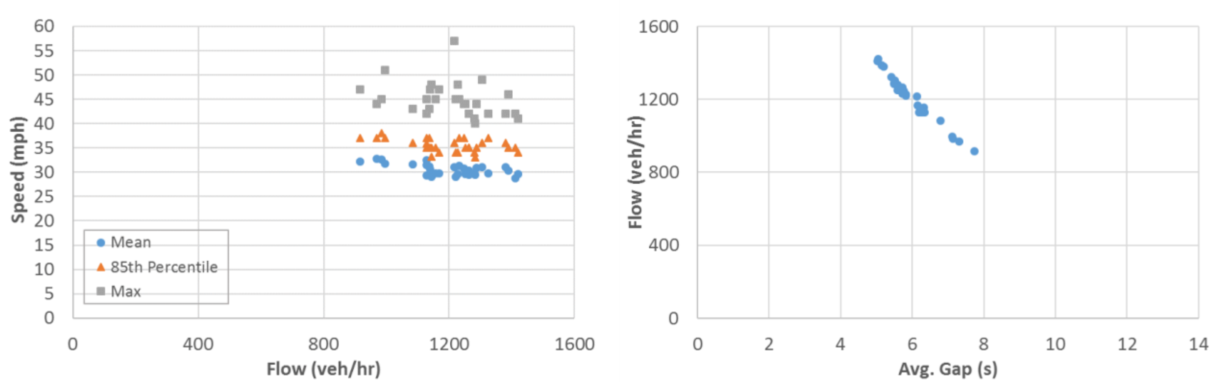

Figure 5.10: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 36th St. Westbound

5.4 SE POWELL BLVD. AND SE 75TH AVE.

The crosswalk at SE Powell Blvd. and SE 75th Ave. is located in SE Portland, OR. At this location, SE Powell Blvd. is a two-way arterial with two travel lanes in each direction with a raised median and a speed limit of 35 mph. On the north end of the crosswalk, a mixture of commercial and residential establishments are located. A church is located on the south end of the crosswalk. Bus stops are present on both sides of the roadway near the crosswalk. The width of the crosswalk was 48 ft. Figure 5.11 shows the location of the crosswalk of SE Powell Blvd. The data collection at this location was conducted on July 20th, 2017. Figure 5.12 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 8.5 hours.

Figure 5.11: SE Powell Blvd. and SE 75th Ave

5.4.1 Qualitative Analysis

At this location, long platoons of vehicles were observed, which resulted in large pedestrian delays, if the vehicles did not yield. This crosswalk was also used cyclists occasionally. There is a bus stop at this location, and observations showed that while the bus stopped to drop off/pick up passengers in the right lane, the drivers in the left lane still kept going, even though pedestrians indicated their intent to cross, leading to potentially unsafe situations.

5.4.2 Traffic Characteristics

Figure 5.13 and Figure 5.14 show the plots of speed vs. flow and flow vs. average gap at this location for the east and westbound directions. The flows in the westbound direction were lower than the flows in the eastbound direction during the study period. The trends in mean, 85th and maximum speeds were similar in both directions.

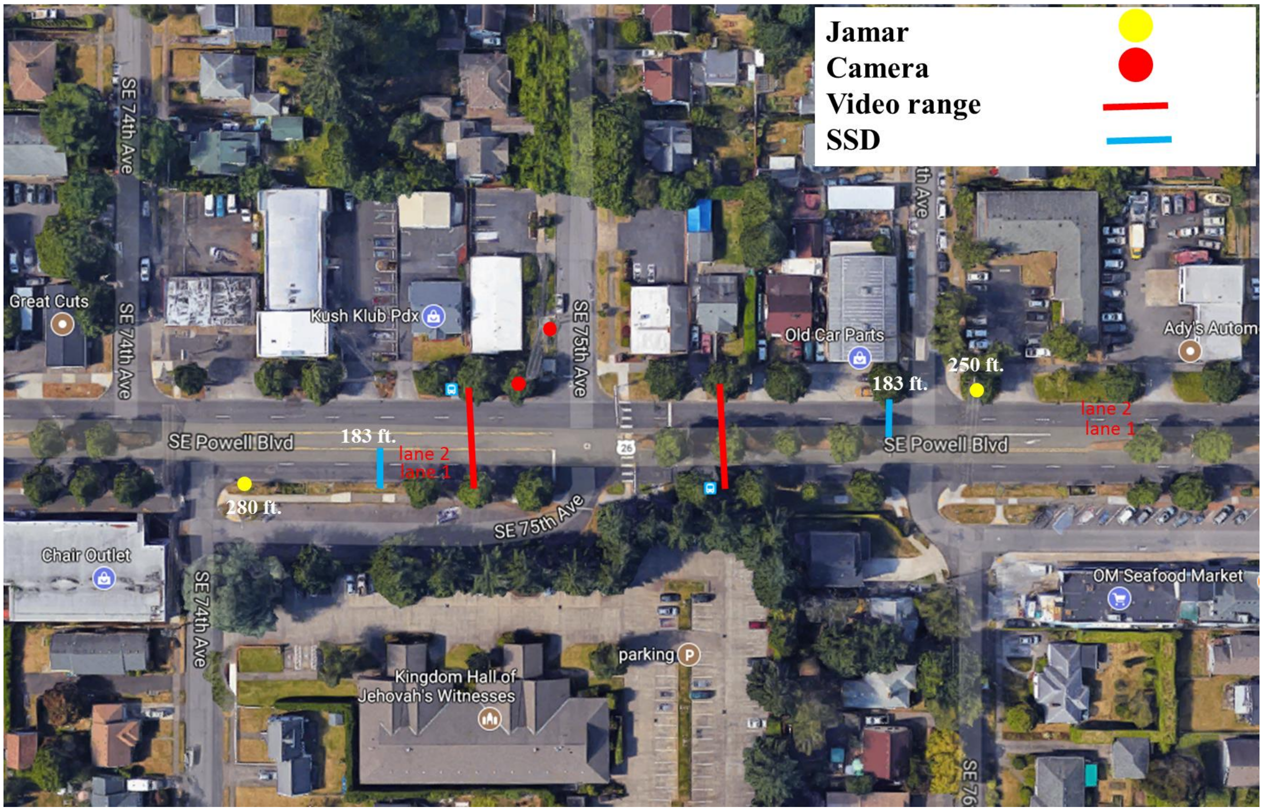

Figure 5.12: Location of data collection equipment at SE Powell Blvd. and SE 75th Ave.

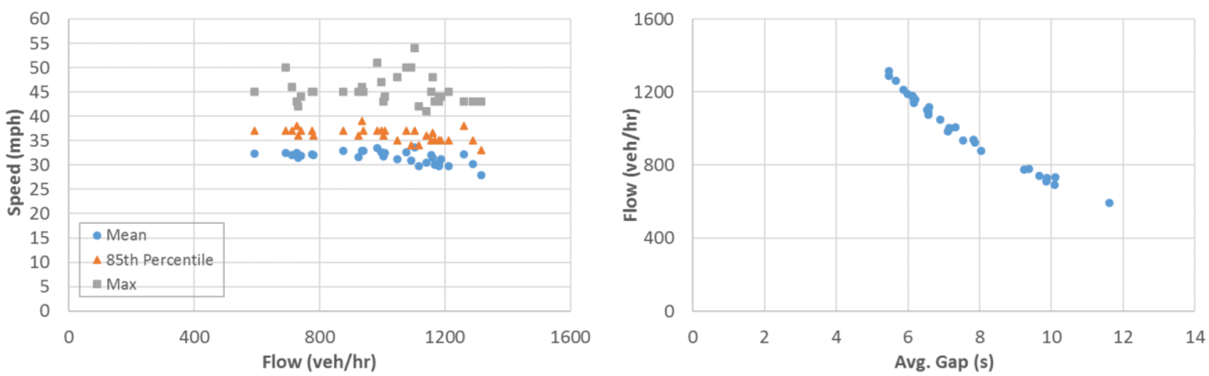

Figure 5.13: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 75th St. Eastbound

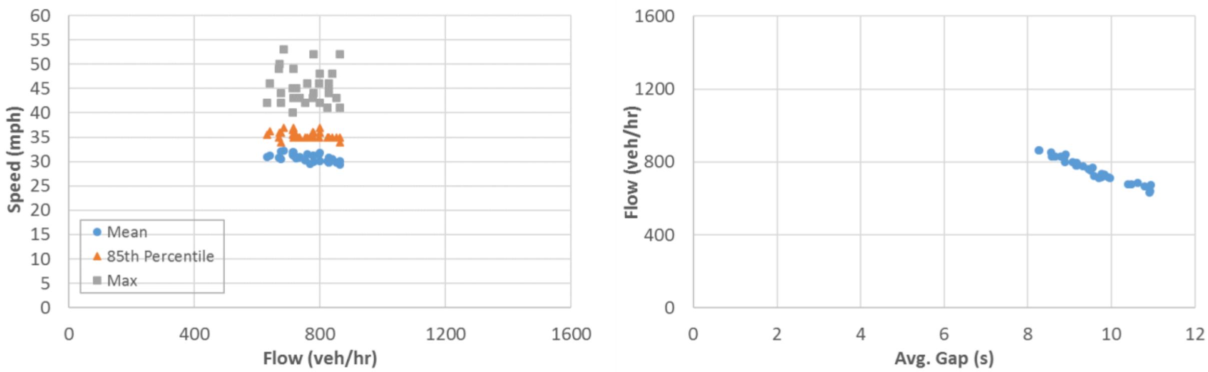

Figure 5.14: Speed vs. flow and flow vs. average gap at SE Powell Blvd. and SE. 75th St. Westbound

5.5 W POWELL BLVD. AND SW DUNIWAY AVE.

The crosswalk at W Powell Blvd. and SW Duniway Ave. is located in Gresham, OR. According to the ODOT classification, Gresham based on its population, is classified as an urban area. At this location, W Powell Blvd. is a two-way arterial with two travel lanes in each direction and a speed limit of 40 mph. In addition to the travel lanes, an auxiliary lane that is used by buses and a bus stop are present in the eastbound direction, and a bike lane is present on the westbound direction. A raised median with a pedestrian island is also present. The width of the crosswalk was 68 ft. (28 ft. and 40 ft. for eastbound and westbound sections respectively). A big retail store (Walmart) is present on the south end of the crosswalk. A residential neighborhood is present at the north end of the crosswalk. Figure 5.15 shows the location of the crosswalk on W. Powell Blvd. The data collection at this location was conducted on August 31st, 2017. Figure 5.16 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 9 hours.

Figure 5.15: W. Powell Blvd. and SW Duniway St.

Figure 5.16: Location of data collection equipment at W. Powell Blvd. and SW Duniway Ave.

5.5.1 Qualitative Analysis

At this location, many vehicles were observed to be traveling at high speeds. Higher rates of sudden braking were also observed compared to other sites. Numerous dangerous interactions were observed between pedestrians and vehicles at this location.

5.5.2 Traffic Characteristics

Figure 5.17 and Figure 5.18 show the plots of speed vs. flow and flow vs. average gap at this location for the east and westbound directions. Maximum speeds that were significantly higher than the posted speed limit of 40 mph were observed particularly in the westbound direction.

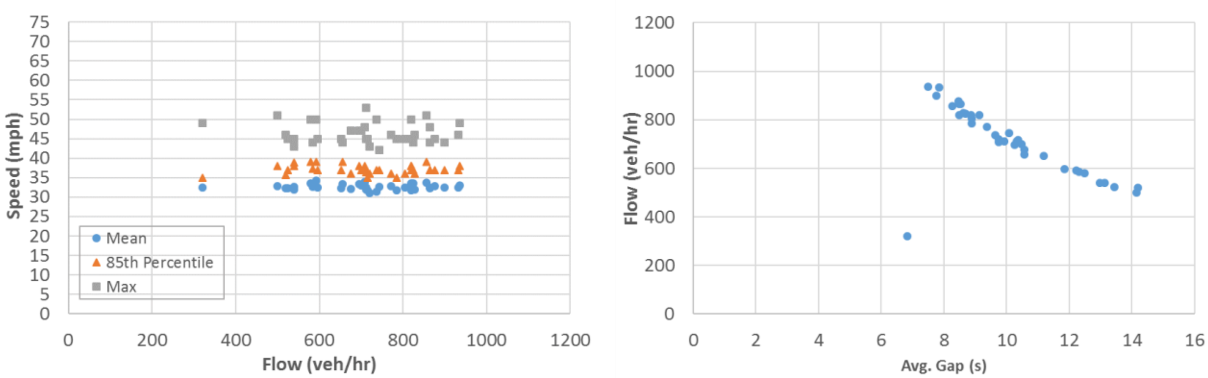

Figure 5.17: Speed vs. flow and flow vs. average gap at W. Powell Blvd. and SW. Duniway Ave. Eastbound

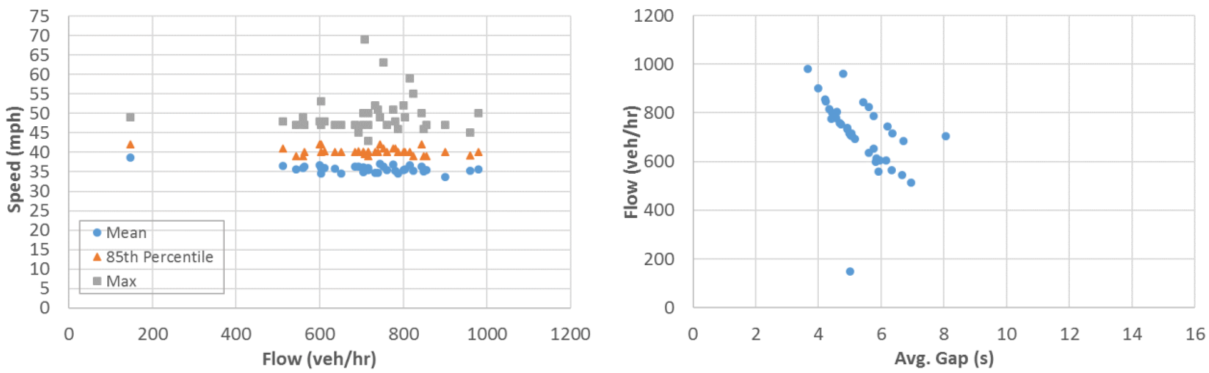

Figure 5.18: Speed vs. flow and flow vs. average gap at W. Powell Blvd. and SW. Duniway Ave. Westbound

5.6 WA NA PA ST. AND SW ONEONTA ST.

The crosswalk at Wa Na Pa St. and SW Oneonta St. is located in Cascade Locks, OR. At this location, Wa Na Pa St. is a two-way arterial with one travel lane in each direction and a speed limit of 30 mph. In addition to the travel lanes, there are parking and bike lanes on both sides of the roadway. The width of the crosswalk was 56 ft. A residential neighborhood and a gas station and diner are located on the east and west ends of the crosswalk respectively. Figure 5.19 shows the location of the crosswalk on Wa Na Pa St. The data collection at this location was conducted on August 17th, 2017. Figure 5.20 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 9.5 hours.

Figure 5.19: Wa Na Pa St. and SW Oneonta St.

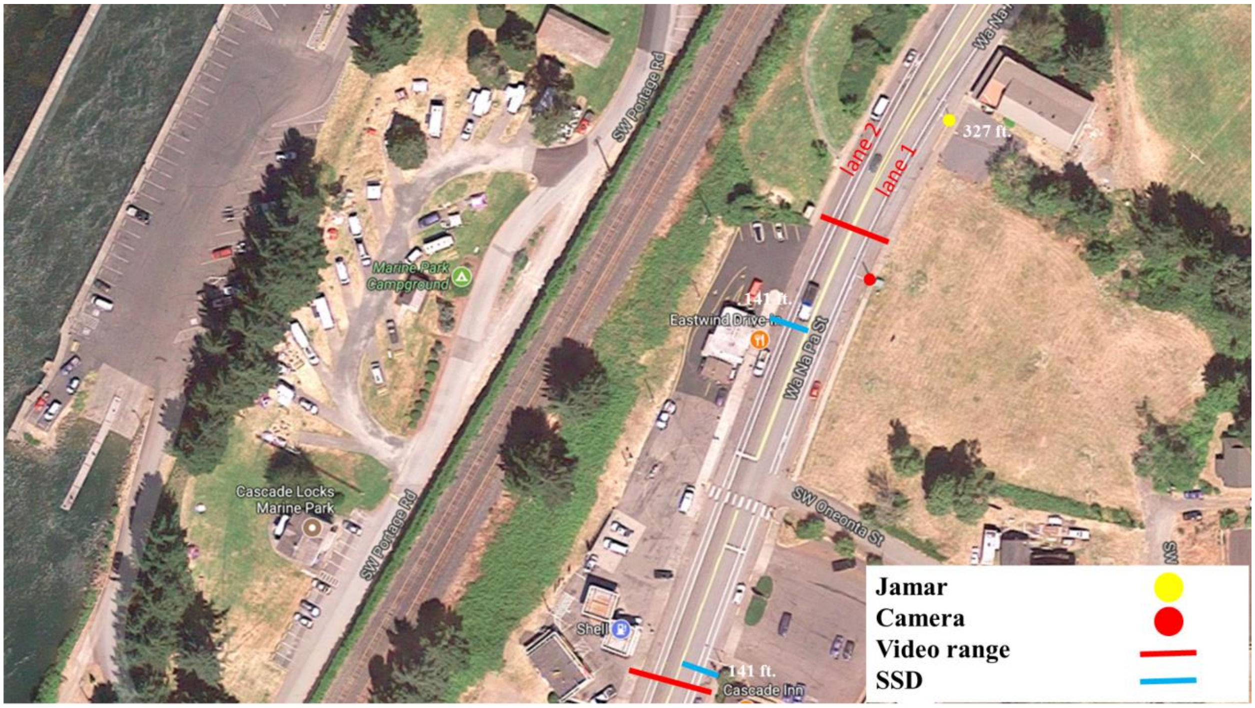

Figure 5.20: Location of data collection equipment at Wa Na Pa St. and SW Oneonta St.

5.6.1 Qualitative Analysis

Majority of pedestrians using this crosswalk were observed accessing the eatery located on the north end of the crosswalk. Long platoons of vehicles were observed that did not yield to pedestrians resulting in large pedestrian delays. Additionally, a number of pedestrian crossings were also observed where the pedestrians did not encounter any vehicles while crossing. A high number of jaywalking incidents were observed at this location (jaywalking defined as crossing not using a crosswalk or at an intersection using the extension of a sidewalk). Figure 5.21 shows the site location with the existing crosswalk highlighted with a solid arrow. At this site, the only attraction is the Eastwind eatery located on the west side of Wa Na Pa St (highlighted with a solid rectangle). The video analysis showed that patrons of the restaurant regularly parked on the east end of the street (highlighted with solid arrows) and jaywalked to the eatery. The jaywalking typically took place in the location highlighted with a shaded rectangle.

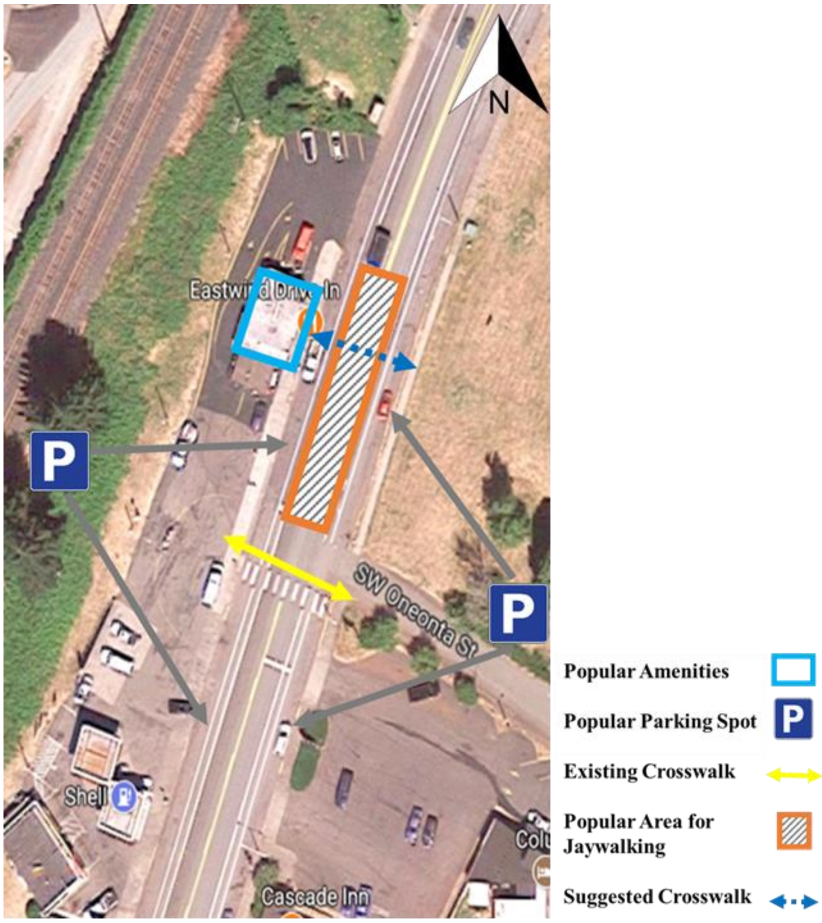

Figure 5.21: Jaywalking location at Wa Na Pa St. and SW Oneonta St.

5.6.2 Traffic Characteristics

Figure 5.22 and Figure 5.23 show the plots of speed vs. flow and flow vs. average gap at this location for the east and westbound directions. In both directions, flows were significantly lower compared to other site locations. Large gaps in traffic were seen especially in the westbound direction.

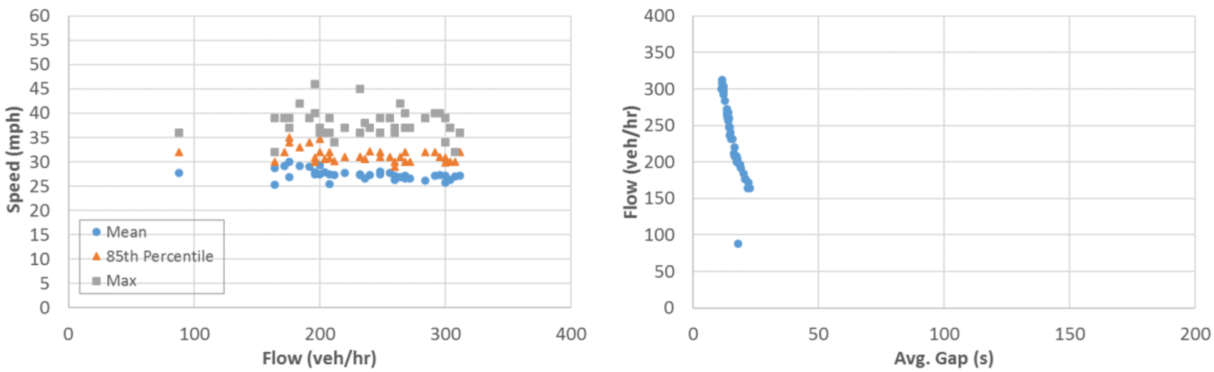

Figure 5.22: Speed vs. flow and flow vs. average gap at Wa Na Pa St. and SW Oneonta St. Eastbound

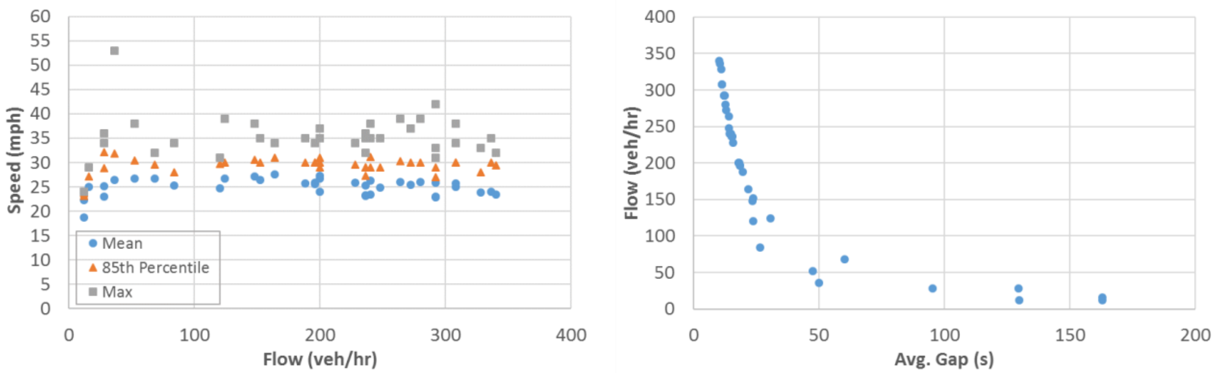

Figure 5.23: Speed vs. flow and flow vs. average gap at Wa Na Pa St. and SW Oneonta St. Westbound

5.7 WA NA PA ST. AND SW REGULATOR ST.

The crosswalk at Wa Na Pa St. and SW Regulator St. is located in Cascade Locks, OR. According to ODOT classification, Cascade Locks based on its population, is classified as a rural area. At this location, Wa Na Pa St. is a two-way arterial with one travel lane in each direction and a speed limit of 30 mph. In addition to the travel lanes, there are parking and bike lanes on both sides of the roadway. The width of the crosswalk was 56 ft. On the east and west ends of the crosswalk, a convenience store and a post office are located. Figure 5.24 shows the location of the crosswalk on Wa Na Pa St. The data collection at this location was conducted on August 17th, 2017. Figure 5.25 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 9.5 hours.

Figure 5.24: Wa Na Pa St. and SW. Regulator St.

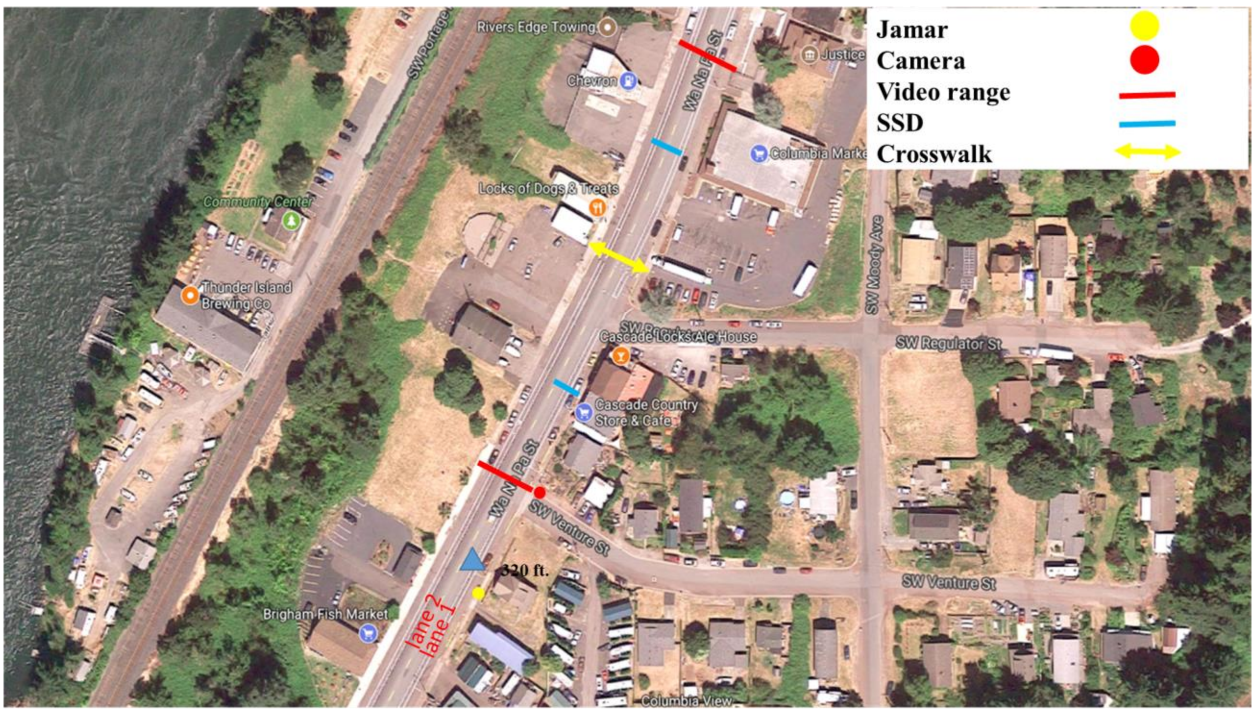

Figure 5.25: Location of data collection equipment at Wa Na Pa St. and SW Regulator St.

5.7.1 Qualitative Analysis

At this location, there was lateral separation between the driver and the waiting pedestrian due to the presence of a parking lane next to the curb, followed by a bike lane. This resulted in drivers failing to notice pedestrians waiting. Light traffic conditions were observed during the day. Similar to the crosswalk at Oneonta St., high rates of jaywalking were also observed at this location. Figure 5.26 shows the aerial image of this site augmented with observed locations of jaywalking. Video observations revealed that drivers parked their vehicles in the parking lot located in the north east corner and jaywalked to the eatery and post office located on the west side of the roadway (highlighted with solid rectangles). Drivers also parked on the west side of the roadway and jaywalked to a restaurant and deli, which were located at the south east corner of the intersection (highlighted with solid rectangles). The existing crosswalk location is depicted by a solid arrow and the dashed arrows represent potential locations for crosswalk relocation and placement, considering the placement of attractions and locations where jaywalking occurs.

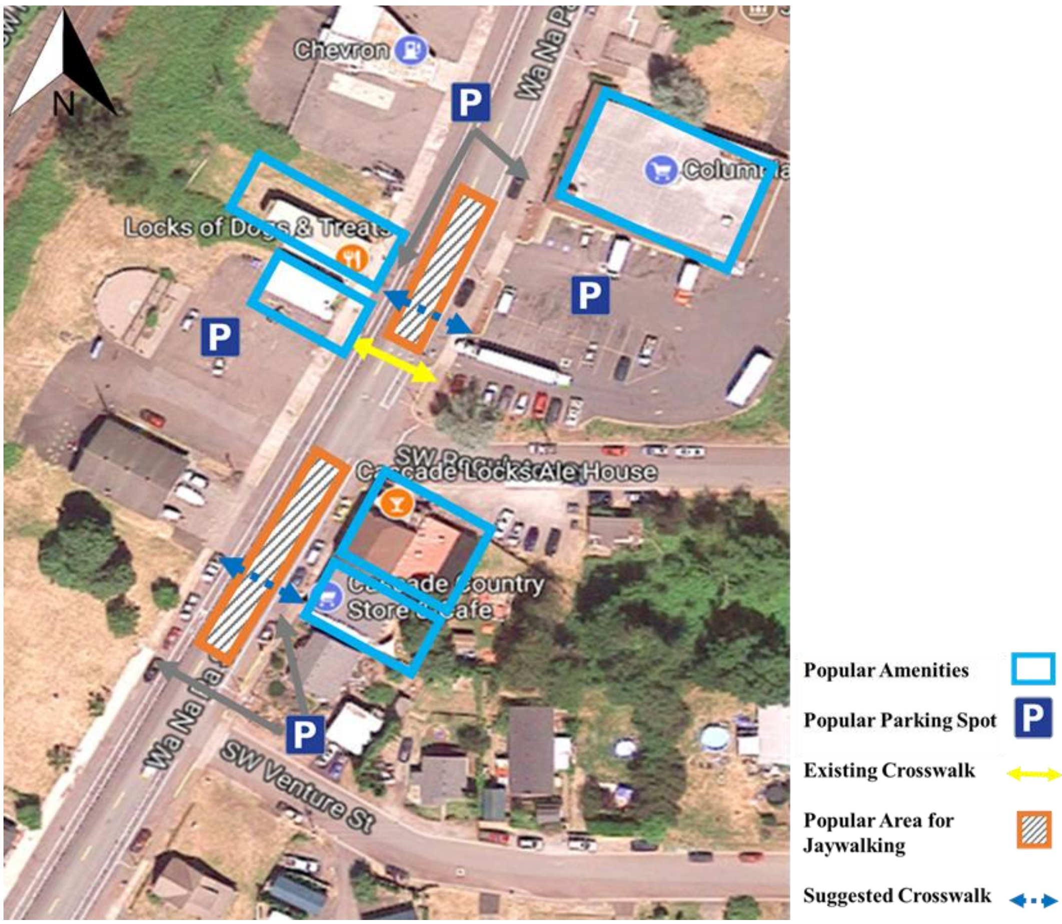

Figure 5.26: Jaywalking location at Wa Na Pa St and SW Regulator St

Table 5.1 shows the jaywalking proportions along this corridor between the two intersections. Based on video observations, 55% of the pedestrians crossing the roadway at the location jaywalked, greater than 5 ft. away from the crosswalk. 2% of the pedestrians were observed to be jaywalking within 5 ft. from the crosswalk.

Table 5.1: Jaywalking Proportions

Event	Percent
Jaywalking (> 5 ft. away from crosswalk)	55%
Jaywalking (< 5 ft. away from crosswalk)	2%
Not Jaywalking	43%

5.7.2 Traffic Characteristics

Figure 5.27 and Figure 5.28 show the plots of speed vs. flow and flow vs. average gap at this location for the east and westbound directions. In both directions, flows were significantly lower compared to other site locations, but were comparable to flows observed at Wa Na Pa St. and SW Oneonta St. Large gaps in traffic were seen especially in the westbound direction. Mean speeds were below the posted speed limit in both directions.

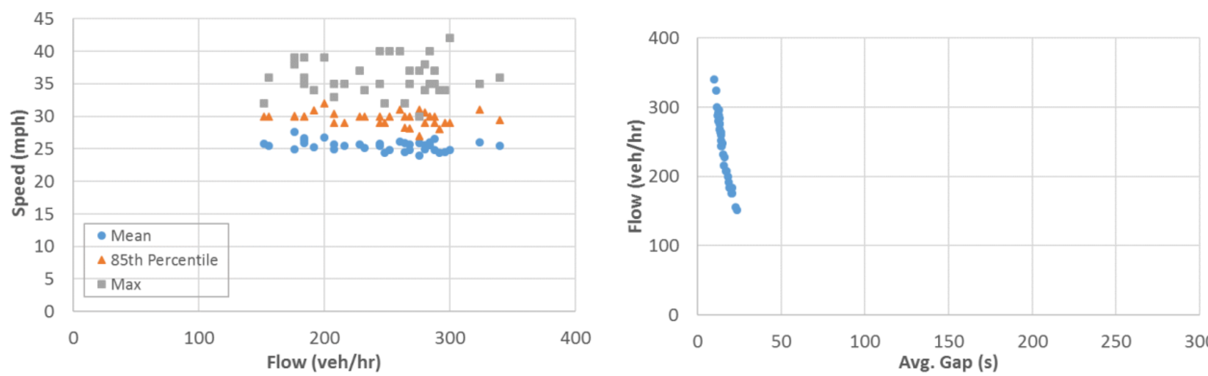

Figure 5.27: Speed vs. flow and flow vs. average gap at Wa Na Pa St. and SW Regulator St. Eastbound

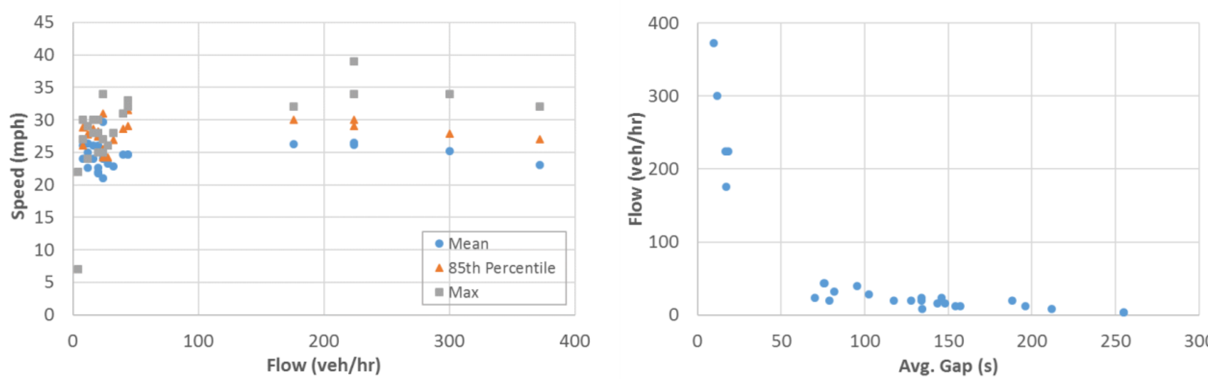

Figure 5.28: Speed vs. flow and flow vs. average gap at Wa Na Pa St. and SW Regulator St. Westbound

5.8 PIONEER BLVD. AND BEERS AVE.

The crosswalk at Pioneer Blvd. and Beers Ave. is located in Sandy, OR. According to ODOT classification, Sandy based on its population, is classified as a small urban area. At this location, Pioneer Blvd. is one-way facility with two travel lanes and a speed limit of 25 mph. A food establishment and a church are located on the north and south ends of the crosswalk respectively. The width of the crosswalk was 30 ft and curb extensions are present on either end of the crosswalk. Figure 5.29 shows the location of the crosswalk on Pioneer Blvd. The data collection at this location was conducted on July 27th, 2017. Figure 5.30 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 9.75 hours.

Figure 5.29: Pioneer Blvd. and Beers Ave.

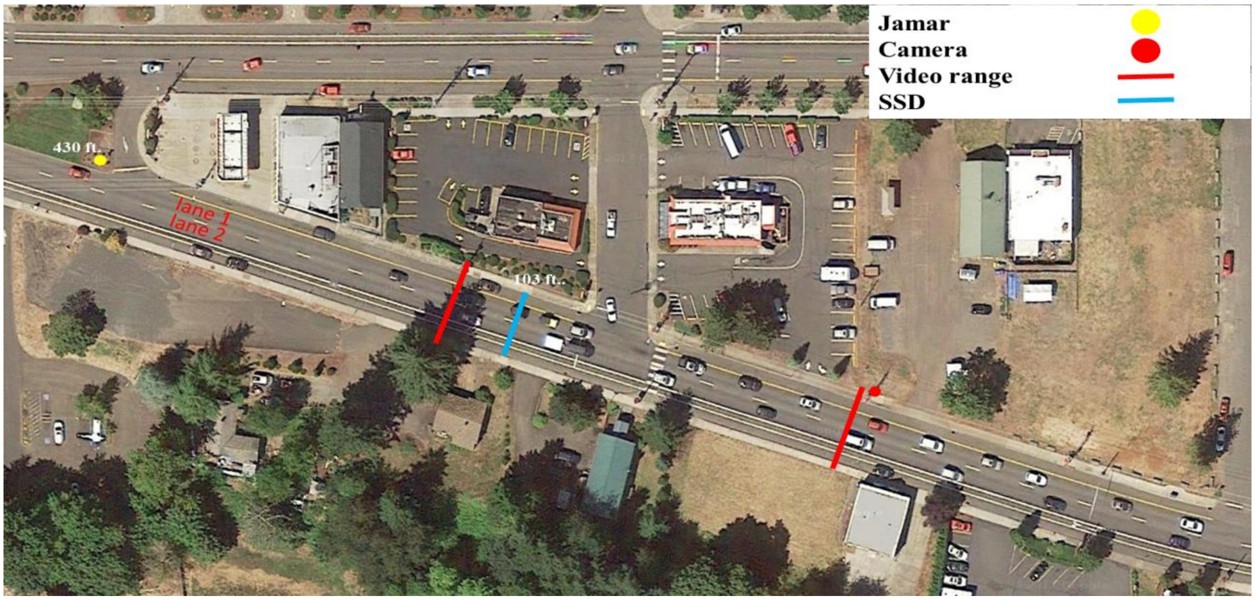

Figure 5.30: Location of data collection equipment at Pioneer Blvd. and Beers Ave.

5.8.1 Qualitative Analysis

The facility at this intersection is one-way. Few pedestrian crossings were observed at this location, primarily accessing the destinations present at the south side of the crosswalk. Light traffic conditions were observed during the day. Several instances of pedestrians incurring delays greater than 15 seconds were observed.

5.8.2 Traffic Characteristics

Figure 5.31 show the plots of speed vs. flow and flow vs. average gap at this location for the eastbound direction. Although the posted speed limit is 25 mph, the 85th speed percentile was closer to 30 mph. Also the distribution of the maximum speeds in the plot were significantly higher than 30 mph. Average gaps were between 4 and 10 seconds.

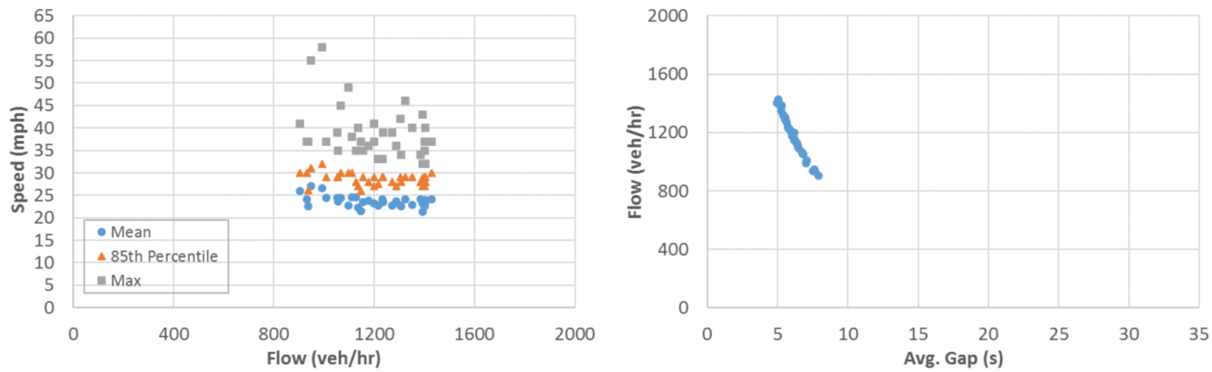

Figure 5.31: Speed vs. flow and flow vs. average gap at Pioneer Blvd. and Beers Ave. Eastbound

5.9 PIONEER BLVD. AND SHELLEY AVE.

The crosswalk at Pioneer Blvd. and Shelley Ave. is located in Sandy, OR. At this location, Pioneer Blvd. is one-way facility with two travel lanes and a speed limit of 25 mph. The crosswalk is bounded by retail stores on the north end of the crosswalk and the Sandy community action center on the south. The width of the crosswalk was 30 ft. and curb extensions are present on either end of the crosswalk. Figure 5.32 shows the location of the crosswalk on Pioneer Blvd. The data collection at this location was conducted on July 27th, 2017. Figure 5.33 shows the location of JAMAR radar and the camera used for the data collection. Data was collected for approximately 7 hours.

Figure 5.32: Pioneer Blvd. and Shelley Ave.

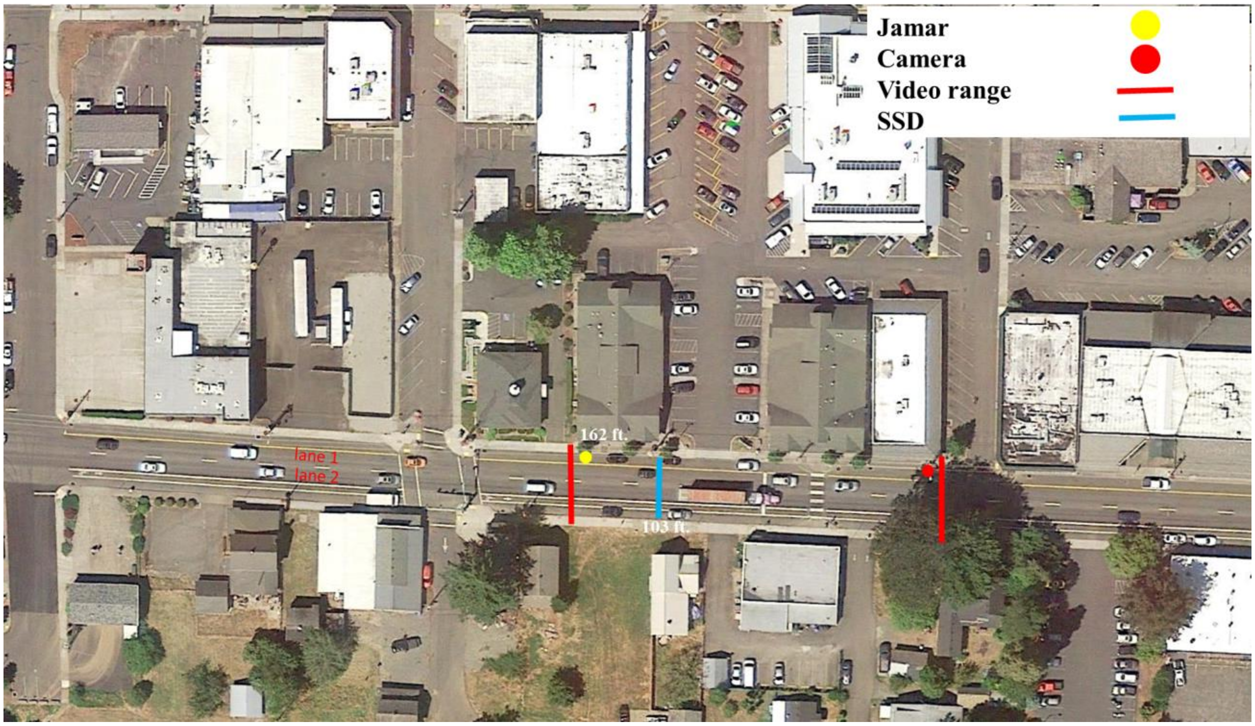

Figure 5.33: Data collection equipment at Pioneer Blvd. and Shelley Ave.

5.9.1 Qualitative Analysis

This crosswalk was situated on a one-way facility. Traffic conditions were mostly light during the day. At this location, drivers in the far lane were commonly observed to not yield to the pedestrian when they were waiting to cross the street. Some pedestrians were also observed to run across the street to avoid exposure in the roadway. During occasional periods of heavy traffic, drivers were observed to execute rolling stops instead of coming to a full stop, in the presence of pedestrians.

5.9.2 Traffic Characteristics

Figure 5.34 show the plots of speed vs. flow and flow vs. average gap at this location for the eastbound direction. Similar to the site at Pioneer Blvd. and Beers Ave., although the posted speed limit on Pioneer Blvd. where the crosswalk is located is 25 mph, a number of vehicles were going over the speed limit as seen by the distribution of the maximum speeds in the plot, which were significantly higher. The majority of the average gaps were between 4 and 10 seconds, expect for one observation with an average gap greater than 30 seconds.

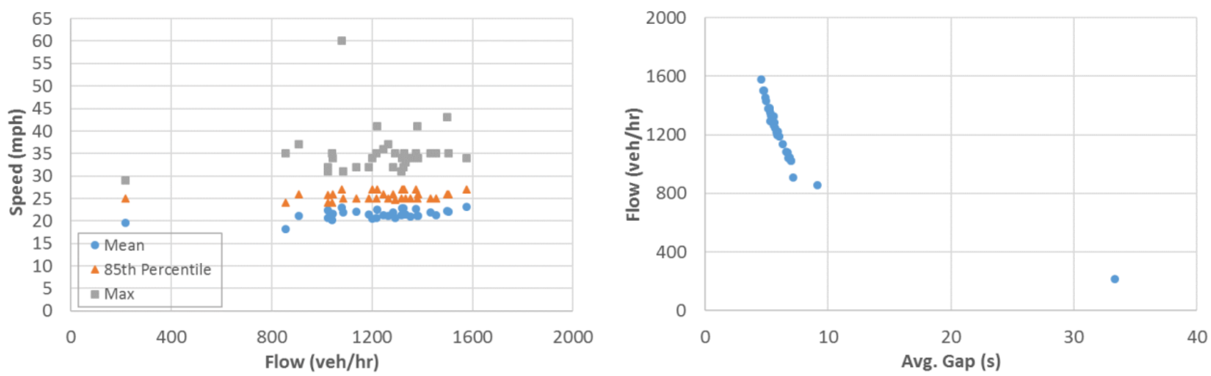

Figure 5.34: Speed vs. flow and flow vs. average gap at Pioneer Blvd. and Shelley Ave. Eastbound

5.10 E. HANCOCK ST. AND N. EDWARDS ST.

The crosswalk at E. Hancock St. and N. Edwards St. is located in Newberg, OR. According to ODOT classification, Newberg based on its population, is classified as a small urban area. At this location, E. Hancock St. is a one-way arterial with three travel lanes and a speed limit of 25 mph. In addition to the travel lanes, there are parking lanes on both sides of the roadway. The width of the crosswalk was 42 ft. Businesses are located on the northeast and northwest ends of the crosswalk respectively. A coffee shop and a bank are present on the southeast and southwest corner of the crosswalk. Figure 5.35 shows the location of the crosswalk on E. Hancock St. The data collection at this location was conducted on August 24th, 2017. Figure 5.36 shows the location of JAMAR radar and the camera used for the data collection. Two radar devices were installed at this location, one on the north and south ends of the crosswalk respectively. Since each radar device was capable of recording two lanes of traffic, the device placed on the north end recorded the right and center lanes and device placed on the south end recorded the left and center lanes. Data was collected for approximately 7 hours.

Figure 5.35: E. Hancock St. and N. Edwards St.

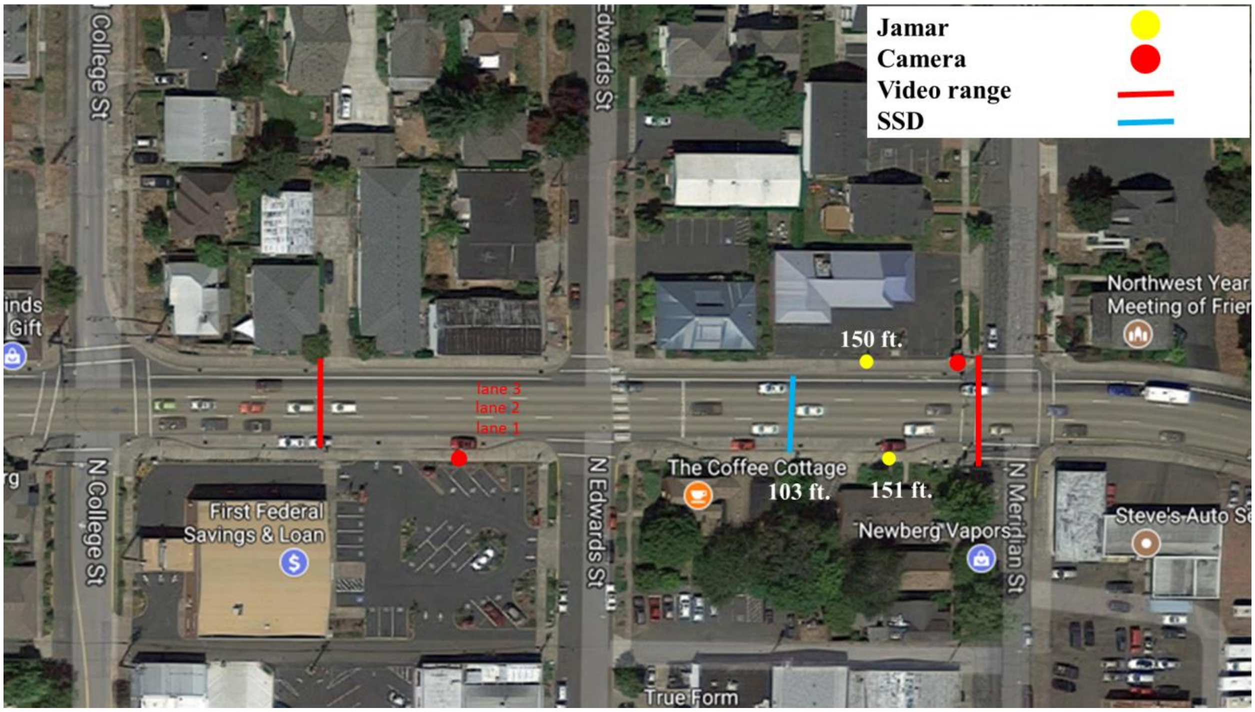

Figure 5.36: Location of data collection equipment at E. Hancock St. and N. Edwards St.

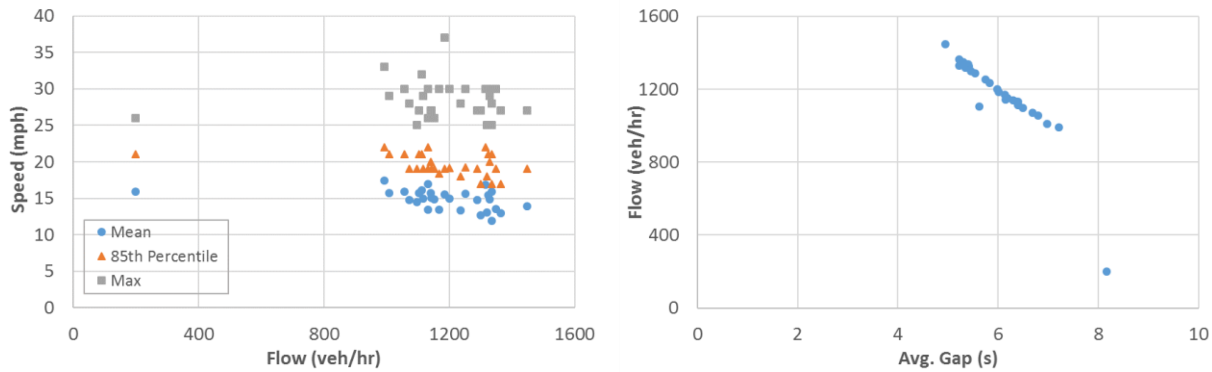

Figure 5.37: Speed vs. flow and flow vs. average gap at E. Hancock St. and N. Edwards St. (center- right lanes)

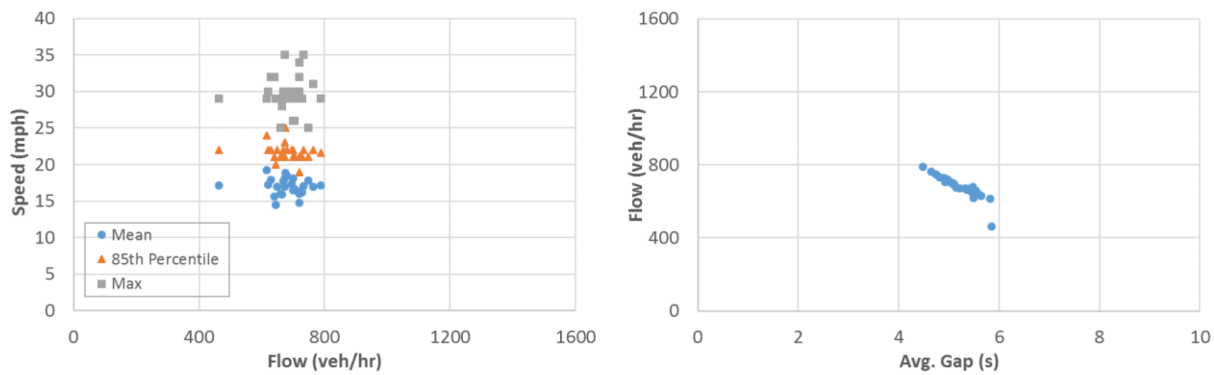

Figure 5.38: Speed vs. flow and flow vs. average gap at E. Hancock St. and N. Edwards St. (left-center lanes)

5.10.1 Qualitative Analysis

This crosswalk was located on a one-way facility, with three lanes of traffic. Heavy traffic was observed at this location at certain times, followed by light traffic. There is an upstream traffic signal which was observed to provide pedestrians with a gap in traffic for crossing. During heavy traffic conditions, yielding rates were observed to decline. Multiple threat scenario was also observed at this location, with drivers in the lane closest to the curb yielding to pedestrians, while drivers in other lanes failed to yield. Although bike lanes were present at this location, all the cyclists observed during the study period used the sidewalk.

5.10.2 Traffic Characteristics

Figure 5.37 and Figure 5.38 show the plots of speed vs. flow and flow vs. average gap at this location for the two radar devices that were placed on the north and south ends of the crosswalk. The flows recorded by the radar device placed at the south end were significantly lower than the flows recorded by the radar device at the north end of the crosswalk.

5.11 SUMMARY

This chapter describes the locations of the data collection sites and also provides qualitative descriptions of the observed traffic and pedestrian crossing conditions. Data was collected at nine sites, which were geographically dispersed and were chosen to encompass a variety of land uses (urban, small urbanized area, rural), varying speed limits, and traffic volumes, direction of traffic (one-way vs. two-way), and presence of median and pedestrian islands. There are several important insights that can be extracted from the initial analysis:

1. Speed can be an issue at some locations, with 85th speed percentiles clearly exceeding the posted speed limit during all the data collection period,

2. Maximum speeds can be more than double the posted speed limits at some of the rural or less populated locations,

3. Jaywalking and crosswalk placement can be an important issue at some locations, and

4. In some locations, e.g. Powell Boulevard, the adaptive corridor signal timing may lead to long platoons of vehicles that may result in low yield rates and long waiting times for some pedestrians.

There is clear value associated to a site visit and traffic data collection effort. The following chapter discusses more detailed results regarding interactions and yield rates.

6.0 ANALYSIS OF SURROGATE MEASURES

The previous chapter describes the traffic and crossing conditions at each site. This chapter deals with the main goal of this research project, the development of simple surrogate safety measures based on field measurements and geometric data. In the first part of the chapter, aggregate data at the location level are compared. Later, motorized traffic and pedestrian flows are utilized to find relationships among the number of interactions, the number of valid interactions, and the number of dangerous interactions. The chapter ends with recommendations regarding complementary information and data collection efforts.

6.1 AGGREGATED ANALYSIS

A comparison across locations is presented in this subsection. Comparisons are introduced to highlight differences regarding pedestrian behavior (jaywalking), groups of pedestrian's crossings, interactions observed, and yield rates. The following classification scheme was used to categorize pedestrian-vehicle interactions: type "N" or "null" if no vehicle is present when the pedestrian is crossing and type "V" or "valid" otherwise. Within type V interactions the following categorization was used:

Type A: Complete stop before the advance stop bar (or 30 ft before the crosswalk)

Type B: Complete stop between 15 and 30 ft from the stop bar

Type C: Complete stop between 0 and 15 ft from the stop bar

Type D: Driver slows down but does not stop

Type E: Driver does not slow down

Type F: Driver takes and abrupt or evasive action (braking, swerving, etc.)

It is important to note that valid interactions (A to F) were recorded and analyzed only for vehicles that can safely yield. The speed limit and Stopping Sight Distance (SSD) were utilized to determine conditions of a safe yield.

The number of legal crossings and the number of jaywalking crossings are displayed in Table 6.1. The jaywalking percentage (rightmost column) clearly shows that the locations in Cascade Locks (Wa Na Pa Str.) have an unusually high percentage of pedestrians that do not utilize the marked crosswalk. On the other hand, some locations like SE. Powell Blvd and SE. 36th Ave. or SE. Powell Blvd and SE. 75th Ave. show a low percentage of jaywalkers.

Table 6.1: Summary of Pedestrian-Vehicle Interactions

Location	Number of Legal Crossings (i)	No of Jaywalking Crossings (ii)	Jaywalking % (ii)/(i)
SE. Powell Blvd. and SE. 28th Pl. (before)	155	9	6%
SE. Powell Blvd. and SE. 28th Pl. (after)	43	11	26%
SE. Powell Blvd and SE. 36th Ave.	102	0	0%
SE Powell Blvd and SE. 75th Ave.	56	1	2%
W. Powell Blvd. and SW. Duniway St.	66	1	2%
Wa Na Pa St. and SW. Oneonta St.	69	70	101%
Wa Na Pa St. and SW. Regulator St.	112	142	127%
Pioneer Blvd. and Beers Ave.	30	10	33%
Pioneer Blvd. and Shelley St.	82	7	9%
E. Hancock St. and N. Edwards St.	41	6	15%

Henceforward, only legal crossings and their interactions are considered. Locations are also very diverse regarding the presence of pedestrian groups. Table 6.2 shows that the ratio of total pedestrians crossing to the number of legal crossing events ranges from 1.07 at SE. Powell Blvd and SE. 28th Pl (after) to 1.73 at Pioneer Blvd. and Beers Ave.

Table 6.2: Summary of Pedestrian-Vehicle Interactions

Location	Number of Legal Crossings (i)	No of Legal Pedestrians (ii)	Ratio (ii)/(i)
SE. Powell Blvd. and SE. 28th Pl. (before)	155	201	1.30
SE. Powell Blvd. and SE. 28th Pl. (after)	43	46	1.07
SE. Powell Blvd and SE. 36th Ave.	102	128	1.25
SE Powell Blvd and SE. 75th Ave.	56	73	1.30
W. Powell Blvd. and SW. Duniway St.	66	77	1.17
Wa Na Pa St. and SW. Oneonta St.	69	102	1.48
Wa Na Pa St. and SW. Regulator St.	112	146	1.30
Pioneer Blvd. and Beers Ave.	30	52	1.73
Pioneer Blvd. and Shelley St.	82	102	1.24
E. Hancock St. and N. Edwards St.	41	50	1.22

A summary of valid pedestrian-vehicle interactions is shown is Table 6.3. Most interactions are type A (full stop, 30 or more feet from the crosswalk) and type E (driver does not yield, continues at the same speed). This is clearly shown in

Table 6.4 that show the distribution of interactions per type and also includes the median at the bottom of the table.

One location stands out for its high level of type E interactions. At the SE. Powell Blvd. and SE. 28th Pl. (after crosswalk removal) location 76% of the interactions were of type E. It was observed from the video that yield rates declined significantly when compared to the before condition and long pedestrian delays were observed. Multiple situations were observed where the drivers in the lane closest to the curb were observed to yield to the pedestrian, however the drivers in the other lanes did not yield, resulting in long pedestrian delays and also potentially dangerous situation. A common situation was also observed where the pedestrians waited in the spot where the median island was previously located, however a higher rate of drivers did not yield to the pedestrians. Overall, at the SE. Powell Blvd. and SE. 28th Pl. (before crosswalk removal) 70% of the vehicles stopped before the crosswalk (sum of types A, B, and C). Only 21% of the vehicles stopped after the crosswalk was removed.

Other locations that stand out are Pioneer and Beers and Pioneer and Shelly in Sandy. These crosswalks are located just 1300 feet apart on the same street. However, Beers is at the start of the commercial area in Sandy and Shelly is four blocks towards the downtown. The stopping rate (sum of types A, B, and C) is 37% at Beers but 82% at Shelly. Events type E were 62% at Beers and 18% at Shelly. It is likely that drivers coming from a rural area along US 26 for many miles have not adjusted to driving in an area with higher pedestrian activity and crosswalks.

Table 6.3: Summary of Pedestrian-Vehicle Interactions

Location	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	TYPE F
SE. Powell Blvd. and SE. 28th Pl. (before)	185	97	74	32	117	1
SE. Powell Blvd. and SE. 28th Pl. (after)	30	17	12	8	211	0
SE. Powell Blvd and SE. 36th Ave.	84	83	56	15	51	0
SE Powell Blvd and SE. 75th Ave.	78	29	7	7	91	1
W. Powell Blvd. and SW. Duniway St.	59	4	2	6	73	0
Wa Na Pa St. and SW. Oneonta St.	42	9	5	7	38	0
Wa Na Pa St. and SW. Regulator St.	63	8	7	8	59	0
Pioneer Blvd. and Beers Ave.	27	7	5	1	66	0
Pioneer Blvd. and Shelley St.	76	22	18	1	25	0
E. Hancock St. and N. Edwards St.	19	18	12	4	24	0

Table 6.4: Percentage Distribution Pedestrian-Vehicle Interactions

Location	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	TYPE F
SE. Powell Blvd. and SE. 28th Pl. (before)	37%	19%	15%	6%	23%	0.2%
SE. Powell Blvd. and SE. 28th Pl. (after)	11%	6%	4%	3%	76%	0.0%
SE. Powell Blvd and SE. 36th Ave.	29%	29%	19%	5%	18%	0.0%
SE Powell Blvd and SE. 75th Ave.	37%	14%	3%	3%	43%	0.5%
W. Powell Blvd. and SW. Duniway St.	41%	3%	1%	4%	51%	0.0%
Wa Na Pa St. and SW. Oneonta St.	42%	9%	5%	7%	38%	0.0%
Wa Na Pa St. and SW. Regulator St.	43%	6%	5%	6%	41%	0.0%
Pioneer Blvd. and Beers Ave.	25%	7%	5%	1%	62%	0.0%
Pioneer Blvd. and Shelley St.	54%	15%	13%	1%	18%	0.0%
E. Hancock St. and N. Edwards St.	25%	23%	16%	5%	31%	0.0%
MEDIAN	37%	11%	5%	5%	39%	0.0%

Finally, it is clear that the number of interactions type F are much rarer than the other type of interactions. Only two locations (SE. Powell Blvd. and SE. 28th Pl. (before) and SE Powell Blvd and SE. 75th Ave) register interactions type F. Over 125,000 motorized vehicles and nearly 1,000 pedestrians were analyzed over almost 80 hours of video. However, this is consistent with the idea of the safety pyramid proposed by Hydén (1987). There is a high number of potential conflicts, a small number of serious conflicts, and an even smaller number of crashes.

No-stop rates are shown in Table 6.5; the median is 45%. The trends discussed in the previous paragraphs can be observed in Table 6.5. It can be added that W. Powell Blvd. and SW. Duniway St. near Gresham also show a high percentage of no-stop interactions. From the traffic data and the video analysis it was observed that at this location many vehicles travel at high speeds and higher rates of sudden braking were also observed.

Table 6.5: Summary of Pedestrian-Vehicle Interactions

Location	No of Valid Interactions (i)	No of Stops - types A, B, and C (ii)	% NO Stops = 1 - (ii)/(i)
SE. Powell Blvd. and SE. 28th Pl. (before)	506	356	30%
SE. Powell Blvd. and SE. 28th Pl. (after)	278	59	79%
SE. Powell Blvd and SE. 36th Ave.	289	223	23%
SE Powell Blvd and SE. 75th Ave.	213	114	46%
W. Powell Blvd. and SW. Duniway St.	144	65	55%
Wa Na Pa St. and SW. Oneonta St.	101	56	45%
Wa Na Pa St. and SW. Regulator St.	145	78	46%
Pioneer Blvd. and Beers Ave.	106	39	63%
Pioneer Blvd. and Shelley St.	142	116	18%
E. Hancock St. and N. Edwards St.	77	49	36%

6.2 INTERACTIONS AND ENTERING VOLUME

In the literature review section dealing with conflict analysis it was mentioned that in the 1980's and 1990's a lot of research was dedicated to perfect the conflict analysis for vehicle to vehicle crashes. The conflict technique is based on the idea that exposure has a major influence on traffic conflict frequency and long-term crash rates. Exposure refers to the frequency of traffic events that create a risk of crashes *(Carroll 1973)*. *Nilsson (1978)* suggested the use of the square root of the product of the volume of pedestrians per hour and the number of motor vehicles per hour that may experience a traffic conflict as a proxy for pedestrian exposure. Other researchers like *Sayed and Zein (1999)* later found (for vehicle to vehicle interactions) that the square root of the product of the volume of pedestrians per hour and the number of motor vehicles per hour is a good predictor of conflicts.

This section defines the *Normalized Entering Volume* or NEV as the square root of the product of the hourly flow of pedestrians utilizing a crosswalk and the hourly flow of motorized vehicles crossing the crosswalk. The following four graphs, from Figure 6.1. to Figure 6.4., show the relationship between NEV and different types of interactions. A second order function that starts at the origin is added to more clearly show the relationship and potential outliers. The NEV graphs combine data from all the crosswalk locations with traffic and video data available.

The relationship between total interactions and NEV is shown in Figure 6.1. Total interactions includes both type N as well as types A to F. There is clear relationship that is also replicated in

Figure 6.2 that shows the relationship between valid interactions (A to F) and NEV. Similarly, a good relationship is shown in Figure 6.3 between Stop interactions (types A, B, and C) and NEV as well as dangerous interactions as a function of NEV in Figure 6.4.

The reader should note that the scale of the Y axis is changing and that the number of interactions is decreasing rapidly as one moves from Figure 6.1. to Figure 6.4. The number of interactions decreases rapidly and it is impossible to show a relationship between interactions type F and NEV with the amount of data collected. Again, this is consistent with the idea of the safety pyramid proposed by *Hydén* (1987) and low frequency of serious conflicts. In terms of the goals of this project, this is a serious limitation. It is unrealistic to expect to see enough serious conflicts by observing a crosswalk for a few hours. Hence, it is necessary to find another proxy to measure the potential for serious conflicts.

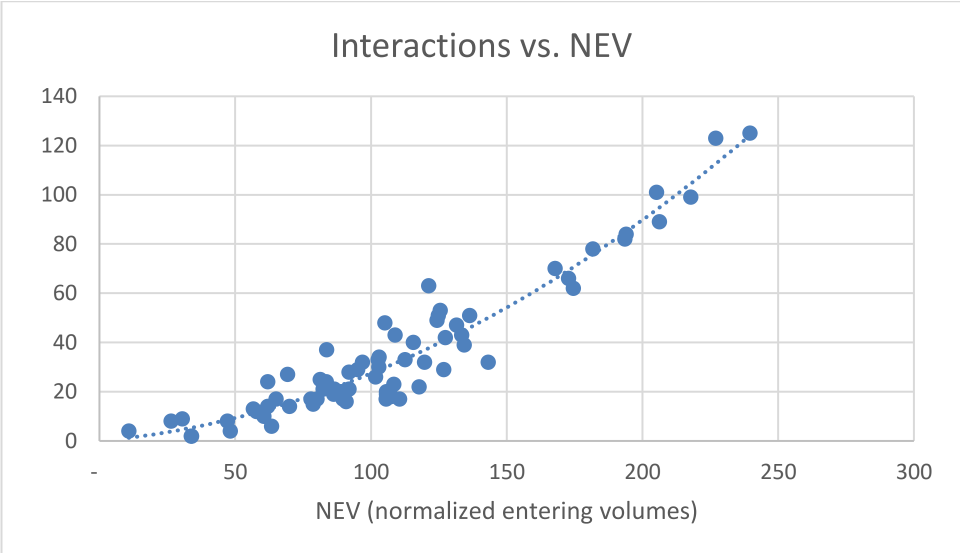

Figure 6.1: Interactions vs. normalized entering volumes (hourly periods)

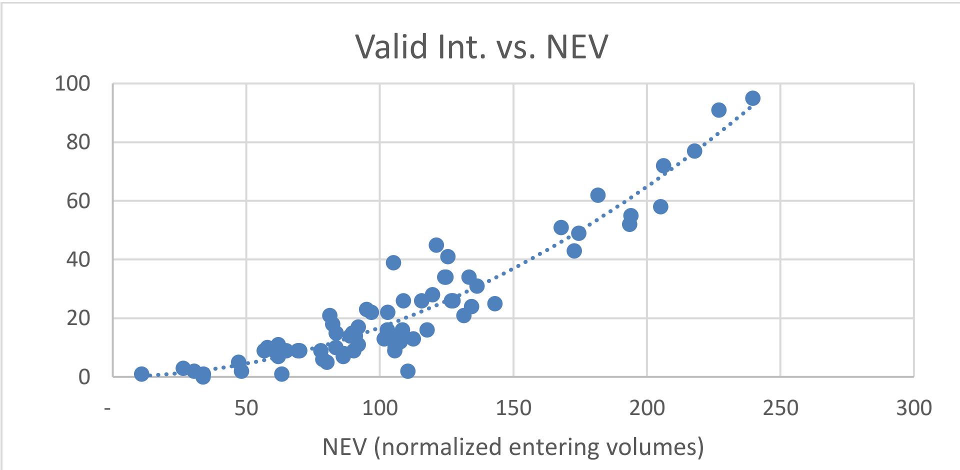

Figure 6.2: Valid interactions vs. normalized entering volumes (hourly periods)

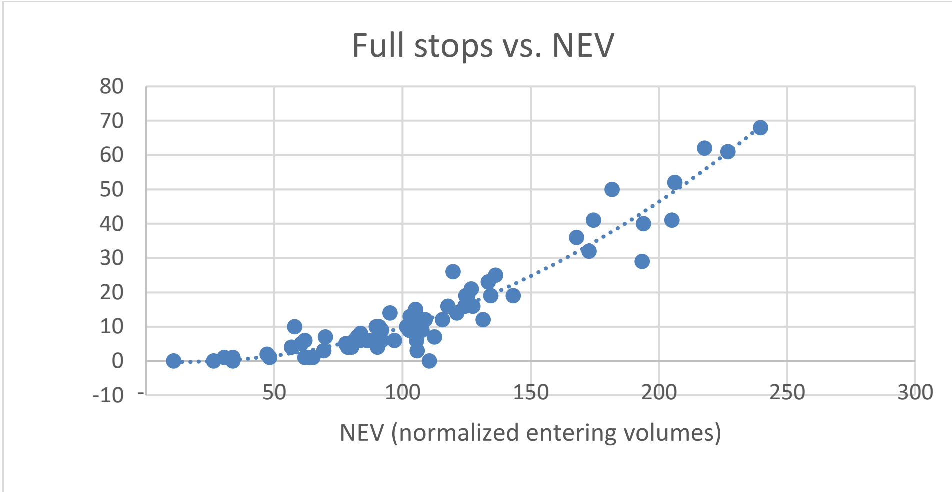

Figure 6.3: Full stops vs. normalized entering volumes (hourly periods)

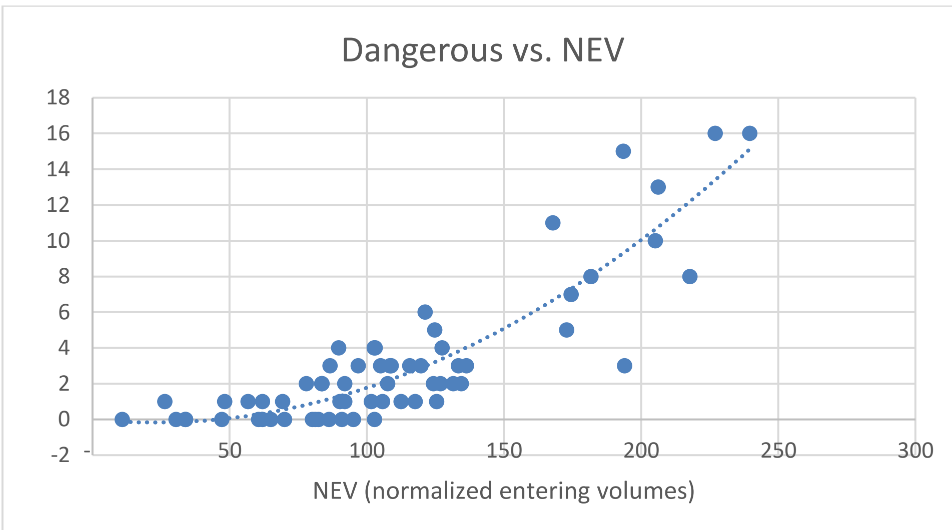

Figure 6.4: Dangerous interactions vs. normalized entering volumes (hourly periods)

The relationship between dangerous interactions and valid interactions is shown in Figure 6.5. Again, a clear relationship is maintained as expected from the observation of Figure 6.1. to Figure 6.4. This is a validation of the pyramid concept as introduced by *Hydén* (1987)**.**

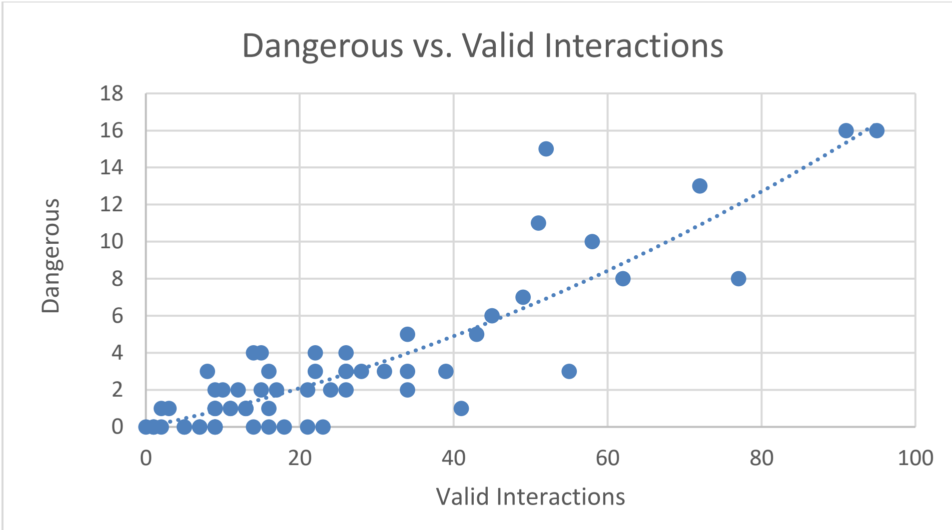

Figure 6.5: Dangerous interactions vs. valid interactions

It is finally noted that there are also strong correlations between the different types of interactions and the product of entering volumes (without taking the square root). Future research efforts are recommended to generalize the results and study alternative specifications of the relationships between pedestrian-vehicle interactions as a function of motorized and pedestrian hourly volumes

6.3 SURROGATE RECOMMENDATIONS

The main objective of this research is to analyze the ability of field measurements and geometric data to predict the expected relative safety of an existing unsignalized marked crosswalk. Noteworthy constraints and/or necessary characteristics for the potential field-based surrogate safety measures or evaluation method include:

1. the staff data collection effort should be limited to a certain number of hours (i.e. it cannot consume full workdays),
2. the data collection effort and/or analysis method should involve no more than two or three ODOT staff members,
3. data collection should be carried out with portable equipment that can be readily deployed, and
4. data post-processing and analysis should not be arduous or involve specialized software or video analysis techniques.

The results found in the first two subsections of this chapter provide the basis to suggest two surrogate measures that meet the goals of the research without violating the constraints established a priori.

The strong relationships found between interactions and NEV are encouraging and therefore it is possible to suggest *macro* surrogate measures that can be used to meet the goals of this research project. The word *macro* is utilized to suggeest large-scale in the temporal sense, i.e. surrogate safety measures in hourly measurements, as opposed to surrogates measures such as TTC or PET (reviewed in Section 2) that must be measured with a precision in the order of decimals of a second. The other suggested macro surrogate measure is No-stop percentage (NSP). It is obvious that NSP is linked to pedestrian safety.

Regarding the data collection and postprocessing constraints, both NEV and NSP can be estimated after a few hours of field data collection. For NEV a motorized traffic data collection device (volumes essential and speed desirable) would be helpful to reduce manual labor. In the case of NSP it can be done manually after having a point of reference for the SSD. It is simpler to use the NSP as a measure because it is simpler to estimate than the legal no-yield percentage (LNYP). According to Oregon pedestrian law, see Figure 6.6, it necessary to take into account the behavior of multiple lanes. According to Oregon crosswalk laws, a driver has to stop and remain stopped for pedestrians until they have cleared the lane in which the vehicle is travelling and at least 6 feet of the next lane. LNYP is preferable but more time consuming and the tradeoffs in terms of staff time must be evaluated carefully by ODOT. Similarly, it would desirable to measere pedestrian delay, however, this is a time intensive field task that may require a dedicated staff person.

Finally, both NEV and NSP (or LNYP) have some desirable properties, these are:

- Conceptually simple and intuitive.
- Based on an observable or readily measurable pedestrian or motorized traffic characteristics.
- Characterized by the lack of crashes as an extreme (with zero NEV or zero NSP pedestrian crashes are not possible).
- NEV is closely related to exposure and also geometric and traffic conditions. Hourly traffic volumes are related to AADT, number of lanes, and functional classification (which are factors positvely associated to crash rates).
- NSP (or LNYP) provides a measure of driver behavior at a given location. Hence, it captures the human element in pedestrian safety and a high rate can indicate issues like bad crosswalk placement or lack of warning and/or adaptation (e.g. Beers and Pioneer in Sandy).
- Finally, the product of NEV and NSP may be a compound surrogate that aims to capture geometric, traffic, and human behavior elements.

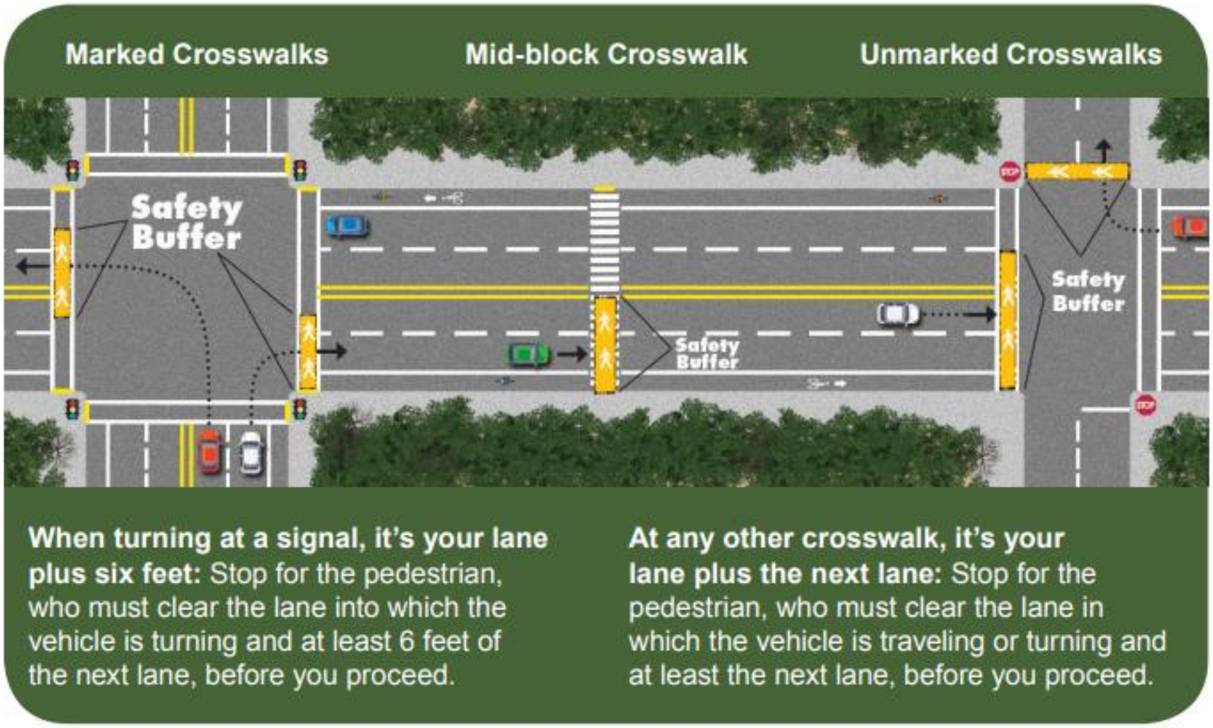

Figure 6.6: Oregon crosswalk laws

6.4 COMPLEMENTARY INFORMATION

Although NEV and NSP are the best numerical surrogates that can be recommended given the data collection restrictions, it is recommended that the final safety analysis for a location also takes into account other information that cannot be readily reduced to a number. The additional information includes:

1. Speed distribution
2. Vehicle classification
3. Pededstrina characteristics (young, elderly, etc.)
4. Number of crossings not ulizing a crosswalk or the extension of a sidewalk
5. Visibility and walking environment (safety audit).
6. Nearby traffic signals and traffic conditions.

The literature has clearly shown that crash severity increases as vehicle speed increases as discussed in *Garder* (2004). If ODOT staff is able to collect speed distributions in the field it may be possible to come up with a methodology to estimate a severity factor. Similarly, the literature has shown that severity increases with the size and mass of the vehicle involved in the crash. Age is also a factor that may have an important role regarding severity (elderly) or crash frequency (younger pedestrians). As shown in a previous section, a high rate of jaywalking may indicate an inadequate placement of the crosswalk. Visibility and the walking environment (e.g. lack of the sidewalk or nighttime illumination) is another factor that is hard to quantify but that may be discusses after a site visit. Finally, the impact of nearby traffic signals and the impact of platoons (or green waves) on stopping (yield rates) is something that is also hard to quantify but that can be observed in a field data collection effort. In the absence of field data a method based on expert opinions can be utilized to complement or replace field data, for example as in Basile et al. (2010). However, the incorporation of methods based on expert opinions is outside the scope of this project and may be the subject of future research efforts.

6.5 DATA COLLECTION AND RECORDING

As a general guideline, the more time is spent collecting data the better. However, there are tradeoffs regarding the cost of staff time and the simplicity of utilizing one day (or part of a day) to complete the data collection effort.

Regarding pedestrian data collection, pedestrian data is much scarcer than motorized traffic data. However, based on previous efforts it is likely that the highest pedestrian activity tends to take place between 11 am and 6 pm (see Appendix A) at most crosswalks. Hence, if staff time is a concern, an appropriate data collection time should be found between 11 am and 6 pm.

Regarding motorized traffic data collection, ODOT has an extensive database of short-term and long-term counts that can be utilized as a reference to estimate volumes and AADT (see also the results of a recently completed SPR 804). In general, motorized volumes are also high between 11 am and 6pm though this window misses the morning peak (see Appendix B).

In terms of future application of the surrogate measures to compare crosswalks, it is important to try to maintain consistence. For example, all NEV and NSP measure are ideally estimated utilizing data collected between 11am and 4pm or a predetermined time window. A similar idea applies regarding general conditions that may impact traffic or pedestrian volumes. For example, data collections should take place on days that are not affected by holidays, high-attraction events, and/or extreme weather conditions (rain, heat, cold, snow, etc.). As much as possible data collection conditions and timing should be comparable and consistent. Otherwise, additional noise is introduced into the datasets and surrogate safety measures comparisons are less likely to be meaningful and/or useful.

6.6 SUMMARY

This section presented data that supports the utilization of NEV and NSP as surrogate safety measures for uncontrolled marked crosswalks. The utilization of NEV and NSP have desirable properties and can meet the data collection restrictions established by ODOT at the start of the research project. Additional recommendations are provided regarding complementary information and data collection efforts. However, a proper analysis of the tradeoffs involved with the utilization of the different metrics or the optimal design of data collection efforts is beyond the scope of this research project and is left as the subject of a future research project.

7.0 CONCLUSIONS

Pedestrian crashes are low frequency and geographically dispersed events; hence, it is very challenging to measure the relative safety of a particular location after a few hours of data collection and analysis.

The literature has proposed several surrogate safety measures that focus on vehicle-vehicle interactions such as TTC or time to collision and PET or post-encroachment time. These surrogates have pros and cons and could be applied to pedestrians, but they are not feasible given the data collection and processing restrictions set out at the start of this research project.

Based on the data collected at a diverse set of crosswalks, it is recommended that NEV and NSP are utilized as the initial surrogate measures to analyze pedestrian safety at marked unsignalized crosswalks. NEV (or normalized entering volumes) is the square root of the product of hourly motorized and pedestrian volumes and is closely related to exposure and also geometric and traffic conditions. NSP (or no-stop percentage) provides a measure of driver behavior at a given location. Data for both NEV and NSP can be collected after a few hours of field work and the post-processing effort is relatively simple when compared to TTC or PET post-processing efforts that are much more time consuming and require specialized software and high quality video. It is an engineering judgement whether additional data collection or the utilization of more ntensive post-processing techniques are necessary after conduction a site visit and estimating NEV and NSP metrics.

Both NEV and NSP have desirable properties and are supported by the general findings of the literature review. They are proxies for the frequency of pedestrian-vehicle conflicts and the traffic conditions necessary for a crash to occur. In addition, NEV is correlated with AADT and other road characteristics such as number of lanes and function classification that are in turn associated with high crash rates. It is recommended that ODOT establishes a consistent data collection effort and program to estimate NEV and NSP at locations across the state and to set up system that can be used to store and analyze NEV and NSP trends over time. After several years of consistent data collection, it may be possible to examine relationships between these surrogates and crash rates. However, pedestrian volume data is necessary to improve the estimation of surrogate measures and the evaluation of crosswalk safety for both near-term and long-term studies.

Concluding, evidence found after analyzing a diverse set of crosswalks indicates that NEV and NSP are surrogate measures strongly associated with pedestrian-vehicle conflicts and therefore likely to be useful to predict the expected relative safety of an existing unsignalized marked crosswalk. Both NEV and NSP are based on readily observable and measurable field measures and geometric data. The utilization of NEV and NSP complemented by additional information regarding speed distributions, vehicle types, jaywalking, visibility, and walking conditions provide valuable information to readily examine the need of crosswalk improvements. For example, a methodology based on these surrogates can be used as a first cut screening tool to reduce a broad set of crosswalk candidates for improvements. Additional and more time-consuming safety studies can be performed after reducing the set of candidates.

8.0 REFERENCES

1000 Friends of Oregon. (1993). *Making the Land Use–Transportation–Air Quality Connection*: Volume 4A, The Pedestrian Environment. Portland, OR.

Abdel-Aty, M., J. Lee, C. Siddiqui, & K. Choi. (2013). Geographical unit based analysis in the context of transportation safety planning. *Transportation Research Part A* 49: 62-75.

Accidents, The Royal Society for the Prevention of. (2009). *Street Lighting and Road Safety*. Edgbsaton, Birmingham.

Allen, B. L., Shin, B. T., & Cooper, P. J. (1978). *Analysis of traffic conflicts and collisions* (No. HS-025 846).

Almodfer, R., Xiong, S., Fang, Z., Kong, X., & Zheng, S. (2016). Quantitative analysis of lane-based pedestrian-vehicle conflict at a non-signalized marked crosswalk. *Transportation research part F: traffic psychology and behaviour*, *42*, 468-478.

Almquist, S., Hyden, C. & Risser, R. (1991). Use of speed limiters in cars for increased safety and a better environment. *Transportation Research Record* 1318: 34-39.

Al-Shammari, N., Bendak, S., & Al-Gadhi, S. (2009). In-depth analysis of pedestrian crashes in Riyadh. *Traffic injury prevention*, *10*(6), 552-559.

American Association of State Highway and Transportation Officials. (2010). *Highway Safety Manual.* Vol. 1st edition. Washington D.C.: AASHTO.

Amundsen, F.H., & Hyden. C. (1977). *Proceeding of First Workshop on Traffic Conflicts*. Lund Institute of Technology, Institute of Transport Economics.

Anderson, R., McLean, A. & Farmer. M. (1997). Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accident Analysis & Prevention* 29 (5): 667-674.

Archer, J. (2000). *Developing the potential of micro-simulation modelling for traffic safety assessment.* ICTCT. Corfu, Greece.

Archer, J. (2005). *Methods for the assessment and prediction of traffic safety at urban intersection and their application in micro-simulation modeling*. Department of Infrastructure, Royal Institute of Technology.

Ardeshiri, A., & Jeihani, M. (2014). A speed limit compliance model for dynamic speed display sign. *Journal of Safety Research* 51: 33-40.

Arman, M. A., Rafe, A., & Kretz, T. (2015). Pedestrian Gap Acceptance Behavior, A Case Study: Tehran. In *Transportation Research Board 94th Annual Meeting* (No. 15-2217).

Asadi-Shekari, Z., Moeinaddini, M., & Zaly Shah, M. (2013). Non-motorised level of service: Addressing challenges in pedestrian and bicycle level of service. *Transport reviews*, *33*(2), 166-194.

Asadi-Shekari, Z., Moeinaddini, M., & Shah, M. (2015). Pedestrian safety index for evaluating street facilities in urban areas. *Safety science*, *74*, 1-14.

Autey, J., Sayed, T., & Zaki M. (2012). Safety evaluation of right-turn smart channels using automated traffic conflict analysis. *Accident Analysis and Prevention* 45: 120-130.

Basile, O., Persia, L., & Usami, D. S. (2010). A methodology to assess pedestrian crossing safety. *European Transport Research Review* 2: 129–137.

Bella, F. & Silvestri, M. (2015). Effects of safety measures on driver's speed behavior at pedestrian crossings. *Accident Analysis & Prevention* 83: 111-124.

Benz, G.P. (1986). *Pedestrian time-space concept, a new approach to the planning and design of pedestrian facilities*. New York, NY: Parsons Brinckerhoff Quade and Douglas.

Beymer, D., P. McLauchlan, B. Coifman, & J. Malik. (1997). A real-time computer vision system for measuring traffic parameters. *Proceedings of the (1997) Conference on Computer Vision and Pattern Recognition* CVPR '97). Washington D.C.: IEEE. 495-501.

Bowman, B., & Vercelli R. (1994). Pedestrian Walking Speeds and Conflicts at Urban Media Locations. *Transportation Research Record* 1438 67-73.

Brewer, M.A., K. Fitzpatrik, J.A. Whitacre J.A., & Lord D. (2006). Exploration of pedestrian gap-acceptance behavior at selected locations. *Transportation Research Record* 1982: 132-140.

Bullough, J., Rea M., & Zhou Y. (2009). *Analysis of Visual Performance Benefits from Roadway Lighting*. NCHRP Project 5-19, Transportation Research Board of the National Academies, Washington D.C.

Cafiso, S., Garcia, A. G., Cavarra, R., & Rojas, M. R. (2011). Crosswalk safety evaluation using a pedestrian risk index as traffic conflict measure. In *Proceedings of the 3rd International Conference on Road safety and Simulation* (pp. 1-15).

Caliendo, C, & Guida M. (2012). Microsimulation Approach for Predicting Crashes at Unsignalized Intersections Using Traffic Conflicts. *Journal of Transportation Engineering* (ASCE) 1453-1467.

Carroll, P. S. (1973). *Symposium on Driving Exposure*. Ann Arbor, Michigan: Highway Safety Research Institute. The University of Michigan.

Charly, A. & Matthew, T. (2017). Estimation of Modified Time to Collision as Surrogate for Mid-Block Crashes under Mixed Traffic Conditions. *Transportation Research Board Annual Meeting*. Washington, DC.

Cheng, G., Wang, Y., & Li, D. (2013). Setting conditions of crosswalk signal on urban road sections in China. In *2013 International Conference on Transportation (ICTR 2013)* (pp. 96-105).

Cherry, C., Donlon, B., Yan, X., Moore, S. E., & Xiong, J. (2012). Illegal mid-block pedestrian crossings in China: gap acceptance, conflict and crossing path analysis. *International journal of injury control and safety promotion*, *19*(4), 320-330.

Chin, H. C., Quek, S. T., & Cheu, R. L. (1991). Traffic conflicts in expressway merging. *Journal of transportation engineering*, *117*(6), 633-643.

Chin, H. C., & Quek, S. T. (1997). Measurement of traffic conflicts. *Safety Science*, *26*(3), 169-185.

Cunto, F., & Saccomanno F. (2008). Calibration and validation of simulated vehicle performance at signalized intersections. *Accident Analysis & Prevention* 17: 1171-1179.

Denton, G. (1980). The influence of visual pattern on perceived speed. *Perception* 9 4: 393-402.

Dijkstra, A., Marchesini, P., Bijleveld, F., Kars, V., Drolenga, H., & van Maarseveen, M. (2010). Do calculated conflicts in microsimulation model predict number of crashes?. *Transportation Research Record: Journal of the Transportation Research Board*, (2147), 105-112.

Dixon, L. (1996). Bicycle and Pedestrian level-of-service performance measures and standards for congestion management systems. *Transportation Research Record* 1538: 1-9.

El-Basyouny, K., & Sayed T. (2013). Safety performance functions using traffic conflicts. *Safety science* 51: 160-164.

Elvik, R. (1995). Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure. *Transportation Research Record* 1485: 112-123.

Federal Highway Administration. (2002). *Pedestrian Facilities User's Guide: Providing Safety and Mobility*. FHWA-RD-01-102, U.S. Department of Transportation.

Figliozzi, M., & Tipagornwong C. (2016). Pedestrian Crosswalk Law: A study of traffic and trajectory factors that affect non-compliance and stopping distance. *Accident Analysis and Prevention* 96: 169-179.

Fitzpatrick, K., Turner, S. M., Brewer, M., Carlson, P. J., Ullman, B., Trout, N. D. & Lord, D. (2006). *Improving Pedestrian Safety at Unsignalized Crossings*. NCHRP Project 3-71) Program and National Cooperative Highway Research Program of the Transportation Research Board.

Florida Department of Transportation. (2009). *Quality/level of service*. State of Florida Department of Transportation, Tallahassee, FL.

Foomani, M. G., Alecsandru, C., & McConnell, L. (2017). Safety Assessment of Backlit Pedestrian Crossing Sign on Stopping Characteristics at Unsignalized Intersection. *Transportation Research Board Annual Meeting*. Washington, DC: National Academy of Sciences.

Fruin, J.J. (1971). *Pedestrian planning and design*. New York: Metropolitan Associations of Urban Designers and Environmental Planners.

Garder, P. (2004). The impact of speed and other variables on pedestrian safety in Maine. *Accident Analysis & Prevention* 36: 533-542.

Garder, P. (1989). Pedestrian Safety at Traffic Signals: A Study carried out with the help of a Traffic Conflicts Technique. *Accident Analysis and Prevention* 435-444.

Gates, T. J., Savolainen, P. T., Stapleton, S., Kirsch, T., & Miraskar, S. (2016). *Development of safety performance functions and other decision support tools to assess pedestrian and bicycle safety* (No. TRCLC 14-6). Wayne State University. Transportation Research Center for Livable Communities (TRCLC).

Gettman, D., & Head, L. (2003). Surrogate safety measures from traffic simulation models. *Transportation Research Record: Journal of the Transportation Research Board*, (1840), 104-115

Gettman, D., Pu, L., Sayed, T., Shelby, S., & Siemens, I. T. S. (2008). *Surrogate safety assessment model and validation* (No. FHWA-HRT-08-051). United States. Federal Highway Administration. Office of Safety Research and Development.

Glauz, W. D., & Migletz, D. J (1980). *Application of Traffic Conflicts Analysis at Intersections*. NCHRP Report 219, Transportation Research Board (No. HS-028 882).

Glennon, J. C., Glauz, W. D., Sharp, M. C., & Thorson, B. A. (1977). Critique of the traffic-conflict technique. *Transportation Research Record*, *630*, 32-38.

Griffin, L., & Reinhardt R. (1996). *A Review of Two innovative Pavement Patterns that have been Developed to Reduce Traffic Speed and Crashes*. AAA Foundation for Traffic Safety, Washington D.C.

Guido, G., Saccomanno, F., Vitale, A., Astarita, V., & Festa, D. (2010). Comparing safety performance measures obtained from video capture data. *Journal of Transportation Engineering*, *137*(7), 481-491.

Guo, F., Klauer, S. G., Hankey, J. M., & Dingus, T. A. (2010). Near crashes as crash surrogate for naturalistic driving studies. *Transportation Research Record*, *2147*(1), 66-74.

Guo, Y., Liu, P., Liang, Q., & Wang, W. (2016). Effects of parallelogram-shaped pavement markings on vehicle speed and safety of pedestrian crosswalks on urban roads in China. *Accident Analysis & Prevention* 95: 438-447.

Cheng, G., Wang, Y., & Li, D. (2013). Setting conditions of crosswalk signal on urban road sections in China. In *2013 International Conference on Transportation (ICTR 2013)* (pp. 96-105).

Guttinger, V. (1984). *Conflict observation in theory and practice*. Edited by Springer-Verlag. Berlin: International Study of Traffic Conflict Techniques.

Hagring, O. (2000). Effects of OD flows on roundabout entry capacity. *Fourth International Symposium on Highway Capacity*. Hawaii.

Haleem, K., Alluri, P., & Gan, A. (2015). Analyzing pedestrian crash injury severity at signalized and non-signalized locations. *Accident Analysis & Prevention*, *81*, 14-23.

Hansson, A. (1975). *Studies in Driver Behaviour, with Applications in Traffic Design and Planning*. Bulletin 11, Department of Traffic Planning and Engineering, Lund Institute of Technology, University of Lund.

Hauder, E., & Garder P. (1986). Research into the validity of traffic conflicts technique. *Accident Analysis & Prevention* 18: 471-481.

Hauer, E. (1978). Design Consideration of Traffic Conflict Surveys. TRB Research Record 667 Highway Capacity, Measures of Effectiveness and Flow Theory 57-66. ww.ictct.org/media/Hauer_1978a.pdf.

Hauer, E. 1982. Traffic conflicts and exposure. *Accident Analysis and Prevention* 359-364.

Hayward, J. (1972). *Near miss determination through use of a scale of danger*. Report No. TTSC 7115, Pennsylvania State University.

Henson, C. (2000). Levels of service for pedestrians. *ITE journal* 70 (9): 26-30.

Himanen, V., & Kulmala. R. 1988. An application of logit models in analyzing the behaviour of pedestrians and car drivers on pedestrian crossings. *Accident Analysis & Prevention* 20 (3): 187-197.

Hine, J., & Russell J. (1993). Traffic barriers and pedestrian crossing behaviour. Journal of Transportation Geography 1 (4): 230-239.

Hipp, J. A., Manteiga, A., Burgess, A., Stylianou, A., & Pless, R. (2016). Webcams, crowdsourcing, and enhanced crosswalks: Developing a novel Method to analyze active Transportation. *Frontiers in public health*, *4*, 97.

Hunter, M., & Rodgers, M. (2012). *Evaluation of Intersection Countermeasures on High-speed Rural Multi-lane Facilities*. Federal Highway Administration, US Department of Transportation, Atlanta, GA: Georgia Tech Research Corporation, 7-10.

Hydén, C. (1977). A *Traffic Conflict Technique for Examining Urban Intersection Problems. First Workshop on Traffic Conflicts*. Oslo, Norway: Royal Norwegian Council for Industrial and Scientific Research. 87-98.

Hydén, C. (1987). *The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique*. Bulletin 70, Lund University.

Hydén, C, & Várhelyi A. (2000). The effects of safety, time consumption and environment of large-scale use of roundabouts in an urban area: A case study. *Accident Analysis & Prevention* 32 11-23.

InDev. (2016). *Review of Current Study Methods for Vulnerable Road Users Safety*. Warsaw, Poland: Horizon 2020.

Ismail, K., Sayed, T. & Saunier. N. (2011). Methodologies for aggregating traffic conflict indicators. *Transportation Research Record* No 2237: 10-19.

Ismail, K., Sayed, T. & Saunier. N. & C. Lim. (2010). Automated analysis of pedestrian-vehicle conflicts using video data. *Transportation Research Record*: Journal of the Transportation Research Board 2140: 44-54.

JAMAR Technologies, Inc. (2016). *Products*. Accessed Nov. 12, 2016 www.jamartech.com/index.html#services.

Katz, A., Zaidel, D., & Elgrishi, A. (1975). An experimental study of driver and pedestrian interaction during the crossing conflict. *Human Factors*, *17*(5), 514-527.

Khisty, C.J. (1994). Evaluation of pedestrian facilities. Beyond the level-of-service concept. *Transportation Research Record* 1438: 45-50.

Kim, K., Brunner, I. M., & Yamashita, E. (2006). Influence of land use, population, employment, and economic activity on accidents. *Transportation Research Record* 1953: 56-64.

Kim, K., Brunner, I. M., & Yamashita, E. (2008). Modeling violation of Hawaii's crosswalk law. *Accident Analysis & Prevention*, *40*(3), 894-904.

Kittelson & Associates, Inc. (2014). *Pedestrian and Bicycle Safety Implementation Plan*. Oregon Department of Transportation, Bend.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data. Report No. DOT HS 810 594, Virginia Tech Transportation Institute, National Highway Traffic Safety Administration.

Currans, K. M., Gehrke, S. R., & Clifton, K. J. (2015). The Use of Images in Transportation Surveys: Testing Respondents Perceptions of Housing, Transportation and Built Environment Characteristics. Transportation Research Board 94th Annual Meeting. 1-20.

Kruysee, H. (1991). The Subjective Evaluation of Traffic Conflicts Based on an Internal Concept of Dangerousness. *Accident Analysis & Prevention* 23 (1).

Landis, B., Vattikuti, V., Ottenberg, R., McLeod, D., & Guttenplan, M. (2001). Modeling the roadside walking environment: pedestrian level of service. *Transportation Research Record: Journal of the Transportation Research Board*, (1773), 82-88.

Laureshyn, A., Svensson A., & Hydem C. (2010). Evaluation of traffic safety, based on micro-level behavioral data: theoretical framework and first implementation. *Accident Analysis & Prevention* 42 (6): 1636-1646.

Lee, J., Abdel-Aty M., & Jiang X. (2015). Multivariate crash modeling for motor vehicle and non-motorized modes at the macroscopic level. *Accident Analysis & Prevention* 78: 146-154.

Liu, P., Zhang X., Wang W., & Xu C. (2011). Driver response to automated speed enforcement on rural highways in China. *Transportation Research Record* 2265: 109-117.

Liu, Y., & Tung Y. (2014). Risk analysis of pedestrians' road-crossing decisions: Effects of age, time gap, time of the day, and vehicle speed. *Safety science* 63: 77-82.

Loukaitou-Sideris, A., Liggett, R., & Sung, H. G. (2007). Death on the crosswalk: A study of pedestrian-automobile collisions in Los Angeles. *Journal of Planning Education and Research*, *26*(3), 338-351.

M.Buhrmester, T. Kwang, & Gosling SD. (2011). Amazon's Mechanical Turk: a new source of inexpensive, yet high-quality, data? *Perspectives on Psychological Sciences* 6 (1): 3-5.

Malaterre, G., & Muhlrad. H. (1977). *A conflict technique*. First Workshop on Traffic Conflicts. Oslo. 47-58.

Malkhamah, S., Tight M., & Montgomery F. (2005). The development of an automatic method of safety monitoring at Pelican crossings. *Accident Analysis & Prevention* 37: 938-946.

Mead, J., Zegeer, C., & Bushell, M. (2014). *Evaluation of pedestrian-related roadway measures: a summary of available research*. Edited by UNC Highway Safety Research Center. Pedestrian and Bicycle Information Center.

Miller, J., Bigelow, J., & Garber, N. (2000). Calibrating pedestrian level-of-service metrics with 3-D visualization. *Transportation Research Record: Journal of the Transportation Research Board*, (1705), 9-15.

Minderhound, M. & Bovy P. (2001). Extended time-to-collission measures for traffic safety assessment. *Accident Analysis & Prevention* 33 (1): 89-97.

Mozer, D. (1994). *Calculating Multi-Mode Levels-of-Service*. International Bicycle Fund.

Nassar, J., & Troyer D. (2013). Pedestrian injuries due to mobile phone use in public places. *Accident Analysis & Prevention* 57: 91-95.

NCHRP. (2008). *Multimodal Level of Service Analysis for Urban Streets*. Report 616, Washington D.C.: Transportation Research Board, 11-15.

Nabavi Niaki, M. S., Fu, T., Saunier, N., Miranda-Moreno, L. F., Amador, L., & Bruneau, J. F. (2016). Road Lighting Effects on Bicycle and Pedestrian Accident Frequency: Case Study in Montreal, Quebec, Canada. *Transportation Research Record: Journal of the Transportation Research Board*, (2555), 86-94.

Nilsson, G. (1978). *Risk Exposure. A study of needs of risk exposure for road accident analysis*. VTI Rapport.

Nordback, K., Kothuri, S., Petritsch, T., McLeod, P., Rose, E., & Twaddell, H. (2016). *Exploring Pedestrian Counting Procedures.* Washington, DC: Federal Highway Administration.

O'Flaherty, C. A., & Parkinson, M. H. (1972). Movement on a city centre footway. *Traffic engineering and control*, *13*(10), 434-438.

Ole, P. (2009). Effects of road lighting: An analysis based on Dutch accident statistics (1987)-(2006). *Accident Analysis and Prevention* 41.

Oregon Department of Transportation. (2014). *ODOT Statewide Crash Data System: Motor Vehicle Traffic Crash Analysis and Code Manual*. Oregon: Transportation Data Section Crash Analysis and Reporting Unit.

Ozbay, K., Yang, H., Bartin, B., & Mudigonda, S. (2008). Derivation and validation of new simulation-based surrogate safety measure. *Transportation Research Record: Journal of the Transportation Research Board*, (2083), 105-113.

Perkin, S.R., & Harris J.I. (1967). *Criteria for Traffic Conflict Characteristics: Signalized Intersections*. Electro-Mechanical Department, General Motors Corporation.

Petritsch, T., Landis, B., McLeod, P., Huang, H., Challa, S., Skaggs, C. & Vattikuti, V. (2006). Pedestrian level-of-service model for urban arterial facilities with sidewalks. *Transportation Research Record: Journal of the Transportation Research Board*, (1982), 84-89.

Pirdavani, A., Brijis T., Bellemans T. & Wets G. (2010). Evaluation of traffic safety at un-signalized intersections using microsimulation:A utilization of proximal safety indicators with TSC-Sim. *Accident Analysis & Prevention* 26: 593-607.

Rea, M., Bullough J., & Zhou Y. (2010). A method for assessing the visibility benefits of roadway lighting. *Lighting Research and Technology* 42 (2): 215-241.

Sarkar, S. (1993). Determination of service levels for pedestrians, with European example. *Transportation Research Record* 1405: 35-42.

Sarkar, S. (2002). Qualitative evaluation of comfort needs in urban walkways in major activity centers. *Transportation Research Board Conference*. Washington D.C. 13-17.

Sarkar, S., Richard T., & Hunt J. (2011). Logistic regression model of risk of fatality in vehicle–pedestrian crashes on national highways in Bangladesh. *Transportation Research Record* No 2264: 128-137.

Saunier, N, & Sayed T. (2006). A feature-based tracking algorithm for vehicles in intersections. *Proceedings of the 3rd Canadian Conference on Computer and Robot Visio*n (CRV'06). IEEE.

Sayed T., & Zein Z. (1999). Traffic Conflict standards for intersections. *Transportation Planning and Technology* 22: 309-323.

Schroeder, B.J., & Rouphail N.M. (2011). Event-based modeling of driver yielding behavior at unsignalized crosswalks. *Journal of Transportation Engineering* 137: 455-465.

Jin, S., Wang, D. H., Xu, C., & Ma, D. F. (2013). Short-term traffic safety forecasting using Gaussian mixture model and Kalman filter. *Journal of Zhejiang University SCIENCE A* 14 (4): 231-243.

Shoarian-Sattari, K., & Powell D. (1987). Measured Vehicle Flow Parameters as Predictors in Road Traffic Accident Studies. *Traffic Engineering and Control* 28 (6): 328-335.

Shurbutt, J., Van Houten R., Turner S., & Huitema B. (2009). Analysis of effects of LED rectangular rapid-flash beacons on yielding to pedestrians in multilane crosswalks. *Transportation Research Record* 2140: 85-95.

Singh, K., & Jain P.K. (2011). Methods of assessing pedestrian level of service. *Journal of Engineering Research and Studies* 2: 116-124.

Smartmicro. (2016). *Smart Microwave Sensors*. Accessed 12 14, (2016). www.smartmicro.de/traffic-radar/traffic-radar-overview/.

Songchitruska, P. & Tarko A. (2004). *Using Imaging Technology to Evaluate Highway Safety. Joint Transportation Research Program*, Purdue University, Indiana Department of Transportation and Federal Highwat Administration.

Stipanic, J. & Miranda-Moreno L. (2015). Traffic Parameter Methods for Surrogate Safety: A Comparative Study of Three Mobile Sensor Technologies. *TRB Annual Meeting*. Washington, DC: Transportation Research Board.

Strauss, J, Miranda-Moreno L. & Morency P. (2014). Multimodal injury risk analysis of road users at signalized and non-signalized intersections. *Accident Analysis & Prevention* 71: 201-209.

Svensson, A. (1998). *A Method for Analyzing the Traffic Process In A Safety Perspective*. Lund University, Department of Traffic Planning & Engineering, Lund, Sweeden.

Tarko, A. (2012). Use of crash surrogates and exceedance statistics to estimate road safety. *Accident Analysis & Prevention* 45: 230-240.

Tarko, A., Davis G, Saunier N., Sayed T. & Washington S. (2009*). Surrogate Measures of Safety.* ANB20 (3) Subcomittee on Surrogate Measures of Safety, ANB20 Comittee on Safety Data Evaluation and Analysis.

Thambiah, M, & Toru H. (2007). Overall Level of Service of Urban Walking Environment and Its Influence onPedestrian Route Choice Behavior: Analysis of Pedestrian Travel in Sapporo, Japan. *Transportation Research Record* 2002: 7-17.

Tiwari, G., Mohan D. & Fazio J. (1998). Conflict analysis for prediction of fatal crash locations in mixed traffic streams. *Accident Analysis and Prevention* 30 (2): 207-215.

Tom, A., & Granié, M. A. (2011). Gender differences in pedestrian rule compliance and visual search at signalized and unsignalized crossroads. *Accident Analysis & Prevention*, *43*(5), 1794-1801.

Ukkusuri, S., Hasan S., & Aziz H. (2011). Random parameter model used to explain effects of built-environment characteristics on pedestrian crash frequency. *Transportation Research Record* 2237: 98-106.

Van der Horst, A. (1990). *A time based analysis of road user behaviour in normal and critical encounters*. Delft University of Technology.

Van der Horst, A. (1991). Time-To-Collision as a cue for decision-making in braking. *Vision in Vehicles III* (Elsevier Science Publishers) 19-26.

Várhely, A. (1998). Drivers' speed behaviour at a zebra crossing: a case study. *Accident Analysis and Prevention* 30 (6): 731-743.

Várhelyi, A. (1996). *Dynamic Speed Adaptation Based on Information Technology-A Theoretical Background*. Bulletin 142, Department of Traffic Planning and Engineering, Lund University.

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident Analysis & Prevention* 35: 427-473.

Vogel, K. (2002). What characterizes a free vehicle in an urban area? *Transportation Research Part F* 5: 313-327.

Walz, F., Hoefliger M., & Fehiman W. (1983). Speed limit reduction from 60 to 50 km/h and pedestrian injuries. *Proceedings of the 27th Stapp Car Crash Conference with International Research Commitee on Biokinetics of Impact*. 277-285.

Wang, X, Yang J., Lee C., Ji Z., & You S. (2016). Macro-level safety analysis of pedestrian crashes in Shanghai, China. *Accident Analysis & Prevention* 96: 12-21.

Wanvik, P.O. (2009). *Road Lighting and Traffic Safety: Do we Need Road Lighting?* PhD dissertation, Norweigan University of Science and Technology, Trondheim.

Wier, M., Weintraub J., Humphreys E.H, Seto E., & Bhatia R. (2009). An area-level model of vehicle-pedestrian injury collisions with implications for land use and transportation planning. *Accident Analysis & Prevention* 41: 137-145.

Williams, M.J. (1981). Validity of the Traffic conflicts technique. *Accident Analysis and Prevention* 13: 133-145.

Wu, K., & Jovanis P.P. (2012). Crashes and crash-surrogate events: Exploratory modeling with naturalistic driving data. *Accident Analysis & Prevention* 45: 507-516.

Yagil, D. (2000). Beliefs, motives and situational factors related to pedestrians' self-reported behavior at signal-controlled crossings. *Transportation Research Part F*: Traffic Psychology and Behaviour 3 (1): 1-13.

Yannis, G., Papadimitriou E. & Theofilatos A. (2013). Pedestrian gap acceptance for mid-block street crossing. *Transportation Planning and Technology* 36 (5): 450-462.

Zajac, S., & Ivan J. (2003). Factors influencing injury severity of motor vehicle-crossing pedestrian crashes in rural Connecticut. *Accident Analysis & Prevention* 35: 369-379.

Zajíc, P. (2012). Traffic conflicts and road transport safety - New development. Electronic Technical Journal of Technology, *Engineering and Logistics in Transport* 7 (4): 174-183.

Zeeger, C., Stewart J., Huang H. & Lagerway P. (2001). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: analysis of pedestrian crashes in 30 cities. *Transportation Research Record* 1773: 56-68.

Zegeer, C., Carter, D., Hunter, W., Stewart, J., Huang, H., Do, A., & Sandt, L. (2006). Index for assessing pedestrian safety at intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (1982), 76-83.

Zheng, L., Ismail, K., & Meng, X. (2014). Traffic conflict techniques for road safety analysis: open questions and some insights. *Canadian journal of civil engineering*, *41*(7), 633-641.

Zhao, Y., Bai Y. & Yang X. (2011). Modeling Conflicts between Right-turning Vehicles and Pedestrians at Signalized Intersections. *International Conference on Transportation Information and Safety*. Wuhan, China: Transportation and Development Institute of the American Society of Civil Engineers. 529-536.

Zhuang, X., & Wu C. (2011). Pedestrians' crossing behaviors and safety at unmarked roadway in China. *Accident Analysis & Prevention* 43 (6): 1927-1936.

APPENDIX A – PEDESTRIAN VOLUME DISTRIBUTION

A review of the literature was conducted to understand how pedestrian volumes were distributed through the day, so that an optimal data collection period could be identified. Aultman-Hall et al. analyzed 12 months of automated hourly pedestrian counts in downtown Montpelier, Vermont to study the impacts of weather and season on pedestrian traffic (Aultman-Hall et al. 2009). The selected location was a sidewalk between on-street parking and commercial storefronts. Figure A.1 shows the hourly distribution of pedestrian volumes. At this location, the volumes peak at noon, possibly due to workers walking to eat lunch and running errands. Weekly volume trends show higher volumes during weekdays and lower volume during weekends.

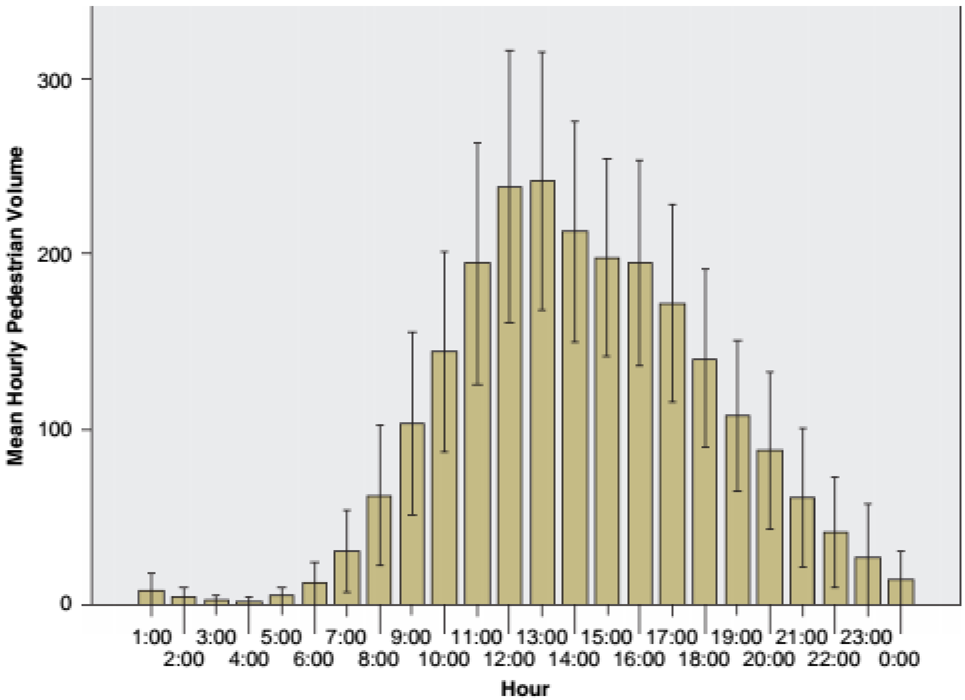

Figure A.1: Mean pedestrian volume by hour of day (Source: Aultman-Hall et al. 2009)

Griswold et al. used visualizations to study fatal single vehicle-pedestrian crashes 1998-2007 (Griswold et al. 2010). To understand the impacts of pedestrian volumes, they studied composite pedestrian volumes that were collected in Alameda County, California as a part of another study over a 14-month period between April 2008 and June 2009 at 13 sites. The sites included both urban and suburban sites. Figure A.2 shows composite volume pattern. This pattern also indicates that pedestrian volumes are higher during middle of the day, and weekday volumes during May-June are higher than weekend volumes. During winter months (Nov-Jan), volumes on Saturday are higher than those on the weekday.

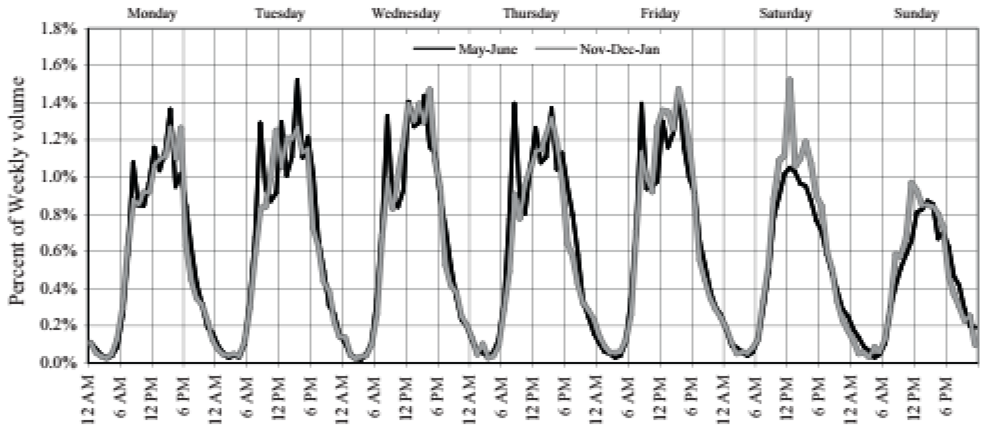

Figure A.2: Composite weekly pedestrian volumes from Griswold et al. (Source: Griswold et al. 2010)

Hankey et al. developed pedestrian and bicycle count models to estimate the use of non-motorized infrastructure (Hankey et al. 2012). They utilized manual counts taken on weekdays in September at various locations in Minneapolis. Their data also revealed that pedestrian counts were higher during the middle of the day (noon and later) and highest during the evening peak hours (4-6 pm). Table A.1 shows the percent of 12-hour counts for each time period.

Table A.1: Percent of 12-Hour Pedestrian Counts by Hour of Day (Source: Hankey et al. 2012)

HOUR OF DAY	PERCENT OF 12-HOUR COUNT
7 – 8 AM	6.9
8 - 9 AM	5.3
9 - 10 AM	6.1
10 -11 AM	5.9
11AM – 12 PM	9.2
12 -1 PM	9.7
1 – 2 PM	8.7
2 – 3 PM	8.8
3 – 4 PM	7.8
4 - 5 PM	10.4
5 – 6 PM	12.3

Milligan et al. assessed two sources of temporal information for expanding short duration counts – pedestrian counts from other cities and local vehicle counts (Milligan et al. 2012). The pedestrian counts were collected at an intersection crosswalk in downtown Winnipeg, Canada using video. Figures A.3a and A.3b show the hourly variation in pedestrian volumes over a 12-month period. Both plots show a peak during the noon hour and higher volumes during the day.

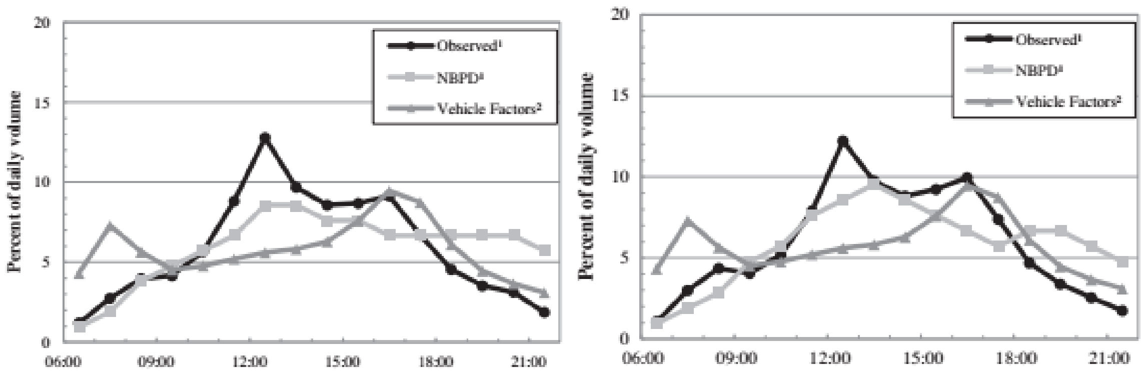

Figure A.3: a) Hourly variation in pedestrian weekday volumes (April – September) b) hourly variation in pedestrian weekday volumes (October – March) Source: Milligan et al. 2012

Miranda-Moreno et al. studied the effect of weather on pedestrian volumes and temporal trends in Montreal, Canada (Miranda-Moreno et al. 2013). They compared the automatic hourly pedestrian counts in five locations, with two types of built environment – low pedestrian volumes with mixed-residential commercial areas and low residential density, and high volume locations in busy commercial-service areas with high residential density for 12 months. Figure A.4 shows the hourly pedestrian volume trends at all study sidewalks. A three peak pattern is observed in Figure A.4 and according to the authors, this was particularly observed for the counters at the downtown locations (Miranda-Moreno et al. 2013).

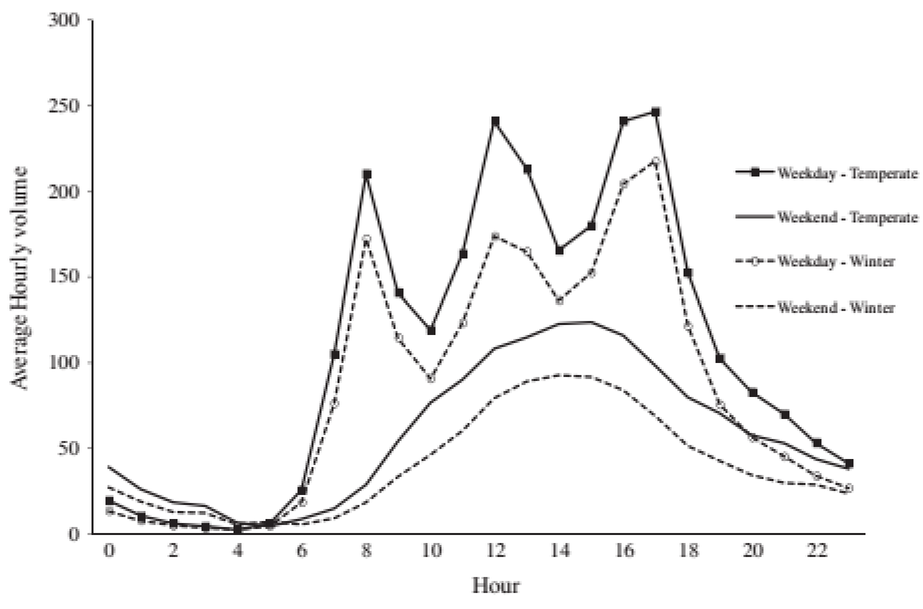

Figure A.4: Average pedestrian volumes (All Study Sidewalks) Source: Miranda-Moreno et al. 2013.

Figliozzi et al. used video data to compare pedestrian volumes at intersection crosswalks with pushbutton phase data for a 24-hour period at a suburban intersection in Tigard, Oregon (Figliozzi et al. 2014). Figure A.5 shows the pedestrian hourly volume distribution. Higher pedestrian volumes were observed during the middle of the day (12 – 6 PM).

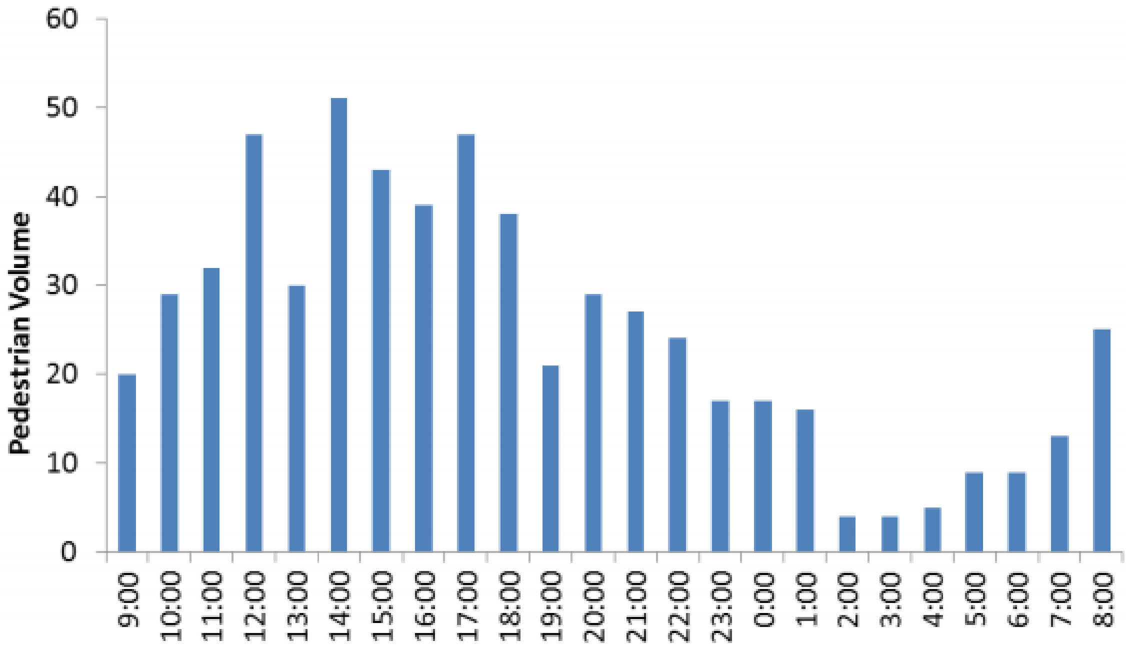

Figure A.5: Total pedestrian volumes (All Crosswalks) Source: Figliozzi et al. 2014

Poapst et al. studied the influence of temporal and spatial factors on hourly pedestrian traffic distribution in commercial zones (Poapst et al. 2015). Hourly pedestrian distributions for one of the site for each day of the week is shown in Figure A.6. Weekday pedestrian volumes are higher between 11 AM – 8 PM as seen in Figure A.6.

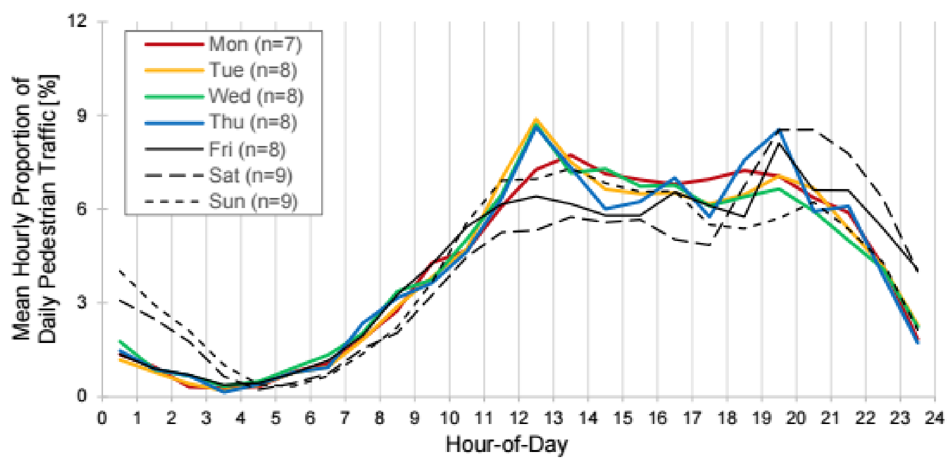

Figure A.6: Mean hourly proportion of pedestrian traffic at a sidewalk on Corydon Avenue Source: Poapst et al. 2015

Table A.2 shows the summary of the available studies that show pedestrian volume distributions by time of day. All the studies show higher pedestrian volumes during noon and afternoon time periods.

Table A.2: Summary of Studies on Pedestrian Volume Distribution

Study	Location of Data Collection	Facility	Time Period	Land Use	Equipment
Aultman-Hall, 2009	Single downtown location in Montpelier, Vermont,	Sidewalk	1 Year, Nov 2006-Nov 2007	Commercial	Eco-Counter Pyro
Hankey et al., 2012	Various locations in Minneapolis, MN	Sidewalk	2007-2010		Manual counts in field
Milligan, 2012	Winnipeg, Canada	Crosswalk	84 days, with 16 hrs. on each day,	Central business district	Video counts
Miranda-Moreno, 2013	Montreal. Canada, 5 locations	Sidewalk	Winter and temperate months	low pedestrian volumes with mixed residential–commercial areas and low residential density, and high volume locations in busy commercial-service areas with high residential density	Eco-Counter Pyro
Figliozzi, 2014	Tigard, OR	Crosswalk	24 hrs, August, 2013	Suburban location	Manual counts from 24 hr video recording
Poabst, 2015	Winnipeg, Canada, 12 study locations	Sidewalks	June-August, September-November, 2013	Commercial	Eco-Counter Pyro

APPENDIX B – VEHICLE VOLUME DISTRIBUTION

ODOT maintains Automatic Traffic Recorder (ATRs) stations for counting vehicles along state highways. Vehicle volumes from select Automatic Traffic Recorder (ATR) stations were gathered for March 2016. The ATR locations were selected based on their proximity to certain corridors (Powell Blvd., US 30, OR 224), where data was collected.

Figure B.1 shows the hourly vehicle distribution from ATR 26-003, which is located on US 26 at milepost 14.36, 0.18 miles southeast of SE Powell Valley Road. The data shown here is from March 2016. The lighter lines on the plot show the distribution during each day in March and the darker lines show the average for each day of the week. The plot shows a typical bi-modal distribution during the weekdays with AM and PM peak, which is indicative of a commute pattern and the absence of peaks on the weekend.

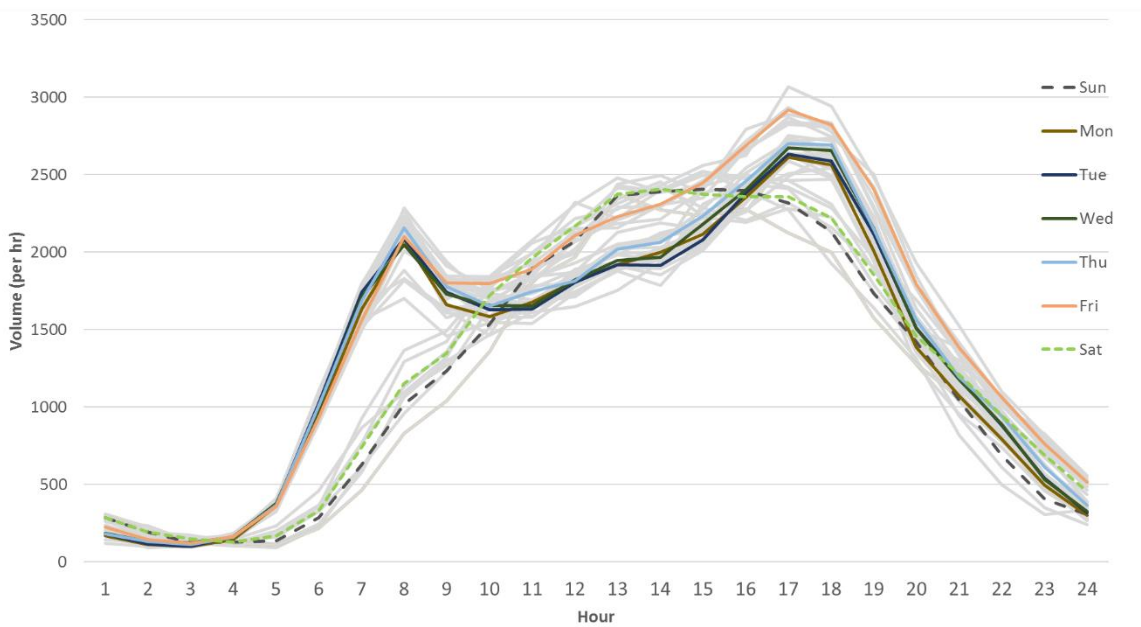

Figure B.1: Hourly vehicle distribution at ATR on Powell Blvd

Figure B.2 shows the hourly vehicle distribution from ATR 26-012, which is located on US 30 at milepost 13.94, 0.10 miles west of Bridal Veil Fall State Park. The data shown here is from March 2016. The lighter lines on the plot show the distribution during each day in March and the darker lines show the average for each day of the week. The plot shows a higher vehicular volumes during the weekend and lower vehicular volumes during the weekday, which is indicative of a recreational pattern.

Figure B.3 shows the hourly vehicle distribution from ATR 03-018, which is located on US 224 at milepost 3.60, 0.13 miles west of Johnson Road. The data shown here is from March 2016. The lighter lines on the plot show the distribution during each day in March and the darker lines show the average for each day of the week. The plot shows a typical bi-modal distribution during the weekdays with AM and PM peak, which is indicative of a commute pattern and the absence of peaks on the weekend.

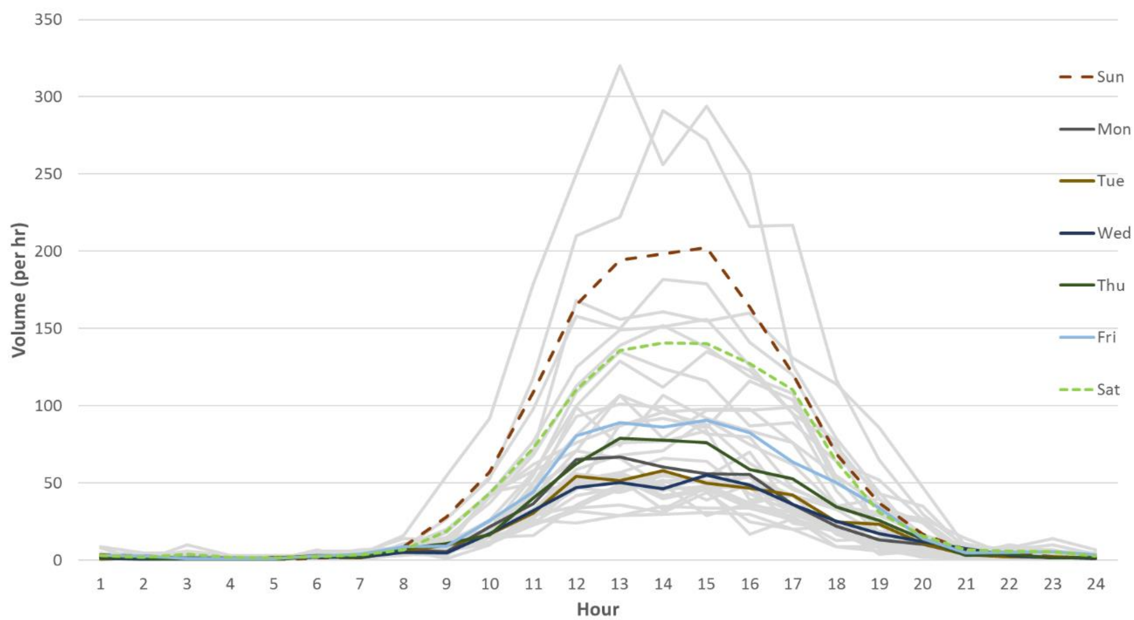

Figure B.2: Hourly vehicle distribution at ATR on US 30

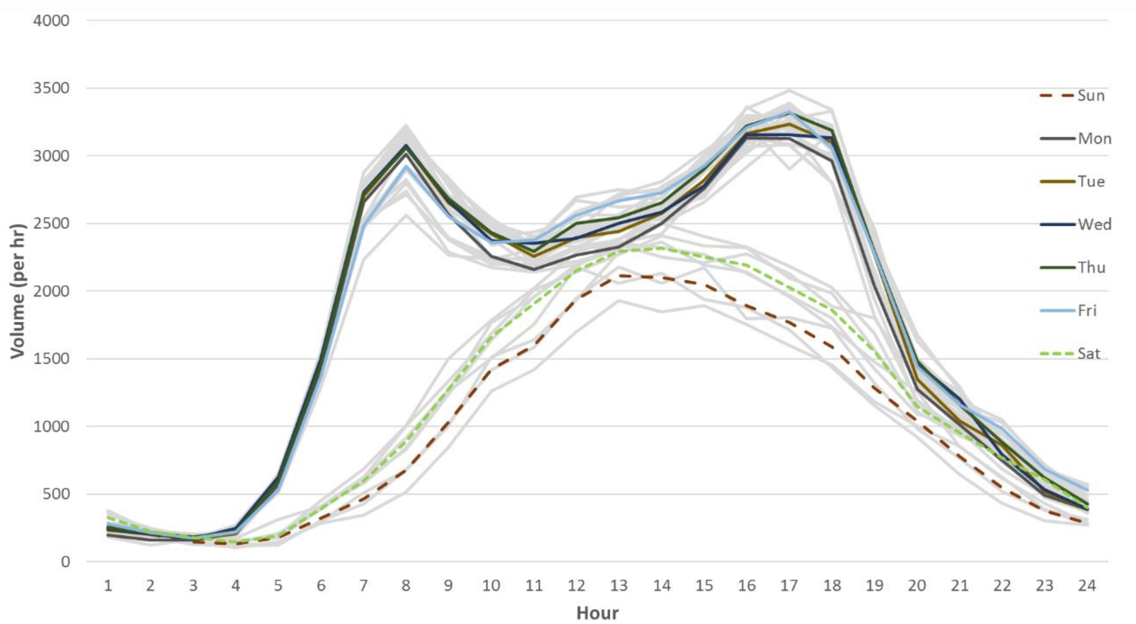

Figure B.3: Hourly vehicle distribution at ATR on OR 224