SAFEST PLACEMENT FOR CROSSWALKS AT INTERSECTIONS

Final Report

SPR 840

Oregon Department of Transportation

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PROJECT SPR 840

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16. Abstract: This research studied the relationship between crosswalk setback and intersection safety. The study included field-based and driving simulator experiments. Video data was collected at 10 crosswalks in Oregon to examine the frequency pedestrian-vehicle conflicts (measured using PET), including how these conflicts vary between corner and setback crosswalks. A total of 507 pedestrians and 47 conflicts with post-encroachment times of less than 5 seconds were observed. The 50 participants driving simulator experiment was used to determine how setback distances, curb radii, and presence of pedestrians affect driver stopping decision and position, speed choice, visual attention, and level of stress. Observations of drivers' speed in a similar scenario were taken from field and simulator data to enhance the evidence provided by each experiment. Stop line speeds were found to be consistent between experiments and turning speeds were found to be slightly higher in the driving simulator experiment. The study results suggest that curb radius should be smaller to control driver speed. Additionally, setback distance of the crosswalk of 20ft is a suitable upper bound when reconstructing intersections.

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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

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DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION AND MOTIVATION

An implementation challenge with ODOT's Americans with Disabilities Act (ADA) settlement agreement is that two curb ramps are required at each street corner. To meet this provision, long ramp runs cause curb ramps to be set back a significant distance from the apex of the intersection corner in many locations. Concerns have been raised that setback crossings may be less safe because drivers expect to see pedestrians waiting to cross the intersection at the corner. However, the assumption that this is less safe is not based on empirical evidence. Some believe that crosswalks are safest when placed as close as possible to the intersection corner so that waiting pedestrians are located closer to a driver's line of sight as they approach the intersection. Others reason that setback crosswalks are safer because vehicles cross the crosswalk at less of an angle and at a distance that allows some separation from other intersection conflicts. A setback crosswalk may give a pedestrian more time to detect and react to a non-yielding vehicle.

This research aims to identify the relationship between the lateral offset of crosswalks (setback crosswalk) at intersections and intersection safety with the consideration of other intersection characteristics. The research goal aims to use the method of driving simulation and video data collection to assess intersection users' behaviors based on the intersection characteristics. The rest of this report is organized in the following way:

- Chapter 2 provides a literature review of previous research related to intersection safety to better understand the research topic. Reviewed topics included but were not limited to the safety and operational impacts of intersection elements related to driver and pedestrian behaviors. The review also discusses appropriate research methodologies to successfully address the stated research objectives.

- Chapter 3 provides information related to the collection and analysis of data collected in the field at 10 crosswalks (five setback, five control) in Oregon.

- Chapter 4 provides the completion of a driving simulator experiment conducted with 50 participants to investigate how the setback crosswalk, curb radius and presence of pedestrian affect the participants.

- Chapter 5 provides the study findings summary, recommendations for practitioners related to the intersection crosswalk placement, and limitations and directions for future research.

2.0 LITERATURE REVIEW

Intersection safety can be influenced by intersection geometric characteristics (e.g., road classification, lane configuration, crossing distance, and curb radius), infrastructure elements (e.g., traffic signals, lighting, and pavement markings), and human factors (e.g., pedestrian, bicycle, and driver behavior). A review of the literature presented in this interim report focuses on the safety and operational impacts of intersection elements related to driver and pedestrian behaviors. The review also discusses appropriate research methodologies to meet the stated research objectives.

This literature review includes peer reviewed journal articles, conference papers, technical reports, and guidebooks produced by state and federal transportation agencies. These documents were obtained from searching journal archives such as those maintained by the Transportation Research Board (i.e., TRID) and Google (i.e., Scholar), general search engines (i.e., Google), Transportation Agency websites (i.e., ODOT), and the reference lists of those identified documents.

2.1 SAFETY AND OPERATIONAL IMPACTS OF INTERSECTION ELEMENTS

Intersection elements including crossing distance, curb radius and intersection skew, can influence the safety, and driver and pedestrian behaviors performance at an intersection. The following sections discuss each of the elements are reviewed, in the context of the relationship between intersection safety and setback crosswalks.

2.1.1 Crossing Distance

According to the ITE Toolbox on Intersection Safety and Design, crossing distance is defined as the lateral distance between two sidewalks of an intersection (Institute of Transportation Engineers & U.S. Department of Transportation Federal Highway Administration, 2004). Crossing distance at intersections plays an essential role in affecting the safe and efficient operation of intersections.

2.1.1.1 Driver Yielding and Speed Choice

Burbidge (2016) collected video data from eight sites in Utah to determine pedestrian risk areas at intersections using statistical analysis and modeling, revealing that vehicle-pedestrian conflicts were most common during turning maneuvers. Especially for left turns, drivers often turn left without successfully yielding to the conflicting crossing pedestrians (Burbidge, 2016). Supporting this finding, Schneider, Sanatizadeh, Shaon, He, and Qin (2018) used video data at twenty intersections, field observations, and public surveys to analyze driver's yielding behavior using statistical modeling. The study found drivers tend to yield for pedestrians on shorter crosswalks (Schneider, Sanatizadeh, Shaon, He, & Qin, 2018).

2.1.1.2 Driver Scanning Patterns

Multiple research articles have indicated that drivers tend to focus more visual attention at the center of the path (Meguia, Chauvin, & Debernard, 2015; Romoser, Pollatsek, Fisher, & Williams, 2013; Vignali et al., 2019). Romoser, Pollatsek, Fisher, and Williams (2013) used a driving simulator to compare older and younger drivers' search and scanning patterns. The study found that both groups of drivers have similar glance patterns focusing on the center of their field of view at the beginning of turning maneuvers, but younger drivers will scan at a wider area and in different directions to attempt to prevent conflicts. Longer crossing distance may affect the performance of older drivers on the search and scanning patterns (Romoser et al., 2013).

2.1.1.3 Pedestrian Behaviors

Alhajyaseen, Iryo-Asano, Zhang, & Nakamura (2015) used video data from three intersections in Nagoya City, Japan to identify pedestrians' speed change behavior at signalized crosswalks. Results stated that pedestrians tend to have speed changes in longer crosswalks because they are less likely to finish crossing within the allotted green time and tend to accelerate during the clearance interval. Such changes in speeds may affect drivers' yielding performance and driver's search patterns (Alhajyaseen et al, 2015; Dozza et al, 2020; Figliozzi & Tipagornwong, 2016). Additionally, Gorrini, Crociani, Vizzari, and Bandini (2018) used video data from an unsignalized intersection in Milan, Italy to assess pedestrian crossing behaviors with statistical modeling. The study indicated that pedestrians would tend to walk off the designed crosswalk at an oblique direction. This tendency placed pedestrians in unexpected locations for drivers to yield to (Gorrini, et al, 2018).

2.1.1.4 Intersection Safety

Several research studies have concluded that intersections with longer crossing distances have a greater probability of vehicle-pedestrian conflict, especially for turning maneuvers. This is because the longer crossing distance requires longer pedestrian crossing times, which increases pedestrian exposure (Muley, Kharbeche, Alhajyaseen, & Al-Salem, 2017; Schneider et al., 2010; Stipancic, Miranda-Moreno, Strauss, & Labbe, 2020; Zhao, Ma, & Li, 2016). Jacquemart (2012) analyzed the benefits and drawbacks of setback crosswalks. Jacquemart stated the fact that intersections with setback crosswalks could minimize crossing distance as the distance would not be increased due to the curb radius, as shown in Figure 2.1(Jacquemart, 2012).

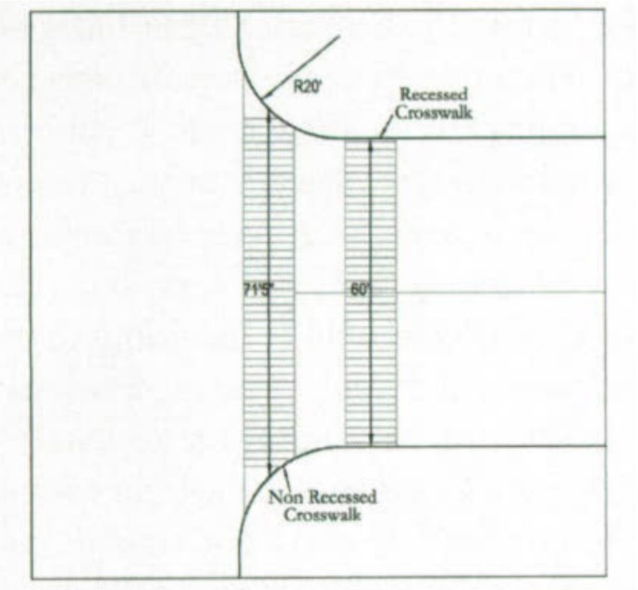


Figure 2.1: Crossing distance based on the crosswalk setbacks (Jacquemart, 2012)

2.1.2 Curb Radius

The corner radius at intersections also referred to as curb radius, curb return, or turning radius, is a vital factor in intersection designs. According to the Corner Design for All Users (CDAU), the curb radius can be classified by physical and effective radius, where physical radius is the actual curb radius; and effective radius is the radius that vehicles required to make a turn with the presence of roadway features for example bike or parking lanes. The selection of curb radius is based on a framework that involved three vehicle types: a manage vehicle (i.e. vehicle that commonly completes the turn), a design vehicle (i.e. largest vehicle that frequently completes the turn), and a control vehicle (i.e. largest vehicle that is expected to, but not frequently completes the turn) (Alta Planning + Design, 2020).

2.1.2.1 Driver Yielding and Speed Choice

The CDAU reported that driver yielding while making a right turn is not related to the curb configuration during a green indication. However, the curb configurations affected driver speeds under scenarios other than the green indication. CDAU explains that higher turning speeds result in the increase of required stopping distance, drivers may not have sufficient distance to stop and may affect the driver sight distance. This will ultimately reduce driver yielding performance and increase the possibility of vehicle-pedestrian/biker conflicts with a higher level of injury severity (Alta Planning + Design, 2020).

Related research has stated that the curb radius will affect vehicle speed during right-turning maneuvers, where smaller radii will lead to lower speeds; and larger radii will lead to higher speeds (Alhajyaseen & Nakamura, 2012; Alta Planning + Design, 2020; Institute of Transportation Engineers & U.S. Department of Transportation Federal Highway Administration, 2004; Suzuki & Ito, 2017; Fitzpatrick, Avelar, Pratt, Das &

Lord, 2021). Suzuki and Ito (2017) used video data from five intersections in Nagoya, Japan to determine intersection user behavior using statistical analysis. The results showed that drivers have a high probability of not slowing during right-turning maneuvers across setback crosswalks because the curb radii tend to be larger in these configurations, resulting in higher vehicle speeds (Suzuki & Ito, 2017).

2.1.2.2 Driver Scanning Patterns

The Federal Highway Administration (FHWA) Older Driver Highway Design Handbook analyzed how curb radius affect driver performance, especially for older drivers, in right turn maneuvers. It has indicated that smaller curb radii negatively impact their capability for turning right on a green light at normal speed because of the limited turning space. Drivers tend to initiate a stop to slow down to improve their turning performance. Older drivers have the following possibilities for performing a right turn with smaller radii (Federal Highway Administration, 2001):

- Shift lateral position to the left at the beginning of a right turn to increase the turning radius, potentially causing the miscommunicating of intentions between vehicles.

- Swing wide to the far lane while completing the right turn to reduce steering wheel rotation, while increasing the turning radius, which may cause vehicle conflicts.

- Cut through the apex of the turn without considering other decisions, which will most likely cause the vehicle to go over the curb and increase potential vehicle-pedestrian conflicts.

2.1.2.3 Pedestrian Behaviors

According to the CDAU, the crossing distance for a 15 ft curb radius is 37 ft with an associated crossing time of 10.6 sec. Assuming that the average pedestrian crossing speed is 3.5 fps, by increasing the radius to 50 ft, the crossing distance increases by 52 ft with an additional crossing time of 14.8 sec (Alta Planning + Design, 2020). Regarding the relationship between curb radius and larger radii lengthen the crossing distance and increase the time for pedestrian clearance, which lead to the increase of pedestrian exposure risk.

2.1.2.4 Intersection Safety

According to the Highway Safety Manual (HSM), Crash Modification Factors (CMFs) are used to quantify the safety effect of roadway characteristics including treatments or countermeasures on the expected average crash frequency (AASHTO, 2010). A study conducted by FHWA indicated that the CMF for pedestrian crash increases as curb radius increases for right turn movement at intersections (Fitzpatrick, Avelar, Pratt, Das & Lord, 2021). The ITE Toolbox on Intersection Safety and Design has further indicated that the smaller curb radii will result in more pedestrian corner waiting spaces, shorter crossing distance, and better visibility for both drivers and pedestrians. However, smaller curb radii will not be efficient for heavy vehicles because they require larger curb radii to perform a right turn. In this case, heavy vehicles will most likely go over the curb with smaller radii (Institute of Transportation Engineers & U.S. Department of Transportation Federal Highway Administration, 2004). According to the National Highway Traffic Safety Administration (NHTSA)'s Fatal Accident Reporting System (FARS), analysis for right turn on red (RTOR) incidents from 1982 to 1992, RTOR incidents account for relatively small proportion (i.e., 0.05%) of the total analyzed traffic incidents. However, pedestrians and bicyclists were frequently involved when RTOT incidents occur, 93% of which resulted in injury (National Highway Traffic Safety Administration, 1995). Larger vehicle-involved incidents may cause more severe consequences for pedestrians and bicyclists. Jacquemart (2012) stated that if corner crosswalks were implemented, the conflicts between pedestrians and heavy vehicles, as shown in Figure 2.2, will increase because pedestrians tend to wait at the corner.

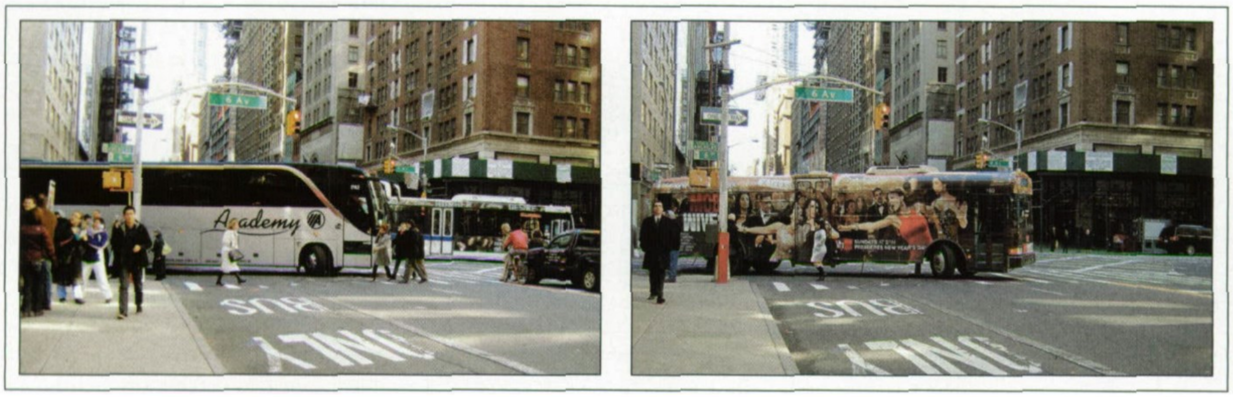


Figure 2.2: Heavy vehicle-pedestrian conflicts in right turn maneuver (Jacquemart, 2012)

In this case, setback crosswalks are more efficient because the crosswalk is located further back from the corner and provides enough turning space for heavy vehicles while simultaneously shifting the pedestrian waiting area away from the corner (Jacquemart, 2012). Further study is required to accurately determine how crosswalk setbacks impact the design of the curb radius.

To further resolve large vehicle turning issues, the CDAU suggests corner treatments include a single radius with mountable zone that is designed for large vehicles to traverse while deterring other vehicles; Dual radius with a defined apron area that allows large vehicles to traverse the defined area while limiting other vehicles to drive over and separating pedestrian and bicyclist waiting areas. The defined apron areas are commonly designed as raised traversable or mountable curb, using colored pavement markings and materials that are different than the adjacent roadways or sidewalks, using textured surfaces (e.g., rumbles, humps, and bumps) and installing detectable warning surfaces to separate pedestrian and bicyclist traffic (Alta Planning + Design, 2020).

Other than solving the large vehicle turning issues, multiple studies have proposed that the curb extension is a treatment recommended for intersections with on-street parking or shoulders to improve intersection safety (Bella & Silvestri, 2015; Miner & Arvidson, 2020). Figure 2.3 shows a curb extension example at an intersection.

Figure 2.3: Curb extension example at intersection

Bella and Silvestri (2015) used a driving simulator with 42 subjects to analyze the driver speeds at crosswalks with different safety treatments. Their study suggested that curb extensions influenced driver speeds when approaching crosswalks. Data showed that more than 80% of drivers perceived the effectiveness of curb extensions towards improving their sight distance; thereby increasing rates of yielding to pedestrians (Bella & Silvestri, 2015). Additionally, the Minnesota Department of Transportation Pedestrian Crosswalk Policy Development Guidelines suggests that curb extensions minimize the crossing distance, increase pedestrian sight distance, and decrease vehicle turning speeds (Miner & Arvidson, 2020).

2.1.3 Intersection Skew

Skewed intersections are configured such that the angle between two of the approaches is not equal to 90 degrees. FHWA defines skewed intersections as having acute angles at 60 degrees or less (Golembiewski & Chandler, 2011). Left skewed intersections are intersections where the acute angle is located to the left of a driver approaching the intersection on the skewed leg; where right skewed intersections are intersections where the acute angle is located to the right of a driver approaching the intersection on the right skewed leg; normal intersections are simply intersections with an angle of approximately 90 degrees (Iasmin, Kojima, & Kubota, 2015). Figure 2.4 presents the visualization of different skews.

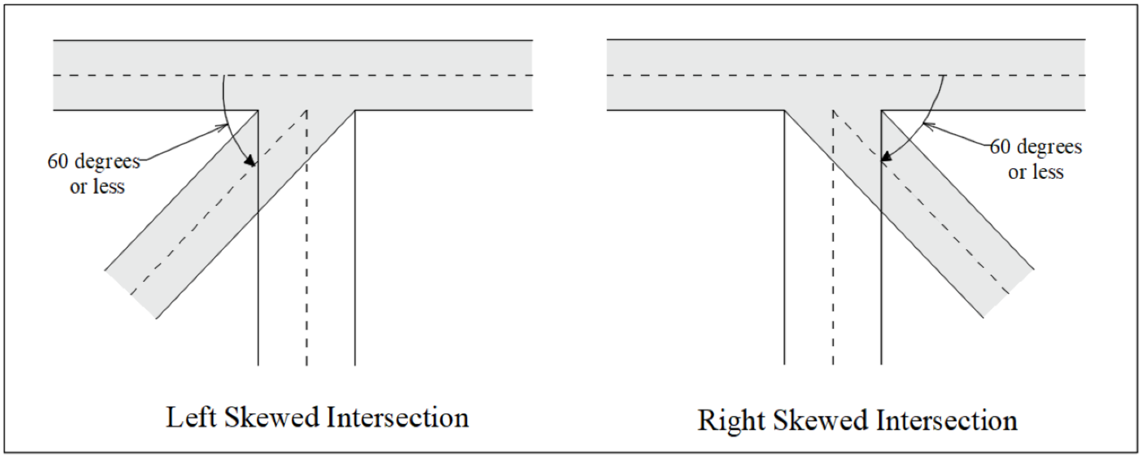


Figure 2.4: Intersection skews

Iasmin, Kojima, and Kubota (2015) and Distefano and Leonardi (2018) have concluded that skewed intersections will lead to more vehicle-pedestrian conflicts during turning maneuvers (Distefano & Leonardi, 2018; Iasmin et al., 2015).

2.1.3.1 Driver Yielding and Speed Choice

Iasmin et al. (2015) used video data from nine intersections in Tokyo, Japan to determine the impact of skewed intersections on driver behavior during left turn maneuvers on the minor street, which is a similar conflict to right turn maneuvers in the US, using the Swedish Traffic Conflict Technique. Study findings suggest that drivers on left-skewed intersection approaches tend to have lower rates of yielding to pedestrians for right-turning maneuvers. This is because the obtuse angles provide greater sight distance and longer turning radii to the right, which will result in higher speeds. In this case, drivers tend to make decisions before approaching the intersection and will likely accept shorter gaps (Iasmin et al., 2015).

For right-skewed intersections, Distefano and Leonardi (2018) used crash analysis at 35 intersections in Sicily, Italy with varying intersection angles to identify the relationship between crashes and intersection skew. Their results stated that intersections with acute angles will limit drivers' sight distance to the vehicles' right. In addition, the vehicle geometry, and passengers or objects adjacent to drivers will also obstruct drivers' sight distance to the right. Especially at unsignalized intersections for left-turning maneuver, drivers tend to pay more attention to the vehicles from the right side on the major road to avoid rear-end crashes, which can increase risk for crossing pedestrians (Distefano & Leonardi, 2018). However, Iasmin et al. (2015) found that drivers tend to have higher rates of yielding to pedestrians for right-turning maneuvers. This is because the limited sight distance to the right increases drivers' alertness, resulting in stopping or decreases in their speeds (Iasmin et al., 2015). As mentioned, vehicle geometry will affect drivers' sight distance. Reed (2008) used driving data from 87 participants to study the influence of vehicle geometry on driver behavior during turning maneuvers. The research proved that the design of the vehicle pillars (i.e., the supports that hold the windshield and roof) limit driver's sight distance to the right when making right turns (Reed, 2008).

2.1.3.2 Driver Scanning Patterns

Dozza, Boda, Jaber, Thalya, and Lubbe (2020) used a driving simulator and evaluation survey to study driver behaviors in vehicle-pedestrian interactions at intersections. Both Figliozzi and Tipagornwong (2016) and Dozza et al. (2020) stated that a driver's search pattern will be affected by pedestrian walking speeds, sight distance to pedestrians, distances between pedestrians or other vehicles, and the behavior of other drivers (Dozza et al., 2020; Figliozzi & Tipagornwong, 2016). Meguia, Chauvin, and Debernard (2015) used video data from a driver recorder database in Japan to assess driver behavior during right turns at intersection, which is similar to left turns in the US. Results further revealed that drivers will first look at and follow the preceding vehicle before making a left turn. When drivers are ready to turn, they glance towards the opposing intersection approach for conflicting vehicles, and lastly detect and stop for pedestrian (Meguia et al., 2015). The same article also explained this behavior in terms of driver head movements, which correspond to glance patterns, determining that drivers focus more on conflicting vehicles than waiting or crossing pedestrians (Meguia et al., 2015). Hurwitz, Monsere, Marnell and Paulsen (2014) used a driving simulator with 27 subjects to study driver behavior in maneuvering permissive left turns at intersection by obtaining eye tracking data. The study indicated that the driver’s average fixation duration was largest on the conflicting vehicles, and followed by the pedestrian area (Hurwitz, Monsere, Marnell, & Paulsen, 2014).

Additionally, Distefano and Leonardi (2018) used crash analysis at 35 intersections in Sicily, Italy with varying intersection angles to identify the relationship between crashes and intersection skew. Their results indicated that the left-skewed intersections negatively affect drivers' performance during right-turning maneuvers. This performance degradation is due to the geometry limiting the driver's sight distance to the left. In this configuration, drivers are required to turn their eyes, head, and torso to the left to sight and yield to oncoming vehicles. Drivers with mobility limitations may experience difficulty with this task (Distefano & Leonardi, 2018). The NCHRP Report 600 on Human Factors Guidelines for Road Systems has further revealed that the drivers with mobility limitations, especially older drivers, would have limitations in the flexibility of their neck and trunk, that would impact their ability to lean forward and ultimately affect the sight distance (Campbell et al., 2012).

2.1.3.3 Pedestrian Behaviors

According to A Guide to Reconstructing Intersections and Interchanges for Bicyclists and Pedestrians developed by the California Department of Transportation (CalTrans), the two possible crosswalk placements at skewed intersections are at a right angle to the roadway and as a continuation of the sidewalk (California Department of Transportation, 2010). Figure 2.5 visualizes these two crosswalk configurations.

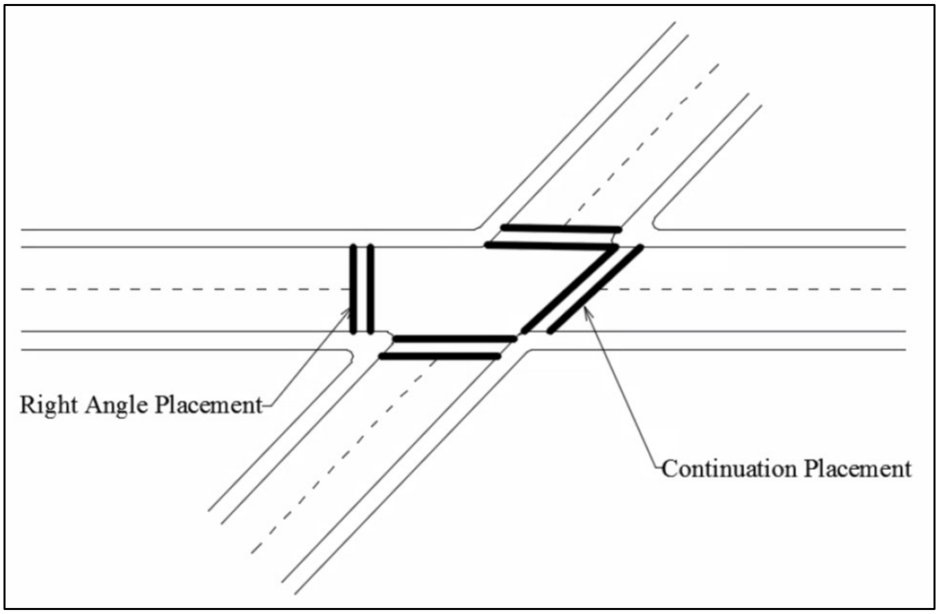


Figure 2.5: Possible crosswalk configurations

As presented in Figure 2.5, the right-angle placement results in a shorter crossing distance that reduces pedestrian exposure and improves sight distance for pedestrians to approaching vehicles that contributes to reducing potential vehicle-pedestrian conflicts. However, drawbacks for this design include longer walking distance to reach the opposite sidewalk, paths between sidewalks not being consistent or continuous, and crosswalks setback at the opposite roadway. The continuation placement avoids some drawbacks of the right-angle placement as the walking distance is smaller, and there is no diversion of the path between sidewalks. However, continuation placement results in a longer crossing distance that increases the exposure and reduces crossing pedestrian sight distance to the conflicting vehicles (California Department of Transportation, 2010).

2.1.3.4 Intersection Safety

The HSM indicates that skewed intersections negatively impact safety as increasing the skew angle (i.e., greater than 90 degree), results in increasing AMF values (i.e., crash frequency increases) (AASHTO, 2010). Techniques to mitigate this affect include striping the vehicle stop line further back from the intersection to improve sight distance, realigning the intersection closer to normal (i.e., 90 degree), installing refuge islands to shorten the crossing distance, and if signalized, adjusting the signal timing such that it accounts for the longer crossing distance (California Department of Transportation, 2010).

2.1.4 Crosswalk Setback

ODOT's ADA settlement agreement which requires the placement of two curb ramps at each street corner, among other design consideration, presents the opportunity to reconsider if crosswalks should be place setback or tight to the curb radius in Oregon. The location of pedestrian crosswalks is an important contributor to pedestrian safety at intersections. From the existing studies, the benefits of setback crosswalk appear to outweigh the negative impacts; however, the research is not conclusive.

2.1.4.1 Driver Yielding and Speed Choice

Jacquemart (2012) proposed that setback crosswalks improve drivers' sight distance for turning maneuvers at normal intersections. Alhajyaseen, Asano, and Nakamura (2013) used video data from eight signalized intersections in Nagoya City and Tokyo, Japan to determine the driver behavior when making left turns, which is similar to right turns in the US, based on pedestrian movements using statistical analysis. Results indicated that right-turning drivers have a high possibility of failing to detect pedestrians on the right side of the vehicle if pedestrians are waiting on the corner crosswalk. This results in drivers having limited distance to make an emergency stop (Alhajyaseen, Asano, & Nakamura, 2013). However, Jacquemart (2012) has suggested that setback crosswalks move pedestrians further back from the corner and allow drivers to detect them more readily at the end of the right turn movement, and provide more emergency stopping distance (Jacquemart, 2012). Figure 2.6 compares the drivers' right turn sight distance between corner and setback crosswalks at intersections.

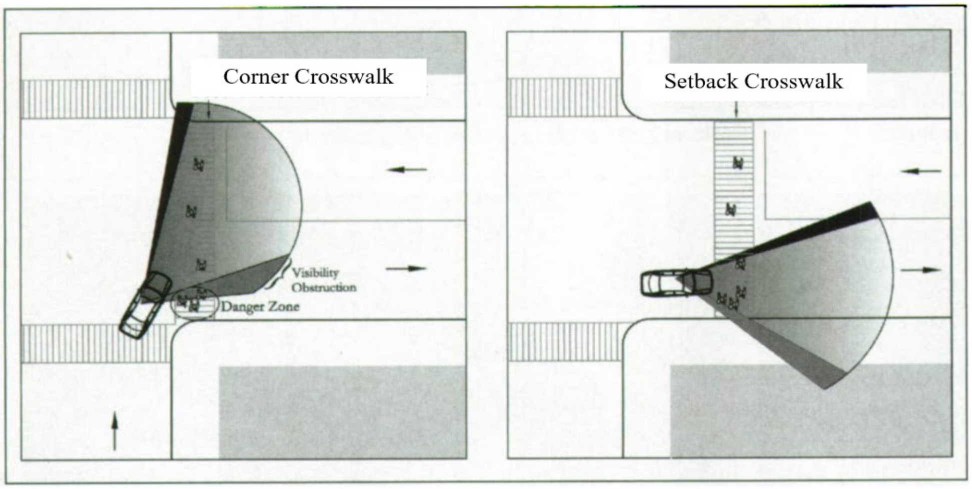


Figure 2.6: Driver right turn sight distance with corner and setback crosswalks (Jacquemart, 2012)

Figliozzi and Tipagornwong (2016) used Portland Bureau of Transportation statistics and video data from an intersection in Portland, Oregon to investigate pedestrian violations using binary logistic regression models. Results indicated that increasing the stopping distance between pedestrians and vehicles improves pedestrian safety (Figliozzi & Tipagornwong, 2016). For left-turning maneuvers, Burbidge (2016) determined that drivers often turn left without successfully yielding and can be required to make an emergency stop for the crossing pedestrians. Jacquemart (2012) proposed that setback crosswalks will improve drivers' sight distance and increase the emergency stopping distance for drivers who failed to yield pedestrians (Jacquemart, 2012). Figure 2.7

compares the drivers' left turn sight distance between corner and setback crosswalks at intersections.

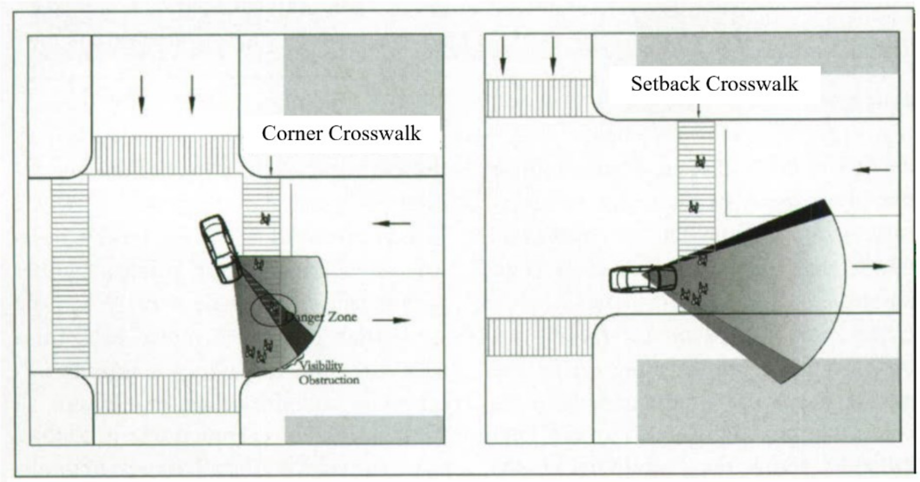


Figure 2.7: Driver left turn sight distance with corner and setback crosswalks (Jacquemart, 2012)

Additionally, setback crosswalks allow more space for pedestrians to wait as spaces for crosswalks at the apex of an intersection curb radii normally concentrate pedestrians for two crosswalks (Jacquemart, 2012). While skewed intersections will likely find similar benefits, the effects of crosswalk setbacks at skewed intersections have not been empirically studied. More research is needed to investigate the relationship between crosswalk setbacks and pedestrian safety at intersections with different skews.

Fu, Hu, Miranda-Moreno, and Saunier (2019) used video data from ten intersections in Montreal, Canada to investigate driver behaviors in vehicle-pedestrian conflicts at the second intersection as they traverse two adjacent intersections using statistical analysis. Their work concluded that drivers tend to accelerate after turning through the first intersection (Fu, Hu, Miranda-Moreno, & Saunier, 2019). This situation was tested by Yoshihira, Watanabe, Nishira and Kishi (2016) using an autonomous driving system, who found that vehicles slow down until sight distance improves and then they accelerate after completing the right turn maneuver (Yoshihira, Watanabe, Nishira, & Kishi, 2016). Fu et al. (2019) concluded that drivers will not have enough time to slow down if the distance to the second intersection is too short. Higher speeds will increase the possibility and severity of vehicle-pedestrian conflicts in such scenarios (Fu et al., 2019). In these configurations, crosswalk setbacks at intersections could be an important factor to alleviate the conflicts.

2.1.4.2 Pedestrian Behaviors and Safety

Previous research has proposed that new sidewalk design criteria including landscaping for setback crosswalks to promote pedestrian sight distance are needed (Institute of Transportation Engineers & U.S. Department of Transportation Federal Highway Administration, 2004; Jacquemart, 2012). Furthermore, Jacquemart (2012) argued these designs would increase both capital (construction) and reoccurring (maintenance) costs. Additionally, Jacquemart (2012) determined that setback crosswalks require an additional 0.5 sec of yellow clearance interval duration for an additional 20 ft of setback distance (Jacquemart, 2012). Guo, Wang, Guo, Jiang, and Bubb (2012) used video data from five intersections in Beijing, China, and a questionnaire for pedestrians to study pedestrian crossing behaviors using reliability analysis. It was determined that pedestrians will attempt to cross the crosswalk before green light if they have waited for more than 50 sec (Guo, Wang, Guo, Jiang, & Bubb, 2012).

Pedestrians with visual impairments normally rely on the Accessible Pedestrian Signals (APS) to safely and efficiently maneuver these crossing. Jacquemart (2012), National Academies of Sciences, Engineering, and Medicine (2014), and Ashmead, Wall, Bentzen, and Barlow (2004) have indicated that audible signals could overlap and will be hard for pedestrians to differentiate if the two signals are placed too close to each other (Ashmead, Wall, Bentzen, & Barlow, 2004; Jacquemart, 2012; National Academies of Sciences, Engineering, and Medicine, 2014).

Ashmead, et al. (2004) conducted a hearing experiment for ten participants with visual impairments to identify the pedestrian reactions to varying APS placements. Results indicated that if the placement of a crosswalk's APS is close to another crosswalk, pedestrians with visual impairments will be confused by the overlapping audible cues from two signals (Ashmead et al., 2004). Therefore, to avoid signal overlap, a setback crosswalk is a good method to separate the signals and their audible cues. However, Jacquemart (2012) claimed that pedestrians with mobility-limitations expect a straight line between crosswalk and sidewalk, therefore, setback crosswalks may cause issues when returning to the sidewalk after crossing the roadway. In addition, the Design Guidance for Channelized Right-Turn Lanes has proposed that crosswalk locations that are not consistent and not aligned with the sidewalk will negatively affect the pedestrians (National Academies of Sciences, Engineering, and Medicine, 2014).

2.2 RESEARCH METHODS

The goal of this research is to identify the relationship between the setback crosswalk and intersection safety. Commonly applied research methods were identified based on the reviewed literature, technical reports, and guidebooks produced by state and federal transportation agencies; Brief discussions of the relevant methods are highlighted in this section.

2.2.1 Crash Analysis

Crash analysis is a common method to identify the relationship between crashes and site characteristics. The advantages of using this method include the availability of standard approaches to data collection and analysis methodologies. For instance, Schneider et al. (2010), Stipancic, Miranda-Moreno, Strauss, and Labbe (2020), and Distefano and Leonardi (2018) performed crash analyses to investigate how intersection characteristics influence intersection safety. According to the HSM, historical crash data, intersection inventory or facility data, and traffic volume data are necessary to conduct these types of analyses. Statistical summaries or frequency analysis have traditionally been used to conduct crash analysis (AASHTO, 2010). For example, Distefano and Leonardi (2018) used this approach to indicate the distribution of crashes regarding crash types and intersection characteristics. The HSM has revealed two main limitations of this approach (AASHTO, 2010):

1. Data collection: Human errors and different judgments from collecting data affected the quality and accuracy of data. Not all crashes will be recorded due to police thresholds of crash reporting; And lower severity crashes are reported less reliably, which contributes to the issue of frequency-severity indeterminacy, which ultimately decreases the effectiveness of the analysis. Also, there are variations in how crashes are classified in different jurisdictions, which leads to data inconsistency.

2. Randomness and change: Crashes are rare events and crash trends change irregularly over time at a given location affecting the accuracy of crash analysis if data was collected in a short period of time. This will negatively impact statistical results producing inaccurate predictions. Alternatively, the fact that site characteristics change over time with the introduction or removal of treatments also affects crash patterns. A shorter period of data collection may be suitable to account for a specific change of site characteristics. As shown, there will be conflicts between the crash trends and changing site characteristics.

To account for the limitations, Schneider et al. (2010) and Stipancic et al. (2020) used regression models for crash analysis. According to the HSM, regression models have commonly been developed to estimate the relationship between crashes and other independent variables. Regression models can address the aforementioned limitations if the estimation result is well-fitting to the original data and calibrated to local data. To connect the results from frequency analysis and statistical analysis, HSM introduces the Empirical Bayes (EB) method, a robust predictive method to apply to a certain site and its calibrated model (AASHTO, 2010). Crash analysis has commonly been conducted to better understand intersection safety. However, this method does not robustly account for human behaviors. As such alternative methods need to be used to understand safety issues from the perspective of an intersection user.

2.2.2 Theoretical Analysis

Theoretical analysis is a method to investigate intersection performance based on the site characteristics. According to Wacker (1998), a theoretical framework needs to be developed to perform the analysis. The first step of developing the framework is to define the research variables and indicate assumptions to align with the research scope. The next step is to develop statistical models that represent the relationship between the variables based on existing research and knowledge. The framework's final step is to test the model by applying certain criteria and produce research estimation or prediction (Wacker, 1998). Specifically, Alhajyaseen and Nakamura (2012) determined the performance of signalized intersections by demonstrating the interactions between intersection geometry and traffic signal control using existing theories and the resulting statistical model was tested through case studies of two intersections (Alhajyaseen & Nakamura, 2012).

According to previous studies, the Non-dominated Sorting Genetic Algorithm-II (NSGA-II) is widely used because of its ability to provide an effective algorithm to find the optimal approximation and a diversity of solutions. NSGA-II is also an effective method to solve multi-objective signal timing problems. In addition, NSGA-II can be used to evaluate the traffic simulation platform (VISSIM), vehicle specific power (VSP), and surrogate safety assessment (SSAM) models of simulation environment platforms to optimize selected variables (Fernandes, Salamati, Coelho, & Rouphail, 2017; Fernandes, Fontes, Pereira, Rouphail, & Coelho, 2015; Yu, Ma, & Yang, 2016). For example, Fernandes, Fontes, Pereira, Rouphail, and Coelho (2015) used NSGA-II to demonstrate that the setback crosswalk is a good solution to balance traffic performance, emissions, and pedestrian safety.

The benefits of using NSGA-II include the generation optimal solutions that can consider congestion distance. NSGA-II can provide researchers with an effective multi-objective optimization method to solve the model and put pedestrians and vehicles in the same framework for cost analysis. Simultaneously, it is a convenient method for researchers to optimize the location and signal to the set of crosswalks (Fernandes et al., 2017; Fernandes et al., 2015; Yu et al., 2016).

Fernandes et al. (2015) suggest the limitations of using NSGA-II include only considering the impacts on crosswalks and that the analysis excluded other crosswalk configurations and pedestrian patterns. Also, there are a lack of specific measurements to reflect pedestrian behaviors, such as delay (Fernandes et al., 2015). In addition, Fernandes, Salamati, Coelho, and Rouphail (2017) stated that the NSGA-II program does not consider different units and degrees of action involved. Fernandes et al. (2017) further indicated that pedestrian delays and pedestrian crossings were excluded in the analysis. Also, the relationship between the optimal crosswalk locations and operating variables, such as primary road traffic and pedestrian flow, has not been adequately addressed (Fernandes et al., 2017).

Overall, the advantages of using theoretical analysis include the use of frameworks that are constructed from existing studies and require less extensive experimental designs. It is an efficient analysis method that integrates different elements of related knowledge. Also, theoretical analysis has high applicability, and it is not complicated to apply (Wacker, 1998). On the other hand, the method’s limitations are the lack of empirical evidence to support the predicted theories (Wacker, 1998). Also, it is hard to predict and analyze human factors with theoretical analysis.

2.2.3 Microscopic Traffic Simulation

Microscopic Traffic Simulation (MTS) is an effective approach to conduct traffic analysis by simulating the individual vehicle movements based on interaction with other vehicles or road users and the site characteristics (Toledo, Koutsopoulos, Ben-Akiva, & Jha, 2001). The MTS framework consists of a traffic flow model, traffic management system representation, and the output and graphical interfaces. The traffic flow model dictates the simulated movements of individual vehicles by modeling traffic demand, routing behavior, and driving behavior. The practicality of the simulated vehicles relies on the models’ correctness and diverseness; the models need to be calibrated and validated to assure the effectiveness of the results. The simulation results are presented through either graphical interfaces or numerical data (Toledo et al., 2005).

According to the Federal Highway Administration, MTS is a robust tool to perform traffic analysis with highly congested traffic situations, complex site characteristics, and newly designed traffic treatments. On the other hand, some limitations of this approach include the demand of resources including money and time as well as calibration difficulties (Types of Traffic Analysis Tools, n.d.). To address these limitations, commercial software, e.g., VISSIM, can be used to conduct simulation directly.

In previous research, Duran and Cheu (2013) used VISSIM to study the effects of the crosswalk locations and the number of pedestrians on the capacity of a two-lane approach to a two-lane roundabout. The MTS method worked well for this research effort as the novel roundabout / crosswalk placements had not been previously constructed (Duran & Cheu, 2013). However, Duran and Cheu (2013) suggested several limitations of VISSIM including limited models and restrictive editing which can affect the accuracy of the results at specific sites (Duran & Cheu, 2013).

2.2.4 Driving Simulators

Driving simulators are gaining popularity as tools for advancing research, training, technology development, and many other purposes. They provide researchers an economical way to evaluate the performance of various driving conditions, such as the location of crosswalks, high accident risk situations, and new design treatments. Moreover, driving simulators can measure many elements of safety relevant driving behaviors at high fidelity and with a significant degree of experimental control derived from the laboratory setting. For example, Dozza et al. (2020) used a driving simulator because of the ability to create a flexible and customizable driving environment. Also, Vignali et al. (2019) used a driving simulator to build multiple scenarios to study driver behavior when approaching crosswalks. Because of the robust ability to study driver behavior based on different conditions, driving simulator applications are a vital tool for transportation researchers.

Driving simulator applications will be used as one of the methods in this research project. This method relies on an Realtime Technologies, Inc. (RTI) Full Cab Driving simulator, and Applied Science Laboratories (ASL) eye-tracker, and a Shimmer3 Galvanic Skin Response sensor that will collectively assess driver behavior (e.g., speed, stop position, yield decision, time to first detection of pedestrian, and stress) when they are turning left and right through conflicting crosswalks at signalized intersections.

Desktop Driving Simulator:

The desktop development simulator, as shown in Figure 2.8, includes both a full-scale driving simulator and a bicycle simulator that can build and test experimental designs and different scenarios. The simulator is a desktop with multiple display platforms with steering wheels and floor pedals that will be used to create, code, and test the designed scenarios. The desktop development simulator can be used to conduct various research and for quick troubleshooting during the development of a study environment. This method provides the researchers with effective feedback to help the experiment run smoothly and test various environments, and reduce the risk of crashes (Hurwitz, n.d.).

Figure 2.8: Desktop development simulator

Full Cab Driving Simulator:

Figure 2.9 shows the full cab driving simulator at OSU. The OSU driving simulator is a high-fidelity simulator that includes a complete 2009 Ford Fusion cab mounted on top of the pitching motion system (rotating ±4°). Three liquid crystals on silicon projectors with a resolution of 1400 * 1050 produces a 180-degree*40-degree front view. Moreover, a fourth projector (a digital light-processing) displays the driver's center mirror's rear image. The rear-view mirrors on both sides embedded liquid crystals displays (LCD). The cab instrument is fully functional, including a steering control loading system, which can accurately represent the steering torque according to the vehicle speed and steering angle. The update rate of projected graphics is 60 Hz, and the ambient and inside sounds are based on the surround sound system (Hurwitz et al., 2018).

Figure 2.9: Full cab driving simulator

2.2.5 Field Study with Video Data

Video data collection is often used to determine the behaviors of road users and their interactions with each other and the build environment. Video data collection has commonly been selected as a research method because of the high applicability to different site conditions. For example, Iasmin et al. (2015) used video data collection to identify driver yielding behavior and interactions with other road users at intersections with different skew angles; Hurwitz, Anadi, McCrea, Quayle, and Marnell (2016) used the same approach to investigate drivers' responses to the yellow change interval; and Alhajyaseen et al. (2015) used video data collection to indicate the speed change behaviors of pedestrians in signalized crosswalks.

Video based field studies commonly consist of data collection, data reduction, and analysis (Alhajyaseen et al., 2015; Alhajyaseen et al., 2013; Burbidge, 2016; Figliozzi & Tipagornwong, 2016; Fu et al., 2019; Gorrini et al., 2018; Guo et al., 2012; Hurwitz, Anadi, McCrea, Quayle, & Marnell, 2016; Iasmin et al., 2015; Meguia et al., 2015; Muley et al., 2017; Schneider et al., 2018; Suzuki & Ito, 2017). Data collection comprises of site measurement determination, site selection, equipment installation, and a site survey of relevant distance measurements. The collected data is then reduced into an analyzable format. It is common to use computer software to overlay the field measurement data to the recorded video data and have researchers execute data transcription through video observation (Hurwitz et al., 2016). The limitations of video data collection are the constraints of collected data, that it is almost impossible to collect most driver demographics and ambient characteristics, which are factors that affect driver behaviors (Hurwitz et al., 2016). In addition, recording video data for longer periods require large data storage, which can cause technical difficulties and limits the collection time. Also, the fixed angles of installed equipment are expensive and limit the overall field of view (Burbidge, 2016).

2.2.6 Pedestrian Conflicts Studies

While crash analysis is the most direct and common method to evaluate traffic safety, crashes are rare and random events and not all crashes are reported (Johnsson, Laureshyn, De Ceunynck, 2018). Therefore, analyzing more frequent conflicts from traffic interactions using surrogate measures has become more popular for safety investigations. While a number of surrogate safety measures have been proposed in the literature, not all are suitable for every setting (Johnsson et al. 2018). An ideal surrogate safety indicator should include both collision risk and injury risk, be valid and reliable (Johnsson et al. 2018).

Surrogate safety measures can largely be divided into four groups: Time-to-Collision (TTC), post-Encroachment Time (PET), Deceleration based surrogates, and Mixed Methods (Figliozzi et al. 2017). TTC is the time it takes two vehicles to reach a common location if they continue along the same trajectories without changing speed (Hayward 1972). Lower TTC values indicate a higher probability of collision. Other TTC based variations include Time Exposed TTC (TET), Time Integrated TTC (TIT), Time-to-Zebra (TTZ) and T2 which is the predicted arrival time of the second user when the first user has not left the conflict area (Laureshyn, Svensson, Hydem, 2010). PET is the time between the first road user leaving and the second arriving at the common spatial zone (Allen, Shin, & Cooper, 1978). PET values less than a predefined threshold are considered conflicts and lower PET indicates a higher probability of collision (Songchitruska & Tarko 2004). Other measures related to PET include Gap Time and Time Advantage. The deceleration group of surrogates estimate deceleration rates that are necessary to avoid a collision. Measures in this group include Deceleration Rate (DR), Deceleration Rate to Avoid a Crash (DRAC), Proportion of Stopping Distance (PSD) and Crash Potential Index (CPI). Mixed surrogate measures include Pedestrian Crash Index (PRI) which combines TTZ with the speed of the approaching vehicle (Cafiso, Gatcia, Cavarra, & Rojas, 2011), evasive action based indicators such as pedestrians' step frequency and step length (Tageldin and Syed 2016), conflict severity which combines change in velocity (DeltaV), TA and the assumed maximum deceleration (Bagdadi 2013), extended DeltaV indicator which combines DeltaV with the T2 indication and a deceleration constant to capture closeness to a collision and potential outcomes (Laureshyn, De Ceunynck, Karlsson, Svensson, & Daniels, 2017).

Várhelyi studied drivers' speed as they approached the crosswalk under varying pedestrian arrivals and compared mean speed profiles for different TTZ values with the mean speed profile when the pedestrians were not present. The results showed 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, to avoid yielding (Várhelyi 1998). Ismail, Sayed, Saunier, and Lim (2009) evaluated pedestrians' exposure and risks of collision at an intersection in Vancouver, British Columbia, Canada using an automated video data analysis system. About 20 hours of video recordings which captured 7000 left-turning vehicles and 2100 pedestrians were analyzed. Key surrogate safety indicators TTC, PET, GT and DST were assessed to characterize the pedestrian-vehicle interactions (Ismail, Sayed, Saunier, & Lim, 2009). Their results showed that while none of the indicators were individually capable of capturing all dangerous interactions, a combination of the four indicators was useful for characterizing conflicts (Sayed et al. 2009). Cafiso, Gatcia, Cavarra, and Rojas (2011) used PRI to investigate changes in driver behavior due to safety improvements at a crosswalk in Spain and found PRI to be a reliable indicator (Cafiso et al. 2011). Chen, Zeng, Yu, and Wang (2017) explored the use of surrogate safety measure approach to analyze pedestrian and vehicle conflicts at intersections (Chen, Zeng, Yu, & Wang, 2017). The study adopted use of unmanned aerial vehicle system to collect video data of vehicle-pedestrian interactions and conflicts at one intersection in Beijing, China. Two safety indicators i.e., PET, and Relative TTC (RTTC) were extracted from the video analysis to characterize the observed conflicts between these road users. RTTC is defined as the difference in arrival times between the first and second road users arriving at the potential conflict location if they keep their current speeds. The results of the analysis showed pedestrian exposure to conflicts both within and outside of the crosswalk and the risky behaviors undertaken by right turning vehicles.

2.3 SUMMARY

This literature review considered previously conducted studies relevant to the relationship between setback crosswalks and intersection safety. The review provided a synthesis of topics including the safety and operational impacts of intersection elements regarding driver and pedestrian behaviors. Then, possible research methods, such as crash analysis, theoretical analysis, microscopic traffic simulation, driving simulator applications, video collection applications, and pedestrian conflicts studies were described. This study will be conducted with a mixed methods approach that will include both the use of a laboratory experiment using a driving simulator and an empirical field study using video data. The driving simulator study will use a within-group, fully counterbalanced, partially randomized factorial experiment to examine drivers’ left and right turn behaviors across the crosswalks on the exiting legs of intersection. The video data collection will be used to perform a conflict-based field study at selected intersections to compare the driver and pedestrian behavior performance between setback and corner crosswalks. The review of the literature has suggested a number of variables that should be considered in the research design and site selection. Some of the key literature review findings include:

Safety and operational impacts of intersection elements:

- Longer crossing distances increase pedestrian exposure at the intersection and lead to more frequent pedestrian speed changes. This scenario increases the probability of vehicle-pedestrian conflicts.

- Longer crossing distances may affect older driver’s yielding performance when required to search for pedestrians across a wider area. Drivers with lower speeds will tend to detect crosswalks further upstream.

- Pedestrians tend to have speed changes in longer crosswalks and walk off the designed crosswalk at an oblique direction. Such behaviors may affect drivers’ yielding performance.

- Curb radius affects vehicle speed during right-turning maneuvers, where smaller radii lead to lower speeds, and larger radii lead to higher speeds. Larger radii lengthen the crossing distance and increase the time for pedestrian clearance, leading to increased pedestrian exposure.

- Higher turning speeds require greater stopping sight distance. Drivers have a higher probability of not slowing down from higher vehicle speeds during right turns across setback crosswalks because curb radii tend to be larger in these configurations.

- Setback crosswalks can improve vehicle-pedestrian interactions as they provide enough turning space for large vehicles, while shifting pedestrians away from the corner and producing more waiting space.

- Corner treatments including mountable zones and curb extensions have been found to minimize large vehicle turning issue, minimize crossing distance, increase pedestrian sight distance, and decrease driver’s turning speed.

- Skewed intersections lead to more vehicle-pedestrian conflicts during turning maneuvers. Left-skewed intersections limit drivers’ sight distance to the left and require eye, neck, and torso movements for right-turning maneuvers. Right-skewed intersections limit drivers' sight distance to the right of the vehicles. Intersection skew is also associated with safety as vehicle crash frequency increases with skew.

- Drivers will first look at and follow the vehicle in front of them before making left turns. When drivers are ready to make a turn, they glance towards the opposing roadway for conflicting vehicles, and lastly search for and react to conflicting pedestrians. The pillars of a vehicle limit driver's sight distance to the right when making right turns.

- Crosswalk placements at a skewed intersection are either right-angle or continuation. Right-angle placements result in shorter crossing distances and better pedestrian sight distances, but longer walking distances and a non-continuous path between sidewalks. Continuation placements result in a shorter walking distance and a continuous path between sidewalks, but a longer crossing distance and worse pedestrian sight distance.

- Setback crosswalks will improve drivers' sight distance for turning maneuvers, move pedestrians back from the corner, allow drivers to detect pedestrians more readily at the end of the right turn movement, and provide more emergency stopping distance. Additionally, setback crosswalks improve driver sight distance and provides sufficient emergency stopping distance for left turn maneuvers.

- Drivers tend to accelerate after turning. If an additional turn at a second intersection is required, and that intersection is closely spaced, deceleration may be more difficult. With this in mind, a setback crosswalk may provide additional stopping distance for the second required turn.

- Setback crosswalks require an additional 0.5 sec of yellow clearance interval duration for an additional 20 ft of setback distance. Pedestrians tend to attempt to cross the crosswalk before the onset of the green indication if they have waited for more than 50 sec (Guo, Wang, Guo, Jiang, & Bubb, 2012), however, the HCM sets this threshold at 30 sec.

- Pedestrians with visual impairments commonly rely on Accessible Pedestrian Signals (APS) to traverse crosswalks. Audible signals could overlap and will be harder for the pedestrians to differentiate if two signals are placed too close to each other. Setback crosswalk can separate adjacent APS signals thereby reducing the audible conflict.

- Setback crosswalks might not be friendly to pedestrians with mobility limitations who expect a straight line between crosswalk and sidewalk. Also, crosswalk locations that are not consistent and not aligned with the sidewalk will negatively affect pedestrians.

Research methods:

- Crash analysis, theoretical analysis, microscopic traffic simulation, and pedestrian conflicts study are commonly used in transportation research to better understand intersection safety. However, these methods are not best suited for this research due to their inherent limitations.

There is a clear gap on the safety effects of the setback crosswalk. Only a few studies directly address the question of setback. This research aims to provide empirical evidence to deeper understand the relationship between the setback crosswalks and intersection safety.

3.0 FIELD DATA COLLECTION AND ANALYSIS

This chapter provides information related to the collection and analysis of data collected in the field at ten crosswalks (five setback, five control) in Oregon. The primary goal of the field data analysis was to examine the frequency pedestrian-vehicle conflicts (measured using PET), including how these conflicts vary between the corner and setback crosswalks.

3.1 VIDEO DATA COLLECTION

The research team initially solicited a list of locations with either corner or setback crosswalks from various agencies (ODOT, Washington County, Clackamas County) and assembled an inventory. Additional site characteristics such as surrounding land use, setback distance, presence of skew, speed limit and ADT were gathered for each site. The research team also tried to obtain pedestrian volumes at each site, but they were unavailable. Therefore, the team assessed likely pedestrian volume (low, medium, high) based on surrounding land use at each site. From this inventory, nine study intersections with ten crosswalks were identified for data collection. These sites were selected based on the following criteria that most closely matched the intersections in the driving simulator experiment: speed limit of roadway between 30 – 35 mph, two-way streets, likely pedestrian volume medium or high, and no skew. These included five locations with setback crosswalks (treatment group) and five locations with corner crosswalks (control group), with one location which had both corner and setback crosswalks.

At each of the nine intersections, the crosswalks of interest were identified for data collection. The research team contracted with a vendor – All Traffic Data – to collect video at the nine sites. Approximately 12 hours of video (7am-7pm) was collected at each of the nine study sites. Two camera angles were requested at each site, so that the queue of left- and right-turning vehicles could be seen clearly, in addition to crossing pedestrians at the crosswalks of interest. Video data were collected between October 14, 2021, and November 16, 2021, and video files were uploaded to Google drive by the vendor. Table 3.1 provides a summary of the video data collection including the site name, type of crosswalk, and date of video collection. The setback distance was measured from the edge of the curb as shown in Figure 3.1 and the measurements for each location are provided in the appendix.

Table 3.1: Summary of Video Data Collection

Site ID	City	Main Street	Cross Street	Type of Crosswalk	Setback Distance (ft)	Data Collection Date (7am-7pm)
1	Portland	SE Powell Blvd.	SE 112th St	Setback	16	11/16/21
2	Portland	SE Powell Blvd.	SE 112th St	Corner	-	11/16/21
3	Salem	Lancaster Dr. NE	Market St. NE	Setback	18	10/14/21
4	Salem	Lancaster Dr. NE	Center St. NE	Corner	-	10/14/21
5	Woodburn	Young St.	OR 99E	Setback	18	10/14/21
6	Woodburn	E Lincoln St.	OR 99E	Corner	-	8/18/20
7	Corvallis	NW Highland Dr.	NW Walnut Blvd.	Setback	10	10/19/21
8	Corvallis	NW 29th St.	NW Walnut Blvd.	Corner	-	10/19/21
9	Monmouth	OR 99W	Main St. E	Setback	21	11/8/21
10	Dundee	OR 99w	SW 5th St.	Corner	-	11/8/21

3.2 PEDESTRIAN VOLUME DATA REDUCTION

After videos were collected at each of the study sites, pedestrian volumes were extracted for the crosswalks of interest at each intersection. While extracting pedestrian volumes, the researchers also noted the time the pedestrian stepped off the curb, if a turning vehicle was present when the pedestrian was crossing and whether the turning vehicle arrived at the crosswalk approximately within five seconds of the pedestrian starting to cross. The presence of the turning vehicle when the pedestrian crossing was specifically noted to extract surrogate safety measures later.

Table 3.2 provides a summary of observed pedestrian volumes at the crosswalk of interest at each site. At ten of these sites, approximately 12 hours of video was reduced to extract pedestrian volumes. At two locations, a shorter amount of video was collected due to adverse weather conditions. These volumes ranged between a low of 13 at OR 99W and SW 5th St. in Dundee and a high of 138 pedestrians observed at Lancaster Dr. NE and Center St. NE in Salem.

Table 3.2: Summary of Pedestrian Volumes at Study Sites

Site ID	City	Main Street	Cross Street	Type of Crosswalk	Hours of Video	Pedestrian Volume
1	Portland	SE Powell Blvd.	SE 112th St.	Setback	12:00	63
2	Portland	SE Powell Blvd.	SE 112th St.	Corner	12:00	60
3	Salem	Lancaster Dr. NE	Market St. NE	Setback	12:00	87
4	Salem	Lancaster Dr. NE	Center St. NE	Corner	11:45	138
5	Woodburn	Young St.	OR 99E	Setback	11:58	36
6	Woodburn	E Lincoln St.	OR 99E	Corner	12:00	26
7	Corvallis	NW Highland Dr.	NW Walnut Blvd.	Setback	12:00	30
8	Corvallis	NW 29th St.	NW Walnut Blvd.	Corner	12:00	20
9	Monmouth	OR 99W	Main St. E	Setback	8:30	44
10	Dundee	OR 99W	SW 5th St.	Corner	9:23	13

3.3 PEDESTRIAN-VEHICLE CONFLICT DATA REDUCTION

After volume data reduction, pedestrian-vehicle conflicts and turning vehicle speeds at the crosswalks of interest for each site were manually reduced from the field-collected videos. At each site, an annotated figure showing the conflict area (determined by the intersection of turning vehicle and pedestrian paths) and other intersection features that were identified in the video frame to measure speed was created. An example of an annotated figure for conflict data collection at Site 5 Young St. and OR 99W is presented in Figure 3.1.

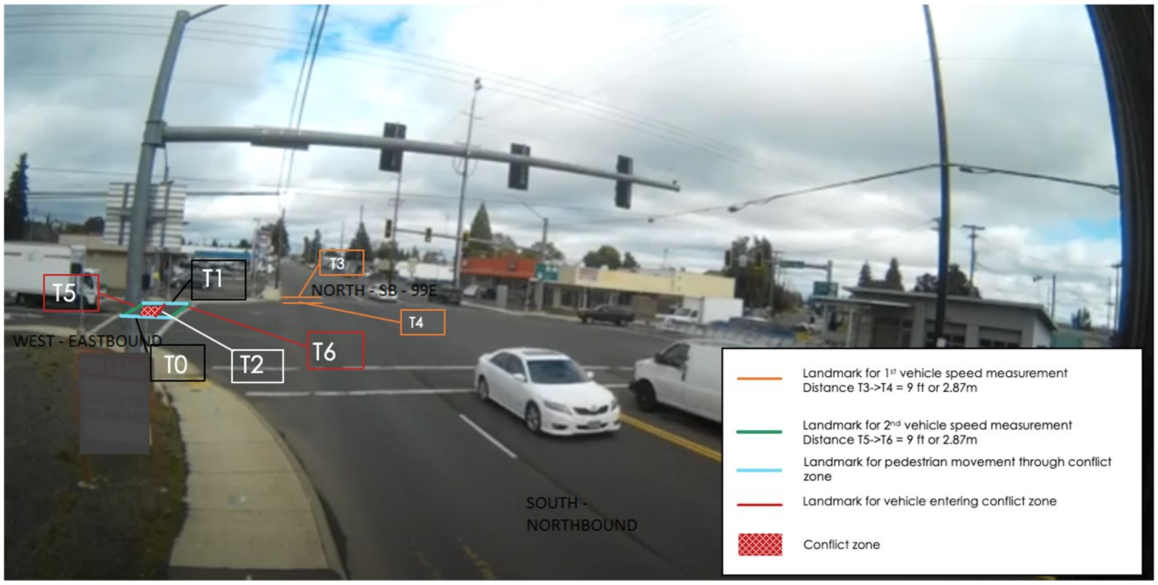


Figure 3.1: Example annotated figure for speed and conflict data reduction

The distance between landmarks used to determine speed were then measured using Google earth before speed and conflict data were reduced. The researchers transcribed a series of time stamps from the video when interactions involving pedestrians and vehicles are observed, and these time stamps are then used to calculate conflict poste-encroachment time (PET) and speed at specified locations. In addition to PET, the researchers noted whether the pedestrian or the vehicle arrived first at the conflict area. Figure 3.1 represents the case where the pedestrian enters the conflict zone (denoted in red) at time T_0 and leaves the conflict zone at time T_1, followed by the turning vehicle which enters the conflict zone at time T_2. The other case i.e., when the turning vehicle arrives and leaves the conflict zone before the pedestrian starts crossing was also considered and included in the data reduction process.

The conflicts were measured using post-encroachment time (PET), and only conflicts with a PET of 5 sec or less were included in this data. Post encroachment time was originally introduced by (Allen et al., 1978), and is defined as "the time between the moment when the first road user leaves the path of the second and the moment when the second reaches the path of the first (i.e., the PET indicates the extent to which they miss each other)" (Johnsson et al., 2018).

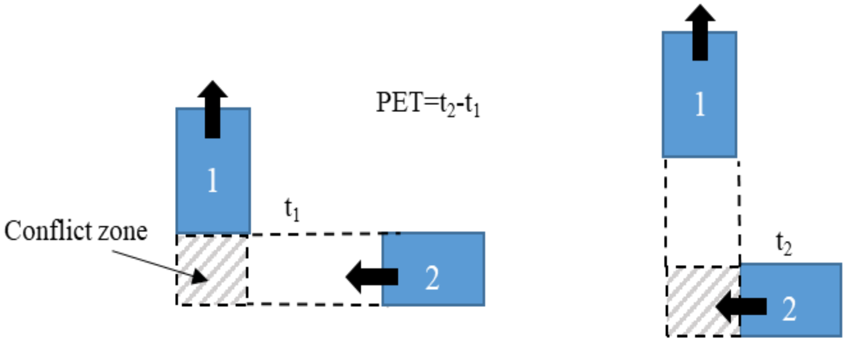


Figure 3.2: PET calculation (Russo, Lemcke, et al., 2020)

PET is calculated as the difference between the vehicle entering the conflict area and the pedestrian leaving the conflict area i.e., $T_2 – T_1$. The speed of the turning vehicle was measured at both crosswalks near the conflict area using measured distances between landmarks and time differences (T_3, T_4, T_5 and T_6). To assist research team members in reducing conflict data uniformly a conflict data collection template spreadsheet and a set of instructions were created. Only conflicts between pedestrians and right-turning vehicles were collected. This was intentionally done because conflicts between pedestrians and left-turning vehicles would only arise if the left-turns were permissive. Since the research team did not have access to signal timing plans at each intersection to make this determination, left-turning conflicts were not considered. Additionally, only conflicts where the time difference between vehicle-pedestrian interaction was 5 seconds or less (i.e., PETs $\leq$ 5 sec) were recorded.

Table 3.3 provides a summary of the observed pedestrian-vehicle conflicts at each study site including total conflicts and conflicts summarized by different PET severity ranges (low, medium and high). Lower PET indicates the potential for more severe conflict. These PET thresholds were drawn from previous research (Zangenehpour et al., 2016). Overall, forty-nine conflicts were observed across eight crosswalks with PET's less than 5 sec. PET for one conflict at SE Powell Blvd. and 112th St. (setback crosswalk) was not included for further analysis, as the camera position made it challenging for the PETs to be estimated accurately. This resulted in forty-eight conflicts across the eight crosswalks. As noted in Table 3.3, there were zero conflicts observed at two sites, Young St. and OR 99E; NW 29th St. and NW Walnut Blvd. The highest number of conflicts and high severity conflicts were observed at Lancaster Dr. NE and Center St. NE (corner crosswalk), followed by SE Powell Blvd. and SE 112th St. (setback crosswalk). These locations also had the highest observed pedestrian volumes of all the sites in the study.

Table 3.3: Summary of Observed Pedestrian-Vehicle Conflicts

Site ID	Main Street	Cross Street	Pedestrian Volume	No. of High Severity Conflicts (PET ≤ 1.5 sec)	No. of Medium Severity Conflicts (PET >1.5-3 sec)	No. of Low Severity Conflicts (PET >3-5 sec)	Total No. of Conflicts (PET ≤ 5 sec)
1	SE Powell Blvd.*	SE 112th St.	63	0	6	3	9
2	SE Powell Blvd.	SE 112th St.	60	4	0	1	5
3	Lancaster Dr. NE	Market St. NE	87	1	4	2	7
4	Lancaster Dr. NE	Center St. NE	138	6	10	7	23
5	Young St.	OR 99E	36	0	0	1	1
6	E Lincoln St.	OR 99E	26	0	0	0	0
7	NW Highland Dr.	NW Walnut Blvd.	30	1	0	0	1
8	NW 29th St.	NW Walnut Blvd.	20	0	0	0	0
9	OR 99W	Main St. E	44	0	1	0	1
10	OR 99W	SW 5th St.	13	0	0	1	1

* Setback crosswalk

Table 3.4 shows the average PETs across the eight crosswalks where pedestrian-vehicle conflicts were observed. The sites are arranged in Table 3.4 based on the ascending order of setback distance at the setback crosswalk sites, followed by the sites with corner crosswalks. The lowest average PET (0.3 sec) was observed at the setback crosswalk at NW Highland Dr. and NW Walnut Blvd, where the setback distance was lowest at 10 ft. At the one crosswalk where setback distance was 16 ft., average PET was 2.86 sec. Average PETs of 2.78 sec and 3.0 sec (avg. 2.89 sec) were observed at crosswalks with setback distance of 18 ft, while an average PET of 2.08 sec was observed at the crosswalk with the setback of 21 ft.

Table 3.4: Average PETs

Main Street	Cross Street	Pedestrian Volume	Setback Distance (ft)	Number of Conflicts (n)	Average PETs (sec)
NW Highland Dr.	NW Walnut Blvd.	30	10	1	0.25
SE Powell Blvd.	SE 112th St.	63	16	9	2.86
Lancaster Dr. NE	Market St. NE	87	18	7	2.78
Young St.	OR 99E	36	18	1	3.0
OR 99W	Main St. E	44	21	1	2.08
SE Powell Blvd.	SE 112th St.	60	-	5	1.46
Lancaster Dr. NE	Center St. NE	138	-	23	2.42
E Lincoln St.	OR 99E	26	-	0	-
NW 29th St.	NW Walnut Blvd.	20	-	0	-
OR 99W	SW 5th St.	13	-	1	3.75

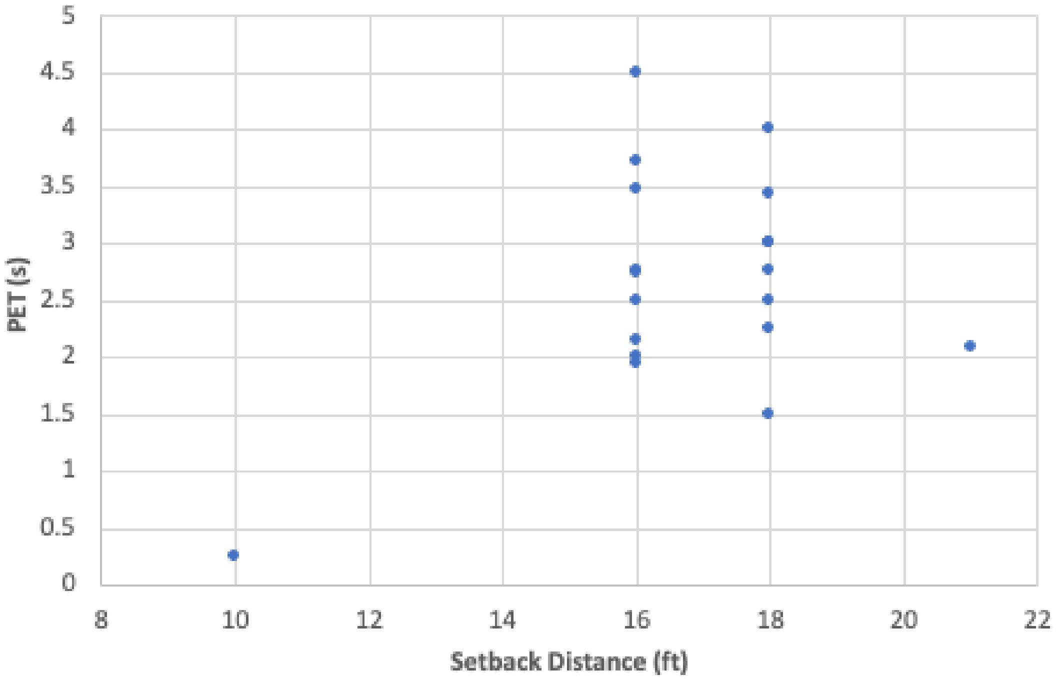


Figure 3.3: Setback distance vs. average PET

Figure 3.3 shows the plot of setback distance and average PET. There was only 1 conflict observed at the locations with 10 and 21 ft setbacks. The plot shows a decreasing trend comparing setbacks of 16 ft. to 18 ft. However, due to the small number of conflict observations, no conclusive findings can be made.

The speed of the turning vehicle was also recorded both at the crosswalk on street it was turning from (Crosswalk 1) and at the crosswalk of interest on the street it was turning to (Crosswalk 2) for each pedestrian-vehicle conflict. The dashes in the table indicate unavailability of speed was at some locations due to the absence of observed pedestrian-vehicle conflicts during the study period. Additionally, of the forty-eight observed conflicts, due to either the vehicle's path and/or the camera angle placement, it was hard to determine speed of the turning vehicle for six conflicts. Speeds of the turning vehicles from those six conflict observations was not included to generate the average speeds at both crosswalks across the various sites shown in Table 3.5. Average turning speeds varied between 5.5 and 11.0 mph across the eight crosswalks where pedestrian-vehicle conflicts with PETs lower than 5 sec were observed. Curb radius was measured at the setback crosswalks and varied between 27 and 51 ft. No discernible trend was observed between curb radius and average turning speed, possibly due to the low number of observations.

Table 3.5: Summary of Average Speeds

Site ID	City	Main Street	Cross Street	Type of Crosswalk	Curb Radius (ft)	Number of Observations (n)	Average Speed at 1st Crosswalk (mph)	Average Speed at 2nd Crosswalk (mph)	Overall Average Speed (mph)
1	Portland	SE Powell Blvd.	SE 112th St.	Setback	31	8	7.2	13.8	11.0
2	Portland	SE Powell Blvd.	SE 112th St.	Corner	-	5	4.2	8.6	6.4
3	Salem	Lancaster Dr. NE	Market St. NE	Setback	43	6	3.3	9.5	6.4
4	Salem	Lancaster Dr. NE	Center St. NE	Corner	-	19	4.5	6.9	5.7
5	Woodburn	Young St.	OR 99E	Setback	50	1	6.9	11.2	9.0
6	Woodburn	E Lincoln St.	OR 99E	Corner	-	-	-	-	-
7	Corvallis	NW Highland Dr.	NW Walnut Blvd.	Setback	27	1	4.4	6.6	5.5
8	Corvallis	NW 29th St.	NW Walnut Blvd.	Corner	-	-	-	-	-
9	Monmouth	OR 99W	Main St. E	Setback	58	1	4.1	11.2	7.6
10	Dundee	OR 99W	SW 5th St.	Corner	-	1	5.1	8.7	6.9

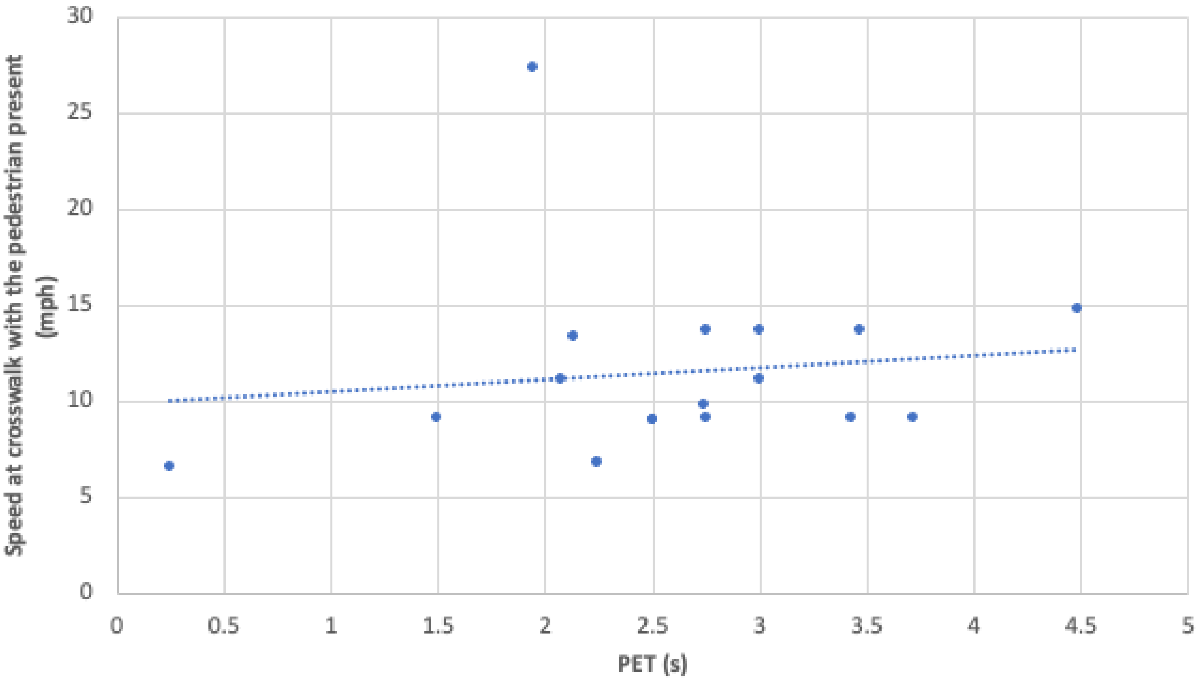


Figure 3.4: PET vs. speed of the turning vehicle at the setback crosswalks with the presence of the pedestrian

Figure 3.4 shows the plot of PETs and the turning vehicle speed at the setback crosswalks when the pedestrian was present. The majority of the turning vehicle speeds are between 5 – 15 mph as expected, with one observation recorded at a higher speed of 27 mph. There appears to be a slight trend of increase in PETs with an increase in turning vehicle speeds. Figure 3.5 shows the plot of turning vehicle speed at corner crosswalks with PETs when the pedestrian was present. Turning vehicle speeds appear to be largely distributed between 4 and 10 mph, with two observations that fall outside this range.

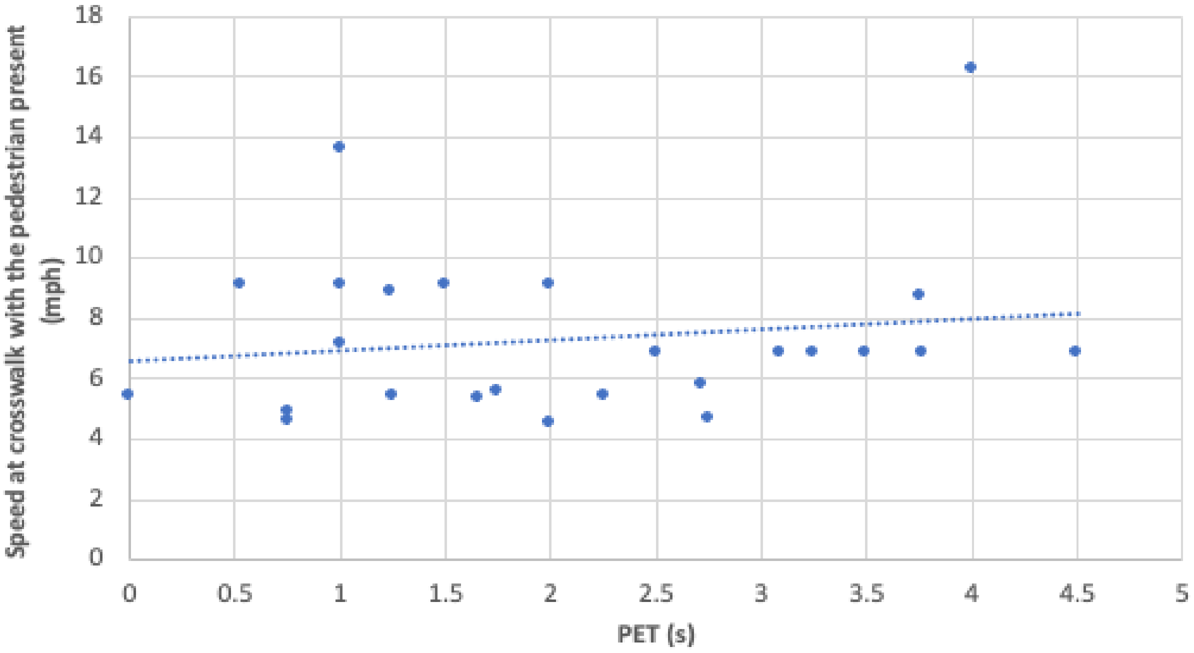


Figure 3.5: PET vs. speed of the turning vehicle at the corner crosswalks with the presence of the pedestrian

In addition to recording speeds during observed pedestrian vehicle conflicts, an additional thirty speed observations were also recorded at the intersection of OR 99 E and Young St. These observations were recorded to allow for comparisons with the speeds collected during the driving simulator study.

3.4 SUMMARY

This chapter presented the findings of the conflict analysis conducted at setback and corner crosswalks. A total of ten (five setback and five corner) crosswalks were selected for field data collection. Video data was collected at these sites and PETs when the pedestrian vehicle interactions were within 5 seconds or less were extracted. Overall, forty-nine conflicts were observed across eight crosswalks, while at two crosswalks there were no observed pedestrian-vehicle interactions within 5 seconds. Average PETs and turning vehicle speeds were extracted for the conflict observations. Due to the small number of conflict observations, no conclusive findings could be made about the impact of setback distance on average PETs and between curb radius and average speed of turning vehicles.

4.0 DRIVING SIMULATOR EXPERIMENT

This chapter provides the detailed experiment conducted in the OSU Passenger Car Driving Simulator Laboratory. Driving simulation was used to analyze driver behaviors at intersections with different intersection characteristics to determine whether setback crosswalks are a safer alternative as compared to corner crosswalks.

4.1 SIMULATOR EQUIPMENT

According to previous research and best-practice, simulator data, eye-tracking data, and Galvanic Skin Response (GSR) data were collected from a driving simulator experiment. This method relies on a Realtime Technologies, Inc. (RTI) full cab driving simulator, and Tobii Pro Glasses 3 eye-tracker, and a Shimmer3 GSR sensor that collectively assessed driver behavior (e.g., speed, stop position, yield decision, time to first detection of pedestrian, and stress) during simulated left and right turn maneuvers through conflicting crosswalks at signalized intersections. This section provides the details of the simulator equipment.

4.1.1 Driving Simulator

The OSU driving simulator is a medium-fidelity, motion-based simulator, consisting of a full 2009 Ford Fusion cab mounted above an electric pitch motion system capable of rotating ±4 degrees. The vehicle cab is mounted on the pitch motion system with the driver's eye point located at the center of the viewing volume. The pitch motion system allows for the accurate representation of acceleration or deceleration. Researchers built and tested the experimental environment by using the desktop development simulator, a multi-monitors platform that contains a steering wheel and floor pedals, as shown in Figure 4.1. The desktop development simulator quickens the troubleshooting during the design process.

Figure 4.1: Desktop development simulator in design (left) and testing (right)

Three liquid crystals on silicon projectors with a resolution of 1,400 by 1,050 are used to project a front view of 180 degrees by 40 degrees. These front screens measure 11 feet by 7.5 feet. A digital light-processing projector is used to display a rear image for the driver's center mirror. The two side mirrors have embedded LCD displays. The update rate for the projected graphics is 60 Hz. Ambient sounds around the vehicle and internal sounds to the vehicle are modeled with a surround sound system. The computer system consists of a quad core host running Realtime Technologies SimCreator Software with an update rate for the graphics of 60 Hz. The simulator software is capable of capturing and outputting highly accurate values for performance measures such as speed, position, brake and acceleration. Figure 4.2 shows views of the simulated environment created for this experiment.

Figure 4.2: OSU Full cab driving simulator simulated environment

An operator workstation, as shown in Figure 4.3, is used to control the full cab driving simulator and track subject drivers, which is out of view from participants in the vehicle. The full cab driving simulator is in a private room aside from the operator workstation and the desktop development simulator to avoid visual or audible disruptions.

Figure 4.3: Full cab driving simulator operator workstation

The virtual environment was developed using Simulator software packages, including Internet Scene Assembler (ISA), Simcreator, AutoCAD, Blender, and Google Sketchup. The simulated test track was developed in ISA using Java Script-based sensors on the test tracks to change the signal indication and display dynamic objects, such as a pedestrian crossing the street towards the turning vehicle based on the subject vehicle's presence.

4.1.1.1 Simulator Data

The simulator data will be collected from the SimObserver data acquisition system. These data files consist of video data and vehicle performance measures including velocity and position. The data file is then processed through computer software, e.g., Data Distillery, and will present the combination of the video data and numerical and graphical outputs. The processed data will be used to analyze driver behavior based on different experimental scenarios (Hurwitz et al., 2018).

The following parameters on both subject vehicle and dynamic objects will be recorded at roughly 60 Hz (60 times a second) throughout the duration of the experiment:

- Time – To map the change in speed and acceleration with the position on the roadway;
- Instantaneous speed of subject vehicle – To identify changes in speed approaching an intersection;
- Instantaneous position of subject vehicle – To estimate the headways and distance upstream from the stop line;
- Instantaneous acceleration/deceleration – To identify any acceleration or deceleration approaching the intersection;
- Instantaneous speed of dynamic vehicle – To record the speed approaching an intersection; and
- Instantaneous position of dynamic object – To locate the distance upstream from the stop line and also to calculate the headway of the subject vehicle.

4.1.2 Eye Tracker

In conjunction with the driving simulator, an eye-tracking system was used to record participant visual attention, specifically where participants would look while driving in the simulator. Tobii Pro Glasses 3 eye tracker was used to collect the eye tracking data through live integration into iMotions, where iMotions is a platform to process biometric data. The Tobii Pro Glasses 3 is an efficient eye tracker that is easy to use and collect precise data. It contains a 50Hz or 100Hz sampling rate with an accuracy of 0.6°. Gaze and eye position are calculated using a sophisticated 3D eye model algorithm based on the pupil center corneal reflection technique. The glasses contain light source to illuminate the eye for reflections, and the reflections will be captured by the mounted camera for further calculations. The Tobii Pro Glasses 3 uses a wide-angle scene camera that provides wider view and the slippage compensation technology with persistent calibration, which allow user unconstrained eye and head movements throughout the recording ("Tobii Pro Glasses 3", n.d.).

Eye movement consists of fixations and saccades. Fixations occur when the gaze is directed towards a particular location and remains still for some period of time. Saccades occur when the eye moves between fixations. The eye tracking system records a fixation when the participant’s eyes pause in a certain position for more than 100 milliseconds. Quick movements to another position (saccades) are calculated indirectly from the dwell time between fixations. Total dwell times are recorded by the equipment as the sum of the time of fixations and saccades consecutively recorded within an area of interest (AOI) (Hurwitz et al., 2018). Figure 4.4 shows the eye-tracking equipment and an OSU researcher demonstration in the driving simulator.

Figure 4.4: Tobii Pro Glasses 3 (left) and OSU researcher demonstration in the driving simulator (right)

4.1.2.1 Eye-Tracking Data

Eye-tracking data describes the eye movements of participants as a combination of fixations and saccades. The participants’ eye fixation and dwell data were extracted within areas of interest and were analyzed with iMotions. The results were exported to other types of files, e.g., Excel and RStudio, for statistical analysis to measure participant visual attention during the experiment.

4.1.3 GSR Sensor

A GSR system was used to collect participants GSR and photoplethysmogram (PPG) signals to measure the level of stress. The Shimmer3 GSR+ measures participant GSR and PPG signals. GSR data is collected by two electrodes attached to two separate fingers on one hand. These electrodes detect stimuli in the form of changes in moisture, which increase skin conductance and changes the electric flow between the two electrodes. Therefore, GSR data is dependent on sweat gland activity, which is correlated to participant level of stress (Bakker, Pechenizkiy, & Sidorova, 2011). PPG signals are collected through photodetectors on skin surfaces (usually a finger or earlobe) which measure volumetric variations in blood circulation, giving an accurate and non-intrusive method to monitor participant heart rates (Castaneda, Aibhlin, Ghamari, Soltanpur, & Nazeran, 2018). Together, GSR and PPG data produce an accurate depiction of participant level of stress.

The Shimmer3 GSR+ GSR and PPG sensors attach to an auxiliary input, which is strapped to the participant's wrist as shown in Figure 4.5.

Figure 4.5: Shimmer3 SGR+ sensor strapped to participant's wrist

4.1.3.1 GSR Data

The collected data was wirelessly sent to a host computer running iMotions EDA/GSR Module software, which feature data analysis tools such as automated peak detection and time synchronization with other experimental data. The results were exported to other file types (e.g., Excel and RStudio) for statistical analysis.

4.1.4 Advantages and Risks

The primary advantages of human-in-the-loop simulation include, but are not limited to:

- Complete control of all independent variables,
- Collection of high-fidelity dependent measures,
- Detailed demographic characteristics of participants,
- Collection of quantitative and qualitative data,
- Ability to evaluate infrastructure types that have not yet been constructed in Oregon,
- Ability to build large samples of data in a cost-effective way,
- Ability to apply a wide variety of experimental designs, and
- Acquisition of increase statistical power due to repeated measures.

The primary disadvantages of human-in-the-loop simulation include:

- Risk of simulator sickness to participants,
- Absolute translation of simulation results to real-world context, and
- Need to correctly map research questions to fidelity of available simulators.

4.2 EXPERIMENTAL DESIGN

An experiment was designed by using the OSU Driving Simulator, eye-tracking and GSR equipment to better understand driver behaviors at intersections with various characteristics during simulated left and right-turn maneuvers through conflicting crosswalks at signalized intersections. The intersection layouts in this experiment were designed based on the various crosswalk setback distances and curb radii by using Blender version 2.79. All other design elements were coded by using ISA version 2.0 to resemble into scenarios that were aimed to feel as authentically as driving in real life.

4.2.1 Roadway Geometry

Intersection approaches in the designed scenarios consisted of one permissive left-turn lane and a straight through right shared lane with posted speed limit of 35mph. The roadway contained two 12 ft lanes in each direction, a 6 ft wide shoulder and an 8 ft wide sidewalk on both sides of the road. Crosswalk placement and curb radii were the experimental variables that were not constant in every scenario, and the measures were obtained based on supplementary documents in addition to the field study sites. Figure 4.6 is an example environment coded in the simulator.

Figure 4.6: Example environment coded in the simulator

4.2.2 Experimental Variables

4.2.2.1 Independent Variables

Four independent variables were proposed for the experiment: turning movement, crosswalk setback, curb radius, and presence of pedestrian. This experiment explored the interaction between the independent variables that affect driver turning behavior. Each independent variable has corresponding levels as shown in Table 4.1. Regarding the turning movement variable, two levels: right turn and left turn were used in experiment to capture driver turning behaviors. Three distances have been selected to represent corner (10 ft) and setback crosswalks (20 ft, 30 ft) based on the descriptive statistics of the provided sites for field study, as shown in Table 4.2.

For the levels of curb radius, Table 4.2 also contains descriptive statistics of the curb radius measured from the provided field study sites. Supplementary documents have also been reviewed and considered. According to the National Association of City Transportation Officials (NACTO), the standard curb radii for urban environment ranges from 10 to 15 ft and radius greater than 15 ft should be avoided (National Association of City Transportation Officials, 2013). Additionally, research sponsored by the Federal Highway Administration (FHWA) provides a range for curb radius from 15 to 70 ft to investigate the driver turning speed at signalized intersections (Fitzpatrick, Pratt & Avelar, 2021). The Oregon Department of Transportation (ODOT) Highway Design Manual (HDM) states that the intersection radii should be kept to a minimum and compound curvature should be used if the size of the design vehicle is larger than a single unit truck (Oregon Department of Transportation, 2012). Since the design vehicle for this experiment is passenger car, compound curve will not be considered. Therefore, a simple circular curve and three measures of curb radius (15 ft, 30 ft, and 45 ft) were selected based on this information.

Additionally, the presence of pedestrian consisted of two levels: no pedestrian crossing and one pedestrian crossing; Where the start position of the pedestrian was at the corner of the intersection and the pedestrian was crossing the crosswalk across the receiving lane.

Table 4.1: Experimental Independent Variables and Levels

Variable	Level	Description
Turning Movement	1	Right turn
	2	Left turn
Crosswalk Setback	1	Corner crosswalk: 10 ft setback from the corner
	2	Setback crosswalk: 20 ft setback from the corner
	3	Setback crosswalk: 30 ft setback from the corner
Curb Radius	1	Curb radius of 15 ft
	2	Curb radius of 30 ft
	3	Curb radius of 45 ft
Pedestrians	1	No pedestrian crossing
	2	One pedestrian crossing

Table 4.2: Crosswalk Placement on Provided Sites and Statistical Calculations

Intersection	Distance from corner to vehicle stop line (ft)		Curb Radius (ft)
	Corner crosswalk	Setback crosswalk	
SE Sunnyside Rd and 122nd Ave		20	47
Molalla Ave and Pearl St	12		25
SW Wilsonville Rd and SW Boones Ferry Rd		30	74
SW Wilsonville Rd and Willamette Way E	10		22
170th and Farmington	10		52
SW Garden Home and SE Oleson		20	37
Murray and Millikan	10		40
SW Allen and Scholls Ferry	10		21
Cornell and 158th	10		50
173rd and Walker		20	25
OR8 and SW Hocken Ave	12		24
OR 8 and SW Murray Blvd		48	32
OR 99E and Lincoln St	10		17
OR 99E and Young St		21	21
OR 99W and Villa		28	25
OR 99W and 5th St	10		45
Pacific Blvd and SW Queen Ave - EB	0		12
Pacific Blvd and SW Queen Ave - WB		20	13
SE 9th Ave and Oak St SE		12	28
Santiam Hwy SE and SE Clay St	0		19
Descriptive Statistics	**Distance (ft)**		**Curb Radius (ft)**
Min	0	12	12
Max	12	48	74
Average	8.54	24.33	31.5
Median	10	20	25
1st Quartile	10	20	21
3rd Quartile	10	28	41.3

4.2.2.2 Dependent Variables

Dependent variables for this experiment were associated with the evaluation of the driver decision making, stop line and turning speed, visual attention, and drivers' level of stress during left- and right-turns based on the effect of the independent variables. The dependent variables included:

- Stopping decision and position: The decision of stop, partially stop, or nonstop during turning movements, and the horizontal and vertical position of the central of the vehicle at the lowest speed (including stop).

- Stop line speed: The vehicle speed when the central of the vehicle passes through the first line of approaching stop line.

- Turning speed: The vehicle speed measured from the first line of approaching stop line to the second line of stop line after turning.

- Eye-tracking fixations: The time spent staring at AOI to define the distribution of visual attention.

- GSR: The GSR in peaks per minute to determine drivers' level of stress during the turning movements with different characteristics.

Position and speed data were recorded using the SimObserver platform for the entire study duration and were then segmented into individual scenarios. The fixation and GSR data were collected with separate equipment and analyzed using iMotion software to evaluate drivers' visual attention and level of stress when maneuvering the experimental scenarios.

4.2.3 Factorial Design

The factorial design for the five independent variables yielded a total of 36 scenarios (2 × 3 × 3 × 2). Since the curb radius variable has no effect on left turn movement, 12 scenarios contain a curb radius other than 15 ft and left turn movement will not be considered. Therefore, the factorial design will conduct 24 scenarios with six intersection grids for the experiment. The order of the intersection grids will be counterbalanced, and the scenarios on each grid will be assigned randomly to control the practice or carryover effects.

4.2.3.1 Presentation of Driving Scenarios

A total of 24 turning scenarios were presented to participants across six grids as shown in Table 4.3. To measure the influence of the experimental factors, participants were exposed to a variety of different configurations.

Table 4.3: Turning (left and right) Scenarios

Track	Turn	#	Crosswalk setback (ft)	Curb radius (ft)	Pedestrian
Grid 1					
8	Right	1	20	15	Pedestrian crossing
4	Right	2	10	30	Pedestrian crossing
22	Left	3	20	15	Pedestrian crossing
24	Left	4	30	15	Pedestrian crossing
Grid 2					
20	Left	1	10	15	Pedestrian crossing
10	Right	2	20	30	Pedestrian crossing
2	Right	3	10	15	Pedestrian crossing
18	Right	4	30	45	Pedestrian crossing
Grid 3					
9	Right	1	20	30	No pedestrian crossing
12	Right	2	20	45	Pedestrian crossing
3	Right	3	10	30	No pedestrian crossing
21	Left	4	20	15	No pedestrian crossing
Grid 4					
5	Right	1	10	45	No pedestrian crossing
15	Right	2	30	30	No pedestrian crossing
1	Right	3	10	15	No pedestrian crossing
17	Right	4	30	45	No pedestrian crossing
Grid 5					
7	Right	1	20	15	No pedestrian crossing
14	Right	2	30	15	Pedestrian crossing
19	Left	3	10	15	No pedestrian crossing
6	Right	4	10	45	Pedestrian crossing
Grid 6					
13	Right	1	30	15	No pedestrian crossing
23	Left	2	30	15	No pedestrian crossing
11	Right	3	20	45	No pedestrian crossing
16	Right	4	30	30	Pedestrian crossing

Figure 4.7 shows the layout of grid 2 as an example grid. The “Path” followed by the participants is indicated by the orange arrows in the figure. The left and right turns are labeled as LT and RT, respectively. In this case, the participant begins at the start line, and follows the left and right turns until the finish line is reached. After finishing the last turning scenario, the participant is prompted to pullover and stop the vehicle at which point the researcher terminates the simulation.

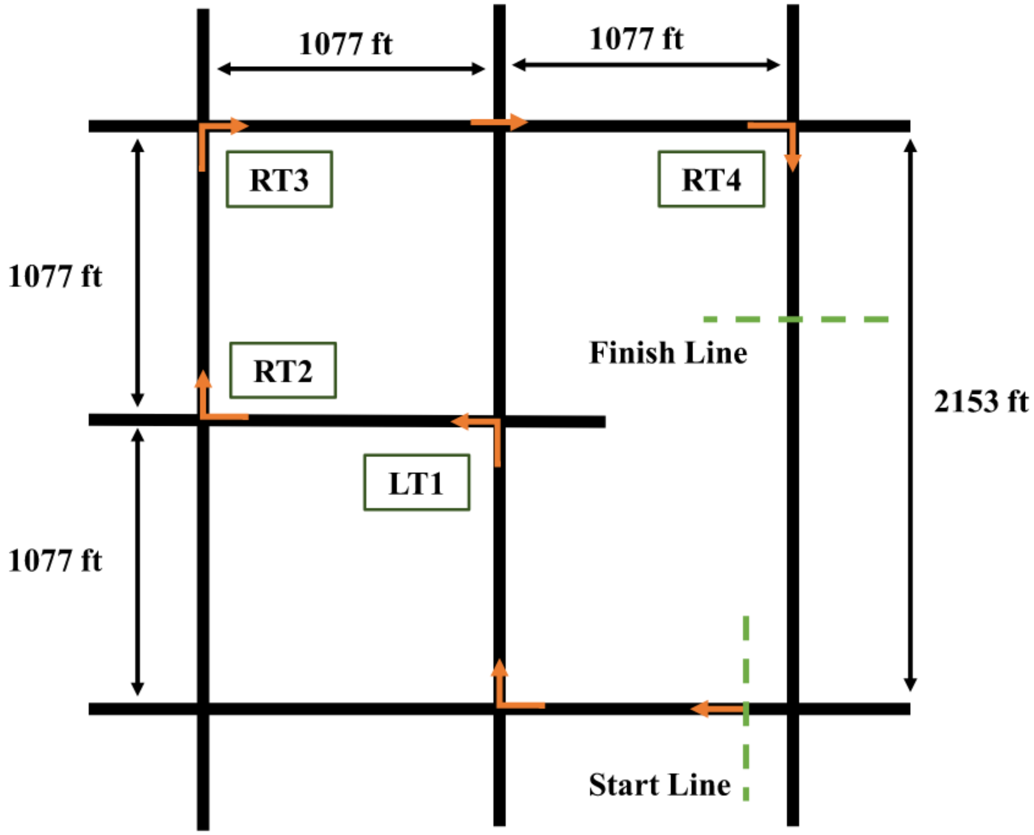


Figure 4.7: Test track example

The participant was given the instruction to turn at an intersection through an automated voice command saying, for example, "*Turn left at the next intersection*". A Java Script based sensor was placed at the turning intersection approach, and the voice command automatically generated when the sensor is trigger by the presence of the participant vehicle.

4.3 DRIVING SIMULATOR EXPERIMENTAL PROTOCOL

The intersections in the scenarios were developed based on the experimental factors, and the experiment consisted of 24 scenarios. A total of seven tracks were developed for this experiment, six of the tracks were used for the data collection portion and the seventh track was used as a calibration drive for the participants. Each track included four scenarios with turning movements. Therefore, participants experienced a total of 24 counterbalanced intersection scenarios during the experiment duration. Track order was partially randomized to limit order effects such as practice or fatigue while driving.

4.3.1 Recruitment

A total of 50 individuals, primarily from the community surrounding Corvallis, OR, were recruited as test participants in the driving simulator experiment. Only licensed drivers with at least one year of driving experience were recruited for the experiment. In addition to driving licensure, participants were required not to have vision prescription higher than five and be physically and mentally capable of legally operating a vehicle. Participants also needed to be deemed competent to provide written, informed consent. Recruitment of participants were accomplished using flyers posted around campus and emailed to different campus organizations and a wide range of email listservs and social media. Older participants were specifically recruited by emails using the Center for Healthy Aging Research (CHAR) registry (LIFE Registry). This registry includes people aged 50 or over who reside in Oregon and wish to volunteer for research studies.

Researchers did not screen interested participants based on gender until the quota for either males or females had been reached, at which point only the gender with the unmet quota was allowed to participate. Although it was expected that many participants would be OSU students, an effort was made to incorporate participants of all ages within the specified range of 18 to 75 years. Throughout the entire study, information related to the participants was kept under double lock security in compliance with accepted OSU Institutional Review Board (IRB) procedures (Study Number IRB-2020-0720). Each participant was randomly assigned a number to remove any uniquely identifiable information from the recorded data.

4.3.2 Informed Consent and Compensation

Consent was obtained from all participants prior to beginning any experimental procedures. The IRB approved consent document was presented and explained to the participant upon arrival to the simulator laboratory. This consent document provides an overview of the study, and the objectives of the study. The document also explains the potential risks and research benefits associated with using the simulator. Participants were given $20 compensation in cash for participating in the experimental trial after signing the informed consent document. If participants experienced simulator sickness or they could no longer continue after signing the consent document, they were allowed to leave without penalty.

4.3.3 COVID-19 Protocols

The operation of COVID-19 protocols was required in the experiment process according to the OSU Driving and Bicycling Simulator Laboratory's approved Research Resumption Plan. The protocols were implemented to ensure the safety of both researchers and participants. The following precautions were followed to minimize the potential spread of COVID-19:

- Maintain six feet of social distance;
- Adherence to cleaning protocols according to the Environmental Health and Safety (EHS);
- Limit the number of people in the lab (two researchers and one participant);
- Ensure researchers were trained in the protocols for on-site resumption;
- Operate two HEPA grade air filtration units during the experiment;

- Researchers wear a KN-95 mask and participants wear at least a surgical level face mask;
- The entirety of the experiment occurred in the OSU Driving and Bicycling simulator lab.

The protocols were carefully followed to provide a comfortable environment in the simulator laboratory during the experiment.

4.3.4 Pre-drive Questionnaire

The pre-drive questionnaire was administered after consent has been obtained and before the participant begins the driving portion of the experiment. This survey targets the demographics of participants (e.g., age, gender, driving experience, highest level of education, type of motor vehicle they typically drive, and prior experience in simulators. Additionally, this survey includes questions from the following areas:

- Vision: Participants need to answer whether or not to use corrective glasses or contact lenses while driving. The eye tracker contains adjustable lenses up to prescription of five. Participants are required to clearly see the simulation environment and read the visual instructions displayed on the screen. This portion is insured during the test drive.
- Simulator sickness: Participants with previous driving simulation experience will be asked about any simulator sickness they experienced. If they have previously experienced simulator sickness, they are encouraged not to participate.
- Motion sickness: Participants will be surveyed about any kind of motion sickness they have experienced in the past. If an individual has a strong tendency towards any kind of motion sickness, they will be encouraged not to participate in the experiment.

The pre-drive questionnaire was aimed to help assess if a participant meets the driving simulator experiment requirements.

4.3.5 Eye Tracking Calibration

The Tobii Pro Glasses 3 eye-tracker was calibrated for each participant after the participant met the inclusion experiment criteria. The participant was asked to wear the glasses and look straight at a target card. The eye tracking recording could be proceeded if the calibration is succeeded as shown in Figure 4.8.

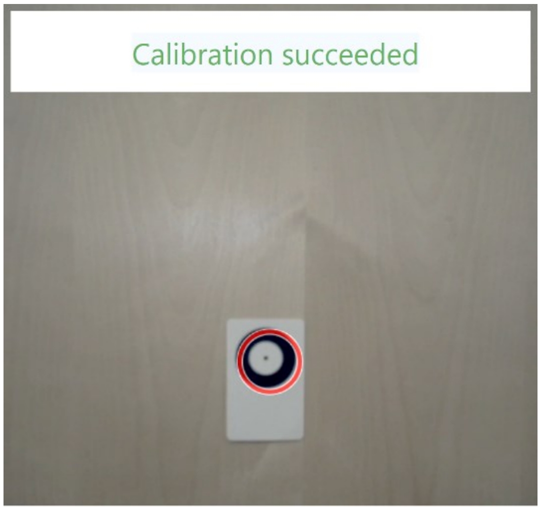


Figure 4.8: Eye-tracking calibration image

The calibration process took less than 10 seconds. Recalibration was needed if the initial calibration failed. If the eye-tracker was unable to complete the calibration after multiple attempts, the experimental trial would be conducted but the eye tracking data would not be used. The participants were allowed to take off the glasses during break without affecting the accuracy. After the eye-tracking equipment has been calibrated, the participant was asked to sit in the vehicle.

4.3.6 Calibration Drive

Once seated in the vehicle, the participant was allowed to adjust the seat, rearview mirror, and steering wheel to maximize comfort and driving performance in the experiment. Each participant then completed a calibration drive. This portion of the experiment took approximately three to five minutes to allow the participant to get familiar with the simulator and confirm if they are prone to simulator sickness. Additionally, the participant was instructed to obey all traffic laws and drive normally as they would in the built environment. The calibration drive was conducted on a generic city environment track with turning maneuvers similar to the experiment, therefore, the participant could become accustomed to both the mechanics of the vehicle and the virtual reality of the driving simulator.

No data was collected during this portion of the experiment, as it was intended to give the participant a chance to become familiar with the equipment and assess whether or not the participant is prone to simulator sickness. In the event that a participant felt simulator sickness or discomfort during the calibration drive, the experimental trials for that participant would no longer continue.

4.3.7 GSR Sensor Equipment

Participants who completed the calibration drive with no simulator sickness were equipped with the GSR sensor, Shimmer3 GSR+. The sensor was placed on the participant’s left-hand index and middle fingers without affecting participant normal driving behavior as seen in Figure 4.5.

The sensors were attached to an auxiliary input that is strapped to the participant's wrist, as shown in previous section.

4.3.8 Experimental Drive

After the calibrated the eye-tracking equipment and calibrated drive was completed, participant was briefed on the tasks that they needed to perform in the test environment. These included aspects including route to follow, obeying traffic laws, and driving as they typically would. The experiment was divided into six grids and the virtual driving course itself was designed to take approximately 20 to 30 minutes for participants to complete and all data mentioned in Section 4.1 were collected during this portion of the experiment.

4.3.9 Post-drive Questionnaire

After completing the experimental drive, the participant was asked to respond to questions regarding their comprehension and perceptions while driving in the simulator. These questions used a Likert scale response method and included aspects such as: participants understanding of the crosswalk placement alternative, perceived level of comfort, and perceived level of safety upon approach. This was the last portion of the study; participants would then be debriefed, and the purpose of the study was stated.

The entire experiment, including the consent process, pre-drive questionnaire, eye-tracker calibration, drive calibration, GSR sensor equipment, experimental drive, and post-drive questionnaire, lasted approximately 50 minutes.

4.4 ANALYSIS TECHNIQUES AND DATA REDUCTION

4.4.1 Statistical Analysis

A two-stage analysis approach was undertaken. The entire data sets were visualized using plots, for example box plots, and the central tendency and spread of the dependent measures across different scenarios were tested statistically. A Linear Mixed Model (LMM) was used to analyze the data because of its ability to (i) cope with errors produced from repeated subject variables as participants were exposed to all scenarios, (ii) manage random or fixed effects, (iii) accommodate categorical and continuous variables, and (iv) lower Type 1 error probability. One potential limitation of using the LMM is more distributional assumptions are needed (Jashami et al., 2020). LMM analysis requires a minimum sample size of 20 (Barlow et al., 2019) and as all the data sets in this study are greater than 30, the requirement to use these datasets for analysis was met. The following formula was used for the analysis:

$$\boldsymbol{y_{ij} = \beta_0 + \beta_1 X_{ij} + b_{i0} + b_{i1} X_{ij} + \varepsilon_{ij}} \tag{4-1}$$

$$\boldsymbol{b_{i0}\ iidN\left(0, \sigma_0^2\right)} \tag{4-2}$$

$$\boldsymbol{b_{i1}\ iidN\left(0, \sigma_1^2\right)}$$

(4-3)

$$\boldsymbol{\varepsilon_{ij}\ iidN(0, \sigma_\varepsilon^2)}$$

(4-4)

Where β_0 is the intercept at the population level and β_1 is the slope (both are for the fixed effect). b_{i0} is the random intercept of the i^{th} participant and b_{i1} is the random slope for the same participant which follow a mean normal distribution with variances of σ_{b0}^2 and σ_{b1}^2, respectively. ε_{ij} is the error term. Therefore, the assumption of (b_{i0}, b_{i1}) and ε_{ij} being independent is made.

R software was used to develop the model considering the independent variables of setback distances, curb radius, and presence of pedestrian. These variables were included in the model as fixed effects, and also included the participant demographic characteristics such as age, gender, level of education, race, income, vehicle type, and miles driven. The model also included random effects for the participant variable (Jashami et al., 2020).

LMM could be used to estimate how the experimental variables affect drivers' stop line speed, turning speed, TFD, and level of stress, which is appropriate given the repeated measures nature of the experimental design, where each participant experiences every scenario. Both fixed and random effects are necessary to include in the model. Pearson's correlation coefficient was used to determine any correlated variables. Regarding the statistically effects, custom post hoc contrasts was performed for multiple comparisons using Fisher's Least Significant Difference (LSD). All statistical analyses were conducted at a 95% confident level and the Restricted Maximum Likelihood estimates was used to develop this model (Jashami et al., 2020).

Visualization and statistical testing at the stop line and turning speed allowed researchers to better investigate the drivers speed and decision making while approaching the different intersections. The speed measured in the driving simulator was compared with the collected field data; the eye-tracking data allowed researchers to better understand where participants most frequently focused their visual attention while approaching the intersection treatments; the GSR data helped researchers to better study the level of stress of the participants which approaching the intersection and maneuvering turning movements with different scenarios. All data sets were analyzed using the LMM analysis to determine the impacts of the experimental factors.

4.4.2 Simulator Data Reduction

The simulator data was used to determine drivers' speed and position and was obtained from the SimObserver platform. The data was analyzed using Excel and RStudio. The output of the simulator data consisted of a coordinate system and time-stamps relative to each grid, which allowed the data to be reduced into scenarios of interest within certain coordinates. The instantaneous speed and position across a time-period of interest was extracted.

4.4.3 Eye-Tracking Data Reduction

To perform the LMM test, the eye-tracking data would need to be reduced to find dwell times for each area of interest (AOI). Dwell time can be defined as the amount of time a participant spends viewing a certain area, made up of fixations and saccades (Bergstrom and Schall, 2014). An AOI is a designated region which describes zones that are of importance to the researchers. The data collected by the eye tracker was wirelessly sent to a host computer that contained the *iMotions* software, and this software allows for AOIs creation for each intersection and provides the total time participants spend viewing these areas when approaching the intersection.

The interest period of each scenario started approximately 100 ft before the intersection and lasted until the driver finished turning, resulting in around 5-55 seconds of clip length per scenarios depending on the participants driving speed and their waiting behavior. Researchers manually coded polygons over the AOIs, and the polygons were adjusted incrementally to fit the AOIs frame by frame. Three AOIs defined in this study were vehicular signal, crosswalk, and pedestrian. Figure 4.9 is the screenshot of the AOIs during the reduction process. For scenarios without pedestrian crossing, only two AOIs were captured. Once dwell times were established for each scenario, the LMM test was run on the data.

Figure 4.9: AOIs example with (left) and without pedestrian (right)

4.4.4 GSR Data Reduction

The data collected by the GSR equipment (GSR data and PPG signal) was wirelessly sent to the host computer running iMotions EDA/GSR Module software, which feature data analysis tools such as automated peak detection and time synchronization with other experimental data. The data would need to be reduced to GSR peaks per minute to control the natural variation between participants' peak measures. Also, GSR peaks per minute have found to be used to study human factors in transportation research (Krogmeier, Mousas, & Whittinghill, 2019). Additionally, GSR peaks per minutes have been often used to indicate the level of stress in research involved human factors (Zou & Ergan, 2019).

4.5 ANALYSIS RESULTS

As mentioned in previous section, 12 scenarios contain a curb radius other than 15 ft and left turn movements will not be considered since the curb radius variable has no effect on the left turn movement. Therefore, the right and left turn movement data will be analyzed separately. The study contains multiple variables and levels to investigate how drivers react to those changes, where the setback distance of 10 ft is considered as a corner crosswalk.

4.5.1 Participants

Table 4.4 records the overall participants and final sample sizes of the desired data sets for this experiment. A total number of 50 participants were recruited from Corvallis and the surrounding area, including 30 males and 20 females, where none of the participants identified as non-binary or prefered not to answer. The participant ages ranged from 18 to 74 years old, with an average age (AA) of 35.6 years and a standard deviation (SD) of 15.6 years. 9 (18%) participants were not able to complete the experiment due to simulation sickness, which brought down the total sample size to 41 (AA = 35.5, SD age = 15.9) participants, including 26 males (AA = 33.9, SD age = 15.8) and 15 females (AA = 38.2, SD age = 16.1).

The final analyzed samples for three data sets were different because of data lost during the experiment. The final analyzed sample for SimObserver is 39 (AA = 35.5, SD age = 16.0) participants, including 26 males (AA = 33.9, SD age = 15.79) and 13 females (AA = 38.8, SD age = 16.6); eye-tracker is 37 (AA = 35.8, SD age = 16.5) participants, including 24 males (AA = 34.3, SD age = 16.2) and 13 females (AA = 38.5, SD age = 17.3); and GSR is 30 (AA = 35.4, SD age = 16.7) participants, including 22 males (AA = 34.6, SD age = 17.0) and 8 females (AA = 37.6, SD age = 16.8).

Table 4.4: Participants and Sample Size

	Total	**Male**	**Female**
Total Enrolled	50 (100%)	30 (60%)	20 (40%)
Simulation Sickness	9 (18%)	4 (44%)	5 (56%)
Total Sample	41 (82%)	26 (63%)	15 (37%)
Age Range	18-74		
	SimObserver	**Eye- Tracker**	**GSR**
Data Lost	2	4	11
Final Analyzed Sample	39	37	30

4.5.2 Questionnaire Results

The study contained a pre- and post-drive questionnaire and below section provides the results from both questionnaires.

4.5.2.1 Pre-drive Questionnaire Results

The pre-drive questionnaire targeted participant demographic and driving experience information. Table 4.5 presents the detailed results of the survey for the total sample size of 41. All participants were licensed drivers in United States and their experience and driving frequencies were well distributed.

Table 4.5: Participants Demographic Information

Category	Demographic Variable	Count	Percentage
Gender	Male	26	63.4
	Female	15	36.6
	Non-Binary	0	0.0
	Prefer Not to Answer	0	0.0
Age	18-24	14	34.2
	25-34	11	26.8
	35-44	6	14.6
	45-54	4	9.8
	55-64	2	4.9
	65+	3	7.3
Race	American Indian or Alaska Native	0	0.0
	Asian	9	22.0
	Black or African American	0	0.0
	Hispanic or Latino/a	1	2.4
	White or Caucasian	27	65.9
	Other	3	7.3
	Prefer Not to Answer	1	2.4
Income	Less than $25,000	10	24.4
	$25,000 to less than $50,000	6	14.6
	$50,000 to less than $75,000	6	14.6
	$75,000 to less than $100,000	4	9.8
	$100,000 to less than $200,000	8	19.5
	$200,000 or more	2	4.9
	Prefer Not to Answer	5	12.2
Education	Some High School or Less	0	0.0
	High School Diploma or GED	3	7.3
	Some College	9	22.0
	Trade/Vocational School	0	0.0
	Two-Year Degree	1	2.4
	Four-Year Degree	8	19.5

	Master's Degree	18	43.9
	Doctorate Degree	2	4.9
	Prefer Not to Answer	0	0.0
Driving Experience	0-5	8	19.5
	5-10	11	26.8
	10-15	5	12.2
	15-20	1	2.4
	20+	13	31.7
	No Answer	3	7.3
How many miles did you drive last year?	0-5,000 miles	13	31.7
	5000-10,000 miles	16	39.0
	10,000-20,000 miles	7	17.1
	15,000-20,000 miles	4	9.8
	20,000 miles or more	1	2.4
What type of motor vehicle do you typically drive?	Passenger Car	25	61.0
	SUV	12	29.3
	Pickup Truck	4	9.76
	Van	0	0.0
	Heavy Vehicle	0	0.0
How often do you drive in a week?	1 time per week	3	7.3
	2-4 times per week	17	41.5
	5-10 times per week	17	41.5
	more than 10 times per week	4	9.8

4.5.2.2 Post-Drive Questionnaire Results

All participants were asked to respond to a post-drive questionnaire after they completed the experimental drive. These questions included participants understanding of the crosswalk placement alternatives, perceived comfort levels and perceived safety levels while approaching the intersections. Table 4.6 documents the participants questionnaire responses.

Table 4.6: Post-drive Questionnaire Results

Question	Options	Count	Percentage
Before the driving simulator experiment, have you seen intersections with a setback crosswalk?	Yes	15	36.6
	No	10	24.4
	Not Sure	16	39.0
If yes, how many intersections with a setback crosswalk have you seen?	*1*	*0*	*0.0*
	2-4	*7*	*46.7*
	5-10	*4*	*26.7*
	More than 10	*4*	*26.7*
During the driving simulator experiment, how comfortable did you feel while approaching an intersection with a setback crosswalk?	Very Comfortable	7	17.1
	Comfortable	13	31.7
	Neutral	16	39.0
	Uncomfortable	4	9.8
	Very Comfortable	0	0.0
	Unable To Say	1	2.4
During the experiment, were you expecting to see pedestrians waiting to cross the intersection in the setback crosswalk?	Yes	28	68.3
	No	8	19.5
	Unable To Say	5	12.2
During the experiment, how comfortable did you feel while making left and right turns across the setback crosswalks on the exiting legs of the intersection with pedestrians crossing?	Very Comfortable	5	12.2
	Comfortable	18	43.9
	Neutral	8	19.5
	Uncomfortable	8	19.5
	Very Comfortable	1	2.4
	Unable To Say	1	2.4
The setback crosswalks made it easier to detect pedestrians crossing.	Strongly Agree	1	2.4
	Agree	9	22.0
	Neutral	15	36.6
	Disagree	11	26.8
	Strongly Disagree	3	7.3
	Unable To Say	2	4.9
Which treatment would allow you to detect pedestrian faster when making left and right turns across the crosswalks on the exiting legs of the intersection?	Corner Crosswalk	25	61.0
	Setback Crosswalk	12	29.3
	Neutral	3	7.3
	No Answer	1	2.4

A total of 63.4% of the participants have not seen or were not aware of intersections with setback crosswalk before the driving simulator experiment. Most of the participants felt comfortable or neutral while approaching the intersections with a setback crosswalk. During the experiment, a majority of the participants expected to see pedestrians waiting to cross the intersection in the setback crosswalk as the setback crosswalk was not anticipated to affect drivers' sight distance. More specifically, a majority of participants felt either neutral or comfortable performing left and right turn maneuvers with a pedestrian crossing in a setback. Many participants were neutral to the idea that setback crosswalks made it easier to detect pedestrian crossing, which corresponded with the next question where a majority of the participants thought that corner crosswalk would allow them to detect a pedestrian faster. Figure 4.10 shows the participants preference of crosswalk placement, where a majority of the participants preferred a corner crosswalk at the intersections.

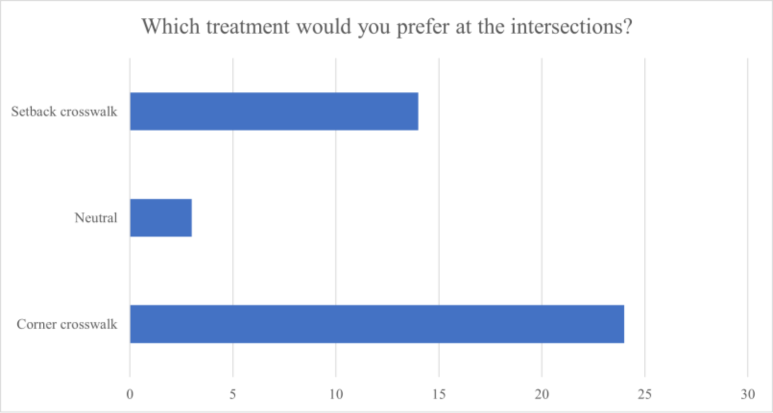


Figure 4.10: Participants preference of crosswalk placement

4.5.3 Stopping Decision and Position

The stopping decision and stopping position of participants while making right and left turns with scenarios that had a pedestrian crossing were obtained from the SimObserver speed and position data. Data were organized and assessed in three categories: Did Not Stop, Partially Stopped, and Stopped. For the Stop category, the stopping positions were grouped into before and after the stop line to determine participants stopping behavior. The three categories were identified considering the average participant approach and turning speed. Vehicle speeds that less than 1.5mph were classified as Stopped; between 1.5mph and 8mph were classified as Partially Stopped; and greater than 8mph were classified as Did Not Stop. Figures 4.11 to 4.14 record the lowest speed locations for did not stop (color coded as red) and partially stopped (color coded as yellow) participants and stopping positions for stopped participants. Additionally, the tables also record the total locations, including did not stop and partially stopped, and stopped participants before (color coded as green) and after (color coded as black) the stop line.

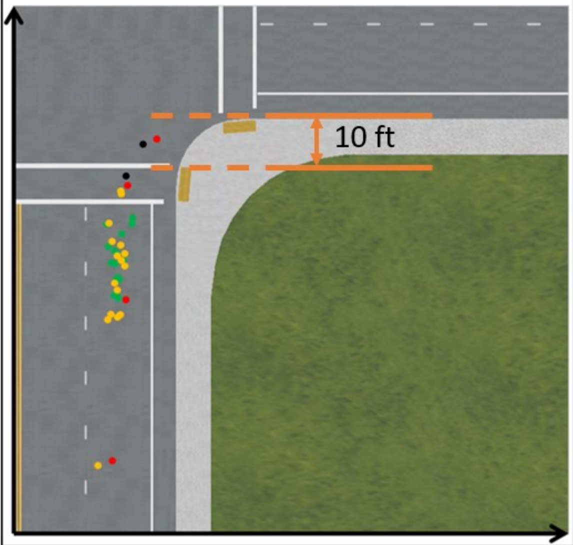
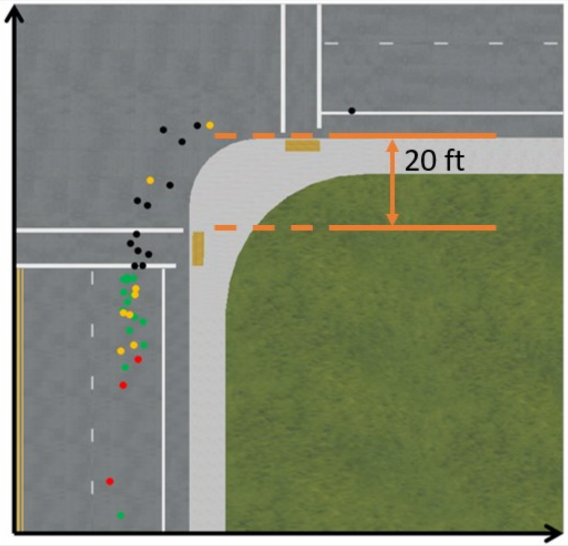
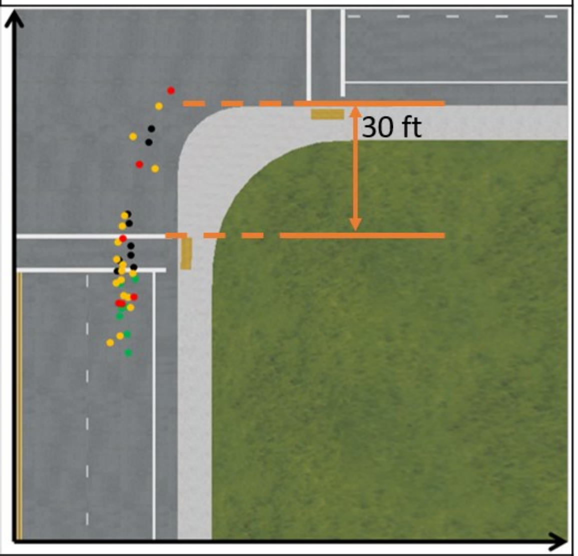
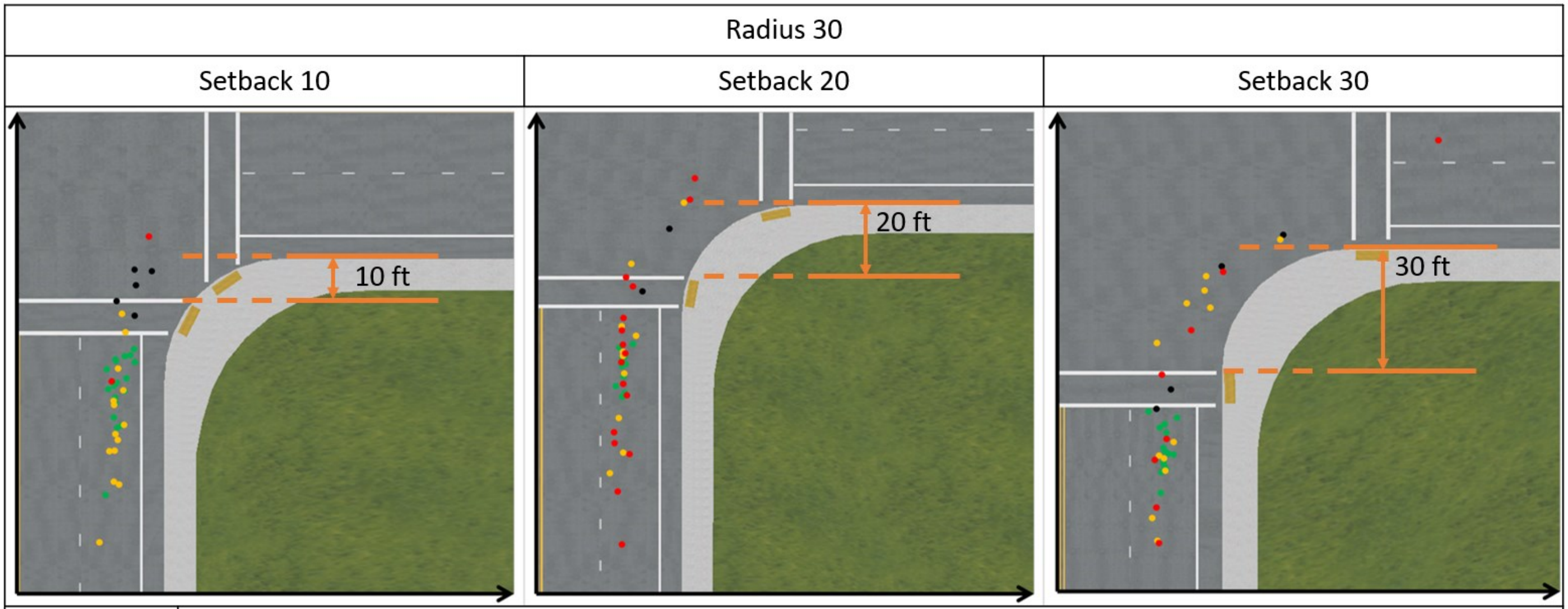
Radius 15								
Setback 10			Setback 20			Setback 30		
								
Total	39							
Non-Stop	6	15.38%	Non-Stop	3	7.69%	Non-Stop	6	15.38%
Partially Stop	15	38.46%	Partially Stop	8	20.51%	Partially Stop	17	43.59%
Overall Stop	18	46.15%	Overall Stop	28	71.79%	Overall Stop	16	41.03%
Before Stop Bar	16	41.03%	Before Stop Bar	15	38.46%	Before Stop Bar	7	17.95%
After Stop Bar	2	5.13%	After Stop Bar	13	33.33%	After Stop Bar	9	23.08%

Figure 4.11: Participant right turn stopping and lowest speed position at radius 15 ft



Total	39							
Non-Stop	2	5.13%	Non-Stop	16	41.03%	Non-Stop	8	20.51%
Partially Stop	13	33.33%	Partially Stop	11	28.21%	Partially Stop	12	30.77%
Overall Stop	24	61.54%	Overall Stop	12	30.77%	Overall Stop	19	48.72%
Before Stop Bar	19	48.72%	Before Stop Bar	10	25.64%	Before Stop Bar	15	38.46%
After Stop Bar	5	12.82%	After Stop Bar	2	5.13%	After Stop Bar	4	10.26%

Figure 4.12: Participant right turn stopping and lowest speed position at radius 30 ft

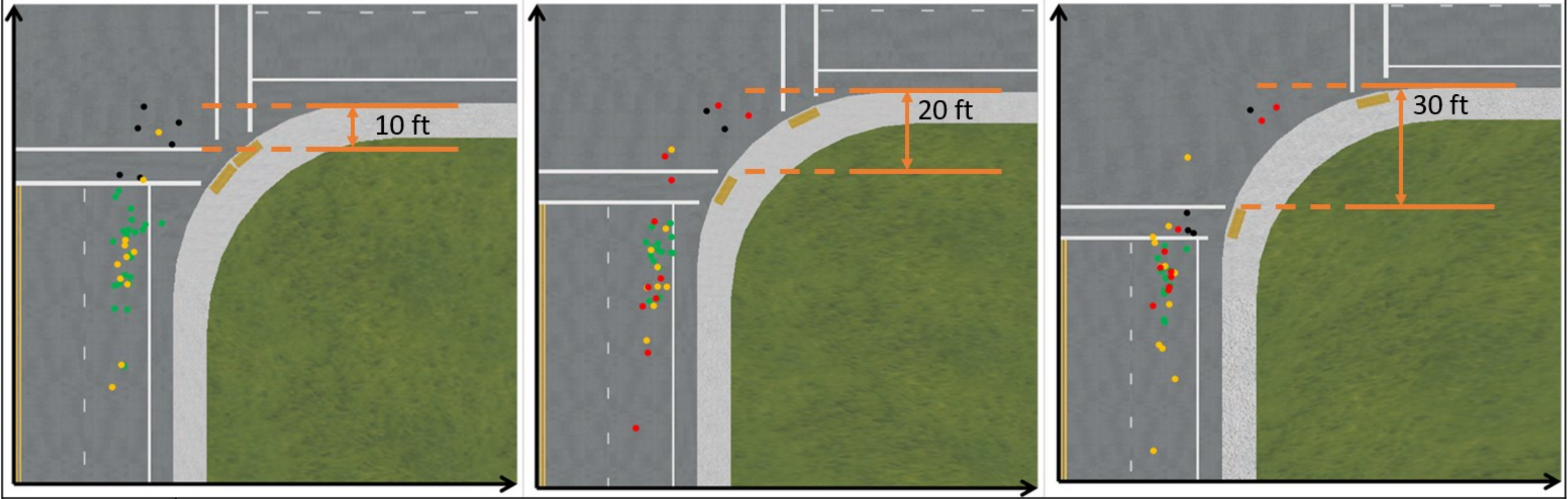
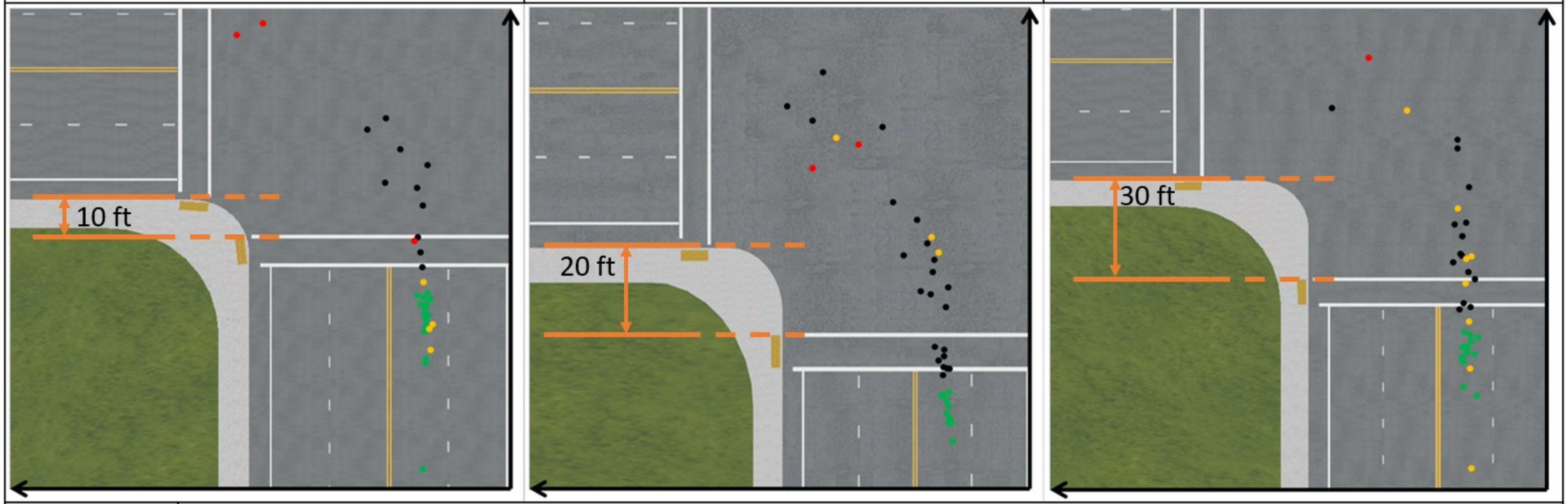
<table>
<tr><td colspan="9">Radius 45</td></tr>
<tr><td colspan="3">Setback 10</td><td colspan="3">Setback 20</td><td colspan="3">Setback 30</td></tr>
<tr><td colspan="9">
</td></tr>
<tr><td>Total</td><td colspan="8">39</td></tr>
<tr><td>Non-Stop</td><td>0</td><td>0</td><td>Non-Stop</td><td>11</td><td>28.21%</td><td>Non-Stop</td><td>10</td><td>25.64%</td></tr>
<tr><td>Partially Stop</td><td>11</td><td>28.21%</td><td>Partially Stop</td><td>9</td><td>23.08%</td><td>Partially Stop</td><td>13</td><td>33.33%</td></tr>
<tr><td>Overall Stop</td><td>28</td><td>71.79%</td><td>Overall Stop</td><td>19</td><td>48.72%</td><td>Overall Stop</td><td>16</td><td>41.03%</td></tr>
<tr><td>Before Stop Bar</td><td>22</td><td>56.41%</td><td>Before Stop Bar</td><td>17</td><td>43.59%</td><td>Before Stop Bar</td><td>12</td><td>30.77%</td></tr>
<tr><td>After Stop Bar</td><td>6</td><td>15.38%</td><td>After Stop Bar</td><td>2</td><td>5.13%</td><td>After Stop Bar</td><td>4</td><td>10.26%</td></tr>
</table>

Figure 4.13: Participant right turn stopping and lowest speed position at radius 45 ft

Radius 15, Left Turn



Setback 10			Setback 20			Setback 30		
Total	39							
Non-Stop	0	0	Non-Stop	2	5.13%	Non-Stop	1	2.56%
Partially Stop	4	10.26%	Partially Stop	3	7.69%	Partially Stop	8	20.51%
Overall Stop	32	82.05%	Overall Stop	34	87.18%	Overall Stop	30	76.92%
Before Stop Bar	22	56.41%	Before Stop Bar	12	30.77%	Before Stop Bar	15	38.46%
After Stop Bar	10	25.64%	After Stop Bar	22	56.41%	After Stop Bar	15	38.46%

Figure 4.14: Left turn stopping and lowest speed position at a 15 ft radius

4.5.4 Speed at the Approach Stop Line and During Turning Maneuvers

The speed data were also obtained from SimObserver. Only scenarios without pedestrians were used for turning speed because the stopping and waiting behaviors affect the measurements.

4.5.4.1 Right Turn Movement

Table 4.7 records the descriptive statistics for 39 participants for the right turn stop line speed with and without pedestrian, grouped by three radii with three setback distances. Figures 4.15 and Figures 4.16 display the box plots visualizing the descriptive statistics for right turn stop line speed with and without pedestrian, respectively. With the presence of pedestrian and with the increasing of setback distances, the mean stop line speed for a curb radius of 15 ft shows a concave upward trend; curb radius of 30 ft shows a positively linearly increasing trend; and a curb radius of 45 ft presents a crest curve trend. The mean values for the stop line speed are closely distributed, with the largest difference being approximately 2mph.

The mean stop line speeds are higher in the absence of a pedestrian. As setback distances increase, the mean stop line speed for a curb radius of 15 ft shows an increasing trend; curb radius of 30 ft shows a concave downward trend; and a curb radius of 45 ft presents a crest curve trend. Overall, the highest speed occurred in scenarios with a radius of 45 ft. Higher speeds were also measured in scenarios with a setback crosswalk as compared to a corner crosswalk with different radii.

Table 4.7: Descriptive Statistics for Right Turn Stop Line Speed (mph)

* Radius (R); Setback (S)	Stats	R 15 ft			R 30 ft			R 45 ft		
		S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft
With Pedestrian	Median	7.2	6.5	5.8	7.5	9.0	8.5	7.9	8.6	6.6
	Mean	7.4	7.8	6.9	8.0	8.8	9.4	7.6	8.7	6.8
	SD	2.5	5.8	4.9	3.8	3.6	6.4	3.0	2.9	3.2
Without Pedestrian	Median	14.1	14.8	16.1	14.2	13.6	15.4	15.2	17.2	16.6
	Mean	15.1	15.2	16.7	14.4	14.1	15.4	15.3	17.0	16.7
	SD	3.9	3.7	4.2	2.8	3.3	3.6	2.9	3.3	3.8

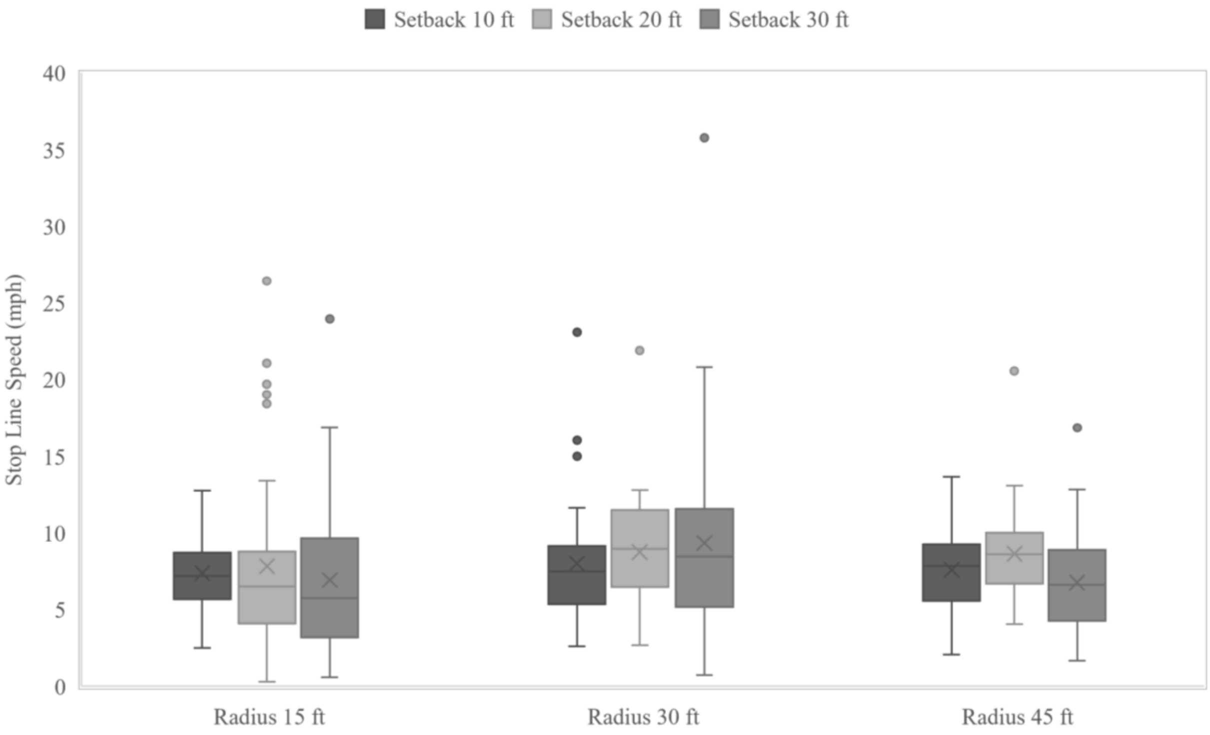


Figure 4.15: Right turn speed taken at the stop line speed with pedestrian

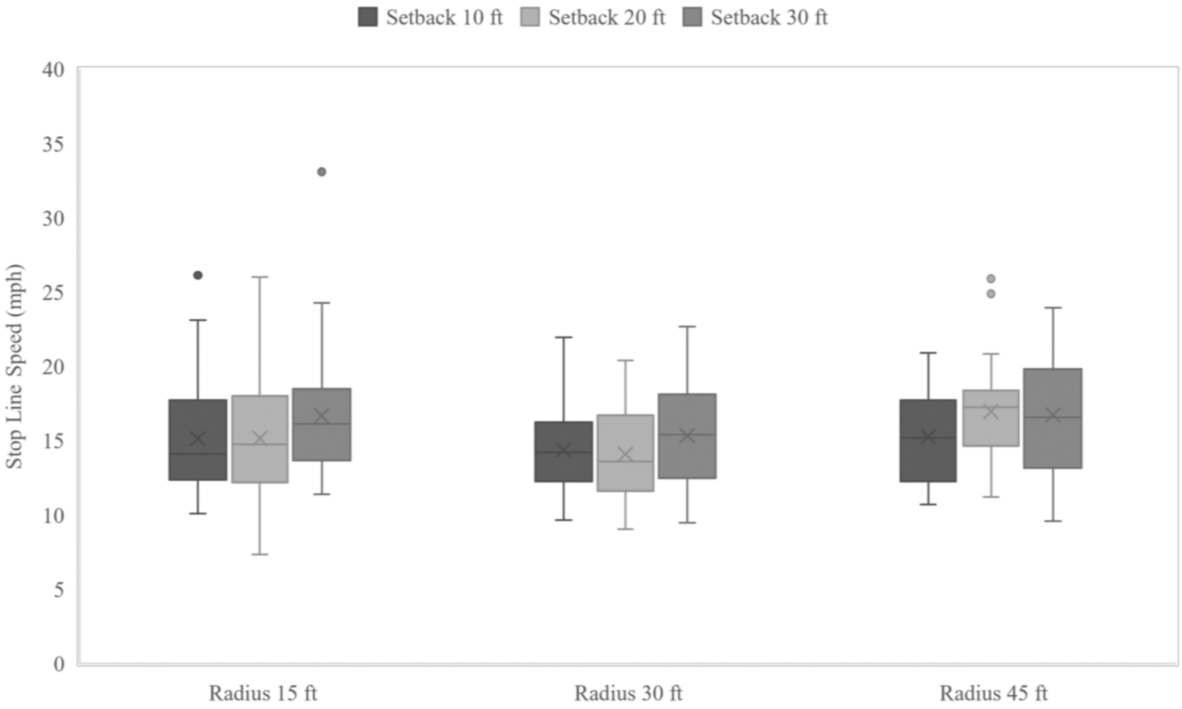


Figure 4.16: Right turn speed taken at the stop line speed without pedestrian

Table 4.8 records the descriptive statistics for the average turning speed for right turn movement in the absence of a pedestrian, grouped by three setback distances with three radii. Figure 4.17 visualizes the data in a boxplot. As shown in the visualization, the mean turning speed increases as the radius increases. Also, turning speeds are higher in those scenarios with a setback crosswalk as compared to a corner crosswalk.

Table 4.8: Descriptive Statistics for Average Right Turning Speed (mph)

*** Radius (R); Setback (S)**	**Stats**	**S 10 ft**			**S 20 ft**			**S 30 ft**		
		R 15 ft	**R 30 ft**	**R 45 ft**	**R 15 ft**	**R 30 ft**	**R 45 ft**	**R 15 ft**	**R 30 ft**	**R 45 ft**
Without Pedestrian	Median	14.2	15.1	16.1	15.3	15.3	18.2	15.3	15.9	18.3
	Mean	14.8	15.4	16.3	15.2	15.5	18.1	16.0	16.7	18.3
	SD	2.9	2.7	2.8	2.4	2.9	3.1	3.0	3.0	2.9

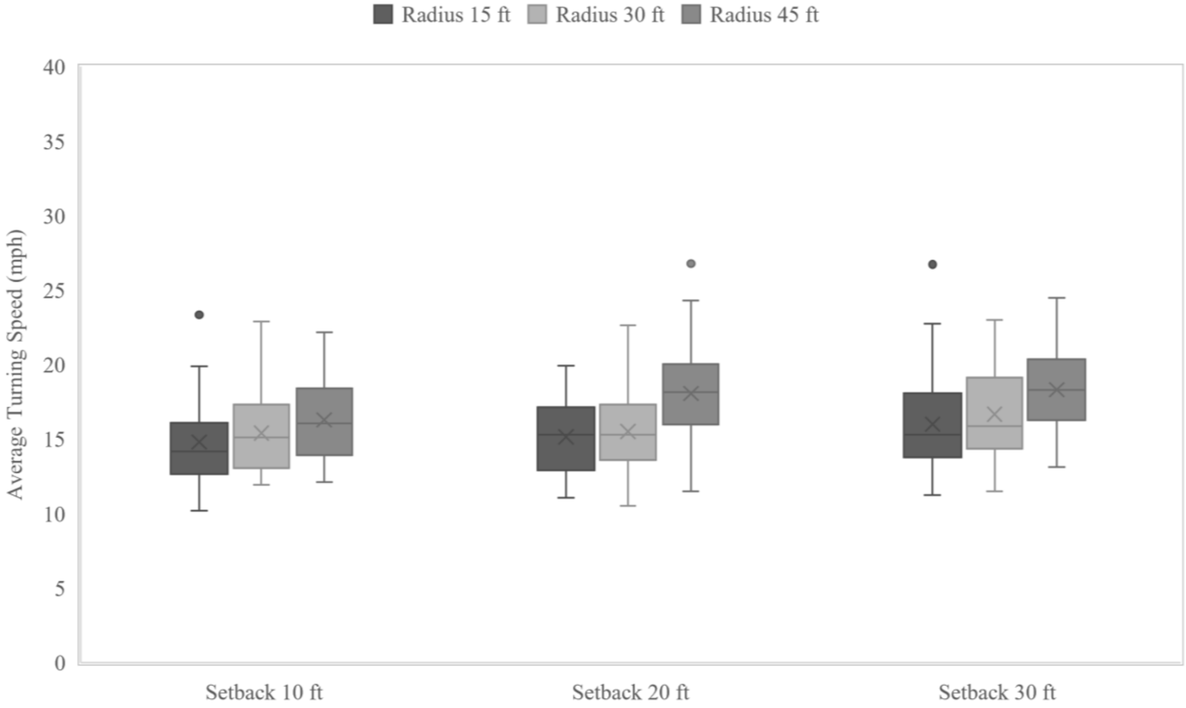


Figure 4.17: Average right turning speed without pedestrian

4.5.4.2 Left Turn Movement

Table 4.9 shows the descriptive statistics for the speed data of 39 participants. Specifically, the speed recorded at the stop line during a left turn movement with and without a pedestrian, and the average left turn maneuver speed without pedestrian at a 15 ft radius, grouped by three setback distances. Figures 4.18 and 4.19 are the box plots to visualize the left turn speed data. As the setback distances increase, the stop line speed mean value with pedestrian shows a decreasing trend; stop line speed mean value without pedestrian shows an increasing trend; and the average turning speed mean value shows a slight sag curve trend where the median value shows a stronger increasing trend.

Table 4.9: Descriptive Statistics for Left Turn Speed Data (mph)

* Radius (R); Setback (S)	Stats	R 15 ft		
		S 10 ft	S 20 ft	S 30 ft
Stop line Speed without Pedestrian	Median	15.0	15.0	17.0
	Mean	15.3	15.6	17.8
	SD	4.2	3.7	4.9
Stop line Speed with Pedestrian	Median	7.7	7.6	7.7
	Mean	9.8	9.7	8.2
	SD	6.0	7.3	5.2
Average Turning Speed without Pedestrian	Median	17.2	18.1	19.3
	Mean	18.0	17.9	19.7
	SD	2.8	3.1	3.5

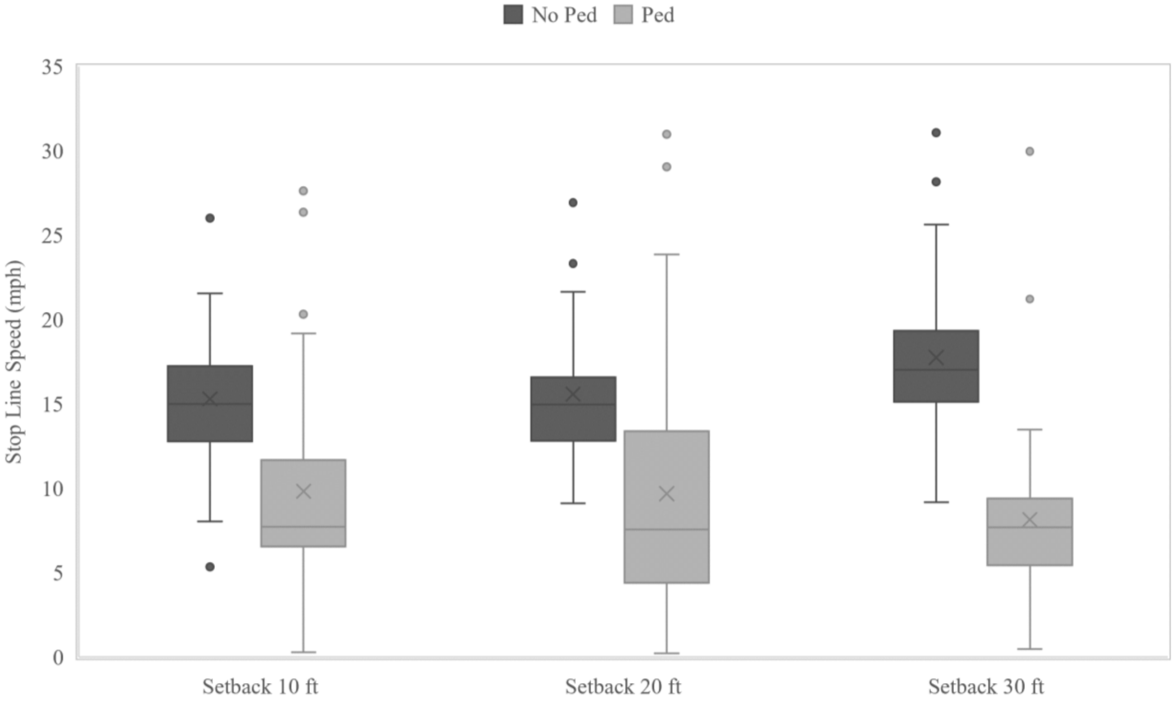


Figure 4.18: Stop line speed with and without pedestrian for left turn at radius 15 ft

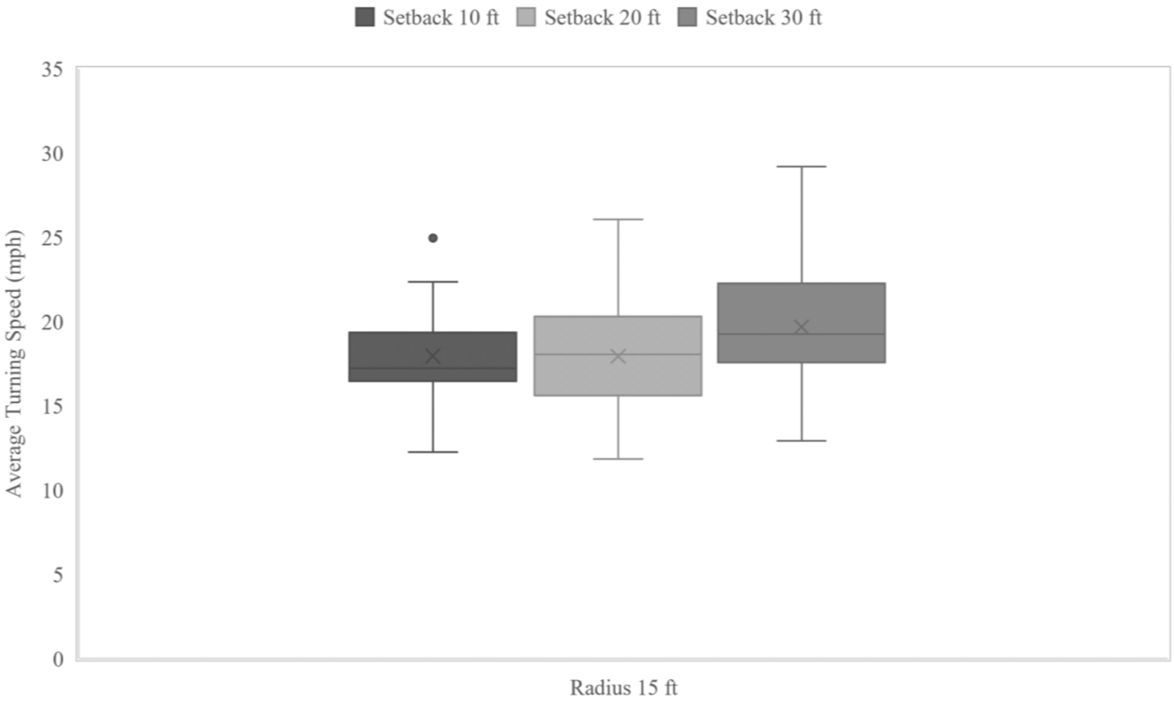


Figure 4.19: Average turning speed without pedestrian for left turn at radius 15 ft

4.5.4.3 Statistical Modeling

Since the results of stop line and turning speed for right and left turn movements have similar trends, the statistical modeling was performed on the data for right turn movement.

Speed at the Stop Line

Results of the LMM model are shown in Table 4.10. Results showed that setback and presence of pedestrians were both statistically significant (p-value <0.05). Two- and three-way interactions between the treatment variables were not statistically significant (p-value > 0.05). The random effect was significant (Wald Z=3.77, p<0.001). Age was found to be statistically significant (p-value = 0.004), which showed that a one-year increase in the driver's age decreased the stop line speed by 0.06 mph while holding all other variables in the model constant. Regardless of other variables, participants' speed at the stop line with a 30 ft setback were about 2mph higher when compared to a 10 ft setback (p-value = 0.025). The presence of a pedestrian was statistically significant (p-value < 0.001). Participants tended to decrease their speed at the stop line by approximately 8 mph in the presence of a pedestrian compared to scenarios without a pedestrian.

Table 4.10: Summary of Estimated LMM Model of Stop Line Speed (mph)

Variable	Estimate	Std. Error	P-Value
Participant random effect (Var)	3.75	0.99	<0.001*
Constant	17.38	0.94	<0.001*
Age	-0.06	0.02	0.004*
Radius (ft)			
15	Baseline		
30	-0.75	0.69	0.280
45	0.13	0.69	0.846
Setback (ft)			
10	Baseline		
20	0.03	0.69	0.965
30	1.55	0.69	0.025*
Pedestrian Presence			
No	Baseline		
Yes	-7.74	0.69	<0.001*
Radius X Setback			
30 20	-0.32	0.98	0.746
30 30	-0.57	0.98	0.559
45 20	1.67	0.98	0.087*
45 30	-0.08	0.98	0.934
Radius X Pedestrian			
30 X Yes	1.37	0.98	0.162
45 X Yes	0.08	0.98	0.933
Setback*Pedestrian			
20 X Yes	0.41	0.98	0.677
30 X Yes	-2.01	0.98	0.040*
Radius X Setback X Pedestrian			
30 X 20 X Yes	0.62	1.38	0.652
30 X 30 X Yes	1.82	1.38	0.190
45 X 20 X Yes	-1.08	1.38	0.435
45 X 30 X Yes	-0.29	1.38	0.833
Summary Statistics			
R^2	70.4%		
-2 Log Likelihood	3607.27		

**significance level is 0.10*

Additionally, all possible interactions among the independent variables were investigated and graphically illustrated in Figures 4.20 and 4.21. The y-axis in these figures shows the probability of a participant's stop line speed (mph) in a given scenario. The x-axis shows the stop line speed in mph. The three setback distances are indicated by color (i.e., blue: 10 ft; red: 20 ft; green: 30 ft) and aggregated by curb radius, with and without pedestrians. In the scenarios without a pedestrian, as shown in Figure 4.20, stop line speeds were found to be consistent across three levels of setback at a 15 ft curb radius. However, as the radius increased, the stop line speed at setbacks of 20 and 30 ft had higher values compared to the 10 ft setback. In other words, the figures at curb radii 30 and 45 ft show that the red and green observations shift away from the blue observations toward higher speed values. In contrast, when a pedestrian is present, as shown in Figure 4.21, the setback effects diminish as the radius increases.

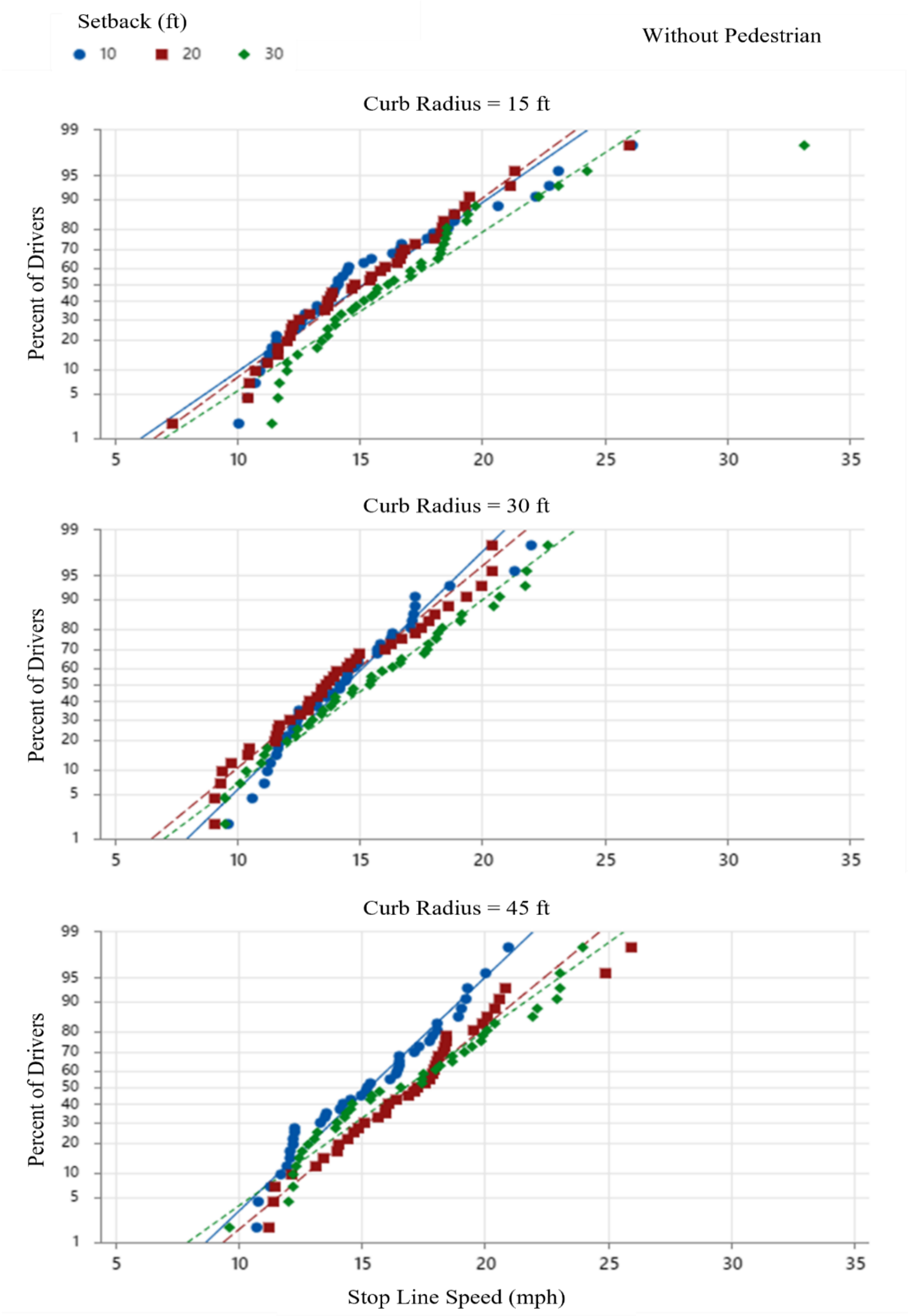


Figure 4.20: Interaction among independent variables without pedestrian

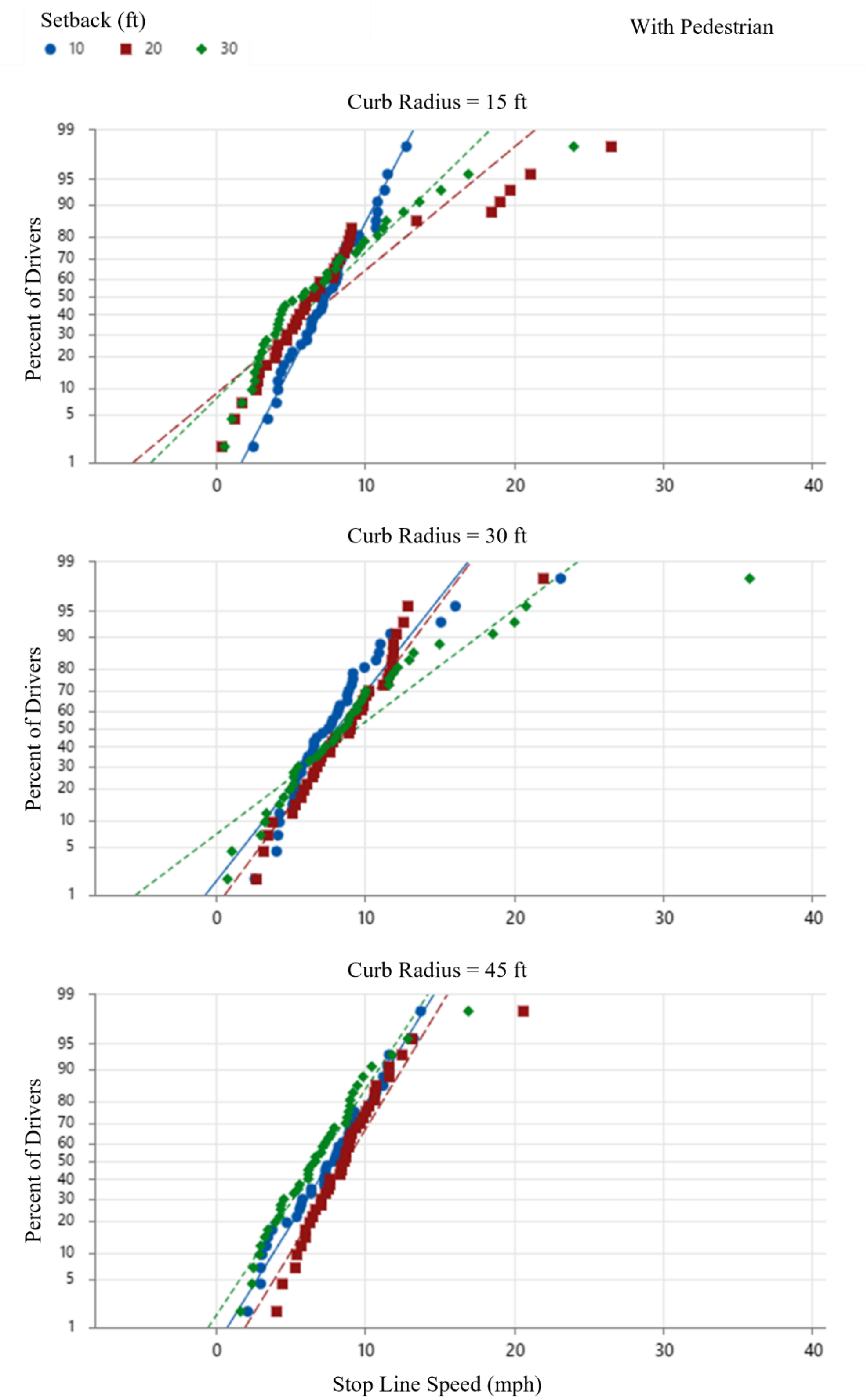


Figure 4.21: Interaction among independent variables with pedestrian

Turning Speed

A similar statistical modeling technique was used to examine differences in average turning speed. The results of the LMM are shown in Table 4.11. Results showed that setback distances, curb radii, and presence of pedestrians were all statistically significant (p-value <0.05). Two-way interactions between the treatment variables were not statistically significant (p-value > 0.05), but the three-way interaction was statistically significant at 90% CI (p-value = 0.065). The random effect was significant (Wald Z=3.81, p<0.001). This supports the argument that an LMM has higher efficiency compared with a fixed effect linear regression model. Age was found to be statistically significant (p-value = 0.01), which showed that a one-year increase in the driver's age decreases the turning speed by 0.04 mph while holding all other variables in the model constant. Regardless of other variables, participants turning right at a 45 ft curb radius or at a 30 ft setback have an approximately 2 mph higher turning speed compared to a curb radius with15 ft (p-value= 0.004) or a setback of 10 ft (p=0.021). The presence of a pedestrian was statistically significant (p-value < 0.001). Drivers tended to decrease their speed by approximately 6 mph in the presence of a pedestrian compared to scenarios without a pedestrian.

Table 4.11: Summary of Estimated LMM Model of Turning Speed (mph)

Variable	Estimate	Std. Error	P-Value
Participant random effect (Var)	3.33	0.61	<0.001*
Constant	16.387	0.732	<0.001*
Age	-0.044	0.016	0.010*
Radius (ft)			
15	Baseline		
30	0.603	0.521	0.247
45	1.492	0.521	0.004*
Setback (ft)			
10	Baseline		
20	0.352	0.521	0.499
30	1.202	0.521	0.021*
Pedestrian Presence			
No	Baseline		
Yes	-5.398	0.521	<0.001*
Radius X Setback			
30 20	-0.254	0.736	0.731
30 30	0.059	0.736	0.936
45 20	1.419	0.736	0.054*
45 30	0.822	0.736	0.264
Radius X Pedestrian			
30 X Yes	0.222	0.736	0.763
45 X Yes	0.21	0.736	0.776
Setback*Pedestrian			
20 X Yes	-1.348	0.736	0.068*
30 X Yes	-0.39	0.736	0.596
Radius X Setback X Pedestrian			
30 X 20 X Yes	2.523	1.041	0.016*
30 X 30 X Yes	0.182	1.043	0.862
45 X 20 X Yes	0.514	1.043	0.622
45 X 30 X Yes	-1.031	1.041	0.322
Summary Statistics			
R^2	71.23%		
-Log likelihood	3225.09		

**Significance level is 0.10*

All possible interactions among the independent variables were investigated and graphically illustrated in Figure 4.22. The y-axis in this figure shows the mean turning speed (mph). The x-axis in Figure 4.22 of plots a and b show the three levels of radius, while c shows the three levels of setback. Figure 4.22a illustrates the interaction between the levels of turning radius and the setback. Regardless of the presence of a pedestrian, on average, participants had a higher mean turning speed when executing the right turn on a 45 ft curb radius compared to a 15 and 45 ft curb radius at all the three levels of setback. Additionally, the 10 ft setback had the lowest turning speed when compared to the 20 and

30 ft setback for the three levels of curb radius. Setbacks 10 and 20 ft did not differ from each other at both 15 and 30 ft curb radii, and they were found to be lower than the 30 ft setback. Furthermore, while holding setback constant, the bigger the radius the higher the speed, both with and without a pedestrian, with a lower magnitude in the presence of a pedestrian (Figure 4.22b). A similar trend was observed in the setback variable when holding the curb radius constant, as shown in Figure 4.22c.

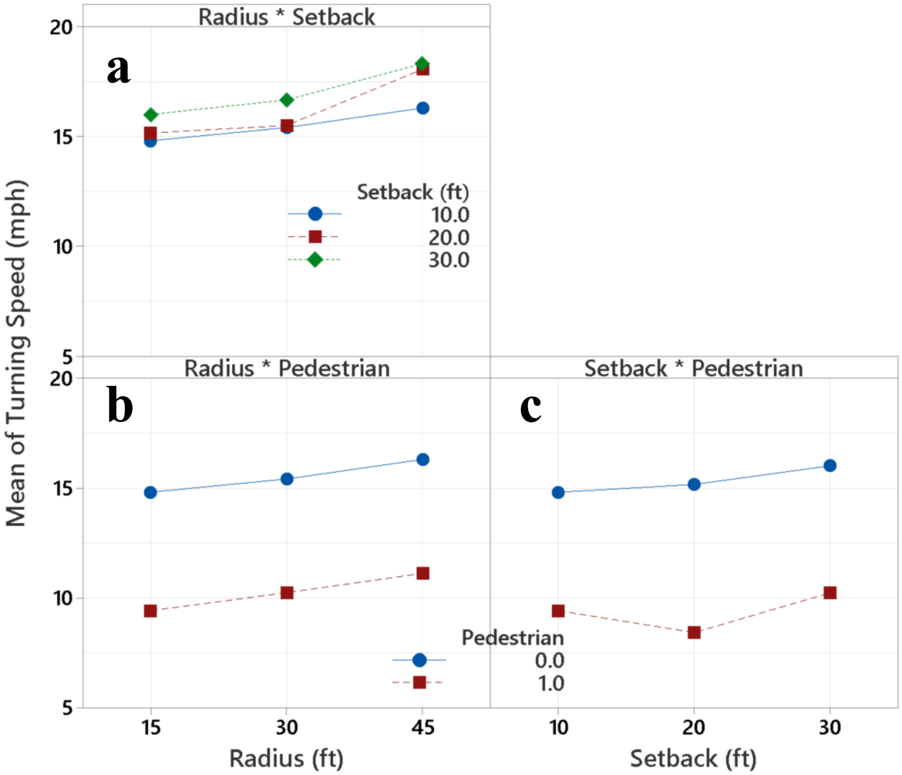


Figure 4.22: Two-way interactions on mean turning speed (mph)

4.5.4.4 Field Observations Compared to Driving Simulator

Observations of drivers' speeds in a similar scenario taken from the field and the driving simulator experiment can be compared to enhance the evidence provided by each experiment independently. For best comparison, the most consistent site from each experimental study was selected for comparison. The field site has a crosswalk setback of 18 ft and radius of 50 ft, while for the simulator environment has a setback of 20 ft and a radius of 45 ft.

In terms of the stop line speed, results from the field and the driving simulator experiments were consistent for conditions with and without the presence of a pedestrian. In the no pedestrian scenario, the average speed of drivers in the field and the driving simulator were found to be approximately 15 mph and 16.5 mph, respectively as is shown in Figure 4.23. A two-sample t-test was performed, and no statistical significance was found (p-value = 0.16). This suggests that speeds measured at the stop line were consistent. When the pedestrian was present, the average speed from both environments field (7 mph) and simulator (8 mph) were also found to have no difference with statistical significance (p-value = 0.11).

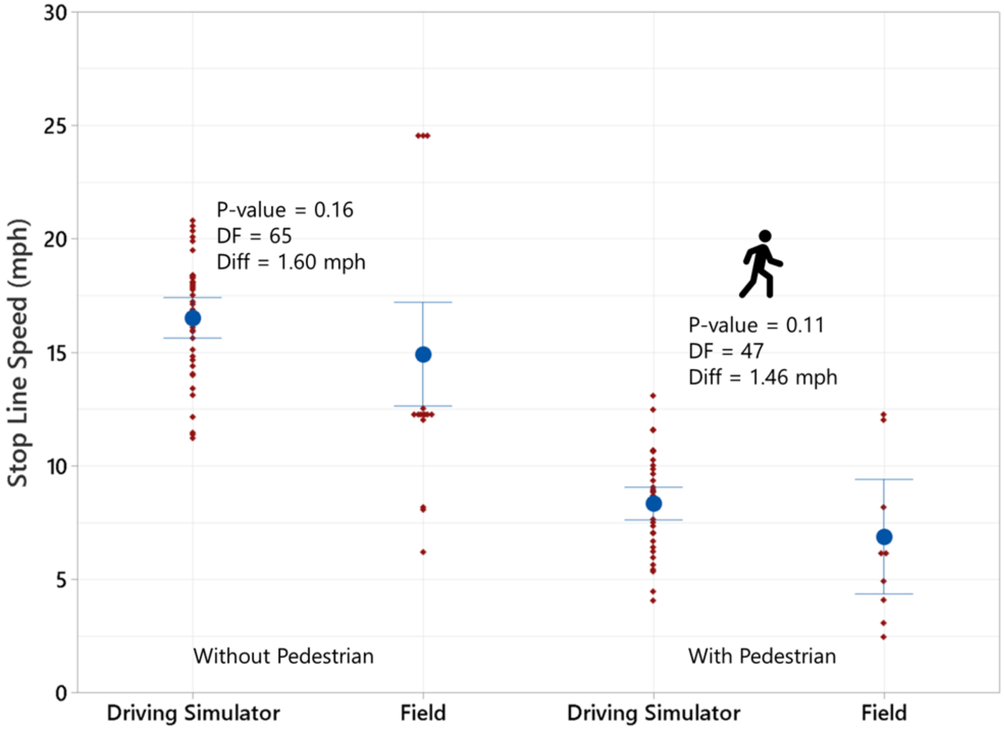


Figure 4.23: Stop Line Speed of field and driving simulator experiments for both with and without the presence of pedestrian

For right turning speed, only without the presence of pedestrian was investigated between the two environments. As shown in Figure 4.24, the average turning speed in the field and the driving simulator were found to be approximately 14.07 mph and 17.67 mph, respectively (Figure 4.23). Two sample t-test was performed, and the difference was statistically significant (p-value < 0.05). Although the difference was 3.60 mph higher in the driving simulator as compared to the field environment, the variability in the observations were higher in the latter environment. The speed in the field environment was found to be as high as 25 mph and as low as 6 mph. On the other hand, the maximum speed in the simulator was found to be 21 mph and the minimum speed was 12 mph. One possible explanation for the difference is that the simulator environment is controlled and, therefore, fewer confounding variables are introduced. On the contrary, the field environment is not controlled and subject to a lot of noise in the data such as- vehicle type, distraction, familiarity, etc. Additionally, it has been demonstrated that speeds in driving simulators can be higher than speeds observed in the field under certain conditions (Hurwitz, Knodler, Jr. & Dulaski, 2005). This does not affect the relative validity measures collected from lab experimentation.

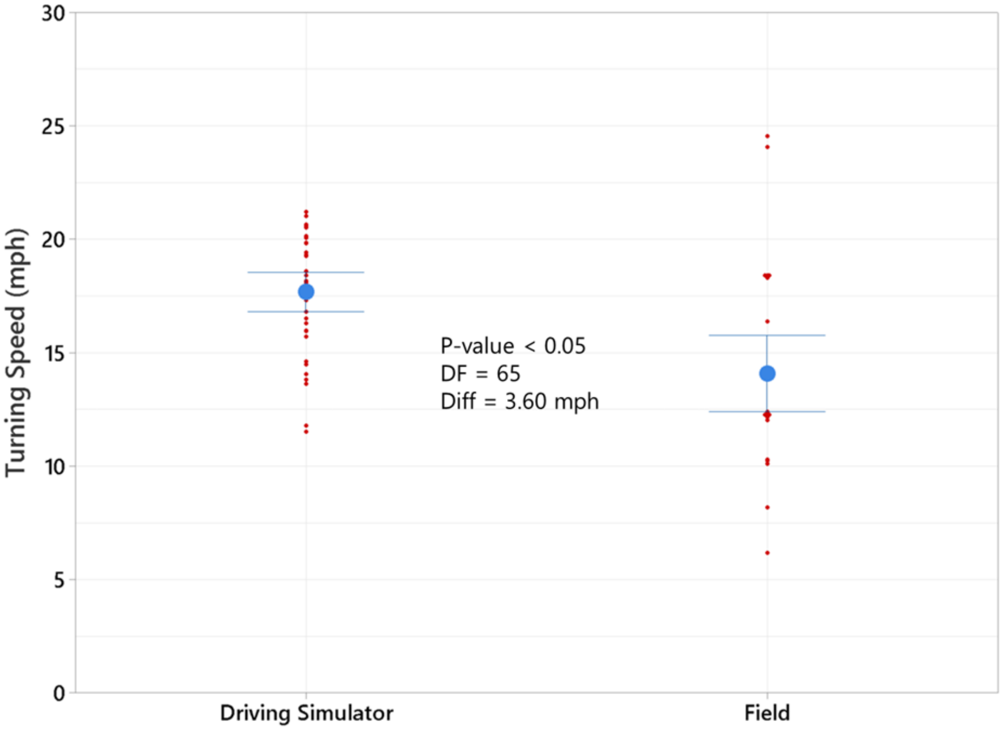


Figure 4.24: Turning Speed of field and driving simulator experiments

4.5.5 Visual Attention

The visual attention data were collected using the iMotion Tobii Glasses 3. As mentioned, data from 37 participants was captured and usable for analysis. Boxes were drawn on three AOIs: signal, crosswalk, and pedestrian to obtain the average total fixation duration (TFD) of participants. The AOI of signal showed if the participants were looking at the signal head to determine the right of way while maneuvering the intersections; AOI of crosswalk indicates if participants were looking at the different placements of the crosswalk; and AOI of pedestrian determines if participants looking at the crossing pedestrian in different scenarios.

4.5.5.1 Right Turn Movement

Table 4.12: records the descriptive statistics for right turn AOIs for 37 participants, grouped by three radii across three setback distances. Figures 4.23, 4.24, and 4.25 present a visualization of the results. Regarding the signal AOI, the mean TFD for all scenarios is around 0s and a slight trend of increasing visual attention as radius and setback distance increased was observed. This indicated that the participants mostly did not look at the signal for too long while making turning movement, slightly more so in those scenarios with a pedestrian.

For the crosswalk AOI, participants looked at the crosswalk more in the scenarios with a pedestrian. Both with and without a pedestrian, the TFD mean value increased as the setback distance increased, except for the scenario of a 45 ft radius with a pedestrian, which showed a slight decreasing trend that has very close mean TFD mean (largest difference 0.05s). There is also a slight decreasing trend between radii and TFD mean value, where the TFD mean values are smaller with larger curb radii. Regarding the pedestrian AOI, the TFD mean values show a decreasing trend with setback crosswalks. For the intersection with a 15 ft curb radius, the TFD mean value shows an increasing trend; both curb radius of 30 ft and 45 ft show a sag curve trend.

Table 4.12: Descriptive Statistics for Right Turn AOIs (s)

* Radius (R); Setback (S)	Stats	R 15 ft			R 30 ft			R 45 ft		
		S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft
Signal without Pedestrian	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	0.02	0.02	0.04	0.01	0.02	0.03	0.03	0.05	0.03
	SD	0.07	0.06	0.11	0.05	0.06	0.07	0.08	0.13	0.14
Signal with Pedestrian	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	0.09	0.07	0.06	0.10	0.12	0.04	0.10	0.04	0.17
	SD	0.17	0.14	0.14	0.28	0.22	0.13	0.25	0.10	0.34
Crosswalk without Pedestrian	Median	0.28	0.77	0.84	0.06	0.28	0.84	0.30	0.56	0.55
	Mean	0.45	0.89	0.92	0.39	0.59	0.92	0.52	0.79	0.71
	SD	0.51	0.79	0.80	0.49	0.71	0.85	0.74	0.83	0.77
Crosswalk with Pedestrian	Median	0.70	1.08	1.48	0.46	1.02	1.42	1.24	0.82	0.30
	Mean	1.23	1.39	1.70	0.83	1.44	1.52	1.33	1.28	1.29
	SD	1.39	1.58	1.63	0.96	1.45	1.55	1.45	1.47	1.70
Pedestrian	Median	1.73	1.73	1.58	1.76	1.56	1.18	2.30	1.96	0.76
	Mean	2.14	2.05	1.92	2.60	1.48	1.72	3.27	2.47	1.83
	SD	2.02	2.01	1.90	2.71	1.32	1.64	2.88	2.43	2.03

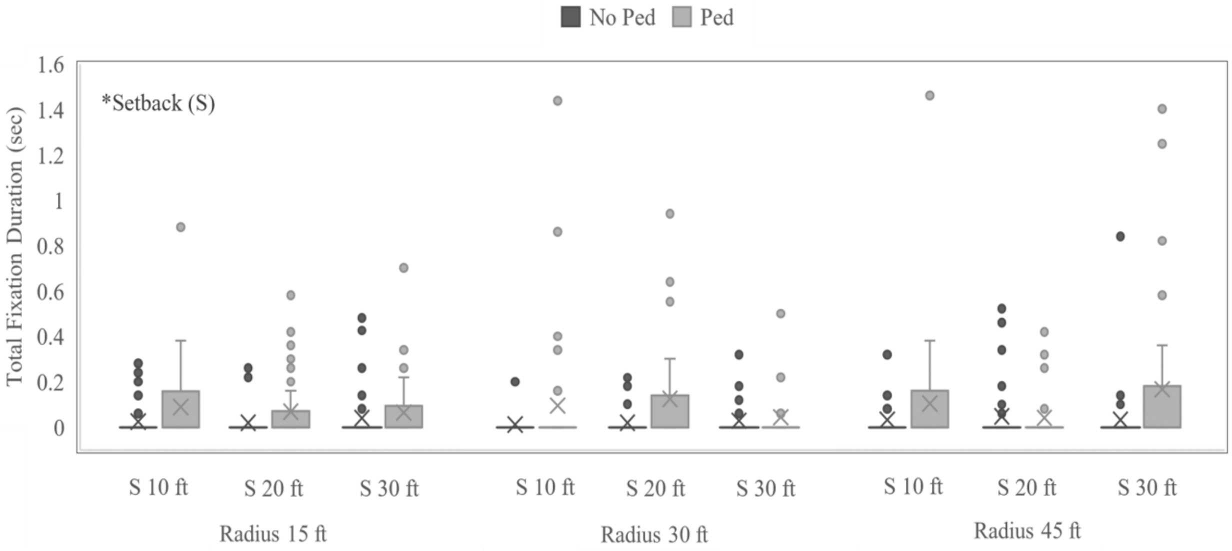


Figure 4.25: AOI - Signal for right turn movement

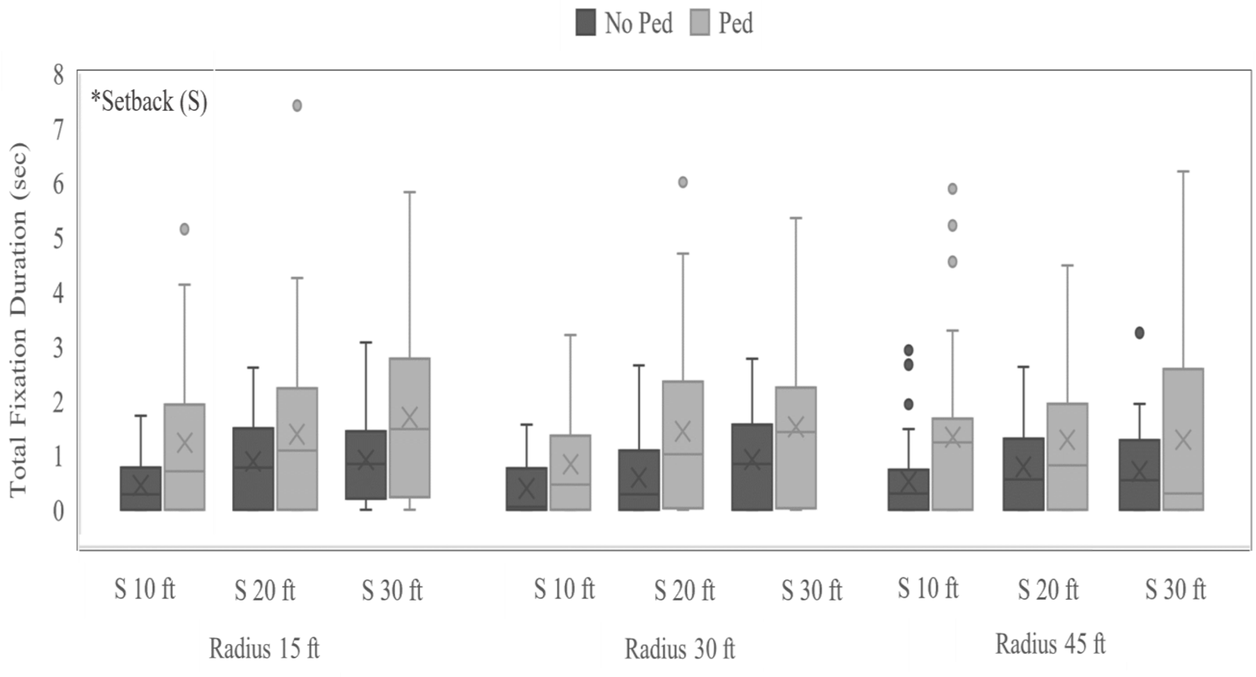


Figure 4.26: AOI - Crosswalk for right turn movement

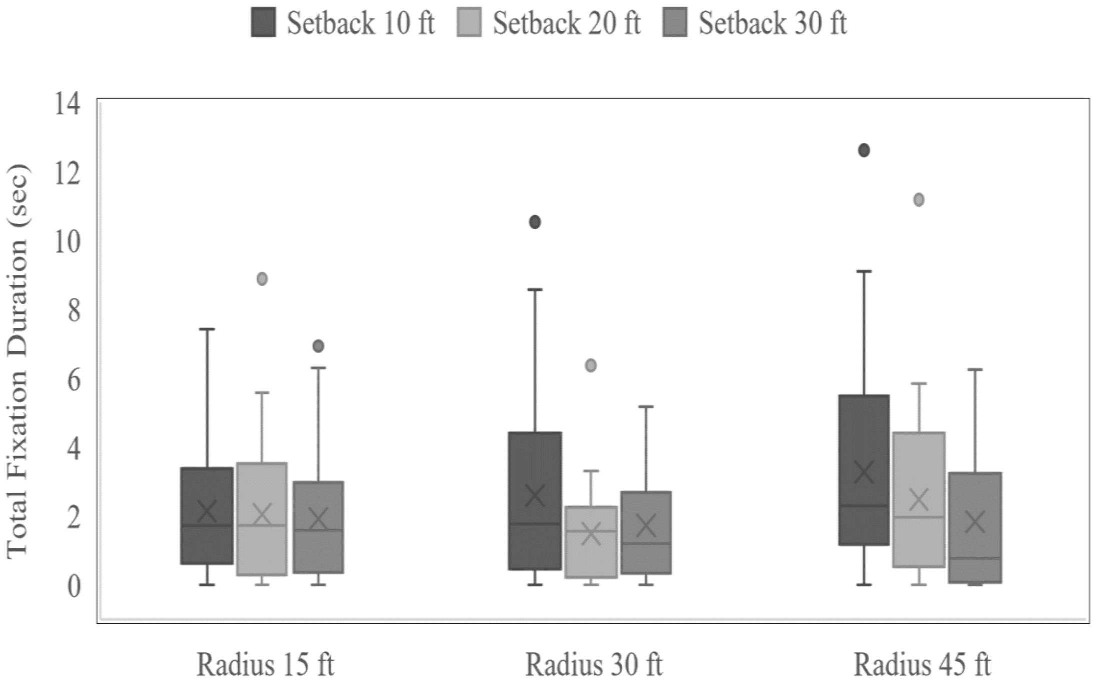


Figure 4.27: AOI - Pedestrian for right turn movement

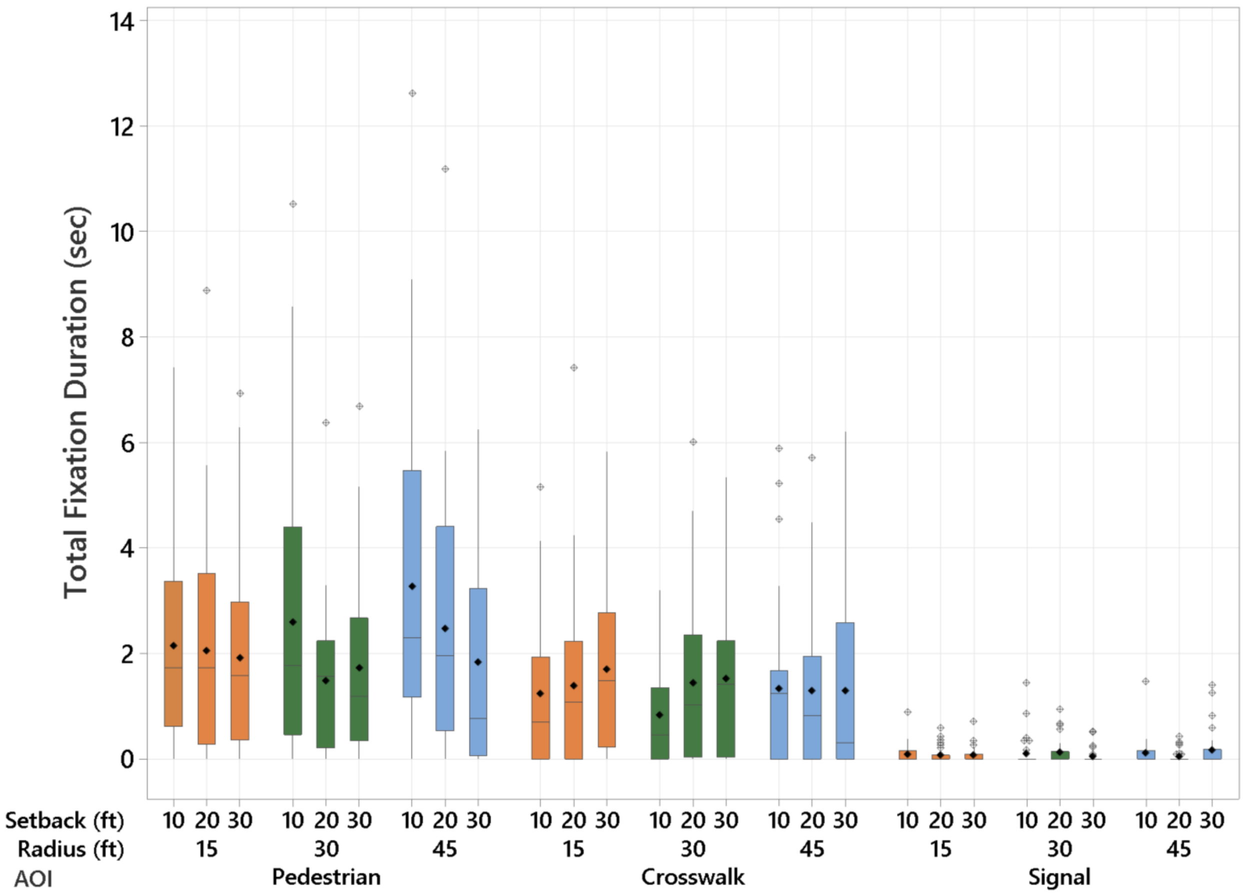


Figure 4.28: Overall TFD with variables

4.5.5.2 Left Turn Movement

Table 4.13: presents the descriptive statistics for AOIs in left turn scenarios for 37 participants, grouped by radius and setback distances. Figures 4.26, 4.27, and 4.28 are visualizations of the results. Left turn movements generally have higher TFD on the AOIs compared to right turn movements. As setback distances increase, the TFD mean value for both signal and crosswalk with pedestrian show a crest curve trend; both signal and crosswalk without pedestrian show a sag curve trend; and the presence of a pedestrian shows an increasing trend.

Table 4.13: Descriptive Statistics for AOIs (s) in Left Turn Scenarios

* Radius (R); Setback (S)	Stats	R 15 ft		
		S 10 ft	S 20 ft	S 30 ft
Signal without Pedestrian	Median	0.00	0.00	0.00
	Mean	0.08	0.05	0.06
	SD	0.15	0.14	0.13
Signal with Pedestrian	Median	0.00	0.00	0.00
	Mean	0.08	0.18	0.17
	SD	0.16	0.35	0.32
Crosswalk without Pedestrian	Median	0.86	0.76	1.56
	Mean	1.21	0.92	1.39
	SD	1.12	0.89	1.03
Crosswalk with Pedestrian	Median	1.64	1.72	2.50
	Mean	2.27	2.81	2.52
	SD	2.24	2.90	2.49
Pedestrian	Median	1.50	2.36	1.96
	Mean	2.05	2.22	2.41
	SD	2.02	1.99	2.41

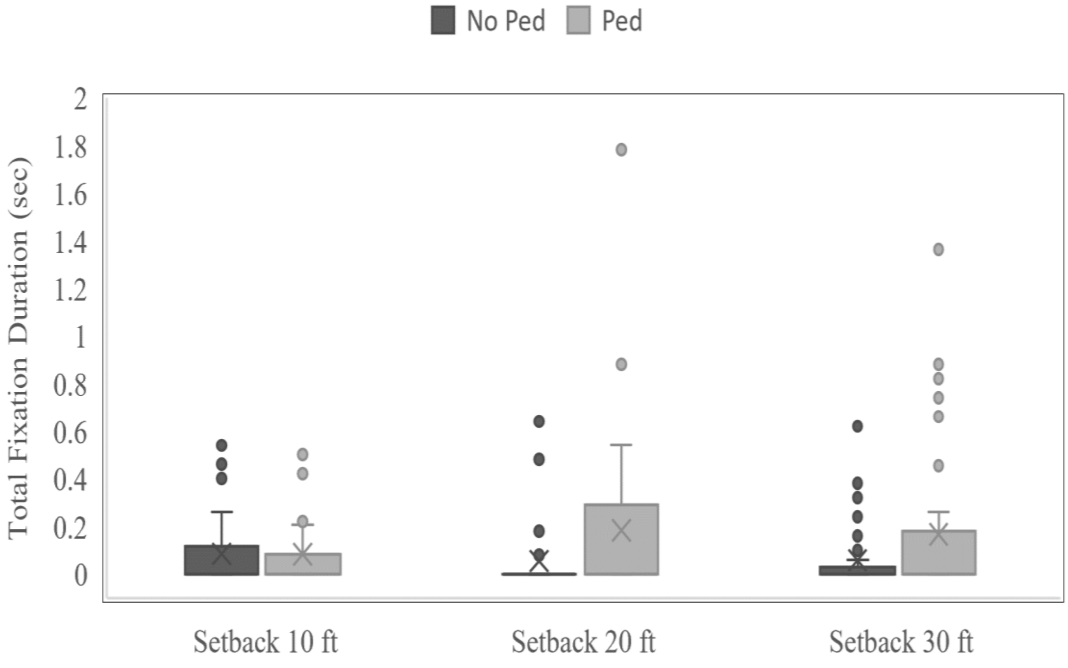


Figure 4.29: AOI - Signal for left turn movement

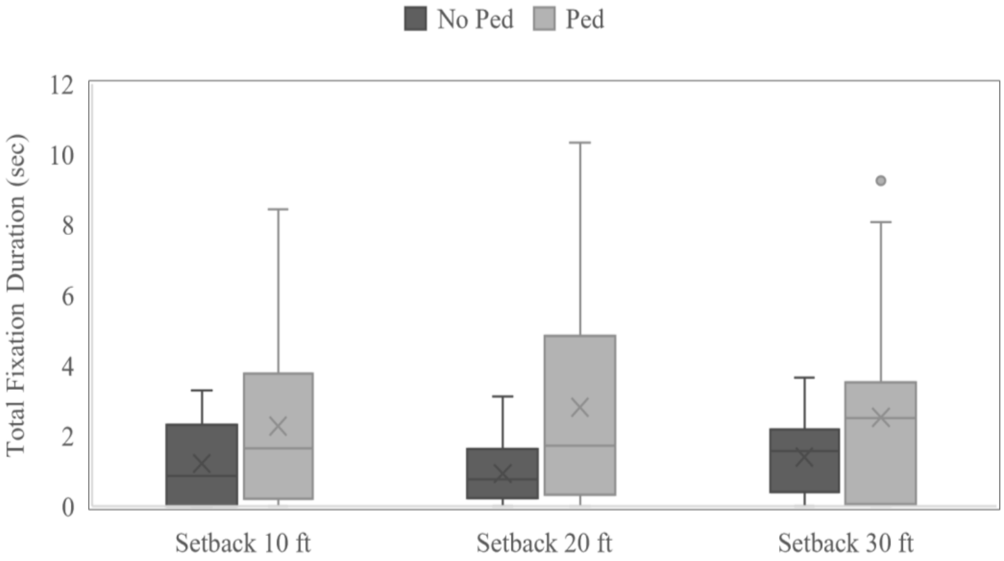


Figure 4.30: AOI - Crosswalk for left turn movement

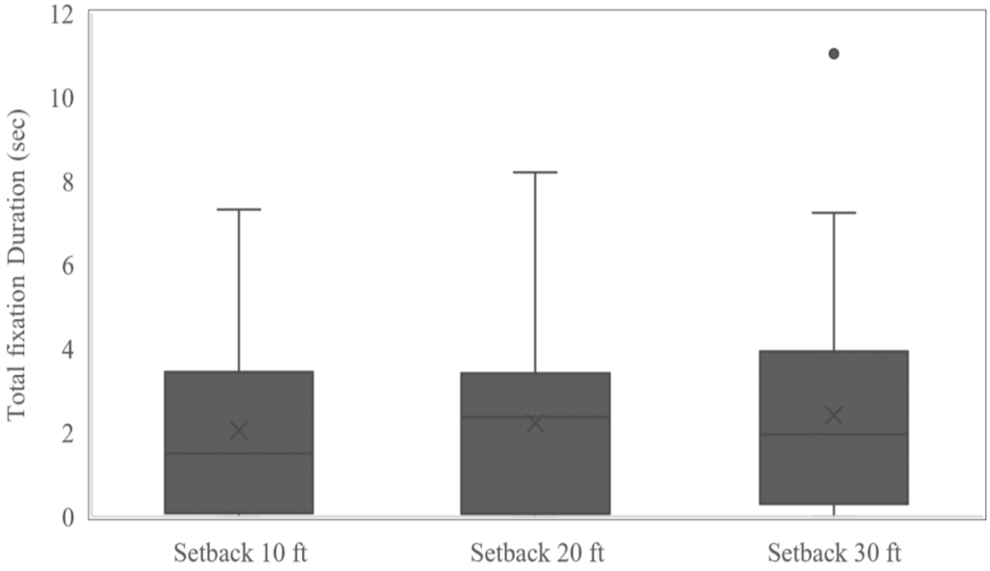


Figure 4.31: AOI - Pedestrian for left turn movement

4.5.5.3 Statistical Modeling

An LMM was used to model the mean TFD at the pedestrian for right turn movements. The results of the model are shown in Table 4.14. Results showed that curb radius was statistically significant (p-value <0.05) but that was not the case for setbacks. Two-way interactions between the treatment variables were statistically significant (p-value < 0.10). The random effect was substantial (Wald Z=4.01, p<0.001). Regardless of other variables, participants turning right at a 45 ft curb radius fixated 1 second longer on the pedestrian when compared to a 15 ft curb radius (p-value= <0.001).

Table 4.14: Summary of Estimated LMM Model of TFD with Pedestrian (s)

Variable	Estimate	Std. Error	P-Value
Participant random effect (Var)	3.05	0.76	<0.001*
Constant	2.14	0.354	<0.001*
Radius (ft)			
15	Baseline		
30	0.46	0.293	0.118
45	1.13	0.293	<0.001*
Setback (ft)			
10	Baseline		
20	-0.09	0.293	0.758
30	-0.22	0.293	0.449
Radius X Setback			
30 X 20	-1.03	0.414	0.014*
30 X 30	-0.66	0.414	0.114
45 X 20	-0.71	0.414	0.089*
45 X 30	-1.22	0.414	0.003*
Summary Statistics			
R^2	71.10%		
-Log likelihood	1206.10		

**significance level is 0.10*

Two-way interactions between the curb radius and the independent variables were also investigated and illustrated in Figure 4.30. The y-axis in this figure shows the mean TFD. The x-axis shows the three levels of radius treatment, while the line types indicate the three levels of setback treatment. Results showed that when encountering a 10 ft setback at a 45 ft curb radius, participants fixated the longest on the pedestrian while crossing (3.27 seconds) compared to other treatment combinations. The three levels of setback distances were similar when participants drove through a 15 ft curb radius. The average total fixation duration was the lowest when participants encountered 20 or 30 ft setbacks at a 30 ft radius (1.48 and 1.72 seconds).

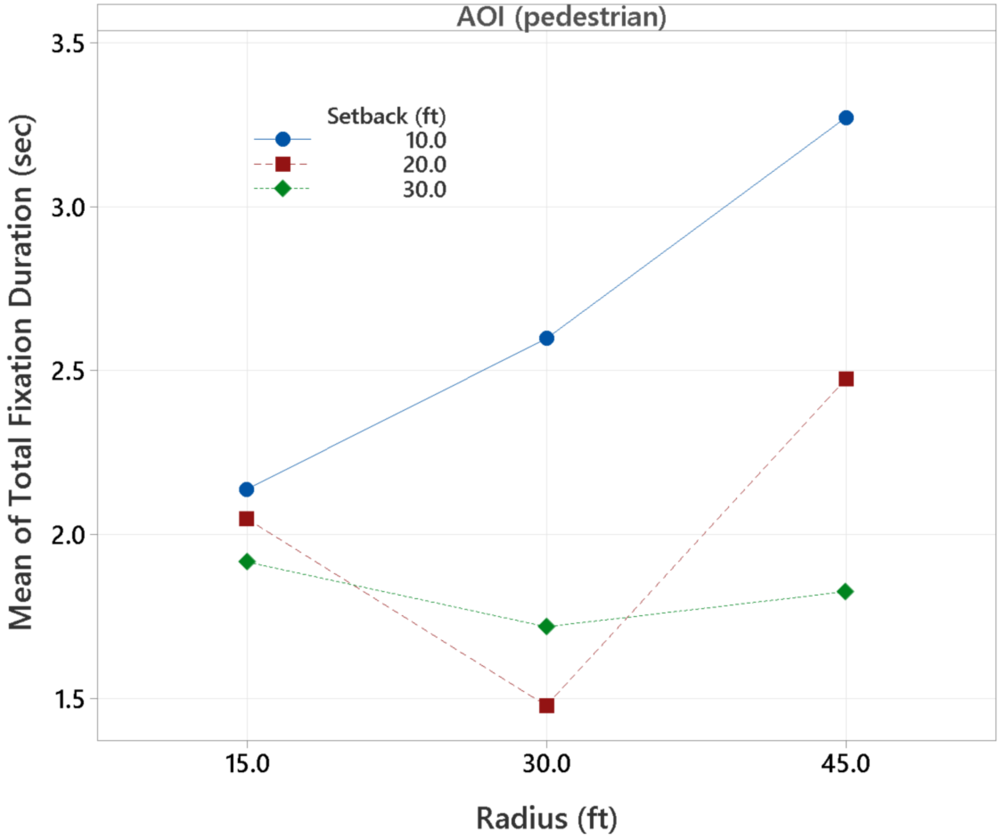


Figure 4.32: Two-way interactions on mean Total Fixation Duration

4.5.6 Level of Stress

The GSR data was reduced to GSR peaks per minute to control the natural variation between participants' peak measures. The results of the data indicate participant stress reactions to the different scenarios.

4.5.6.1 Right Turn Movements

Table 4.15 shows the descriptive statistics for 30 participants for the right turn movement GSR data with and without pedestrian, grouped by three radii with three setback distances. Figure 4.32 displays box plots to visualize the GSR data. As shown by the results, the mean GSR peaks per minute for all scenarios without a pedestrian are higher than those with a pedestrian in the crossing. The mean GSR peaks per minute have a crest curve trend with increasing setback distances for most scenarios; and have a sag curve trend with increasing radius for most scenarios. Figure 4.33 presents the GSR between male and female, and female generally has higher GSR values.

Table 4.15: Descriptive Statistics for Right Turn GSR (peaks/min)

* Radius (R); Setback (S)	Stats	R 15 ft			R 30 ft			R 45 ft		
		S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft	S 10 ft	S 20 ft	S 30 ft
Without Pedestrian	Median	13.0	10.4	8.0	9.8	9.8	8.4	8.8	10.7	11.6
	Mean	13.4	12.1	9.3	11.7	10.6	10.7	11.8	12.8	11.3
	SD	9.0	7.1	6.9	7.1	6.0	7.1	7.1	8.8	5.0
With Pedestrian	Median	8.5	9.9	8.4	10.9	8.9	8.5	10.1	11.4	8.2
	Mean	9.3	10.0	8.8	10.0	9.4	8.2	9.7	12.4	8.8
	SD	6.0	5.2	5.2	6.7	5.3	5.9	5.1	7.5	4.8

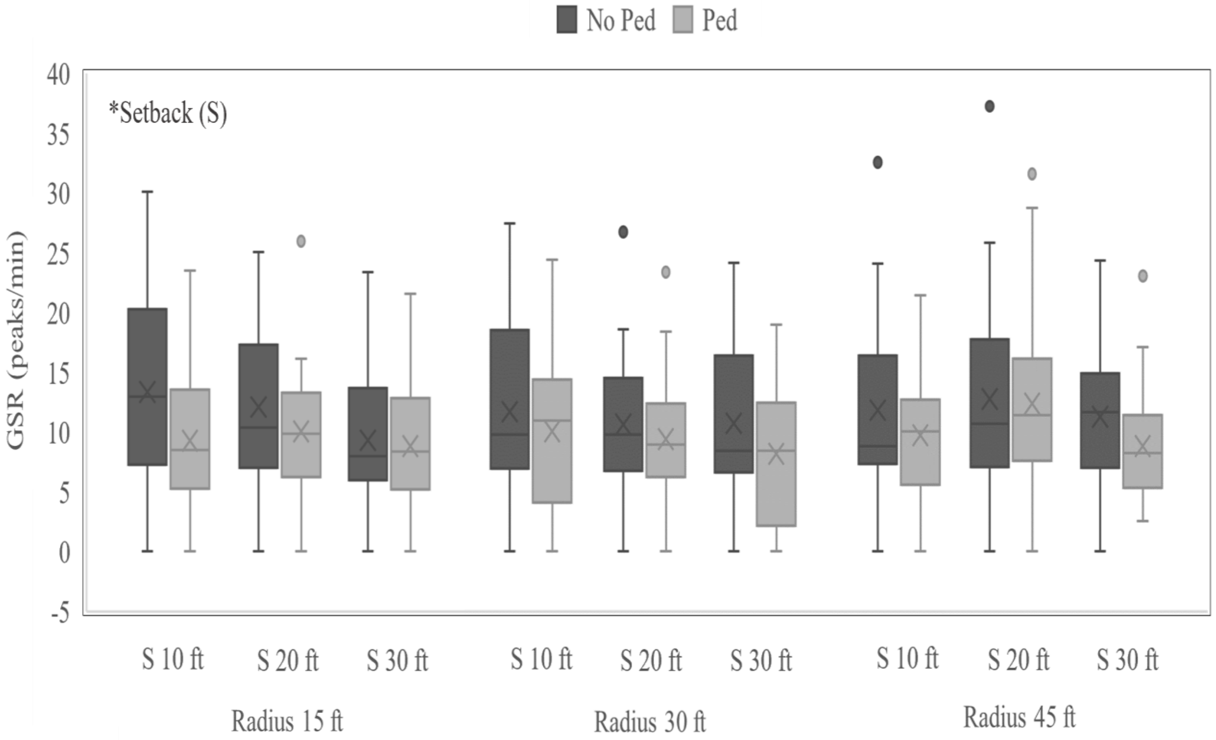


Figure 4.33: GSR for right turn

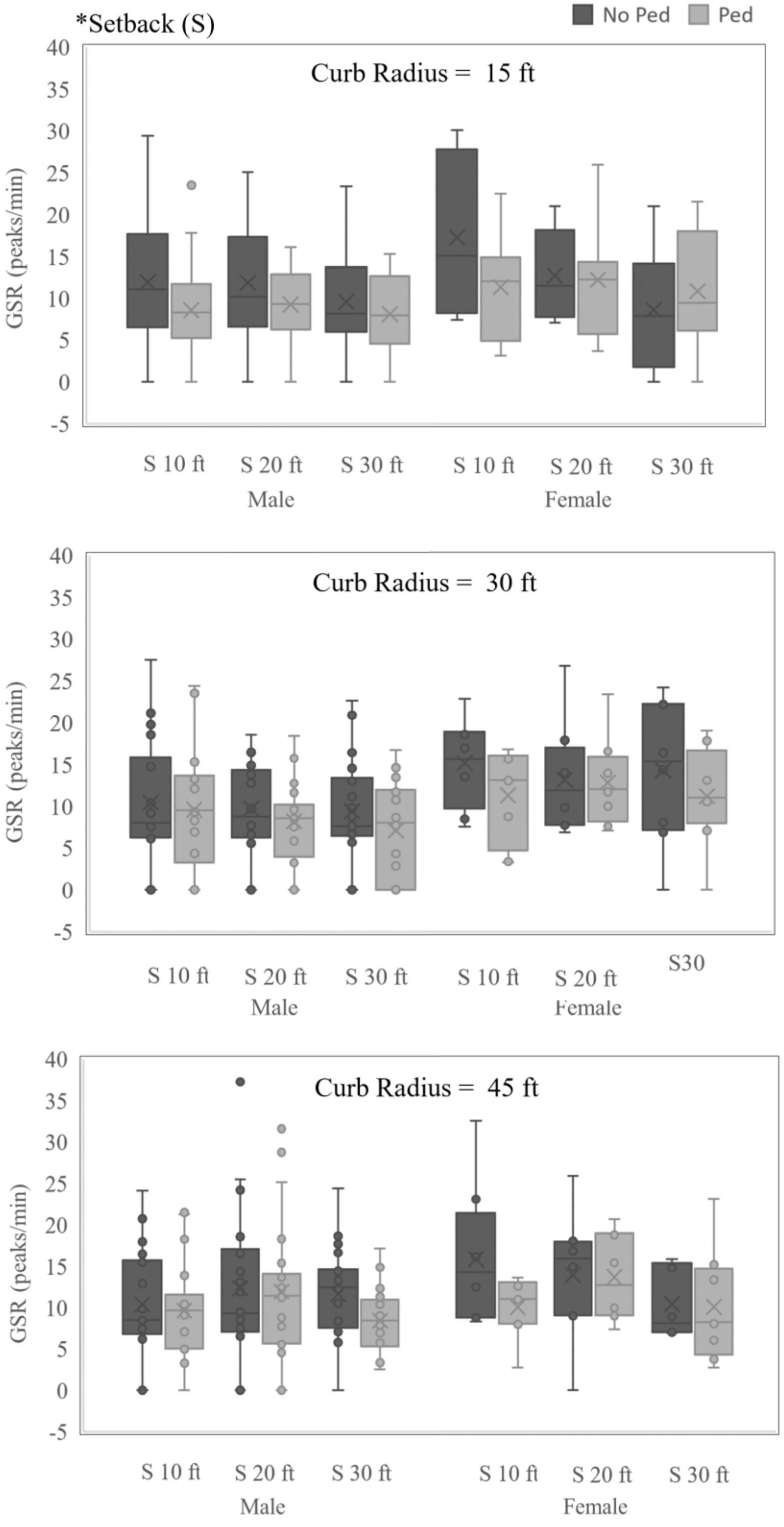


Figure 4.34: GSR between male and female for right turn movement

4.5.6.2 Left Turn Movement

Table 4 shows the descriptive statistics for 30 participants for the left turn movement GSR data with and without pedestrian, grouped by radius 15 ft with three setback distances. Figure 4.35 is the visualization of the data. The performance measures produced patters similar to that of the right turn movement, where the GSR peaks per minute mean values were higher in the scenarios without a pedestrian compared to those with a pedestrian. The mean values are close with various setback distances. It was also observed in Figure 4 that females had a higher GSR response compared to males.

Table 4.16: Descriptive statistics for left turn GSR (peaks/min)

*** Radius (R); Setback (S)**	**Stats**	**R 15 ft**		
		S 10 ft	**S 20 ft**	**S 30 ft**
Without Pedestrian	Median	11.6	11.8	11.9
	Mean	12.5	12.6	11.9
	SD	5.7	7.0	7.1
With Pedestrian	Median	11.6	11.7	8.1
	Mean	10.3	10.4	8.3
	SD	6.1	5.0	4.3

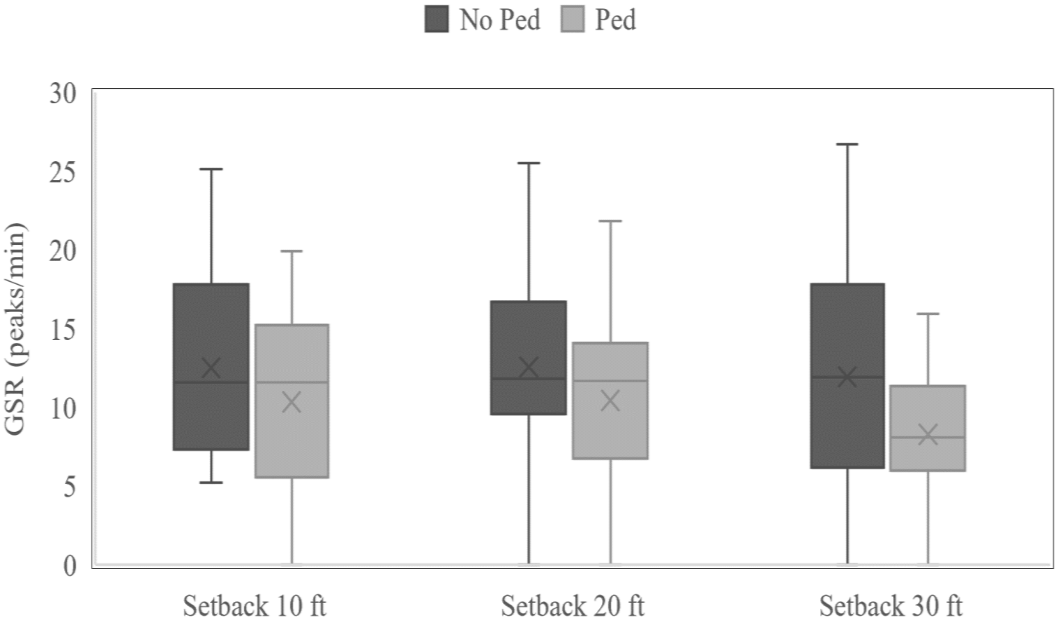


Figure 4.35: GSR for left turn at radius 15 ft

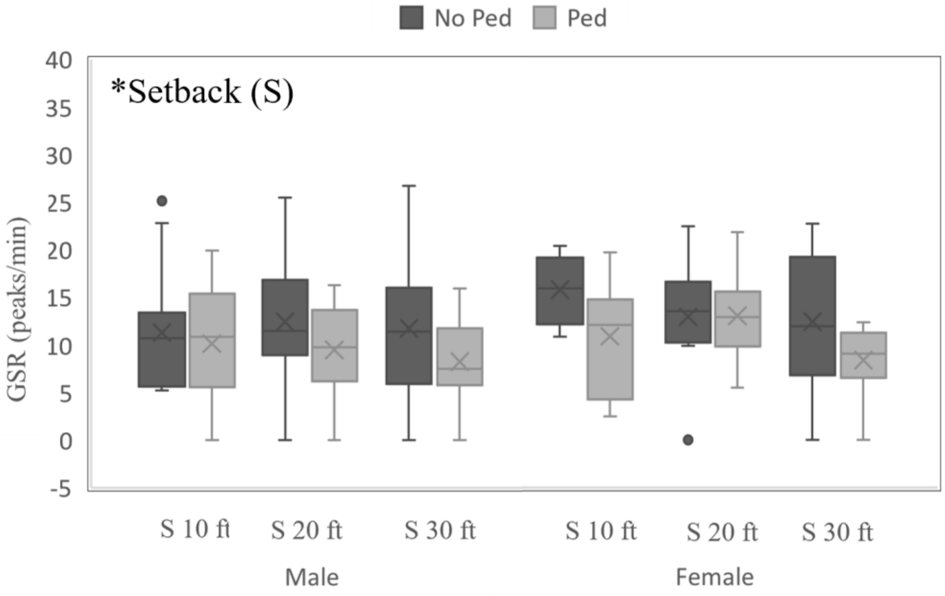


Figure 4.36: GSR between male and female for left turn movement at radius 15 ft

4.6 DISCUSSION AND SUMMARY

4.6.1 Stopping Decision and Position

As stated in the Oregon Driver Manual (ODM), stopping before the stop line is the correct way to stop in an intersection as blocking a crosswalk can put pedestrians in a dangerous situation and limit driver visibility to see crossing pedestrians (Oregon Department of Transportation, 2022). According to the study results, stopping after the stop line was observed. Additionally, did not stop and partially stopped behaviors were observed and their lowest speed positions were located after the stop line more frequently at intersections with setback crosswalk. Participants chose to stop after the stop line at intersections with crosswalk setbacks while yielding or waiting for the pedestrian to cross because they wanted to be closer to the intersection corner for better visibility. Such behavior could raise concerns as it will potentially block the approaching crosswalk, affect sight distance, and yield shorter conflict distance that might cause stress for crossing pedestrians.

According to the ODM, pedestrians must be at least six feet away from the lane that the driver is turning into (receiving lane) at signalized intersections (Oregon Department of Transportation, 2022). Regarding the right turn movements, participants were less likely to fully stop at intersections with setback crosswalk yielding the right-of-way to a crossing pedestrian, instead, they chose not to stop or to slowly perform the turning movements while waiting for the pedestrian. Typically these turns were completed without waiting pedestrian to fully finish crossing the street. This is because a setback crosswalk provides extra space for drivers before reaching the apex of the intersection corner and allows a pedestrian to clear the receiving lane before drivers arrive. The displayed traffic indication during the left turn movement was green without the presence of other conflicting traffic. The results for left turns show that many participants yield or wait for the pedestrian after the stop line, especially on the intersections with setback crosswalk as they wanted to be in a better position to perform the permitted left turn. The did not stop behavior happened more frequently at intersections with a corner crosswalk for left turn. In this scenario participants finished the turning movement before the pedestrian reached the receiving lane. Such behavior might be against the law and increase potential conflicts between intersection users and further affect either comfort or safety.

4.6.2 Stop Line and Turning Speed

For the right turn movement, the mean speed taken at the stop line in the presence of a pedestrian in all scenarios are compairable, due to similar behaviors of waiting or yielding for crossing pedestrians. In correspondance with the stopping behavior discussion above, increasing setback length increased the probability of participants who did not stop, where higher speeds were observed in intersections with a setback crosswalk. This might be because participants tend to yield or wait for a pedestrian closer to the corner and slow down after the stop line. In that situation the speed measured at the stop line will be their approach speed. Regarding the increasing relationship between curb radius and turning speed, study results matched well with the literature review of the impacts of curb radius at intersections, where the smaller radii led to lower speeds and the larger radii led to higher speeds (Alhajyaseen & Nakamura, 2012; Alta Planning + Design, 2020; Institute of Transportation Engineers & U.S. Department of Transportation Federal Highway Administration, 2004; Suzuki & Ito, 2017; Fitzpatrick, Avelar, Pratt, Das & Lord, 2021). Our driving simulator study results also showed that the vehicle speeds are higher at intersections with setback crosswalks. These higher speeds may impact intersection safety.

On the other hand, the effects of setback crosswalk were less significant for left turn movements. Higher speeds were observed at intersections with setback crosswalks, this corresponded with right turn movements where drivers tried to be closer to the intersection to scan for the presence of a pedestrian.

4.6.3 Visual Attention

Regarding the right turn movement, participants tended to finish turning with less attention on the signal AOI in scenarios without a pedestrian. This might be because the green indication was displayed in all scenarios and there were no pedestrian or other interferences to affect the driver's action. Participants looked at the traffic signal head more in scenarios with a setback crosswalk because the setback increases the required turning distance, and drivers might be concerned with not being able to complete the turn before the traffic indication turns red. As for the pedestrian AOI, the setback crosswalk increases the distance between the driver and the crossing pedestrian, which means the driver needed to travel a longer distance to reach the intersection corner for yielding as compared to the corner crosswalk. Therefore, the pedestrian might have cleared the receiving lane in advance of the driver reaching the receiving lane, which would require less visual attention from the approaching driver on the pedestrian.

The TFD values for the left turn movement were higher than for the right turn movement. The results are reasonable because left turn movements require more attention to the surrounding environment. Setback crosswalks shift pedestrian further away from the intersection corner and drivers might spend more time searching for and looking at the pedestrian in order to finish the turning movement before the traffic signal displays the red indication.

4.6.4 Level of Stress

Stress was anticipated to be higher in the presence of a pedestrian, however, the results indicated higher stress without a conflicting pedestrian. Drivers might feel less stress during the scenarios with a pedestrian present because there is no uncertainty involved. In the scenario when the pedestrian is present, drivers have already detected the pedestrian crossing and felt comfortable yielding the right of way and waiting, while drivers might be more alert when actively searching for a conflicting pedestrian. The mean GSR peaks per minute are mostly higher at those intersections with larger radii, which might be related to the vehicle speed as higher speeds were observed when larger radii were present, and drivers might be on higher alert when driving at a higher speed. An interesting finding was that the level of stress experienced by females was greater than that of males.

5.0 CONCLUSION AND RECOMMENDATIONS

The purpose of this research was to identify the relationship between the setback of crosswalks at signalized intersections and conflicts between pedestrians and turning vehicles. There is a clear gap in our understanding of the safety effects of crosswalk setback, where only a few studies have directly addressed the question of setback. Therefore, this research to provides empirical evidence to better understand the relationship between setback crosswalks and intersection safety with the consideration of other intersection characteristics, in this case the setback distance, curb radii, and presence of a pedestrian.

To achieve the research goals, two experiments were conducted:

- Field video data collection at 10 crosswalks (five setback, five control) in Oregon. The 10 crosswalks were located at nine intersections and approximately 12 hours of video (7am-7pm) was collected at each of the nine study sites. The field video data was used to examine the frequency pedestrian-vehicle conflicts (measured using PET), including how these conflicts vary between the corner and setback crosswalks.
- A driving simulator experiment with 50 participants where the participants were asked to drive through scenarios that contained different combinations of experimental factors (i.e., setback distances, curb radii, and presence of pedestrian). The collected data were used to investigate how the factors affected drivers' speed, position, visual attention, and level of stress.

From these experiments, three primary findings were produced:

- The effect of setback, in terms of stopping behaviors and the approach speed taken at the stop line, diminishes as the curb radius is increased (i.e., larger than 30ft).
- Driver speed selection was affected by curb radius and setback distances. The mean turning speed increased as radius increased, and larger setback distances resulted in slightly higher speeds.
- For right turns, larger setback distances reduced visual attention on the pedestrian because drivers are further from the intersection and the pedestrian cleared the receiving lane by the time the drivers reach the intersection apex for the turning movement.

An extended summary of the primary findings and results from both experiments is included in the subsections below.

5.1 FIELD STUDY

A total of 10 crosswalks (five setback and five corner) were selected for field data collection. Video data was collected at these sites and PETs when the pedestrian vehicle interactions were within 5 seconds were extracted. Overall, 49 conflicts were observed across eight crosswalks, while at two crosswalks there were no observed pedestrian-vehicle interactions within 5 seconds. Average PETs and turning vehicle speeds were extracted for the conflict observations. Due to the small number of conflict observations, no conclusive findings could be made about the impact of setback distance on average PETs and between curb radius and average speed of turning vehicles from the field data, however, the general observations from the field are consistent with the observations in the driving simulator experiment.

5.2 DRIVING SIMULATOR

An experiment was conducted using the OSU Driving Simulator to further investigate the relationship between crosswalk setback and intersection safety with the consideration of other intersection characteristics. The roadway geometry and pavement markings were designed using Blender version 2.79 and all other design elements were coded using ISA version 2.0. Scenarios were designed to feel as authentic to real-world driving as possible.

A total of 50 participants were recruited from the Corvallis, Oregon, and the surrounding area, including 30 males and 20 females, where none of the participants self-identified as non-binary or prefer not to answer. The participant ages range from 18 to 74 years old, with an average of 35.6 years and a standard deviation of 15.6 years. The participants were asked to drive through all scenarios containing combinations of experimental factors to investigate how the factors affected driver behavior (e.g., stopping decision and position, stop line and turning speed, visual attention, and level of stress). With nine participants experiencing simulation sickness or technical difficulties with equipment during the data collection process, the final analyzed sample for SimObserver was 39 participants with 26 males and 13 females; Eye-Tracker was 37 participants with 24 males and 13 females; and GSR was 30 participants with 22 males and eight females.

The participants completed a pre- and post-drive questionnaires that collected demographic information and driving experiences before the experiment and comfort level while approaching the intersections with various characteristics after the experiment.

According to the study results, increasing crosswalk setback was found to reduce the probability of driver yielding and slightly increased turning movement speed. For the left turn movement, many drivers yield or wait for the pedestrian after the stop line at intersections with setback crosswalks. The proportion of drivers not stopping was greater at the intersections with corner crosswalks, which might increase potential conflicts between intersection users.

Participants had a similar mean speed at the stop line during right turn movements in all scenarios due to similar yielding and waiting behaviors. Setback crosswalks appear to affect yielding probability and higher speeds. Participants tended to yield or wait for a pedestrian closer to the corner and slow down after the stop line, and the speed measured at the stop line was consistent with their approach speed. A proportional relationship between turning speed and curb radii was found. The study results also showed that vehicle speeds were higher at intersections with a setback crosswalk. These higher speeds could impact overall intersection safety.

Alternately, the effects of setback crosswalks were less significant on turning speed for left turn movements and participants presented similar yielding behavior. For left turn movements, higher speeds were observed at intersections with setback crosswalks. This corresponded with right turn movements where drivers slowed down closer to the intersection to scan for the presence of a pedestrian.

Eye movement data were used to examine participants' visual attention on the traffic signal heads, crosswalk placement, and pedestrians. Participants looked at the traffic signal head more and allocated slightly more visual attention towards the crosswalk in scenarios with a setback crosswalk. Participants tended to look at the pedestrian less in the setback crosswalk configuration. For the left turn movement, participants spent more visual attention on the surroundings, where setback crosswalks move the pedestrian further away from the corner. In those instances, drivers spent more time searching and staring at pedestrian to finish the turning movement before the signal turns red.

The results indicated higher stress levels without pedestrian. The drivers might feel less stress in scenarios with a pedestrian because there is less uncertainty involved. The level of stress was mostly higher in those intersections with higher radii, which might be related to vehicle speed as larger radii led to higher speeds. Generally, female's level of stress was higher than males.

5.3 LIMITATIONS OF THE RESEARCH

This research delivers data-driven results to investigate the relationship between crosswalk setback and intersection safety. The results aim to provide valuable recommendations for transportation practitioners to consider when designing or reconstructing intersections with setback crosswalk. These recommendations should be considered in the context of the limitations of this particular research.

There were some limitations related to the field video data reduction at the 10 crosswalk sites in this study. First, data were collected during fall of 2021, when the Covid-19 pandemic was still active. Although vehicle volumes were approaching pre-pandemic levels when the videos were recorded, it's unknown whether the pandemic had any impact on motorist or pedestrian behaviors. Second, the volume, conflict, and speed data reduction from the field-collected videos was completed in an office setting by members of the research team. While training was provided, there is likely inherently some small level of counting or measurement error associated with this type of data collection in almost any context.

With respect to the driving simulator experiment, the within-subject design provides higher statistical power without requiring significantly larger sample sizes. However, one potential limitation is fatigue, which might affect participants performance over the experiment if they felt bored or tired due to the repeated measures. As mentioned, the order of the scenarios was partially randomized, experimental driving time was minimized, and breaks were offered during the experiment to reduce the potential effects of fatigue and learning. Additionally, the experiment was performed in a simulated environment. Although the designed scenarios were based on real world conditions and were drawn as authentically as possible, participants might behave differently than in real life. However, even in that condition the relative validity of scenarios provides a means to differentiate the experimental factors.

In the experiment, GSR equipment was used to collect and quantify the stress experienced by participants using their physiological responses. Previous research pointed out the conflicting discussion of the correlation between collected data and actual stress because external factors during the experiment are hard to control (Cobb et al., 2021). To minimize the external factors, participants were driving in a private room and the experimental variables were controlled, however, the ability to control all external factors is still a limitation because of the differences between false positive and actual physiological responses to events happening during the experiment. Participants were asked to equip the GSR equipment on their non-dominant wrist as less movement was expected during the experiment, however, it was hard to validate the implications of slight movements while driving. Of all the different sources of collected data, the greatest data loss was experienced from the GSR measure. Additionally, there is still some disagreement in the research community regarding the interpretation of physiological response in the form of GSR measures in an active experiment that involved physical movement because there is no widely agreed upon way to differentiate actual stress and arousals obtained.

Furthermore, the experiment used a limited number of independent variables and variable levels due to the constraints of time and resources. Future work could increase the number of variable levels or introduce new variables that might affect driver performance related to the safety effects of setback crosswalks.

5.4 RECOMMENDATIONS FOR PRACTICE

Based on the findings, the research suggests that in a lower speed environment (e.g., urban or suburban areas under 45 mph), a setback distance between 10 ft and 20 ft should not negatively affect driver behaviors. In a higher speed environment (e.g., suburban area or rural area over 45 mph), a setback distance between 10 ft and 30 ft is recommended. It should also be noted that a curb radius above 30 ft diminished the effects of setback.

If the agency widely adopts setback crosswalks, or similar configurations associated with designs such as protected intersections, changing the vehicle code with regard to the stopping position relative to the crosswalk may be worth considering.

For existing intersections based on the roadway context (e.g., high and low speed environments), the two curb ramps could be installed closer or further from each other to adjust the setback distance. If curb radius could not be modified, adjusting the setback could be an approach to mitigate conflicts.

The research does not investigate other potentially contributing factors and the results might not be able applicable to every intersection. More research and testing may be needed prior to scaled adoption.

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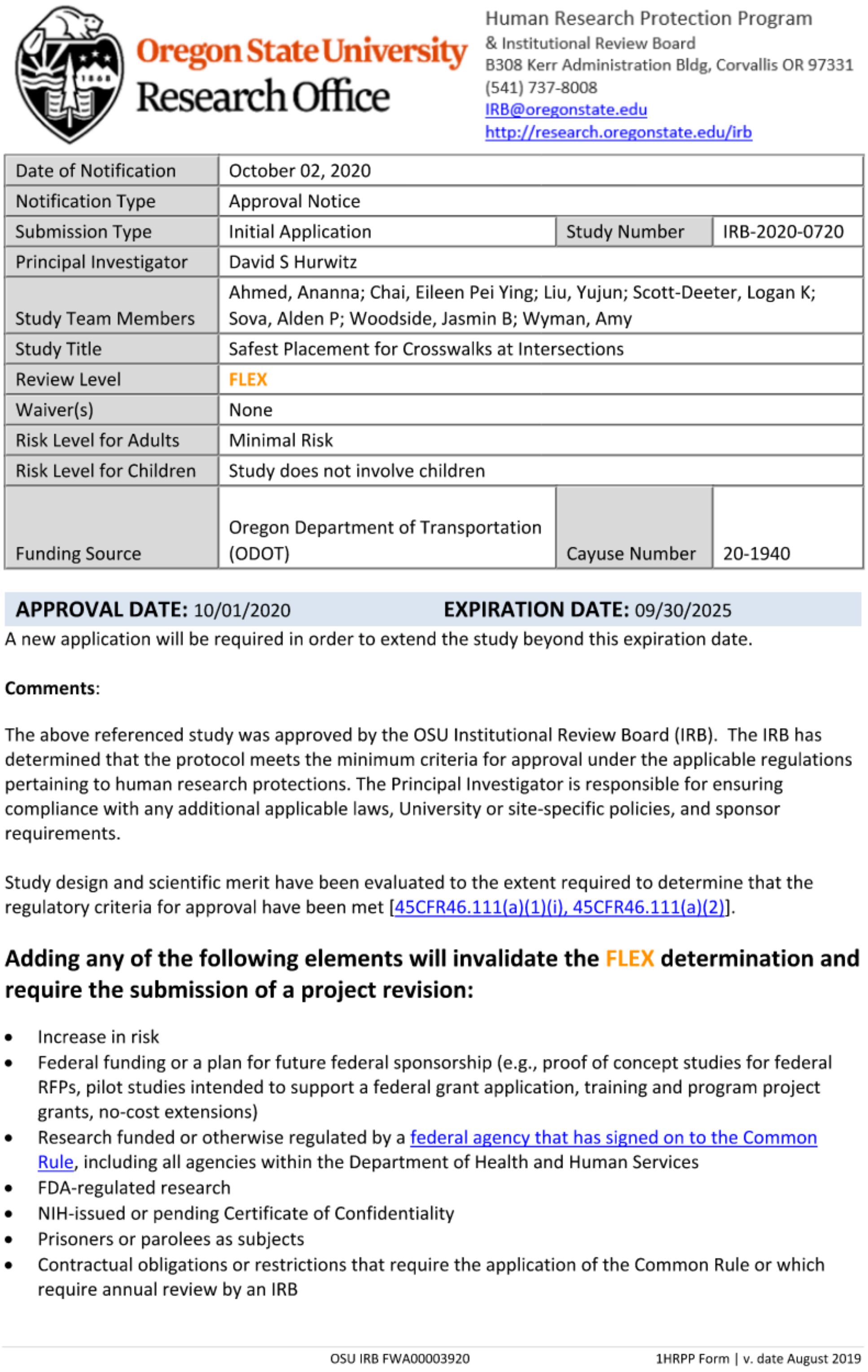
APPENDIX A: IRB APPROVAL DOCUMENT

IRB Approval Document



Oregon State University
Research Office

Human Research Protection Program
& Institutional Review Board
B308 Kerr Administration Bldg, Corvallis OR 97331
(541) 737-8008
IRB@oregonstate.edu
http://research.oregonstate.edu/irb

Date of Notification	October 02, 2020		
Notification Type	Approval Notice		
Submission Type	Initial Application	Study Number	IRB-2020-0720
Principal Investigator	David S Hurwitz		
Study Team Members	Ahmed, Ananna; Chai, Eileen Pei Ying; Liu, Yujun; Scott-Deeter, Logan K; Sova, Alden P; Woodside, Jasmin B; Wyman, Amy		
Study Title	Safest Placement for Crosswalks at Intersections		
Review Level	FLEX		
Waiver(s)	None		
Risk Level for Adults	Minimal Risk		
Risk Level for Children	Study does not involve children		
Funding Source	Oregon Department of Transportation (ODOT)	Cayuse Number	20-1940

APPROVAL DATE: 10/01/2020 **EXPIRATION DATE:** 09/30/2025

A new application will be required in order to extend the study beyond this expiration date.

Comments:

The above referenced study was approved by the OSU Institutional Review Board (IRB). The IRB has determined that the protocol meets the minimum criteria for approval under the applicable regulations pertaining to human research protections. The Principal Investigator is responsible for ensuring compliance with any additional applicable laws, University or site-specific policies, and sponsor requirements.

Study design and scientific merit have been evaluated to the extent required to determine that the regulatory criteria for approval have been met [45CFR46.111(a)(1)(i), 45CFR46.111(a)(2)].

Adding any of the following elements will invalidate the FLEX determination and require the submission of a project revision:

- Increase in risk
- Federal funding or a plan for future federal sponsorship (e.g., proof of concept studies for federal RFPs, pilot studies intended to support a federal grant application, training and program project grants, no-cost extensions)
- Research funded or otherwise regulated by a federal agency that has signed on to the Common Rule, including all agencies within the Department of Health and Human Services
- FDA-regulated research
- NIH-issued or pending Certificate of Confidentiality
- Prisoners or parolees as subjects
- Contractual obligations or restrictions that require the application of the Common Rule or which require annual review by an IRB

- Classified research
- Clinical interventions

Principal Investigator responsibilities:

- ➢ Keep study team members informed of the status of the research.
- ➢ Obtain IRB approval for project revisions <u>prior</u> to implementing changes as required by section 8.6 of the Policy Manual.
- ➢ Report all unanticipated problems involving risks to participants or others within three calendar days.
- ➢ Use only approved consent document(s).

APPENDIX B: EXAMPLE SIMULATOR META DATA

Funded Research Project Final Dataset Metadata Worksheet

Please include the following information with the project data submission and any additional details that you think might be useful to anyone searching for or using your data. Remember that, by providing rich supporting documentation for your dataset, you make it easier for other researchers to find, use, and cite your work.

Data files: All data and metadata files should be submitted in a single folder or zip file.

1. *Truck commercial vehicle loading zone measurement data is contained in the project report.*
2. *Simulation data in two different excel files (pre-post survey and speed & lateral position)*

Title: The dataset title should be descriptive of the dataset contents; the project title will not be sufficient in general. For example, for a dataset which contains bicycle volumes collected by volunteers at various intersections in Spokane, WA, an appropriate title might be "Intersection Bicycle Counts in Spokane, WA".

Commercial Vehicle Loading Zone Delivery Envelope Measurements and Simulator Data

Authors: The Author should be the project PI(s), include the ORCID for all authors.
- *Edward McCormack, 0000-0002-2437-9604*
- *David Hurwitz, 0000-0001-8450-6516*
- *Anne Goodchild, 0000-0003-1595-0570*

Author Contacts: The contact for the dataset should be the project PI(s). Please include name, affiliation, and email address.

Edward McCormack, University of Washington, edm@uw.edu

David Hurwitz, Oregon State University, david.hurwitz@oregonstate.edu

Creation Date: This is the date at which the Dataset was created. If the data was collected over multiple days, simply enter the start and end dates. If the date(s) at which the data was collected do not coincide with the time period described by the data, please include both the collection date(s) and the date(s) covered by the data.
The truck envelope measurement data was collected between February and March of 2018.
The bicycling simulator data was collected between September 2nd to September 26th 2019.

Data File Type/Format and Size

File Name	**File Type**	**File Size**
PacTrans-Datasets truck envelope-Bicycling-Simulator-Data	**Microsoft Excel Worksheet**	**60KB**

PacTrans-Datasets truck envelope-Pre-Post-Survey-Data	**Microsoft Excel Comma Separated Values File**	**24 KB**

Description and Data Dictionary: Please describe the dataset and its intended use. Include a brief description of each data file that is submitted, including any metadata files. Details should include where and how the data was collected, processing steps that have been applied, and any known quality or consistency issues. For more complex datasets, consider including a schema describing the structure and relationships present in the dataset.

The CVLZ measurement database (in the report) contains measurements, tailored to different types of truck configurations, loading equipment and accessories, of the operating envelope around a commercial vehicle.

Three different data types were obtained from Oregon State Driving and Bicycling Simulator Laboratory for purpose of this report and they are as follow:

1) *Pre-post survey data (all included in one excel file) consists of series of questions that were answered in an online Qualtrics survey by 48 participants to a) identify their demographic variables, and b) map their self-reported responses to their behavior while riding through the experiment so that results can be validated.*

2) *Speed data was collected based on the cyclist's speed while riding through the scenarios. For each scenario, the average speed (m/sec) of 48 cyclists from 25 meter before the location of the commercial vehicle to 15 meter after was recorded.*

3) *Lateral position data was collected based on cyclist's divergence from the center of the bike lane. The average lateral position (m) of 48 cyclists from 25 meter before the location of the commercial vehicle to 15 meter after for each independent variable level was recorded. Note that center of the bike lane was defined as 0 m making the left edge -0.92 m (travel lane side).*

50 participants were recruited, two of them had a simulator sickness so they were excluded from the data and the analysis. Therefore, the data has no quality or consistency issues and it is ready to be used. The average values were calculated to easily apply the optimal statistical analysis for such data (speed and lateral position). As the experiment consists of 3x3x2 factorial design, each participant had to ride 18 scenarios; therefore, 864 observations were obtained and recorded in the excel file.

A data dictionary was also submitted.

Issues with Sharing: Please describe any protections, privacy or confidentiality concerns, embargo periods, non-disclosures, or any other liabilities to ODOT associated with this data.
There are no issues with sharing.

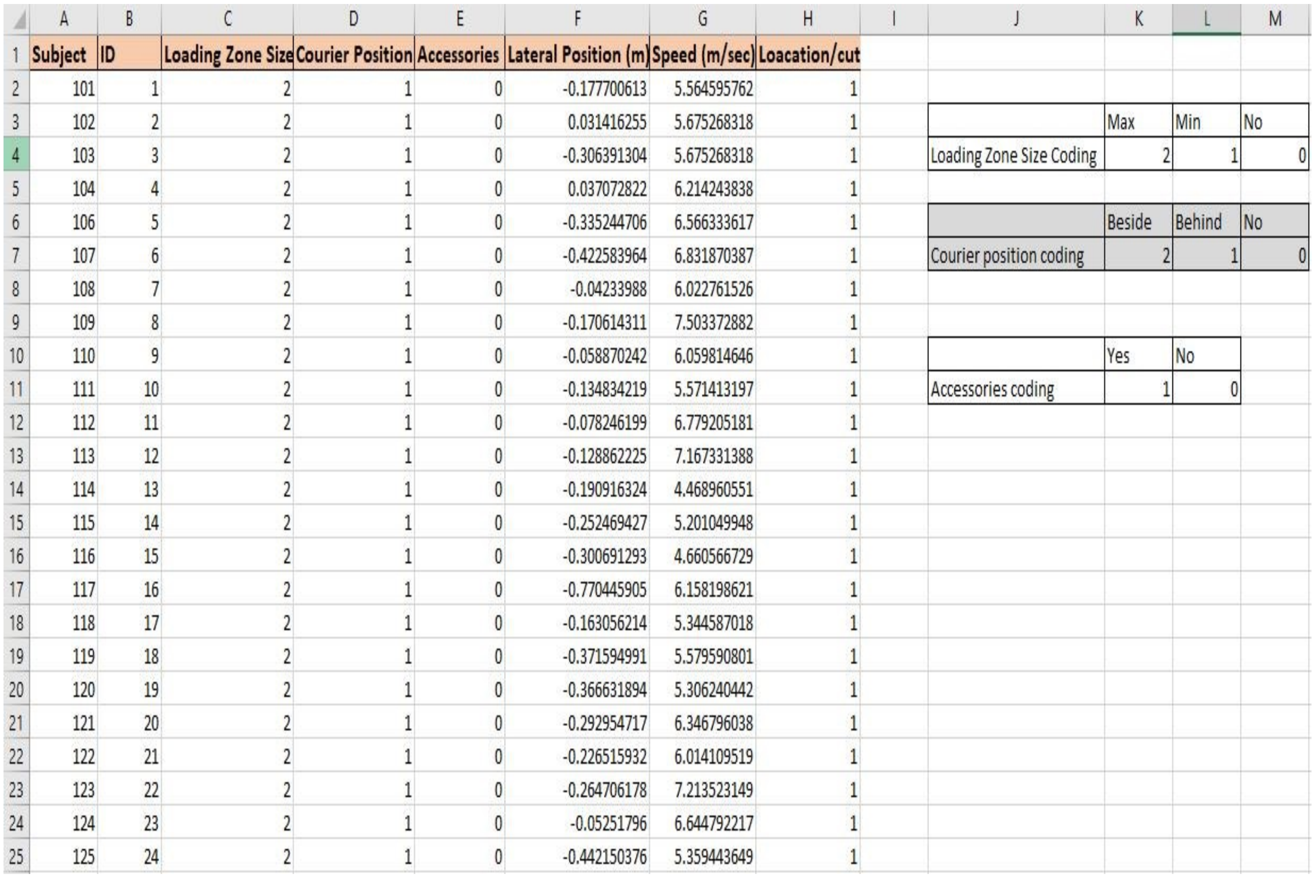
Keywords: Submit any key words that may help people discover the dataset. If any publications have resulted from this work, consider including the keywords associated with the publication(s).

Commercial Vehicles, Loading Zones, Bicycle Simulator, Street Design, Freight Operations, CVLZ

Period of Relevancy: How long will this data remain relevant for and how so how long should we make it available for?
The data collected for this project should remain relevant for many years.

Additional Notes: Any additional notes that might help people understand the dataset should be entered here. The only additional information required by PacTrans is the date at which the dataset is no longer useful and should be removed from the Dataverse, i.e. the dataset expiration date.

APPENDIX C: EXAMPLE SIMULATOR DATA



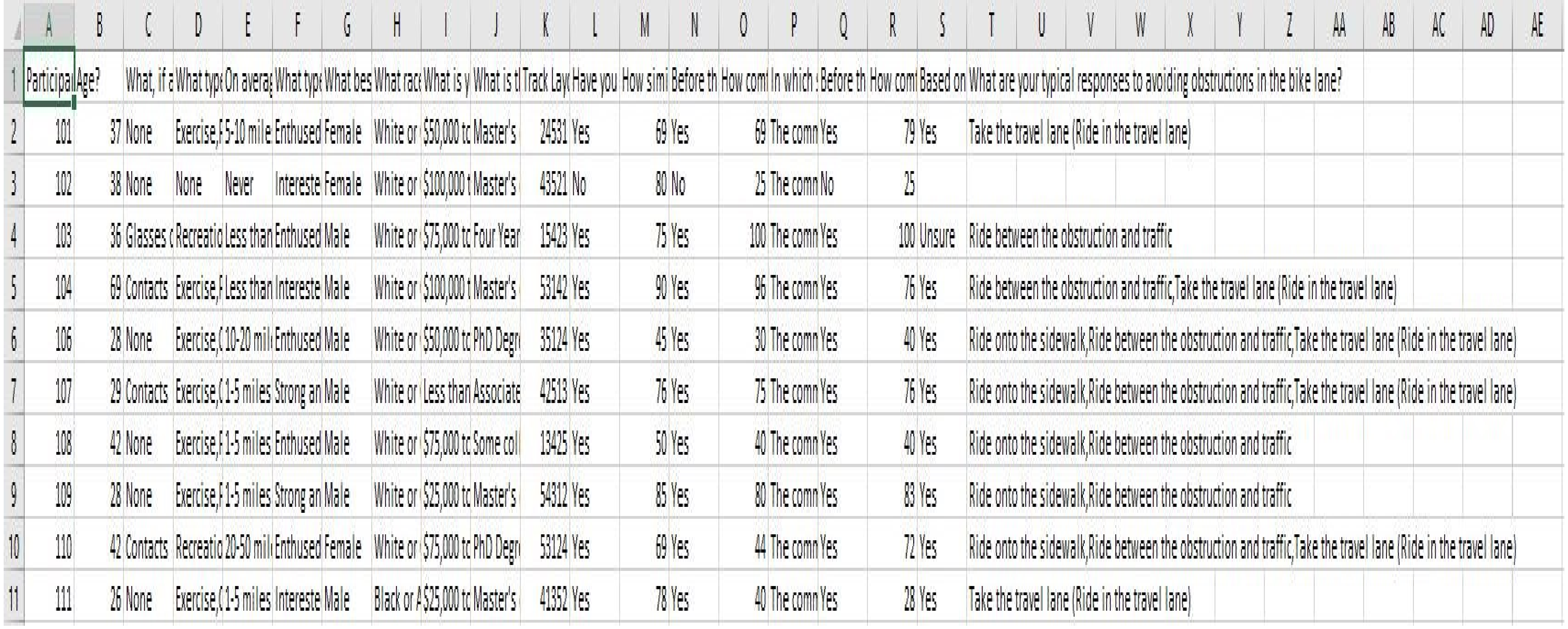
Subject	ID	Loading Zone Size	Courier Position	Accessories	Lateral Position (m)	Speed (m/sec)	Loacation/cut
101	1	2	1	0	-0.177700613	5.564595762	1
102	2	2	1	0	0.031416255	5.675268318	1
103	3	2	1	0	-0.306391304	5.675268318	1
104	4	2	1	0	0.037072822	6.214243838	1
106	5	2	1	0	-0.335244706	6.566333617	1
107	6	2	1	0	-0.422583964	6.831870387	1
108	7	2	1	0	-0.04233988	6.022761526	1
109	8	2	1	0	-0.170614311	7.503372882	1
110	9	2	1	0	-0.058870242	6.059814646	1
111	10	2	1	0	-0.134834219	5.571413197	1
112	11	2	1	0	-0.078246199	6.779205181	1
113	12	2	1	0	-0.128862225	7.167331388	1
114	13	2	1	0	-0.190916324	4.468960551	1
115	14	2	1	0	-0.252469427	5.201049948	1
116	15	2	1	0	-0.300691293	4.660566729	1
117	16	2	1	0	-0.770445905	6.158198621	1
118	17	2	1	0	-0.163056214	5.344587018	1
119	18	2	1	0	-0.371594991	5.579590801	1
120	19	2	1	0	-0.366631894	5.306240442	1
121	20	2	1	0	-0.292954717	6.346796038	1
122	21	2	1	0	-0.226515932	6.014109519	1
123	22	2	1	0	-0.264706178	7.213523149	1
124	23	2	1	0	-0.05251796	6.644792217	1
125	24	2	1	0	-0.442150376	5.359443649	1

	Max	Min	No
Loading Zone Size Coding	2	1	0

	Beside	Behind	No
Courier position coding	2	1	0

	Yes	No
Accessories coding	1	0

APPENDIX D: EXAMPLE SIMULATOR SURVEY DATA

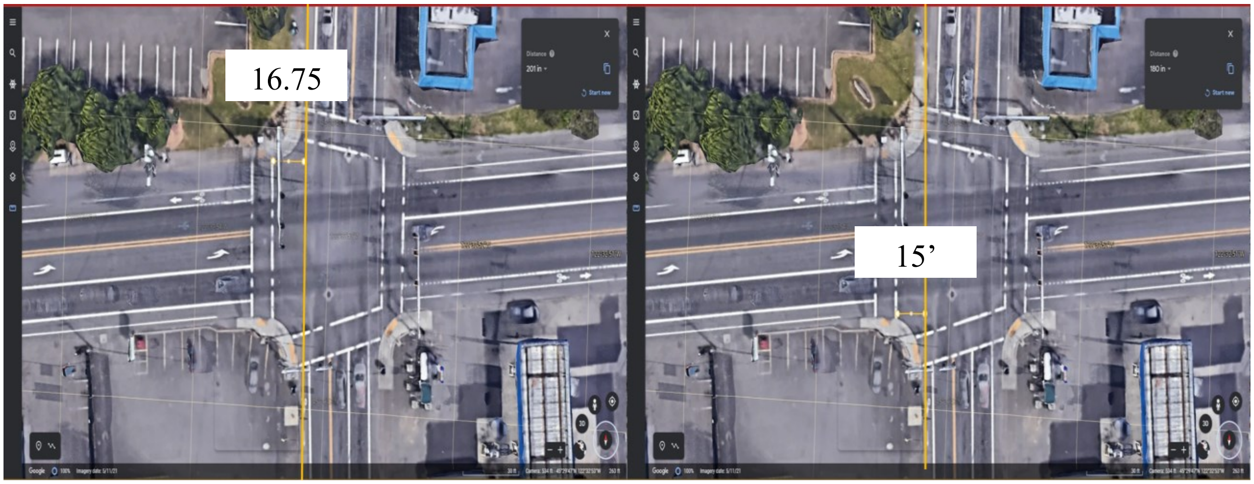


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Participa	Age?	What, if a	What typ	On averag	What typ	What bes	What rac	What is y	What is t	Track Lay	Have you	How simi	Before th	How com	In which	Before th	How com	Based on	What are your typical responses to avoiding obstructions in the bike lane?
2	101	37	None	Exercise,F	5-10 mile	Enthused	Female	White or	$50,000 tc	Master's	24531	Yes	69	Yes	69	The comn	Yes	79	Yes	Take the travel lane (Ride in the travel lane)
3	102	38	None	None	Never	Intereste	Female	White or	$100,000 t	Master's	43521	No	80	No	25	The comn	No	25		
4	103	36	Glasses (	Recreatio	Less than	Enthused	Male	White or	$75,000 tc	Four Year	15423	Yes	75	Yes	100	The comn	Yes	100	Unsure	Ride between the obstruction and traffic
5	104	69	Contacts	Exercise,F	Less than	Intereste	Male	White or	$100,000 t	Master's	53142	Yes	90	Yes	96	The comn	Yes	76	Yes	Ride between the obstruction and traffic,Take the travel lane (Ride in the travel lane)
6	106	28	None	Exercise,(	10-20 mil	Enthused	Male	White or	$50,000 tc	PhD Degr	35124	Yes	45	Yes	30	The comn	Yes	40	Yes	Ride onto the sidewalk,Ride between the obstruction and traffic,Take the travel lane (Ride in the travel lane)
7	107	29	Contacts	Exercise,(	1-5 miles	Strong an	Male	White or	Less than	Associate	42513	Yes	76	Yes	75	The comn	Yes	76	Yes	Ride onto the sidewalk,Ride between the obstruction and traffic,Take the travel lane (Ride in the travel lane)
8	108	42	None	Exercise,F	1-5 miles	Enthused	Male	White or	$75,000 tc	Some col	13425	Yes	50	Yes	40	The comn	Yes	40	Yes	Ride onto the sidewalk,Ride between the obstruction and traffic
9	109	28	None	Exercise,F	1-5 miles	Strong an	Male	White or	$25,000 tc	Master's	54312	Yes	85	Yes	80	The comn	Yes	83	Yes	Ride onto the sidewalk,Ride between the obstruction and traffic
10	110	42	Contacts	Recreatio	20-50 mil	Enthused	Female	White or	$75,000 tc	PhD Degr	53124	Yes	69	Yes	44	The comn	Yes	72	Yes	Ride onto the sidewalk,Ride between the obstruction and traffic,Take the travel lane (Ride in the travel lane)
11	111	26	None	Exercise,(	1-5 miles	Intereste	Male	Black or A	$25,000 tc	Master's	41352	Yes	78	Yes	40	The comn	Yes	28	Yes	Take the travel lane (Ride in the travel lane)

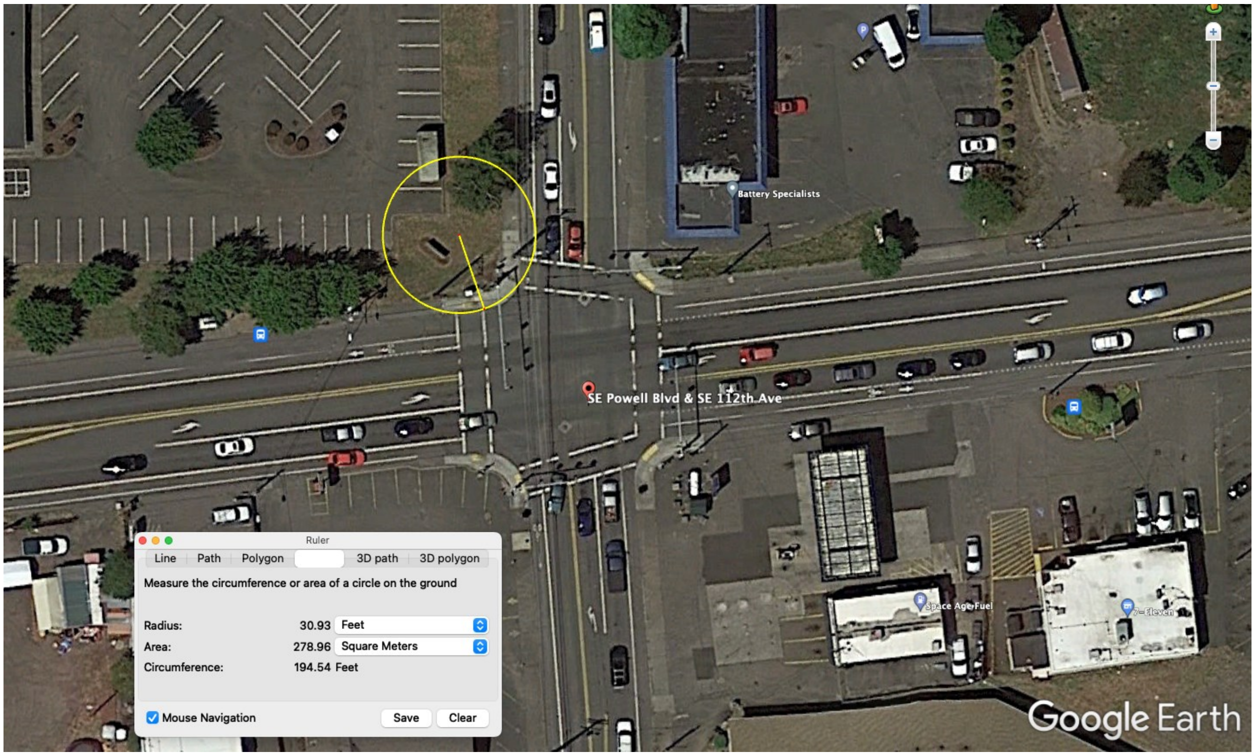
APPENDIX E: FIELD LOCATIONS AND MEASUREMENTS

Location 1: SE Powell Blvd. and SE 112th St

Setback (highlighted in red) and corner (highlighted in yellow) crosswalks at SE Powell Blvd. and SE 112th St



Average Setback Distance Measurement at SE Powell Blvd. and SE 112th St



Measure the circumference or area of a circle on the ground

Radius: 30.93 Feet

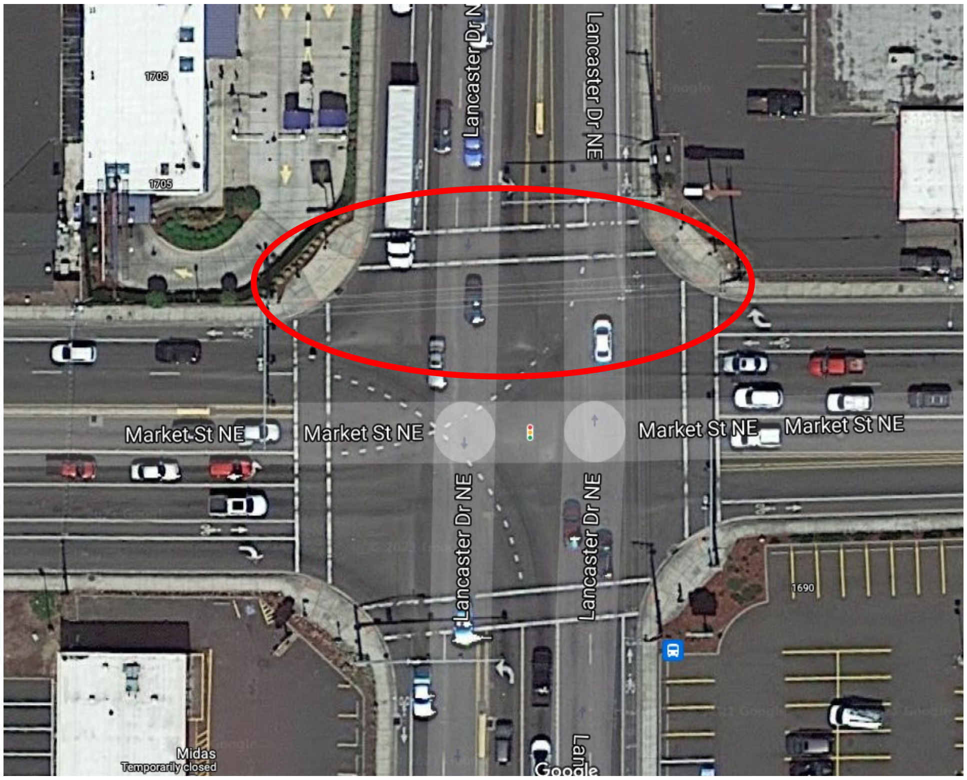
Area: 278.96 Square Meters

Circumference: 194.54 Feet

☑ Mouse Navigation

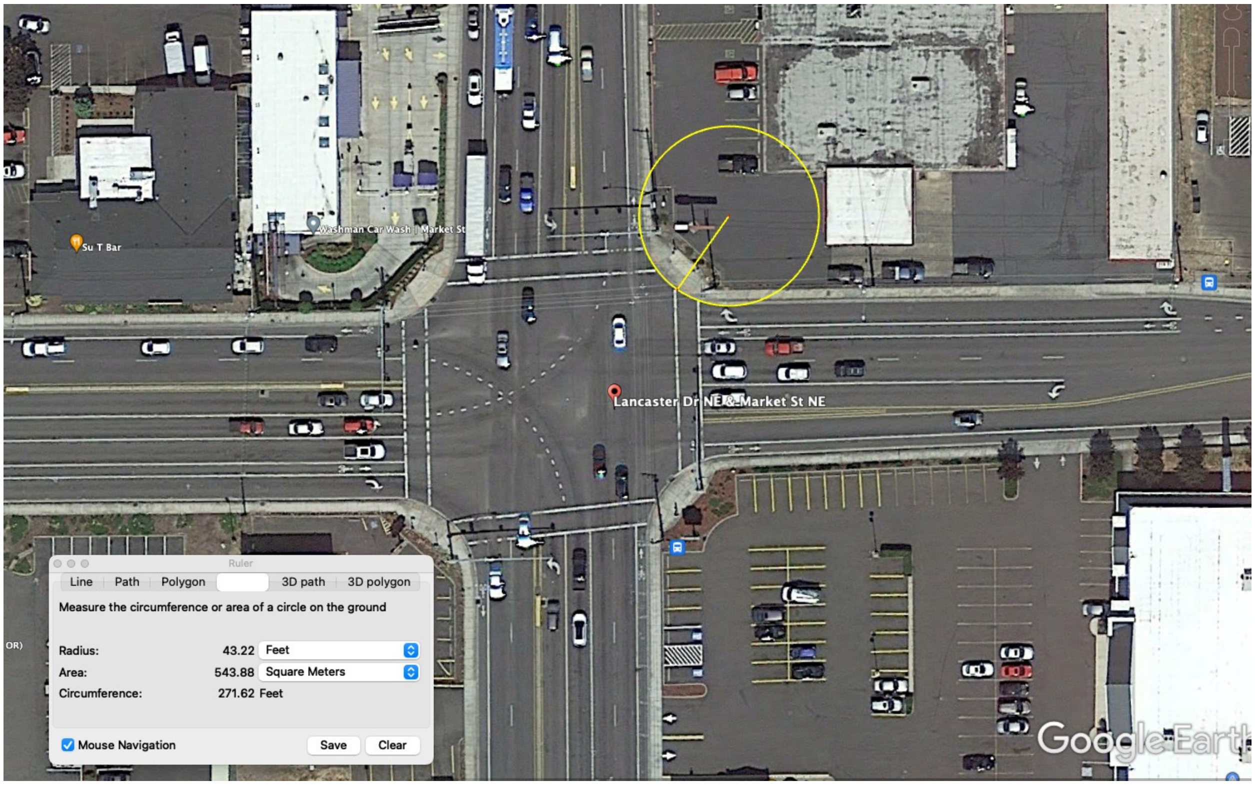
Curb Radius Measurement at SE Powell Blvd. and SE 112th St.

Location 2: Lancaster Dr. NE and Market St. NE



Setback (highlighted in red) crosswalk at Lancaster Dr. NE and Market St. NE

Average Setback Distance Measurement at Lancaster Dr. NE and Market St. NE



Measure the circumference or area of a circle on the ground

Radius: 43.22 Feet

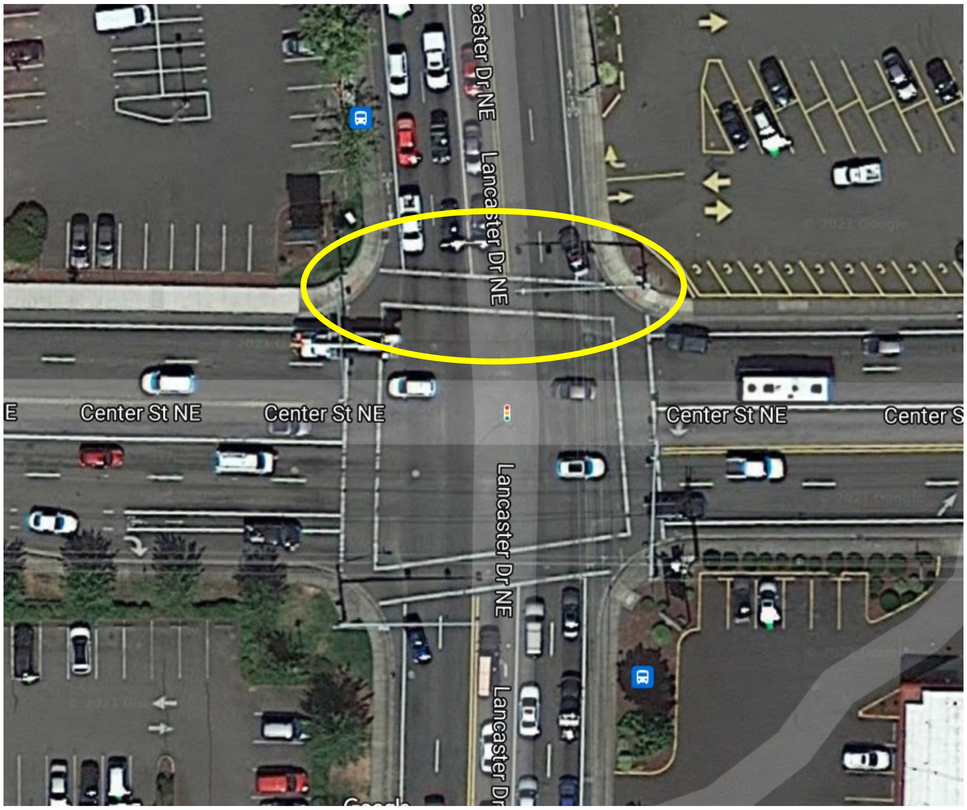
Area: 543.88 Square Meters

Circumference: 271.62 Feet

☑ Mouse Navigation

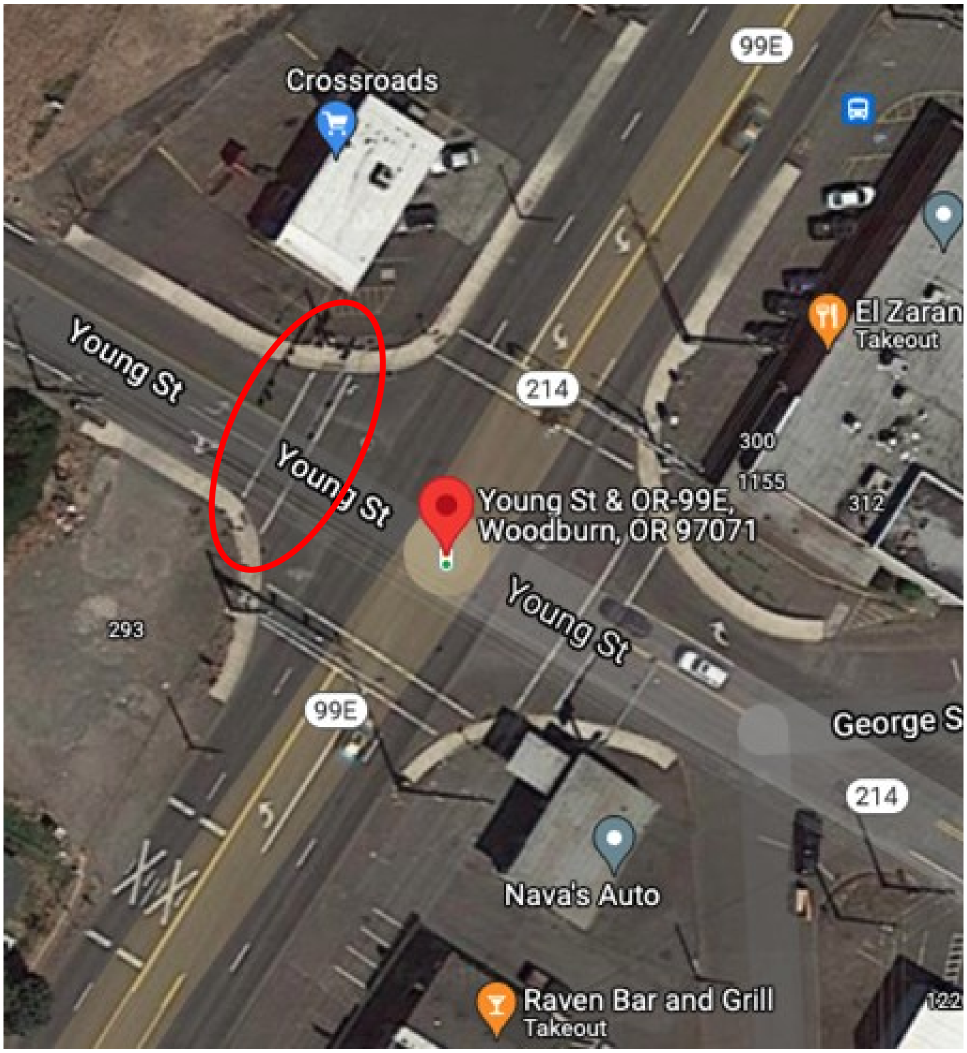
Curb Radius Measurement at Lancaster Dr. NE and Market St. NE

Location 3: Lancaster Dr. NE and Center St. NE



Corner (highlighted in yellow) crosswalk at Lancaster Dr. NE and Center St. NE

Location 4: Young St. and OR 99E



Setback (highlighted in red) crosswalk at Young St. and OR 99E

Average Setback Distance Measurement at Young St. and OR 99E

Measure the circumference or area of a circle on the ground

Radius: 50.52 Feet
Area: 744.79 Square Meters
Circumference: 317.86 Feet

☑ Mouse Navigation

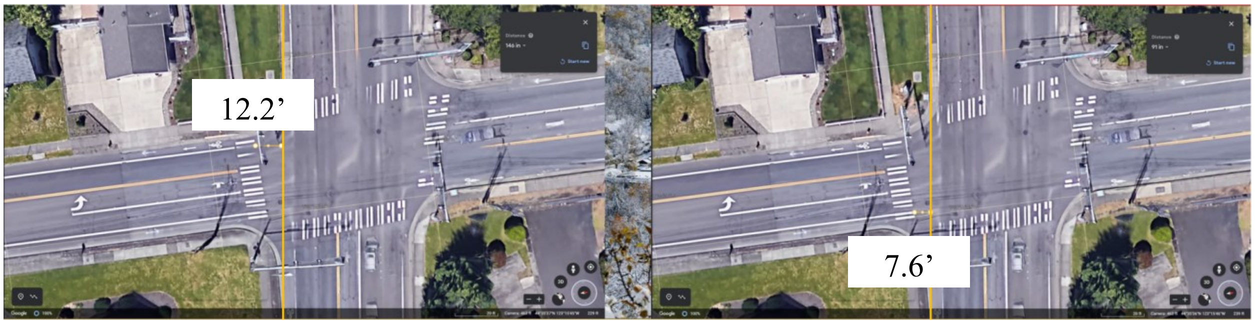
Curb Radius Measurement at Young St. and OR 99E

Location 5: E Lincoln St. and OR 99E

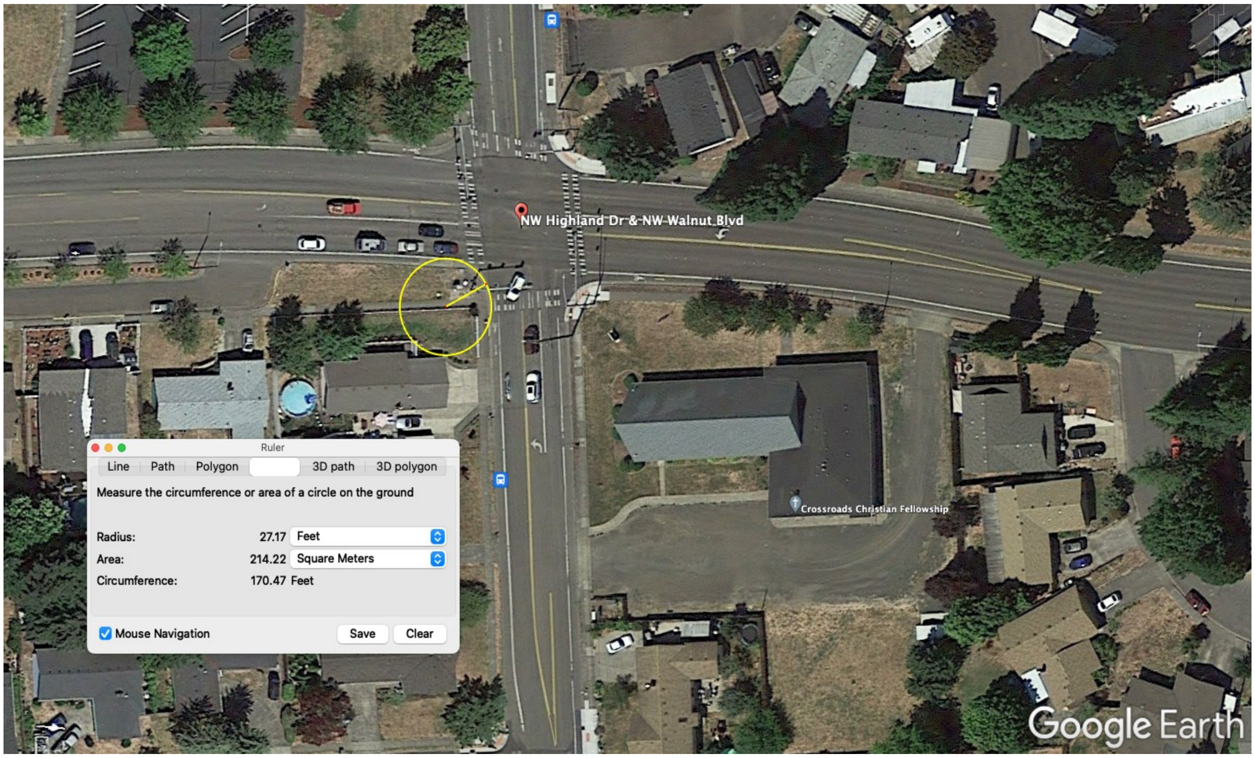
Corner (highlighted in yellow) crosswalk at E Lincoln St. and OR 99E

Location 6: NW Highland Dr. and NW Walnut Blvd.

Setback (highlighted in red) crosswalk at NW Highland Dr. and NW Walnut Blvd.



Average Setback Distance Measurement at NW Highland Dr. and NW Walnut Blvd.



Measure the circumference or area of a circle on the ground

Radius: 27.17 Feet
Area: 214.22 Square Meters
Circumference: 170.47 Feet

☑ Mouse Navigation

Curb Radius Measurement at NW Highland Dr. and NW Walnut Blvd.

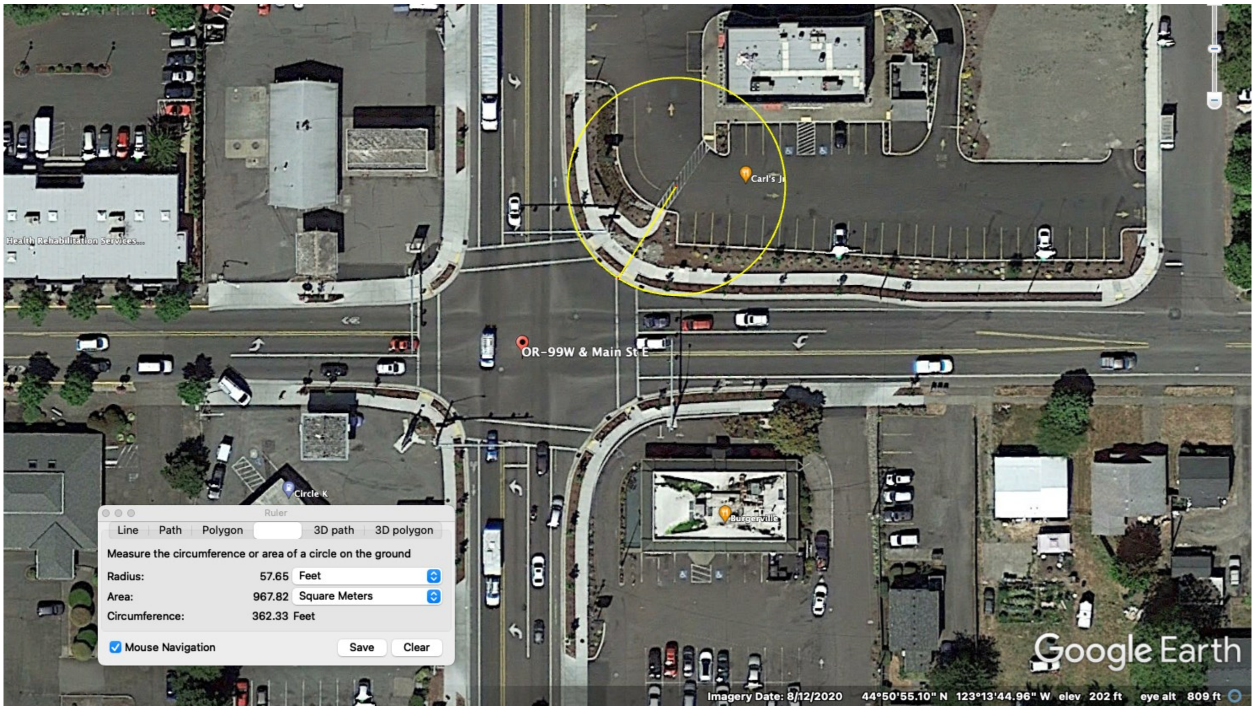
Location 7: NW 29th St. and NW Walnut Blvd.

Corner (highlighted in yellow) crosswalk at NW 29th St. and NW Walnut Blvd.

Location 8: OR 99W and Main St.

Setback (highlighted in red) crosswalk at OR 99W and Main St.

Average Setback Distance Measurement at OR 99W and Main St.



Measure the circumference or area of a circle on the ground

Radius: 57.65 Feet

Area: 967.82 Square Meters

Circumference: 362.33 Feet

☑ Mouse Navigation

Curb Radius Measurement at OR 99W and Main St.

Location 9: OR 99W and SW 5th St.

Corner (highlighted in yellow) crosswalk at OR 99W and SW 5th St.