ABSTRACT

SALAMATI, KATAYOUN. Proxy Methods for Quantifying Pedestrian Accessibility at Complex Street Crossings. (Under the direction of Professor Nagui M. Rouphail and Dr. Bastian J. Schroeder).

This research intends to introduce three reproducible proxy methodologies to understand the contributing factors and assess safety and accessibility of pedestrians (who are blind). These methodologies are; 1) a field observational study of pedestrian-vehicle conflicts, 2) a controlled field study of driver yielding behavior to pedestrians, and 3) a controlled laboratory study of the effect of different treatments at roundabout approaches to increase driver yielding rate. Each of three proxy methods for evaluating pedestrian accessibility offers its own advantages and shortcomings. This research demonstrates that each of the three methods can be applied to the study of pedestrian access to modern roundabouts, targeting different aspects of accessibility with an emphasis on access to pedestrians who are blind.

The first proxy method is the Conflict-based Assessment of Pedestrian Safety (CAPS) framework. The CAPS method is based on measurements of microscopic traffic variables and relates pedestrian crossing decisions (interaction between a pedestrian and a vehicle) to advanced measurements of vehicle dynamics to estimate lane-by-lane conflicts. The CAPS framework is applied to a study of blind pedestrian crossings at a multi-lane roundabout, and it is calibrated using optimization techniques in the form of three clustering methodologies (K-mode, K-means and K-median). The clustering algorithms assisted in reducing the number of variables for CAPS from five to three:

Time-to-collision, deceleration rate and lane condition. However the methodology requires more data collection for calibration and error reduction.

The second proxy method aims to identify the contributing factors affecting the likelihood of a driver yielding to pedestrians at two-lane roundabouts approaches. The method contributes a controlled field data collection protocol that provides event-level data on driver decisions, and is evaluated using a logistic regression approach. The logistic regression models developed from the collected data show that the likelihood of a driver yielding at the entry leg of roundabouts is higher than at the exit. Drivers tend to yield to pedestrians carrying a white cane more often than to sighted pedestrians. Drivers traveling in the far lane, relative to pedestrian location, have a lower probability of yielding to a pedestrian. As the speed increases, the probability of driver yielding decreases. At the exit leg of the roundabout, drivers turning right from the adjacent lane have a lower propensity of yielding than drivers coming from other directions. The research enables researchers to explicitly account for these factors contributing to (low) yielding at multilane roundabouts, thus target specific strategies that may improve yielding and thereby accessibility.

The third methodology is a controlled laboratory study with a driving simulator, which offers a cost-effective opportunity to test various treatments that might affect the driver yielding behavior, as a pre-screening to field installation and testing. It also enables researchers test driver behavior by not only controlling the pedestrian, but also the type of environment and treatment that the driver is exposed to. The treatments evaluated by the simulator are stop bar and crosswalk re-location away from the beginning of exit leg, and two types of beacons: a Pedestrian Hybrid Beacon (PHB) and a Rectangular Rapid Flashing Beacon (RRFB). The study shows that the installation of any kind of beacon

(PHB or RRFB) with or without crosswalk relocation, increases driver yielding rates significantly. The results of using an eye tracker on drivers to track their gaze pattern while exiting the roundabout shows that having a beacon installed with crosswalk relocation increases drivers' attention both on the beacon and the pedestrian along the road. The study suggests the need for a more in-depth field test of crosswalk relocation at multi-lane roundabouts.

The controlled field study and controlled laboratory study are both effective in helping understand the factors that increase crossing opportunities for pedestrians and ultimately increases the accessibility of the intersection. However, the field observational study of pedestrian-vehicle interactions and the CAPS framework enables the researcher to quantify the risk level of crossing decisions made by pedestrians. The simulator study is a highly useful approach for screening potential treatment alternatives prior to filed installation of only the most promising options.

Overall, this research described and applied there divers proxy methods for quantifying different aspects of pedestrian accessibility, and illustrated how each method can contribute significantly to the understanding of the complex interaction of drivers and (blind) pedestrians at complex street crossings.

Proxy Methods for Quantifying Pedestrian Accessibility at Complex Street Crossings

by
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DEDICATION

This dissertation is dedicated to my family and the educators I have had the privilege of learning from throughout my life. My entire family has supported me in all of my academic aspirations, for which I am eternally grateful.

To an amazing person and the best husband, *Ramin*, who provided unwavering support throughout our life together, especially during my graduate education.

To my best childhood friend and my biggest fan, grandma *Maheen*.

To my parents, *Homa* and *Manouchehr*, who always have unconditional love and support, provide guidance throughout my life and try to make me a better person every day.

To my brother *Koroush*.

To *Shirin* and *Mehraban* who supported me when I moved to the United States.

BIOGRAPHY

Katayoun (Katy) Salamati is a graduate assistant at North Carolina State University and Institute for Transportation Research and Education (ITRE). She is fulfilling the requirements for her Ph.D. in Civil Engineering with minor in Industrial and Systems Engineering. She is originally from Tehran, Iran. Katy received her Bachelor of Science from Sharif University of Technology in Industrial and Systems Engineering. She received her Master of Science in Industrial and Systems Engineering from University of Southern California, Los Angeles.

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1 INTRODUCTION AND MOTIVATION

Pedestrians are vulnerable users of transportation facilities and are subjected to a higher risk than other road users (FHWA 2004). In recent years awareness about the challenges that pedestrians face using different transportation facilities has increased. Therefore, designing multipurpose facilities involves constant trade-offs between safety and efficiency for their users, especially when the user group include pedestrians. Pedestrian facilities must be accessible to all pedestrians, including those with vision or mobility impairments, as required by the American with Disabilities Act (ADA) (DOJ 1990).

Intersections are the type of transportation facility where pedestrians and vehicles directly interact, which may result in *conflicts*. Signals and other types of traffic control devices (such as roundabouts or stop signs) represent engineering approaches intended to balance the *safety* and *efficiency* of different types of users at intersections. These devices prioritize and enforce right-of-way rules for users by controlling the traffic movement, while assuming equal access to pedestrians with vision or mobility impairments.

There are mainly two types of intersections, signalized and unsignalized. Traffic signals explicitly prescribe the right-of-way rules (for example, by designating a pedestrian phase while stopping the conflicting vehicle movements at a red signal). Right-of-way rules for unsignalized intersections are based on the type of traffic control used at those intersections. Since all vehicles are required to stop at stop signs, pedestrians are given a crossing opportunity. However, studies have shown that drivers fail to observe the right-of-way rules for yield control unsignalized intersections

(Schroeder et al. 2011a, Fitzpatrick et al. 2006). Modern roundabouts and channelized right turn lanes are forms of yield controlled unsignalized intersections.

Modern roundabouts represent an intersection form that has demonstrated safety benefits for motorized traffic and further offers significant operational benefits over signalized or stop control intersections in many applications (Rodegerdts et al. 2010). However, due to the mixed priority right-of-way rules at roundabouts, research has documented significant pedestrian accessibility challenges at these intersections (Schroeder et al. 2011a) for pedestrians who are blind. The Schroeder et al. (2011a) research and other prior work (Ashmead et al. 2004, Guth et al. 2005) traditionally focus on filed-based experiments at crossings with and without treatments, often involving blind study participants making supervised crossings or crossing decisions. While such approaches represent a valid and useful data collection approach, results can be subject to various sources of variability and error as described later in this section.

This research focuses on the development of propose proxy methodologies to quantify pedestrian accessibility at complex yield-controlled intersections. The methodologies are based on studies conducted at several multilane roundabouts across the United States or tested in a state-of-the-art driving simulator of multilane roundabout operations. However, all methods are applicable to other complex unsignalized intersections. The primary motivators for this research are:

a) Need for methodologies to quantify pedestrian accessibility to intersections in a safe, objective way which would addresses the shortcomings of current field studies; and

b) Need for methodologies for evaluating different treatments at roundabouts to provide objective empirical performance data and lend decision-support when comparing treatment alternatives.

The motivation for focusing on roundabouts stems from:

a) Increasing interest in building roundabouts in the United States;

b) Specific accessibility requirements by ADA for roundabouts

The following sections further explain why roundabouts are chosen as the focal point of this dissertation, offer a definition of accessibility, describe the current state of practice in studying pedestrian accessibility at complex street crossings, and discuss the shortcoming of current research approach. At the conclusion of this chapter, the objectives and limitations of this research are stated.

1.1 Background

In spite of the fact that the idea of modern roundabouts had been developed and applied in Europe back in the 1950s, the first two modern roundabouts in the United States were not built until 1990 in Summerlin, Nevada (Jacquemart 1998). Modern roundabouts have now been used in the United States for over 20 years. Because of their operational and safety benefits for vehicles compared to signalized and stop controlled intersections, there has been an increasing interest among engineers and designers to build more roundabouts. There were only 38 modern roundabouts in the United States as of 1997, but that number has increased to more than 2000 single and multilane roundabouts as of 2010 (Rodegerdts et al. 2010).

The National Institutes of Health (NIH), Federal Highway Administration (FHWA), National Cooperative Highway Research Program (NCHRP), and other organizations have sponsored a series of research projects on the safety and accessibility of modern roundabouts for pedestrians, especially those who are blind (for example NIH R01 EY12894-03, TOPR #34 and NCHRP 3-78) .

Accessibility and safety of a transportation facility are not the same, but safety is one component of accessibility. The following sections distinguish safety and accessibility analysis of roundabouts for pedestrians.

1.1.1 Pedestrian Safety Analysis of Roundabouts

The frequency of crashes at an intersection is related to the number of *conflict points*. “A conflict point is a location where the paths of two motor vehicles, or a vehicle and a bicycle or pedestrian path, diverge, merge or cross each other” (Rodegerdts 2010). Pedestrians at roundabouts face fewer conflict points compared to signalized, two-way stop-controlled and all-way stop-controlled intersections, which would arguably make them a safe intersection form. For those road users; however, the number of conflict points increase as the number of lanes increases at multilane roundabouts.

Single-lane roundabouts are considered safer for pedestrians, vehicles and cyclists, compared to multilane roundabouts (Rodegerdts et al. 2010). Multiple lanes can create multiple threat situations for pedestrians and cyclists therefore increase the number of conflicting and interacting movements for drivers and pedestrians (PEDSAFE, 2012). Pedestrians are forced to cross multiple lanes of traffic and, since the approaches are not signalized, they can be faced with a *multiple threat* situation from traffic. A multiple threat situation describes an event where a yielding vehicle in the near lane (relative to the pedestrian) may visually and auditorily mask the arrival of a vehicle in the far lane, while also obscuring the presence of the pedestrian for the driver of that vehicle (PEDSAFE 2012). Further the auditory environment is more complex than other forms of intersections and therefore challenging for blind pedestrians (Schroeder et al. 2009).

Although there have been attempts to develop crash models for roundabouts in the United States, the models are only applicable to vehicular crashes. NCHRP report 572 (Rodegerdts et al. 2007) and NCHRP report 672 (Rodegerdts et al. 2011) successfully calibrated the U.K. roundabout crash models with U.S. data, for vehicles. To date, it has not been possible to model pedestrian crashes at roundabouts in the United States since pedestrian exposures are oftentimes low, and U.S. data therefore have a very small proportion of pedestrian crashes (only 5 crashes as of 2007) (Rodegerdts et al. 2007).

Due to the fact that most multilane roundabouts in the United States are in suburban or rural areas with low pedestrian volumes and small number of pedestrian collisions, a safety study of multilane roundabouts using crash analysis in the United States is simply not feasible. The research on roundabouts in the United States has yet to explore the safety effects of roundabouts on pedestrian-vehicle crashes. Current studies available in European countries fail to clearly distinguish pedestrian crash rates between single and multilane roundabouts (Rodegerdts et al. 2011). However, separate studies of pedestrian collision data in Great Britain (Maycock and Hall 1984, Crown 1998), the Netherlands (Schoon and Minnen 1993) and Norway (Seim 1991) shows that the safety benefits of roundabouts compared to other signalized intersections carries over from vehicles to pedestrians as reported by Rodegerts et al. (2011) in NCHRP report 762. British statistics show a 34% decrease in the number of pedestrian crashes per million trips for modern roundabouts than signals (33% and 67% respectively) (Maycock and Hall 1984, Crown 1998). A pedestrian collision study of 181 intersections converted to roundabouts in Netherlands shows a 73% reduction in pedestrian crashes and 89%in pedestrian injury crashes (Schoon and Minnen 1993). A collision study of 59 roundabouts and 124 signalized intersections in Norway shows only 3% of the crashes in roundabouts involved pedestrians versus 20% at signalized intersections (Seim 1991).

1.1.2 Pedestrian Accessibility at Roundabouts

According to The Americans with Disabilities Act (ADA) Glossary of Terms, *Accessible* " refers to a site, facility, work environment, service, or program that is easy to approach, enter, operate, participate in, and/or use safely and with dignity by a person with a disability" (US Access Board 2011). Specifically ADA legislation requires that public transportation facilities be "accessible to and usable by" all road users, including pedestrians with vision or mobility impairments. Accessibility of a roundabout implies that all pedestrians, especially those who are disabled, are able to identify safe crossing opportunities, in terms of crossable gaps or driver yielding to pedestrians, with reasonable delays (US Access Board 2011). Therefore a low or zero pedestrian crash rate does not imply that multilane roundabouts are accessible to all pedestrians, because a highly inaccessible location may be perceived as so challenging that actual pedestrian exposure is very low. Crossable gap is the time between arrivals of two consecutive vehicles at the crosswalk which is long enough so pedestrian can safely being crossing and clear the crosswalk before the next vehicle arrives. Values of crossable gap vary based on width of the crosswalk and pedestrian speed.

Several recent studies have shown that roundabouts are not easily accessible by pedestrians, especially those with vision impairments, for three primary reasons: 1) motorists fail to yield to pedestrians where the crossing is not signalized, 2) noise from circulating traffic can make auditory detection of gaps difficult (especially at the exit), and 3) gaps large enough to be aurally detected may be infrequent (Schroeder et al. 2006, Schroeder et al. 2009). As a result, the United States Access Board has drafted guidelines that call for the provision of accessible pedestrian-actuated signals at multi-lane roundabouts to make them accessible (US Access Board 2011). There is concern in the engineering community that such general requirements will unnecessarily increase the cost of this very safe intersection form. Further, research has already identified non-signal treatments that may be adequate in some cases including a raised pedestrian crossing (Schroeder et al. 2011a). The roundabout and accessibility community is in need of more research to evaluate and compare different crossing geometries, as well as the effectiveness of pedestrian crossing treatments.

This document concentrates on developing methods which assist in quantifying pedestrian accessibility to complex intersections, with focus a on blind pedestrians and multi-lane roundabouts. However, the methodologies can be applied to other forms of complex intersections. The next sections briefly describe the current studies and methodologies for quantifying accessibility for pedestrians at complex intersections, discuss the shortcomings and sources of error in the status quo approaches and explain how and where the methods in this document are applicable to fill some of the gaps in research.

1.1.3 Current Studies in Accessibility of Roundabouts and Limitations

The Americans with Disabilities Act (ADA) requires that new and altered facilities be designed and constructed to meet an equivalent ('accessible') standard. The draft Public Rights-of-Way Accessibility Guidelines (PROWAG) set minimum criteria for meeting this legal requirement, thus serving as a safe place for designers (who may pursue other methods that can be shown to provide equivalent facilitative) (US Access Board 2011). The draft PROWAG presently stress the use of accessible pedestrian-actuated signals for multi-lane crossings at roundabouts and channelized turn lanes. There is a need to develop a method or methods that can be used to efficiently and safely evaluate the accessibility of an intersection to various groups of pedestrians, including those with vision impairments. At the same time, the methods should provide detailed data on the interaction of pedestrians and vehicles that are sensitive to variations in pedestrian behavior, traffic operational parameters, and roadway design changes from one intersection to another, including the use of infrastructure-based crossing treatments.

The accessibility challenges of blind pedestrians for street crossings include: locating the crosswalk, aligning to cross, identifying a crossing opportunity and maintaining alignment during crossing (Schroeder et al. 2011a). Identifying a crossing opportunity is the matter that is addressed in this dissertation.

NCHRP Report 674, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities (Schroeder et al. 2011a) and NIH/NEI Bioengineering Research Grant R01 EY12894-03 (NIH 2010) are national research efforts intended to study and improve accessibility for visually impaired pedestrians at various facilities, and under consideration of different types of infrastructure-based crossing treatments. These research studies created and applied an analysis framework to "quantitatively describe the crossing performance of individual pedestrians as well as to quantify the accessibility impacts of the tested crossing treatments" (Schroeder et al. 2011a). The "*Accessibility Framework*" consists of four components:

1- Availability of sufficient crossing opportunity in forms of vehicle yields and crossable gaps;
2- Detection and utilization of crossing opportunity by (blind) pedestrians;
3- Reasonable delay time associated with utilizing a crossing opportunity; and
4- Degree of risk (safety) associated with each crossing opportunity.

Studies to evaluate crossing performance of individuals and different treatments are often *time-consuming*, *expensive,* and most importantly are *associated with a certain degree of risk* to the (blind) study participants. Past studies evaluating treatments generally involved having blind participants, accompanied by an Orientation and Mobility (O&M) specialist, cross at different locations, observing their crossing behavior under varying treatment conditions, and documenting risky crossing decisions (Schroder et al. 2011a, Ashmead et al. 2005).

Besides being time-consuming and expensive, there are six different sources of noise or error in such studies of blind pedestrian crossings. The sources of error and/or variability are subjectivity by the O&M specialist, pedestrian behavioral differences, driver behavioral differences, random arrival of pedestrians and traffic, differences across sites and different types of treatments. Figure 1 shows the six sources of error and/or variability in study of blind pedestrian crossings. Each of these errors is explained below.

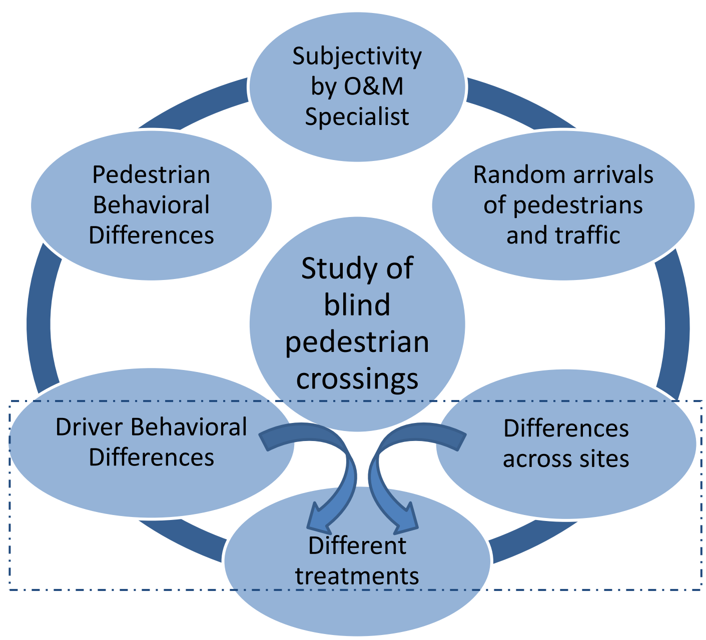


Figure 1 Sources of Error in Study of Blind Pedestrian Crossings

Subjectivity by the O&M Specialist: The current studies of pedestrian crossings available in literature put participants in potentially risky and unsafe situations, and participants must at all times be accompanied by an Orientation and Mobility (O&M)

specialist to assure participant safety. A primary safety measure in these studies is the *O&M Intervention*, which is defined as the O&M specialist physically stopping the participant if he or she decided to step into the roadway to begin crossing at a potentially dangerous time.

Although interventions are a valid measure and have significantly helped bring this area of research forward, they have some drawbacks. Crossing experiments are costly and require more time and professional human resources (O&M specialist), therefore it is difficult to maintain consistency in running the experiment and replicate the results. Clearly, these intervention events or pullbacks are important indicators of risk, but are limited for several reasons. Interventions are:

- <u>Subjective</u>, in that they are critically linked to one individual's perception of risk (the O&M specialist);
- <u>Binary</u>, in that they can only distinguish between 'safe' and 'risky' without distinguishing between different levels of risk;
- <u>Dangerous,</u> since they are the direct result of a potentially dangerous crossing decision.

With (blind) pedestrian safety being the primary measure to evaluate accessibility, a study approach and evaluation framework is needed that can quantify pedestrian risk in a safe, objective, and consistent manner.

Random Arrivals of Pedestrians and Traffic: One of the components of accessibility of pedestrians to intersections is the availability of crossing opportunities in the form of crossable gaps and driver yields, and the safe judgment of pedestrians of these crossing opportunities. Studies of blind pedestrian crossings occur during different traffic patterns, time of day, peak or off peak conditions. Not availability of crossable gaps is affected by traffic volume but driver behavior may also be influenced by time of day (e.g. peak or off peak time periods). In addition to that, a driver that approaches one pedestrian standing at the crosswalk might have a different reaction than approaching a group of pedestrians waiting for crossing opportunity. The hypothesis that random arrivals of pedestrians and traffic affects the study of blind pedestrian crossing and to the size of the effect need to be tested by controlling for these variables. Current field studies may test some participants at low traffic conditions and others during much busier traffic periods. The performance of each participant is thus always tied to operating conditions, making general conclusions about accessibility challenging.

Pedestrian Behavioral Differences: Blind study participants who volunteer their time for such research studies are local people living close to study location. The subjects have different commuting and navigation skills, which adds more variability to the data. Some subjects are experienced travelers and can recognize the traffic patterns and find the crossing opportunities earlier than others. NCHRP report 674 shows variability in the performance of different subjects in areas of detecting and utilizing crossing opportunities and pedestrian delay and emphasizes the importance of being able to control for such (Schroeder et al. 2011a). In most prior studies, at least one participant has “good” performance (low risk and delay), while others struggled with the task at hand.

Driver Behavioral Differences, Differences across Sites and Different Treatments: These three sources of variability are related to each other as shown in Figure 1. Yielding is mainly a behavioral attribute of each driver and is related to how drivers in different traffic conditions choose whether to yield to a pedestrian or not. Driver yielding behavior also changes considerably across regions and throughout the country, but may do so differences across regions or among drivers. Different treatments such as signals, beacons, speed bumps or traffic calming strategies may affect the driver yielding behavior. In addition, other factors such as pedestrian behavior, level of law enforcement in the region, and general cultural factors also affect driver behavior. Therefore it is difficult to isolate the driver behavior from a pedestrian crossing study. NCHRP report 572 (Rodegerdts et al., 2007) collected data on pedestrian crossings at 10 single lane and multilane roundabout approaches and captured the behavior of the motorist interaction with pedestrians. The yielding rates varied from 0% to 84% based on the approach that pedestrian was crossing (entry or exit), or the type of yield by driver (active or passive). NCHRP report 562 (Fitzpatrick et al., 2006) reported variable yielding rates for various treatments. A study of overhead flashing beacon system shows driver yielding rates varied from 30% to 76% across 18 studied sites (Fitzpatrick et al., 2006). Although these studies report the variability of driver yielding behavior different treatments and regions, they fail to give proper detail in the analysis. Knowing only a single yielding rate poses challenges for treatment evaluation. Therefore, this research considers other types of studies as proxy methods to gain more in-depth knowledge and quantification of driver behavior.

1.2 Research Objectives and Contribution

This research aims to develop objective and reproducible proxy methodologies to quantify pedestrian accessibility at complex unsignalized intersections such as multilane roundabout, while controlling for pedestrian behavior, driver behavior, traffic patterns, site geometric attributes, and presence of crossing treatments. The previous section discussed the sources of error in current methodologies for blind pedestrian crossings which is to describe the crossing performance of blind pedestrians and an attempt to quantify pedestrian accessibility. The objective of this dissertation is to addresses these sources of variability by introducing three proxy methodologies. Each of the tested methods controls for one or more common sources of error reducing the amount of observed variability and noise in collected data.

Each of the methodologies presented here attempt to address one of the components of the “Accessibility Framework” as well as controlling for sources of error. However, these methods have their own limitations which are addressed in the next section.

The research offers three principal contributions in the form of different methodological approaches for studying pedestrian accessibility and for overcoming one of more of these sources of variability:

1. Field observational studies of vehicle-pedestrian interaction for pedestrian crossings at multilane roundabouts and development of a conflict-based assessment of pedestrian safety (CAPS) framework. This field study explores the dynamics of the pedestrian decision-making process for choosing a safe crossing opportunity at multilane roundabouts. It addresses the fourth component of the

accessibility framework which is “degree of risk associated with each crossing decision” and attempts to control for the error originated from “subjectivity by O&M specialist”. The goal of CAPS is to present a consistent framework that quantifies the level of risk for each pedestrian crossing decision based on the characteristics of pedestrian-vehicle interaction and aims to control for subjectivity of O&M decision by introducing a formulized and objective risk assessment metric.

2. Controlled field experiment for evaluating driver yielding behavior to pedestrians at multilane roundabouts. This study explores the dynamics of the driver decision making process to yield to pedestrians at multilane roundabouts. The approach attempts to address the first component of the accessibility framework which is the availability of crossing opportunities. However this study only focuses on driver yielding as a form of crossing opportunity. Availability of crossable gaps is not discussed in this document but is well covered in the traffic literature. The methodology attempts to control for pedestrian behavioral differences and differences across sites.
3. Laboratory based study that explores different pedestrian treatments at the exit leg of roundabouts to increase driver yielding rate, in a driving simulator environment. This study aims to address the first component of the accessibility framework which is availability of crossing opportunity by testing different treatments which would provide more crossing opportunities for pedestrians. The driving simulator study enables the research to control for different treatments and

random arrival of pedestrians and traffic. It also controls for driver behavioral differences by enabling the researchers to test the study on a particular cohort of drivers as needed.

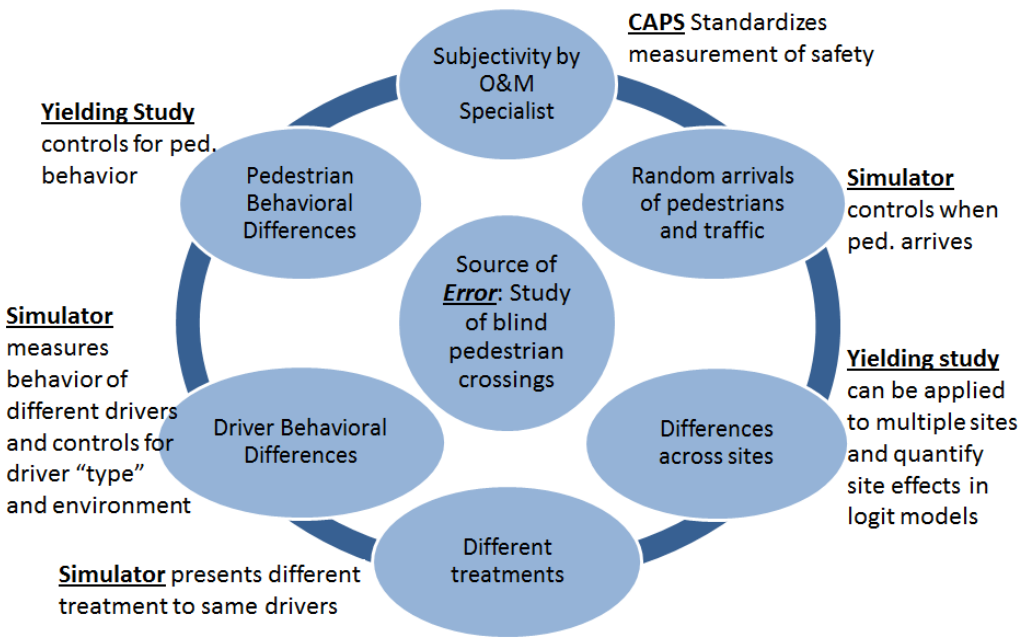


Figure 2 Application of Each Methodology to Control for Sources of Error and Varibility

The first study focuses on the *pedestrian decision-making process* as study participants respond to traffic patterns at multilane roundabouts. The second study tries to understand the *driver decision-making process*, by controlling pedestrian behavior and evaluating drivers' response in the form of yielding to pedestrians. The third study introduces further control in the form of a driving simulator study geared at testing and comparing infrastructure-based treatments that are aimed at improving accessibility. A key theme in this research therefore is the isolation of various factors contributing to pedestrian accessibility, under the premise that different types of studies are needed to evaluate different aspects of pedestrian access. The chart presented in Figure 3 outlines the research methodology.

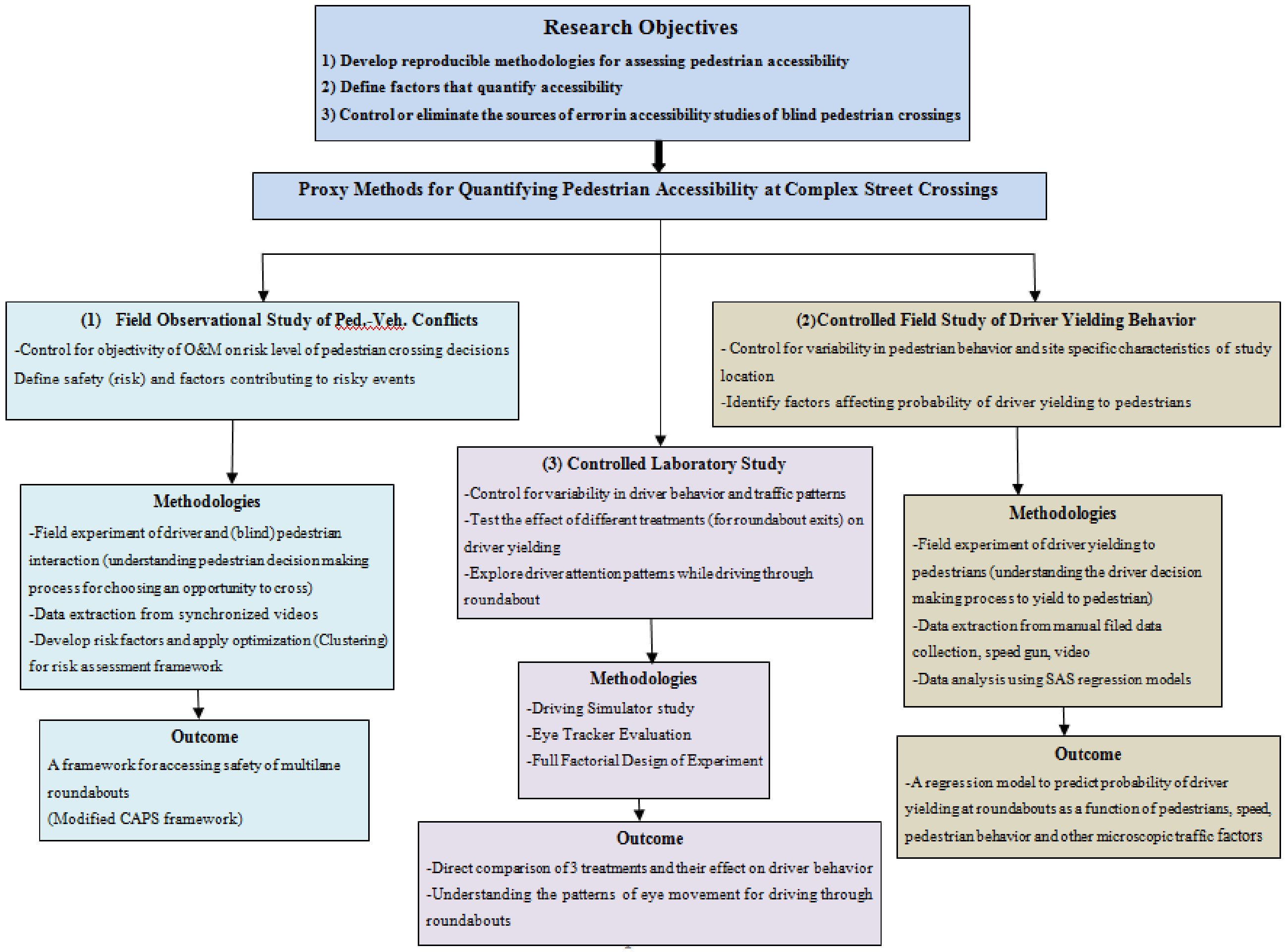


Figure 3 Outline of the Research

1.3 Limitations of the Research Approach

The research presented does not address all components of the accessibility framework. Regarding the crossing opportunity component, the studies do not focus on availability of crossable gaps as a form of crossing opportunity. They also do not address what factors might affect the availability of crossable gas. The studies also do not provide methods to quantify crossing opportunity utilization by pedestrians, which is the second component of accessibility framework. In other words they don't explain why or when blind pedestrians do not detect or utilize a crossing opportunity, or why they made a crossing decision when it wasn't crossable.

The proxy methodologies described in this research do not deal with pedestrian delay while making a crossing decision at complex street crossings. Schroeder et al. (2011 a) attempted to formulated pedestrian delay based on data collected from previous blind pedestrian crossings. However, this research focuses on risk assessment rather than delay.

Although the proxy methodologies in this document attempt to control for various sources of error in data collection and study of blind pedestrian crossings, each proxy method has its own limitations. This research consists of observational and controlled field data collection studies, and a controlled laboratory experiment using a driving simulator. The limitations of the research are therefore also associated with the limitations of the data collection methods themselves.

For the observational study:

-The sample size of blind and sighted participants (as pedestrians) in the observational study is limited to two datasets. The datasets are collected from two-lane and three-lane approaches of two multilane roundabouts in Michigan. The first data set include 141 pedestrian crossings and the second dataset includes 114 indications of when the pedestrians would cross.

-The calibration of the CAPS framework is based on human judgment of O&M specialists on safe and risky events, therefore is somewhat subjective.

-Data collected for the observational study is limited to two roundabouts in Michigan.

For the controlled field study:

-Data collection is limited to six two-lane roundabouts in North Carolina, Tennessee, Maryland and Indiana.

- No treatments (other than roundabout geometric differences) were considered

For controlled laboratory study with driving simulator:

-The pedestrian treatments are only studied for the exit leg of the roundabouts.

- The subjects do not represent all the driver population, but reflects a sample of 45 study participants

- Simulator driving is not necessarily synonymous with real-world performance

1.4 Dissertation Organization

The organization of this document leads the reader through the background and motivation for this research. It then presents in chapter 1 a literature review of pedestrian safety and accessibility issues at multi-lane roundabouts as one type of unsignalized complex intersection.

The document then develops a pedestrian-vehicle framework to evaluate the risk level of an interaction between a pedestrian and a vehicle at the crosswalk in Chapter 2. Chapter 3 aims to understand the contributing variables to increasing the driver yielding rate. Chapter 4 presents a controlled driver simulator study to evaluate various treatments for increasing driver yielding rates.

Chapter 5, summarizes the research and draws comparisons about the effectiveness and appropriateness of the three methods for the study of pedestrian accessibility. It further provides recommendations for future research and implementation of the frameworks and methodologies provided in the dissertation

2 OBSERVATIONAL FIELD STUDY: CONFLICT-BASED ASSESSMENT OF PEDESTRIAN SAFETY (CAPS) FRAMEWORK

2.1 Introduction

One of the components of Accessibility framework is whether pedestrians make safe crossing decisions or not and to quantify the level of risk associated with each crossing decision. Unsafe crossing decisions will result in a conflict between pedestrian and vehicle and might also lead to a collision. Collision data is currently the primary source of assessing safety of a transportation facility. However, it is in the best interest to avoid collision and focus on other substitute measures to assess safety of a pedestrian crossing.

In absence of collision data, traffic conflict techniques are being used. For the study of blind pedestrian crossings the judgment of O&M specialist for a pedestrian-vehicle interaction is used to classify the event as safe or potential collision. The goal of this chapter is to introduce a proxy method, in form of a pedestrian-vehicle conflict framework that substitutes the judgment of O&M specialist about the risk level of each pedestrian crossing decision. Another goal is to quantify the level of risk for each pedestrian crossing decision and describe the pedestrian-vehicle interaction based on the dynamics of the factors involved in the interaction.

This chapter first reviews the existing literature on pedestrian-vehicle conflict studies and attempts to explore what a conflict is, why it is often substituted for pedestrian-vehicle collisions, and what the existing conflict frameworks are. A conflict-based pedestrian safety (CAPS) framework is introduced in this chapter which is built on a pedestrian-vehicle conflict framework. The framework consists of five microscopic traffic attributes that describe the interaction between a pedestrian and a vehicle while the pedestrian is utilizing a crossing opportunity at a crosswalk. The overall structure of CAPS framework is developed and calibrated using the data from 141 crossing events of blind and sighted pedestrians at two-lane and three-lane approaches of a multilane roundabout. For all of these crossing events the risk level of crossing decision (safe or dangerous) is identified by an Orientation and Mobility (O&M) specialist. The performance of the framework is evaluated by correctly identifying the safe and dangerous events against the O&M ranking of each crossing events.

The CAPS framework is based on five factors and a matrix which assigns a grade of conflict to each crossing event. However, collecting data for all of the five factors are not feasible as it is time consuming and expensive. One of the factors is also a qualitative factor. Therefore later in this chapter several optimization techniques, namely clustering methodologies are applied to the data set to modify and simplify the CAPS framework. The objective of applying optimization techniques are: a) create a reproducible methodology (framework) that could identify the safe and dangerous crossing decisions with the lowest amount of error, b) it is simple, effective and inexpensive to collect data for the framework. The modified framework is then applied to a second data set for validation. More details on the optimization methodologies, evaluation and validation of the framework are explained in this chapter.

2.2 Literature Review

2.2.1 Pedestrian Conflict Study, Safety and Accessibility

According to the National Highway Traffic Safety Administration (NHTSA), 12% of the fatal crashes that took place across United States were pedestrian fatalities in 2009 (NHTSA 2010). Crash analysis is one of the ways to evaluate the safety of a transportation facility, identify the hazardous locations and factors causing collisions, and suggest countermeasures to improve safety of transportation facilities by means of reducing collisions. In order to do so, however, collisions must have happened, reported and documented properly. Studies show there is a lack of sufficient pedestrian-vehicle collision data at multilane roundabouts in United States (Schroeder et al. 2011a, Rodegerdts et al. 2010).

Other approaches for quantifying the safety of a transportation facility have been developed, including Traffic Conflict Techniques. The use of such one alternative, Traffic Conflict Techniques (TCT), is justified by the following key characteristics (Muhlrad 1993)

a. Unreliability and lack of quality of collision statistics in many countries.
b. Unavailability of detailed collision data either because it does not exist or it is not stored and classified properly.
c. Even with existence of collision data, usually additional information is needed to test any safety hypothesis.

Muhlrad (1993) also lists the goals of a comprehensive approach to conflict study and road safety as following:

a) *"To get some control on the development of transportation and traffic systems in order to avoid creating malfunctions that could later produce collisions.*

b) *To prepare corrective action in connection with actual collision problems identified through objective studies.*

c) *To select or design safety measures which only influence some of those particular elements of the transportation system that have been found to contribute to the main collision problems.*

d) *To coordinate planning and implementation of comprehensive safety measures with a view to increasing their joint effects.*

e) *When possible, to coordinate design and implementation of safety measures and other measures that may include or support them.*

f) *To avoid redundancies and/or contradictions in road safety programs or between safety and other programs related to transport and development.*

g) *To make the best use of past experience in other cities, countries or regions of the world, after checking its relevance and possible adaptation to the conditions in the country (or the city).*

h) *To contribute to produce relevant knowledge by following up the effects of the measures and policies implemented in the country (or the city)."*

Hayden (1987) describes conflicts as undesired conditions in traffic. Serious conflicts, which are highly correlated with traffic collisions…" are the result of a breakdown in the interaction between the road user, environment and vehicle. A serious conflict is characterized by the fact that no one voluntarily gets involved in such a situation." (Hayden 1987).

Traffic conflict analysis has been viewed as an effective way of preventing collisions from happening since its origin in the late 1960's (Hamilton-Baillie, 2004) as it can provide valuable information on potentially dangerous road sites before collisions actually happen on them. A substantial amount of research has been conducted on the topic, resulting in development of many traffic conflicts techniques (Huhlrad 1993, Hyden 1987, Allen 1978). While initial analysis methods were more qualitative and applied subjective measures to identify and characterize evasive actions of road users in response to conflicts, newer methods have become more quantitative and have provided more precise definitions for measures of the severity of conflicts (Muhlrad 1993).

Several international studies were aimed at assessing traffic safety for different types of road users. Three well-known traffic conflict techniques are the "Swedish Traffic Conflicts Technique" (STC) (Hyden 1987), the "Institute of Highways and Transportation Conflicts Technique" (IHTCT) from the Transport and Road Research Laboratory in the UK (Swain 1987), and the "US Department of Transportation Traffic Conflict Technique" (USDTCT) (Parker et al. 1989). All define a conflict as a situation in which two or more road users approach each other in space and time in a way that evasive action must be taken in order to avoid a collision. All three frameworks take into account two major factors, namely the *time to collision* and *speed* at the time of the conflict.

More specifically, the STCT focuses upon evaluating the time to collision and vehicle speed at the beginning of an evasive action to categorize the different conflicts according to severity. The USDTCT and the IHTCT, on the other hand, are based on categorizing the various elements of the conflict and creating levels of severity for each element, such that by summing up the given element levels an overall grading of the severity of the conflict can be obtained.

Although the concepts underlying these methods are applicable to various modes of transportation, conflict analyses are most often applied to vehicle-to-vehicle conflicts. However, some examples of work on conflicts between vehicles and other road users can be found in the literature, mostly for the purpose of assessing the safety of pedestrian crossings and the interactions within traffic flows. Some researchers have implemented existing traffic conflicts methods for modeling vehicle-pedestrian interactions. Both the STCT and the USDTCT have been used to analyze conflicts with pedestrians; in other studies. USCTCT method by Parker et al. (1989) is used by Lord (1996) to model the interaction between left-turning vehicles and pedestrians at signalized intersections and the STCT is used by Chen et al. (2009) to assess the efficiency of the safety regulations for vulnerable road users at intersections in Beijing.

2.2.2 Methodology for Vehicle-Pedestrian Conflicts

Although a number of conflicts analysis methods have been used to model vehicle-pedestrian interactions, none of them has been developed for unsignalized complex intersections with mixed priority rules (for example, yield-controlled intersections like roundabouts). Since in such transportation facilities there is ambiguity when and where pedestrians have priority over vehicles or vice-versa. This has an effect on behavior of pedestrians and vehicles and therefore traffic conflicts.

Kaparias et al. (2010) developed a vehicle-pedestrian conflict analysis method based on the IHTCT framework. The authors' vehicle-pedestrian conflict analysis method was developed to evaluate shared vehicle and pedestrian spaces in the UK. The method uses four factors to describe different aspects of a conflict, with each factor further having different classes of severity. Based on the class of severity of each factor, a composite safety rating is obtained to classify the overall pedestrian-vehicle interaction event. The four factors in the Kaparias et al. (2010) framework are as follows.

- **Factor A, 'time to collision', (TTC)** is the time between an approach point and the potential collision between a pedestrian and a vehicle. TTC is illustrated in three classes of long, moderate, and short, with short being the most severe of the three classes.
- **Factor B, 'Severity of evasive action' (SEA)** is related to the value of deceleration rate. For pedestrians, this corresponds to different qualities of reaction to change course from walking to running or emergency action. Factor B has four classes of severity: light, medium, heavy, and emergency.
- **Factor C, 'complexity of evasive action' (CEA)** refers to the quality of action that the road user, pedestrian or vehicle, takes in order to avoid collision. Factor C has two classes: simple and complex.

- **Factor D, 'distance to collision' (DTC)** is the distance of the following vehicle from the point of conflict when an evasive action has taken place. Factor D has three classes: far, medium, and short.

In the Kaparias et al. (2010) framework, all four measures are obtained from video observations of pedestrian crossings in shared-space environments. All four factors are qualitative. For example, time-to-collision is classified into three broad categories by an expert observer, rather than relying on actual measurements of vehicle dynamics (vehicle speed and position relative to the crossing point). This research adopts the framework developed by Kaparias et al. (2010) and customizes it to make it appropriate for quantifying the study in order to access the safety of pedestrian crossings at multilane roundabouts.

2.3 Framework Development

This section of research builds on extensive prior research experience with pedestrian crossings to develop a methodology that allows a more efficient assessment of the accessibility of an intersection. Since the framework developed here uses quantitative estimates of driver and pedestrian attributes to define the risk level associated with the crossing decision. The framework builds on a vehicle-pedestrian conflict method for shared environments (Kaparias et al. 2010), explained in the previous section, and uses it to develop a conflict-based pedestrian safety assessment framework for multilane roundabouts. The conflict method is tested and calibrated using data collected for actual crossings of sighted and blind pedestrians at multilane roundabouts. It can therefore be used to quantify crossing risk at a site for all categories of pedestrians.

The objective of this section is to describe a framework that can be used to efficiently and safely evaluate the accessibility of an intersection to various groups of pedestrians, including those with vision impairments. The Conflict-based Assessment of Pedestrian Safety (CAPS) method is compatible with indicator-based studies, in which visually impaired participants stand at the crosswalk and indicate when they would cross by raising their hand as oppose to physically stepping into the road (Guth et al., 2005). At the same time, the method should provide detailed data on the interaction of pedestrians and vehicles that are sensitive to variations in pedestrian behavior, traffic operational parameters, and roadway design changes from one intersection to another, including the use of infrastructure-based crossing treatments. These objectives are motivated by findings and recommendations for future research of two multi-year research projects on the accessibility of complex intersections to pedestrians with vision impairments (Schroeder et al. 2011a, NIH 2010).

The CAPS framework consists of five safety factors that jointly describe the risk of a pedestrian-vehicle interaction event. Based on the severity level of each of these factors, a conflict grade is assigned to each crossing event. The conflict grade describes the risk level of the crossing decision on a quantitative scale from safe to very risky. The framework is intended for use in empirical research studies of pedestrian crossings at complex intersections, and geared at quantifying pedestrian risk during those studies. The five factors are measured from video or real-time data entry during the studies.

The CAPS risk factors are based on measures of vehicle dynamics, which are estimated at the instance the pedestrian steps into the roadway (crossing study); or alternatively, at the time when the pedestrian indicates that he or she would cross (indicator study). In this research, the framework was calibrated from actual crossings (with some interventions), but for future applications, all factors are compatible with indicator studies. A total of five factors are used to define various aspects of the pedestrian-vehicle interaction. They are combined to develop the composite safety score of the crossing decision. The five factors are defined as follows:

- **Factor A, "Time to Collision".** Defined as the expected arrival time of the vehicle at the crosswalk given its instantaneous speed and relative position to the crosswalk. Time to collision (TTC) is calculated separately for each approach lane considering when the pedestrian would arrive in that lane based on his or her walking speed. TCC for each lane is calculated based on the formula in Equation 1:

Equation 1

$$TTC\ (i) = \frac{d_{cw}}{V} - \frac{(LW) * (i-1)}{V_p}$$

where,

TTC (i) (sec.): TTC for lane i, where i has levels 1, 2, and 3 for a three-lane and levels 1 and 2 for a two-lane crossing. Lane 1 is defined as the lane closest lane to the pedestrian or indicates intent to cross

d_{cw} *(ft.):* The distance from the vehicle to the crosswalk at the time pedestrian starts crossing

LW (ft.): Lane width of each vehicular travel lane.

V (ft/sec): Vehicle speed measured at the time the pedestrian starts crossing or indicates intent to cross

V_p*: (ft/sec):* Pedestrian walking speed

According to this definition, TTC can take on a negative value. A negative TTC implies that the vehicle would have passed the collision point by the time the pedestrian reached the lane it is traveling in. In the CAPS framework, Factor A is divided into three classes with thresholds given in Table 1. Class 1 is a long (and safe) TTC which describes as either the vehicle passed the course of the crosswalk before pedestrian arrives at the conflict point (-2 seconds) or is far enough (8 seconds) that it will not cause any threat for the pedestrian. Class 2 or moderate TTC is chosen between 5 to 8 seconds. Class 3 or short TTC is identified as the most risky and with high likelihood of a conflict between pedestrian and vehicle. The thresholds for factor A were defined by observing hours of video data for pedestrian street crossings and measuring the TTC for each crossing. Each of the thresholds for TTC levels of severity were chosen conservatively.

Table 1 Thresholds for Factor A, Time to Collision

Factor A	Time to Collision (sec.)
Long [Class 1]	TTC> 8, TTC< -2
Moderate [Class 2]	5 <TTC< 8
Short [Class 3]	-2 <TTC< 5

- **Factor B, “Severity of Evasive Action”.** This factor describes how much a driver would have to decelerate to come to a full stop before the crosswalk to avoid a collision with the pedestrian. Similar to TTC, it is calculated from the instantaneous speed and relative position of the vehicle at the time of a pedestrian event. In Kaparias et al (2010) research, the factor was defined qualitatively as light, moderate, sharp or sudden and uncontrolled. In this research, it has been converted to a continuous scale, since actual vehicle dynamics measurements are available. The necessary deceleration rate (DECEL) was defined as the rate of deceleration necessary for a vehicle to come to a full stop just prior to the crosswalk, given its current speed and position from the crosswalk (Schroeder 2008). According to the Highway Capacity Manual (TRB 2010), a reasonable range of deceleration rates for passenger cars varies between 7 ft./sec^2 and 26 ft./sec^2. Research shows that the maximum comfortable deceleration rate in non-emergency situations varies between 6.56 ft/sec^2 to 11.31 ft/sec^2 (2 m/sec^2 to 3.45 m/sec^2) (TRB 2010, Mehmood et al. 2009). In emergency situations, the maximum deceleration rate varies from 16.40 ft./sec^2 to 27.88 ft./sec^2 (5 m/sec^2 to 8.5 m/sec^2). Using the literature findings above, the thresholds for the four classes of Factor B are given in Table 2.

Table 2 Thresholds for Factor B, Severity of Evasive Action

Factor B	Deceleration Rate (ft./sec^2)	Deceleration Rate (m/sec^2)
Light [Class 1]	DECEL < 6.56	DECEL < 2.00
Medium [Class 2]	6.56 <DECEL< 11.31	2.00 <DECEL< 3.45
Heavy [Class 3]	11.31 <DECEL< 16.40	3.45 <DECEL< 5.00
Emergency [Class 4]	DECEL > 16.40	DECEL > 5.00

- **Factor C "Complexity of Evasive Action".** This factor describes qualitatively any evasive action by pedestrian or driver that would signify a potentially risky interaction. This factor is estimated by observing the pedestrian behavior while crossing the street (for example if they are running or swirling around a vehicle to avoid conflict) or by estimating the speed of the vehicle and observing driver behavior (for example changing lane or not paying attention to the pedestrian).The factor is largely consistent with factor C that Kaparias et al.(2010) and is estimated by watching video recordings of the pedestrian crossing study. The factor has two levels, *simple* and *complex*, where the latter is any event associated with a vehicle swerving into adjacent lanes or a pedestrian jumping out of the way of an approaching vehicle.
- **Factor D "Distance to Collision".** This factor describes the relative distance of the approaching vehicle to the crosswalk. The factor is divided into three classes and thresholds for the classes were estimated based on field observations at the test locations and under consideration of observed O&M interventions (Table 3). The thresholds for factor D is defined with the following assumptions. An average lane width is assumed to

be 10 ft. (3 meters). Therefore, with pedestrian speed of 3.5 ft/sec. (as defined in HCM 2010) the pedestrian needs approximately 3 seconds to finish crossing one lane. Most roundabouts have entry speed limit of 25 mph (11 m/sec.) and vehicles are decelerating while approaching the crosswalk. However it is assumed that an average speed for vehicle approaching the roundabout is considered to be 30 mph (44 ft/sec. and 13.4 m/sec.). Therefore the vehicle should be approximately 130 ft. (40 m) away to allow pedestrian enough time to clear the crosswalk, hence the 130 ft. thresholds for class1. Thresholds for class2 and class 3 are also defined based on same calculations and assumptions.

Table 3 Thresholds for Factor D, Distance to Collision

Factor D	Distance to Collision (ft.)	Distance to Collision (m)
Far [Class1]	DTC>130	DTC>40
Medium [Class2]	50<DTC<130	15<DTC<40
Short [Class3]	DTC<50	DTC<15

- **Factor E "Lane Condition Factor".** This last safety measure was added in order to describe the relative state of each conflicting lane. At a multi-lane crossing, the multiple threat crash type is common, Factor E in the CAPS framework is assigned four classes based on the state of the vehicle in each lane at the time when the pedestrian initiates crossing. The vehicle state in each lane is defined as empty (E) , stopped/yielding (S), or moving (M). A lane condition factor is developed based on the situation of each lane and it is presented in Table 4. The matrices in Table 4 are the results of several discussions to define what condition should be considered safe or risky. In general where there is a moving vehicle in near lane with respect to pedestrian, the condition is risky (lane condition factor of 4). In case of a stopped vehicle in near lane, the multiple threat condition may happen which is also risky (lane condition factor of 3 or 4).

Table 4 Lane Condition Factor

a) Lane Condition Factor for Two Lane Approach

Two Lane	L1:M	L1:S	L1:E
L2:M	4	3	2
L2:S	4	1	1
L2:E	4	1	1

b) Lane Condition Factor for Three Lane Approach for Lane 3, L3 (M/S/E)

Three Lane	L1:M	L1:S	L1:E
L2: M	4/4/4	3/3/3	2/2/2
L2: S	4/4/4	3/1/1	3/1/1
L2: E	4/4/4	2/1/1	2/1/1

L1 refers to the near lane, L2 to the middle lane and L3 to the far lane with respect to pedestrian starting position. Vehicle states are defined as M: Moving, S: Stopped/Yielding and E: Empty. Lane condition factor is defined on the scale from 1 to 4, with 1 being safest and 4 being the most risky situation.

2.3.1 Development of an Overall Risk Score

Each of the five factors mentioned above has two to four levels, providing a rank of the severity of the factor for each of the crossing events. To assess the overall risk score of a pedestrian crossing event, the five factors must be aggregated into a single numerical risk estimate. A conflict grade matrix to estimate this overall risk score was developed by Kaparias et. al. (2010), which shows different combinations of factors and assigns a conflict grade to each combination. By taking into account the new factor E, the conflict grade matrix is revised and presented in Table 5. The modification consists of adding new combinations and assigning the proper conflict grade to those. Overall conflict severity increases from level 1 (slight) to 4 (severe).

Table 5 Modified Conflict Grade Matrix Based on Adding the Lane Condition Factor

Factor	**Grade 1 conflict**															
A	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3
B	1	1	1	2	2	2	1	1	1	1	1	2	2	1	2	2
C	1	1	3	1	3	1	1	3	1	3	1	1	3	1	1	3
D	1	1	1	1	1	1	2	2	1	1	2	1	1	1	1	1
E	1	2	1	1	1	2	1	1	1	1	1	1	1	2	1	1

Factor	**Grade 2 conflict**																				
A	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	1
B	1	1	2	2	3	3	1	1	2	2	3	3	1	1	1	3	1	2	3	1	1
C	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	3	1	1	1	3
D	3	3	2	2	1	1	3	2	2	2	1	1	2	2	3	1	3	2	1	1	1
E	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	2

Factor	**Grade 3 conflict**																				
A	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
B	2	2	3	3	1	2	2	3	3	3	3	2	2	2	3	3	4	4	4	4	1
C	1	3	1	3	3	1	3	1	3	1	3	3	1	3	1	3	1	3	1	3	1
D	3	3	2	2	3	3	3	2	2	3	3	2	3	3	2	2	1	1	2	2	1
E	3	3	3	3	2	3	2	3	3	4	4	3	4	4	4	4	4	4	4	4	4

Factor	**Grade 4 conflict**					
A	2	2	3	3	3	3
B	4	4	3	3	4	4
C	1	3	1	3	1	3
D	3	3	3	3	3	3
E	4	4	4	4	4	4

In the application of Table 5, the analyst reads the factor combination for a crossing event from the table to assign an overall safety score from 1 to 4. There were various attempts to develop other simplified methods for determining the overall safety score of a crossing attempt by simple summation of the individual factors or weight the summation equation in favor of one or more factors. But they did not result in notable improvements in model fit.

Later in this chapter other methodologies such as optimization methods (three clustering algorithms) are used to substitute the conflict grade matrix in Table 5.

2.3.2 Data Collection

The case study below explains implementation of CAPS to data collected Figure 4 shows the aerial view of the data collection site.

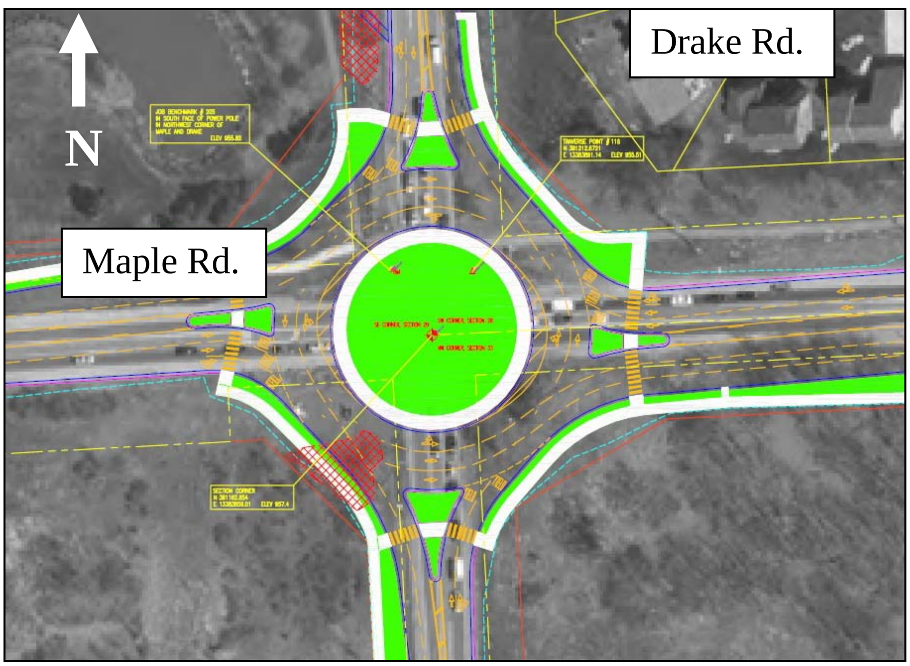


Figure 4 Aerial View of Data Collection Site: Intersection of Maple and Drake Rd. West Bloomfield MI Source: http://www.nwconnector.com

The CAPS method was implemented and calibrated from a dataset of actual pedestrian crossings collected at a multilane roundabout at the intersection of Maple Rd. and Drake Road in West Bloomfield Township in Michigan. This roundabout has two-lane approaches going north-south and three-lane approaches going east-west. With the distinction of the entry and exit portions of the crossing, a total of four conditions can be compared: two-lane entry, two-lane exit, three-lane entry, and three-lane exit.

Entering and exiting approach volume counts were performed by the Road Commission for Oakland County in late June 2009. Daily traffic volumes in reveal that flows on Maple Road are expectedly higher than along Drake Road. The total daily traffic volume entering the roundabout is about 41000 vehicles per day and total daily traffic volume exiting the roundabout is about 42000 vehicles per day. The highest flow period is approximately 3-6pm, although traffic volumes are fairly comparable throughout the day. The traffic on Maple Rd. is overall higher than Drake Rd. Figure 5 shows the hourly distribution of entering volumes at Maple and Drake roundabout.

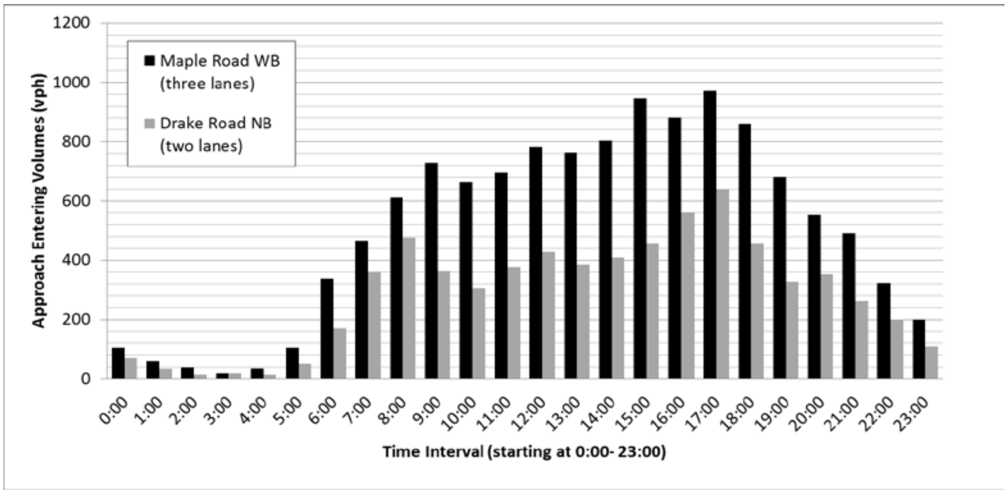


Figure 5 Hourly Distribution of Volumes at Maple and Drake Roundabout

Fourteen blind and six sighted individuals participated in this study. After consent was obtained from each participant, they were oriented to the roundabout by the O&M specialist. Orientation included exploring a tactile map of the intersection and walking around the roundabout in a counterclockwise direction, beginning at the northwest corner. The O&M specialist described features, guided participants across the crosswalks, monitored their independent crossings, and provided instruction on the study procedures (e.g., starting point for trials, verbal instructions, safety concerns). Participants were encouraged to ask questions about the layout of the intersection and crosswalks, the traffic movement, the pedestrian facilities available, and any other features of interest. They also asked questions about the study procedures.

Participants were asked to make four round trip crossings at each of two locations (east crosswalk across Maple, south crosswalk across Drake). Each round trip crossing involved the crossing of four legs of traffic (for example entry-exit-exit-entry). The eight round trip crossings therefore yielded 32 crossings per participant Practice crossings prior to beginning trials helped to familiarize the participants with the study protocol, but these were not included in the analysis.

Participants were told to begin crossing whenever they believed it was appropriate to do so, using the cues that were available to them (visual cues for sighted participants, the sounds of traffic for blind participants, and additional visual and/or auditory information cues. They were not requested or required to have any verbal interaction with the spotter prior to initiating the crossing. The starting location (e.g. entry or exit leg at a roundabout) was systematically varied to control for order effects. Trials were blocked, or grouped, by crosswalk to save time and to avoid confusing the participants. For example, all crossings across Drake Road were completed consecutively, and then the team moved to Maple Road and completed all crossings there.

For each crossing trial, participants were guided to the middle of the curb ramp and were aligned to face across the crosswalk. While approaching the crossing location, participants were told which lane of the roundabout they were crossing, which direction traffic would approach from, and whether they were crossing from the island or curb. For example: "You are crossing the entry lane of Maple Road from the curb, with traffic coming from your left. Cross whenever you are ready." Participants were reminded that the O&M specialist/spotter merely informed them when the trial began, which was their cue to begin monitoring traffic and other cues. They were told that the instruction to "cross when you are ready" was not an indication that it was a safe time to begin crossing. Before beginning trials, they were told that after the O&M specialist said "cross whenever you are ready", they should identify a safe time to begin crossing, and then begin to cross the street without verbal interaction with the O&M specialist. The O&M specialist stopped each participant on the opposite side of the street (or on the splitter island) at the end of each crossing. The O&M specialist then guided the participant along the sidewalk and away from the crosswalk approximately 50 feet (if on the curb), turned around, and then approached the crosswalk to start the next trial. On the splitter island proper, the O&M specialist guided the individual forward to the crossing point on the opposite side of the splitter island. Participants were allowed to take a break as needed, and refreshments were provided. After all crossings were completed, each participant completed a short debriefing questionnaire

In total, 224 crossings for blind participants and 96 crossings for sighted participants occurred on each approach. The actual number of crossings for some participants is less than 32 due to inclement weather conditions or other factors.

Vehicle dynamics measurements for the CAPS framework were facilitated by multi-angle video coverage, involving the use of three overhead video cameras and one ground-level video camera. An Omni-directional camera was installed in the center island of the roundabout to obtain a 360-degree view of the roundabout. Cameras were also installed on both of the test approaches at a distance of approximately 300 feet upstream of the crosswalk. The Omni-directional camera allowed the author to view the two exit approaches at the roundabout, while the two rear-facing cameras at each of the approaches allowed viewing the entry legs of the two approaches. The ground-level camera was positioned at the crosswalk and also recorded sound from a wireless microphone used by the O&M specialist. All four camera views were synchronized in the office and recorded onto one common DVD with a split-screen view of all four video angles. These video discs were used to estimate vehicle-related measures such as distance to collision, speed, time to collision and required deceleration rate. Vehicle data were estimated for each vehicle that was in the approach of the crosswalk when a pedestrian crossing decision was made. Figure 6 shows a screen shot of the composite video angle used for data collection in the office. A detailed video time-stamp and known distances obtained from field measurements were superimposed on the video during playback to estimate vehicle speed and position data.

Figure 6 Screenshot of Composite Video View of Test Site

The dataset used to calibrate the CAPS framework was extracted from approximately 168 hours of video observations.

2.3.3 Results

This section presents the results of implementing different combination of factors in the CAPS framework to the dataset. The objectives of this effort for the Maple Rd. and Drake Rd. dataset were to; a) demonstrate the feasibility of the CAPS approach, and b) calibrate the optimal combination of factors in the framework. At the two-lane approach, 28% (58/209) of the crossings by blind participants took place when there was a moving car in either of the two lanes. For the three lane approach, 37% (83/222) of the crossings took place when there was a moving car in one of the three lanes. For the six sighted participants at the two-lane approach, 14% (14/96) of the crossings occurred when there was a moving vehicle in either of the lanes. For the three-lane approach, only, 10% (10/96) of the crossings took place when there was a moving vehicle in any of the three lanes. The rest of the crossings occurred when all lanes were either empty or had stopped vehicles. The threshold for considering an approach lane as "empty" was defined at a distance of 300 ft. (100 m) from the crosswalk which corresponds to a time of approximately 10 seconds at a speed of 20 mph (30 ft./sec, 10 m/sec). In the CAPS framework, crossings that occur at times when all lanes are empty (or when all lanes have yielded) are defined to be safe. For consistency the crossing of sighted pedestrians are separate from blind pedestrians. The crossings by sighted pedestrians were all identified as safe decisions by O&M specialists. They were also identified as conflict grade of 1 (safe) by CAPS framework. The relative risk of the remaining 141 events was evaluated using the five CAPS factors. The calibration goal of the CAPS framework is to correctly predict the O&M intervention events with grades 3 and 4.

2.3.3.1 Definition of Performance Measures (Difference)

In order to evaluate the performance of the CAPS framework and any clustering optimization methodology, two performance measures are defined to measure the error of framework in correctly indentifying safe and dangerous (intervention) events. It is important to note that the O&M ratings of safe and intervention are considered "ground truth" and outcomes of the CAPS framework (and the three optimization algorithms used later in this chapter) are compared with the O&M ratings.

The definitions regarding the performance measures are:

True state of each event: safe or dangerous (as identified by O&M intervention)

Declared state of each event: safe or dangerous (as estimated by the CAPS framework)

Therefore we have;

TS: Number of "true safe" data points;

TD: Number of "true dangerous" data points;

DS: Number of "declared safe" data points by framework or clustering algorithm;

DD: Number of "declared dangerous" data points by framework or optimization clustering algorithm.

Based on the definitions "False Positive" and "False Negative" rates, as performance measures are defined in Table 6

Table 6 Performance measures for Clustering Methodology

State of the data point	True Safe	True Dangerous
Declared Safe	Correct Safe=(DS given TS)/TS	**False Negative**=(DS given TD)/ TD
Declared Dangerous	**False Positive**= (DD given TS)/ TS	Correct Dangerous= (DD given TD) /DS

It is very important to reduce the value of false negatives to zero. Although the optimum combination is the one with the smallest false positive and false negative values, false positive values greater than zero only shows that the model may overestimate dangerous events. False negatives, on the other hand, mean that the framework missed a potentially dangerous crossing event. A (systematic) false positive error is acceptable, since in the interpretation this simply makes the framework somewhat more conservative than the O&M intervention measures.

Given the aforementioned binary nature of the O&M intervention measure, a greater frequency and distribution of dangerous events can be beneficial to get a more complete picture of the interaction. Table 7 and Table 8 show the results for different combinations of factors using the conflict grade matrix presented in Table 5. Table 7 and Table 8 show different combination of factors that were tested to find an optimum framework for two-lane and three-lane approaches of the roundabout. The various combinations are compared using measures of percent false positives, percent false negatives, and the number of interventions that were missed by the framework (i.e. did not result in a rating of 3 or 4). It is important to note that since all the data

Table 7 Comparison of Different CAPS Model Combinations for Two-Lane Approach, Blind Pedestrian Crossing (n=58 events)

Model	**False Positive %**	**False Negative %**	**Number of Missed Interventions (out of 12)**
ABCD	1.8%	8.6%	5
ABCDE	4.3%	0%	0
AE	13.4%	8.6%	5
BE	12.9%	8.6%	5
ABE	13.4%	8.6%	5
ADE	13.9%	8.6%	5
BDE	19.1%	8.6%	5
ABDE	50.0%	0.0%	0

Table 8 Comparison of Different CAPS Model Combinations for Three-Lane Approach, Blind Pedestrian Crossing (n=83 events)

Model	**False Positive %**	**False Negative%**	**Number of Missed Interventions (out of 23)**
ABCD	6.7%	5.6%	5
ABCDE	9.0%	0.0%	0
AE	14.6%	10.1%	9
BE	19.1%	6.7%	6
ABE	49.4%	2.2%	2
ADE	50.6%	3.4%	3
BDE	19.1%	5.6%	5
ABDE	22.5%	1.1%	1

An examination of Table 7 and Table 8 indicates that the model with factors ABCDE using the conflict grade matrix yields the lowest fraction of false negatives for both two and three-lane approaches. A close second is model ABDE, which, while yielding some small fraction of false negatives, omits the use of the rather subjective factor “C”. The tables thus could assist future researchers to focus on those combinations that show promise in capturing the actual crossing conflict severity.

2.4 Optimization of CAPS

The full model (ABCDE) gives the best results; alternatively, a model with factors ABDE that omits the use of the arguably subjective factor C, delivers a close second contender. Other attempts were made to simplify the CAPS model to fewer factors, in order to reduce the data collection, extraction and reduction process. The data collection procedure for the all factors of CAPS is time consuming and requires human and equipment resources. Although interventions are judgments of professional and trained O&M specialists and considered as a performance measure, they are nevertheless subjective and potentially risky to pedestrians. The final output of the CAPS framework is a risk score that ranks the safety (risk) of a crossing event by a pedestrian at the intersection. Based on values of each factors for O&M intervention events available for the case study described here, the author looked into the existing literature to define the thresholds for the five factors of CAPS, and modified the conflict grade matrix so that actual interventions are associated with high-risk scores. However, a more systematic approach is needed to define the thresholds for factors of CAPS framework based on the actual data collected to correctly address safe and unsafe crossing decisions. These issues and caveats resulted in pursuing optimization tools to develop a simpler and more efficient framework with fewer factors. The desired framework needs to be simple and economic in data collection and be able to efficiently evaluate safety of pedestrian crossings at multilane roundabouts and assess their accessibility, without imposing any serious risks on human subjects, and being compatible with the indicator studies.

The next step is to use optimization. Optimization will be used for three purposes:

a) Assign a risk score to each crossing event which is compatible with O&M's evaluation of safe and risky events;

b) Reduce the number of factors if possible; and

c) Reduce the grades of conflict (risk scores).

Three clustering algorithms, K-mode, K-median and K-means are used. The methodologies are briefly described in the following sections along with their application for optimizing the CAPS framework.

2.5 Cluster Analysis

Cluster analysis groups data objects based only on information found in the data that describes the objects and their relationships. The goal is that objects within a group be similar (or related) to one another and different from (or unrelated to) the objects in other groups. The greater the similarity (or homogeneity) within a group, and the greater the differences between groups, the better or more distinct are the clustering (Everitt et al. 2001).

There are various techniques for cluster analysis. Regardless of the methods used, cluster analysis has been used as a means of achieving two totally different objectives. The first objective is to detect and delimit natural clusters, where the points within any one cluster are relatively compact while between any two clusters there are only few points. It is generally assumed that each point is uniquely assigned to a single cluster. Unfortunately the best methods for detecting these clusters are graphical and cannot be used when the objects do not lie on a two-dimensional plane.

As the second objective, the points in a scatter diagram may be partitioned into a specified number of clusters, **k**, so as to minimize some measure of the loss that results when the objects within any one group are not exactly alike.

There are different methods for clustering, mainly k-means, k-mode and k-median (Kulkarni and Fathi 2007, Mulvery et al. 1979). These methods are used for solving homogeneous clustering problems. A homogeneous clustering problem can be formulated as an optimization model in Equation **2** (Mulvey et al., 1979):

Equation 2

$$z = \triangleq minimize \ \sum_I \sum_J d_{ji} x_{ij} \quad (1)$$

$$x_{ij} \geq 0$$

Subject to:

$$\sum_J x_{ij} = 1 \ for \ all \ i, \ (2)$$

$$\sum_J x_{jj} = k, \ (3)$$

$$x_{ij} \leq \ x_{jj} \ \ all \ i, j, \ (4)$$

$$x_{ij} = \{0,1\} \ all \ i, j \ \ (5)$$

Where d_{ji} indicates the distance or dissimilarity between object **i** and object **j**, which is calculated by Euclidean distance formula in Equation 3:

Equation 3

$$d(i,j) = \sqrt{(|\, x_{i1} - x_{j1}|^2 + |\, x_{i2} - x_{j2}|^2 + \cdots + |\, x_{ip} - x_{jp}|^2} \quad (6)$$

x_{ij} is a binary variable designating whether object **i** is assigned to cluster centroid (can be mean, mode or median) **j**; x_{jj} =1 indicates the occurrence of a cluster centroid (can be mean, mode or median) at j; **i** is the set of n objects; **j** is the set of eligible centroids (**i** and **j** are identical for most applications); and **k** is the desired number of clusters. It is assumed that the matrix of distances has been provided, which is something that needs to be calculated for every step where a data point is chosen as a centroid. It should be noted that the distances are usually symmetric, i.e. $d_{ij} = d_{ji}$ for all **i**, **j**, and $d_{jj} = 0$ for all **j**.

In other words, the objective function **z** aims at **k** points as centroid of clusters from the set of j-constraints in (3) such that the sum of distances from all points to their respective cluster centroids are minimized. Every point is assigned to a single centroid by constraint in (2); constraint in (4) insures that points are assigned exclusively to centroids (Mulvey et al., 1979).

K-means defines a centroid, which is usually the mean of a group of points, and is typically applied to objects in a continuous n-dimensional space. K-mode defines a centroid in terms of a mode, which is the most representative point for a group of points, and can be applied to a wide range of data since it requires only a proximity measure for a pair of objects. K-median defines the centroid of clusters as the medians which are the numerical value separating the higher half of members of each cluster from the lower half. Median does not necessarily correspond to an actual number in the cluster and can be the mean of the two middle values. K-mode is applied to categorical or arbitrary data while K-median and K-means are applied to real data. K-median and K-mode are variations of k-means clustering, however, they have the effect of minimizing error over all clusters with respect to the distance matrix which calculates the distance of the member of each cluster from their centroid (Everitt et al., 2001).

2.6 Implementation of Clustering to CAPS

The ultimate objective of optimized CAPS framework can be described as: *given a center characteristic vector of pedestrian crossing, one should be able to identify whether that crossing is safe or predicted as an intervention*. The decision is made based on applying CAPS framework to the values of the attributes of that characteristic vector. For the case of pedestrian crossing the characteristics vector can have up to 5 attributes (A, B, C, D and E). However, one of the goals of this section is to eliminate some of these factors for simpler and economically feasible data collection procedures. Ideally, any method that is used to modify CAPS framework should be able to correctly identify all the safe and dangerous (predicted intervention) crossing events with false positive and false negative rates of 0%. However, since the methodologies are applied to field experimental data, achieving 0% error rate is hardly possible. Figure 7 shows the process of advancement of CAPS framework from the original pedestrian-vehicle conflict method.

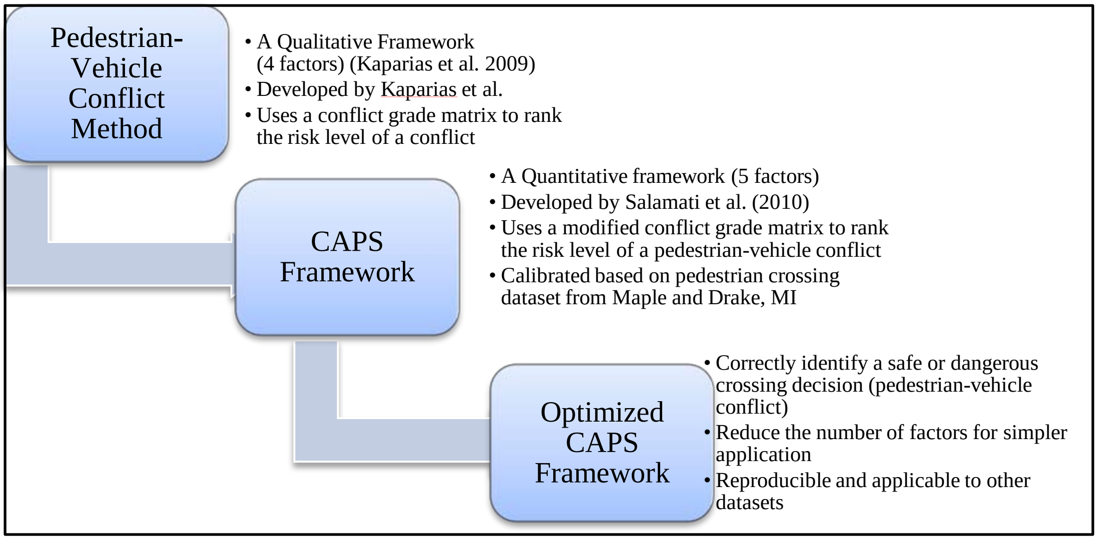


Figure 7 Advancement of CAPS Framework

The steps taken for optimizing the CAPS framework are shown in Figure 8. As shown in Figure 8, first, the three clustering methodologies are applied to dataset 1 (Maple and Drake crossings). Different combinations of factors are also tested at this step and eventually the clustering methodology with combination of the factors that is more feasible and has lower error rate (false negative and false positive rate) is chosen. Clustering, assigns each data (vector) based on the minim Euclidean distance of the data from the center of the clusters. Therefore, for the chosen clustering methodology the center of the two clusters are identified. The crossing events from Maple and Drake are ranked (safe and intervention) by an O&M specialist. Therefore the dataset can be clustered into two clusters of safe and dangerous which are called the "true clusters". Intuitively the error rates, both false negative and false positive rate of the "true clusters" are 0%. In addition to the clusters formed by the clustering methodology, the centers of the “true clusters” are also identified.

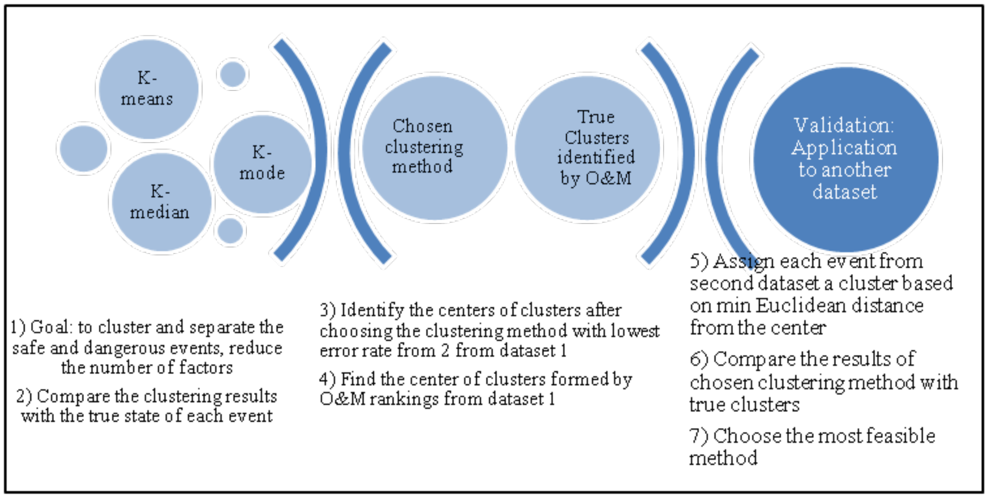


Figure 8 Process of Optimizing CAPS Framework

2.6.1 Results of Clustering for CAPS

The three clustering methodologies (k-mode, k-median and k-means) are applied to the two-lane and three-lane pedestrian crossings events of the Maple and Drake dataset (dataset 1). For clustering SAS functions CLUSTER (method= AVERAGE for k-mean clustering, method= MEDIAN for k-median clustering) and MODECLUS for k-mode clustering) are used. The output of SAS programs shows the values of the center of the clusters and the list of the data points that were assigned to each node.

The results of false positive and false negative rates are shown in Table 9, Table 10 and Table 11.

Table 9 K-Mode Clustering Results for Maple and Drake Crossings

Model	Two-Lane (n=58)			Three-Lane (n=83)		
	False Positive %	False Negative %	# Missed Interventions (Out of 12)	False Positive %	False Negative %	# Missed Interventions (Out of 23)
ABCDE	52%	14%	8	30%	11%	9
AE	48%	12%	7	29%	14%	12
BE	52%	12%	7	25%	14%	12
ABE	45%	9%	5	25%	12%	10
ADE	45%	12%	7	28%	11%	9
BDE	45%	10%	6	29%	12%	10
ABDE	48%	9%	5	30%	11%	9

Table 10 K-Median Clustering Results for Maple and Drake Crossings

Model	Two-Lane (n=58)			Three-Lane (n=83)		
	False Positive %	False Negative %	# Missed Interventions (Out of 12)	False Positive %	False Negative %	# Missed Interventions (Out of 23)
ABCDE	45%	9%	5	43%	8%	7
AE	41%	10%	6	36%	11%	9
BE	38%	12%	7	35%	12%	10
ABE	33%	10%	6	35%	8%	7
ADE	33%	10%	6	36%	10%	8
BDE	38%	12%	7	34%	8%	7
ABDE	45%	7%	4	40%	7%	6

Table 11 K-Means Clustering Results for Maple and Drake Crossings

Model	Two-Lane (n=58)			Three-Lane (n=83)		
	False Positive %	False Negative %	# Missed Interventions (Out of 12)	False Positive %	False Negative %	# Missed Interventions (Out of 23)
ABCDE	45%	10%	6	37%	7%	8
AE	24%	14%	8	36%	10%	10
BE	41%	14%	8	37%	12%	12
ABE	38%	7%	4	37%	6%	7
ADE	38%	9%	5	35%	6%	7
BDE	38%	7%	4	37%	8%	9
ABDE	38%	7%	4	37%	6%	7

In order to achieve the goal of reducing the factors in the CAPS framework, and establishing a framework which is more applicable, different combinations of the factors are applied to clustering methodologies. A simpler framework might sacrifice the accuracy of the framework. However it might not be feasible to collect all the five factors. The author decided to eliminate factor C from the combinations since this is a qualitative factor and subject to human judgment. Factor E, lane condition factor, is easy to collect and describes the condition of each lane when pedestrian started the crossing therefore the author decided to keep this factor. Factor A, time to collision, is easy to collect in the field. Between factor B, deceleration rate and factor D, distance to collision, the author decided to choose only one factor because they are related. For example, by knowing time to collision (factor A) and distance to collision (factor D) one can estimate the required deceleration rate for a vehicle (factor B) to stop at the point of conflict, assuming constant speed. Therefore the author only considers ABE, ADE and BDE combinations for this research.

The criteria for choosing the best clustering methodology is to choose the method (K-mode, K-median and K-means) and the combination (ABE, ADE and BDE) with the least value for false negative rate. If the false negative rates are similar for more than one case then the author chooses the clustering methodology and combination with the least false positive rate. Considering the results in Table 9, Table 10 and Table 11, K-means clustering methodology results in the lowest false positive and false negative rates among the other clustering methodologies for ABE, ADE and BDE. Among the three combinations ABE and has the lowest false positive and false negative rates. The next option is ADE with low error rates close to ABE combination. Table 12 shows the values of the factors for the two centers of the clusters (safe and dangerous) for K-means ABE and for the true clusters.

Table 12 Values of the centers of the two safe and dangerous clusters

Factors	**Center for the Safe Cluster**		**Center for the Dangerous Cluster**	
	K-means: safe cluster	True: safe cluster	K-means: dangerous Cluster	True: dangerous Cluster
A Time-to-Collision (Sec.)	7.5	5.5	0.1	-0.6
B: Deceleration Rate(ft/sec.^{2})	6.9	4.1	12.7	9.4
E: Lane Condition	2.1	2.3	4.0	3.2

2.7 Validation of CAPS to a Dataset (Maple and Farmington)

The next step to validate the clustering methodology is to apply the methodology to a second dataset (Maple and Farmington). The second dataset (dataset 2) consists of a study of blind and sighted pedestrians indicating when they would cross two-lane and three-lane approaches of a multilane roundabout located at the intersection of Maple Rd. and Farmington Rd. in West Bloomfield Township, Michigan. Both Maple and Farmington are two-lane roadways that flare out to multiple lanes at the approaches to the roundabout node. At the crosswalk, the cross sections on entry and exit legs on Maple Road have three lanes of traffic each. The cross section along Farmington Road, the north-south cross-street, has two lanes at the entry and exit legs for northbound traffic, and three lanes southbound. Figure 9 shows the aerial view of the roundabout located at Maple Rd. and Farmington Rd.

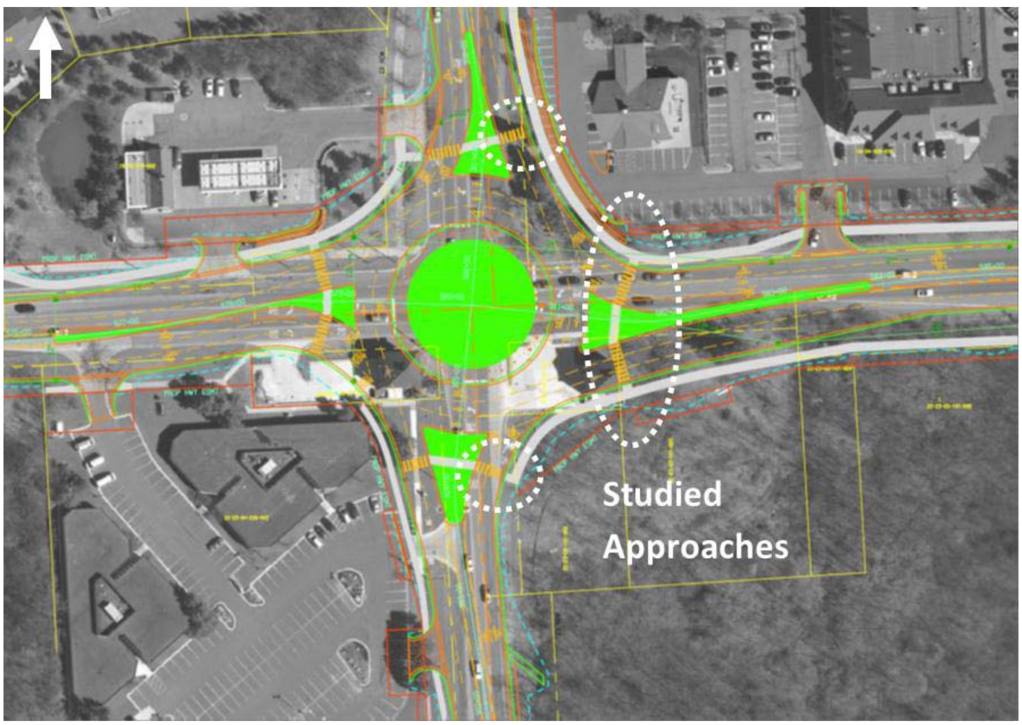


Figure 9 Aerial view of Second Study Location, Roundabout at Maple Rd. and Farmington Rd. MI (Source: http://www.nwconnector.com)

The dimensions highlight the inscribed circle diameters for Maple/Drake and Maple/Farmington of approximately 240 and 250 feet, respectively, and central island diameters of approximately 160 feet. Entering and exiting approach volume counts were performed by the Road Commission for Oakland County in late June 2009.Entring and exiting total daily traffic volumes on Maple Rd. and Farmington Rd. are both about 41965 vehicles per day.

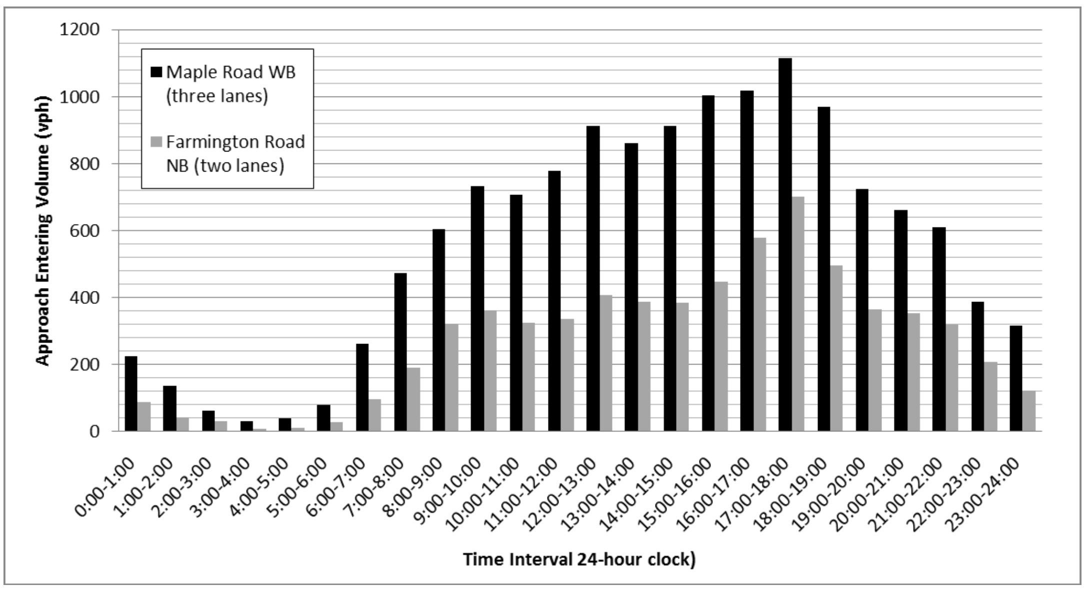


Figure 10 Hourly Distribution of Volumes at Maple and Farmington Roundabout

Daily traffic volumes reveal that flows on Maple Road are expectedly higher than along Farmington Road. Figure 10 shows that the highest flow period is represented by a peak period from 5-6pm, although traffic volumes are high throughout the afternoon.

The study included total ten (and for some cases twelve) trials for each of the four approaches studied (two-lane entry, two-lane exit, three-lane entry and three-lane exit). During each trial an O&M specialist evaluated the safety of the crossing decisions by showing a hand signal to the computer operator to indicate whether the crossing decision was either (1) risky or (2) estimated intervention, which is a very risky event that likely would have resulted in an intervention in a crossing study protocol. The absence of a hand signal indicated a safe crossing. The resulting protocol assigned one of three categories to each crossing event: “safe”, “risky”, and “estimated intervention”. In the analysis, only the estimated interventions were included in the safety assessment of the pedestrian decision-making, since these very clearly describe a potentially dangerous decision.

In each trial, participants were guided toward the crosswalk, aligned properly and told which approach of the roundabout was in front of them. For example they were told "You are judging the entry lane for Farmington from the curb; traffic will be coming from your left. Raise your hand when you would cross". A trial was concluded by the participant's indication that he/she would cross or by timing-out after two minutes. At that time, the participant was asked to step back from the crosswalk and walk for a short distance along the sidewalk to allow for traffic to be cleared and then walk back to start a new trial. In addition to the O&M specialist, an independent expert observer would also rate each crossing event as safe, risky, or estimated intervention. These judgments were independently made by the expert observer without seeing the hand signal of the O&M specialist. These two independent risk indicators were then compared later to arrive at an overall risk assessment of the crossing decision. Only the estimated interventions are reported here to quantify the safety of the crossing decision, since those most directly correspond to the safety rating in prior studies, including at the Maple/Drake roundabout

The video camera set-up for this study involved the use of three overhead video cameras and one or two (posttest) ground-level video cameras. For each of these crossing events all the four factors A, B, D and E (time-to-collision, deceleration rate, distance-to-collision and lane condition factor) are extracted from the multi-angle video cameras similar to the set up shown in Figure 6. Since this experiment does not involve actual pedestrian crossing, factor C, complexity of evasive action, could not be identified. Each of the crossing events are predicted as safe or potential intervention by an O&M specialist.

The procedure for validating the clustering methodology is to calculate the Euclidean distance of each of the crossing events in dataset 2 from the center of the clusters, identified and calibrated based on dataset 1. Then measure the false negative and false positive error rates and evaluate the clusters. Based on error rate we can decide whether to choose the clusters (centers) chosen by clustering methodology or the "true clusters" (centers).

2.7.1 CAPS Conflict Grade Matrix

The results of application of original CAPS framework to a new dataset (Maple and Farmington, dataset 2), show high values of false positive and false negative rates. The original CAPS framework and the conflict grade matrix is developed and calibrated by using dataset 1. The framework might result in high error rates if it is applied to a second set of crossing data, as for this matter high error rates are observed in Table 13.

Table 13 Original CAPS framework applied to Maple and Farmington Data Set

Model	Two-Lane (n=49)			Three-Lane (n=65)		
	False Positive %	False Negative %	# Missed Interventions (Estimated 20)	False Positive %	False Negative %	# Missed Interventions (Estimated 27)
AE	54%	29%	14	51%	31%	20
BE	54%	31%	15	51%	29%	19
ABE	41%	24%	12	27%	26%	17
ADE	33%	24%	12	26%	26%	17
BDE	48%	27%	13	31%	25%	16
ABDE	26%	20%	10	27%	22%	14

2.7.2 Application of Clustering Methods to Dataset 2: Results and Discussion

The next step is to apply dataset2 to the ABE K-means clusters and the true clusters. The procedure is to measure the Euclidean distance of the each data point from the center of the two clusters identified by ABE k-means, find the minimum distance and assign the data point to the cluster with minimum distance. Then measure the false negative and false positive error rates after the assignment of all data points by comparing the O&M ratings with the clusters that data points were assigned to. The procedure is repeated using the center of the true clusters, then false positive and false negative rates are measured and the results are presented in Table 14.

Table 14 Validation of selected clustering methodologies to dataset 2

Clustering Method (ABE)	Two-Lane (n=49)			Three-Lane (n=65)		
	False Positive %	False Negative %	# Missed Interventions (Estimated 20)	False Positive %	False Negative %	# Missed Interventions (Estimated 27)
K-means	20%	20%	10	23%	15%	10
True Clusters	22%	16%	8	22%	17%	11

Contrasting the false positive and false negative rates in Table 14 with Table 13 shows that both optimized CAPS clustering methodologies (K-means and true clusters) resulted in lower false negative and false positive errors compared to the Original CAPS framework. However considering the two k-means and "true clusters" methodology the results are very similar. K-means resulted in higher false negative rates for two-lane dataset (20% compared to 16% for true clusters) but showed lower false negative rates for three-lane dataset (15% compared to 17% for true clusters). K-means false positive rate is lower than true clusters methodology for two-lane (20% and 22% respectively) but slightly higher for three-lane (23% and 22% respectively). None of the methodologies were able to completely eliminate the false positive and false negative rates and correctly identify and separate the safe and dangerous (potential intervention) crossing decisions.

2.8 Discussion and Future Work

This goal of this chapter was to introduce a framework to measure and quantify the risk level of a pedestrian-vehicle interaction (conflict) at the crosswalk for a pedestrian crossing decision. This framework is intended to address one of the components of accessibility framework introduced by Schroeder el at (2011a) in NCHRP report 674 which is the safety criterion. The CAPS framework also enact as a proxy measure to evaluate the safety of a crosswalk and eliminate the error in subjectivity by O&M specialist in study of blind pedestrian crossings.

The original CAPS framework generates a level of risk based on five factors that describe the attributes of an interaction between pedestrian and vehicle. These five factors are time-to-collision, deceleration rate, complexity of evasive action, deceleration rate and distance to collision which are measured from field data. The clustering optimization methodology is applied to field data in order to reduce the number of these factors for more effective and economically feasible data collection. Clustering was also intended to calibrate the thresholds of these factors to better identify the safe and dangerous crossing decisions.

K-means clustering method resulted in lower false positive and false negative difference rates from the true risk level of each crossing event compared to k-mode and k-median clustering methods. The results of clustering on the available data shows the original CAPS framework with five factors can be reduced to a three-factor framework consists of time-to-collision (A), deceleration rate (B) and lane condition factor (E). The CAPS (ABE) framework has reasonably small false positive and false negative rates. However the clustering method was not able to completely eliminate the false positive and false negative rates. The outcome of the framework did not completely match with the judgment of O&M specialists of the risk level of all crossing events. Normalizing the values of each factor to values between 0 and 1 is recommended for future clustering of the data.

Although the original CAPS framework and the optimized CAPS framework are in progress of eliminating the error of “subjectivity by O&M specialist” shown in Figure 2, the result is not ready for implementation. One caveat of the framework is the number of risk levels. The current framework has only two categories of safe and dangerous (intervention worthy) for the state of each crossing event. However more risk levels are needed to cover the events which are not completely safe neither completely dangerous. The hypothesis is that more risk levels may reduce the false positive and false negative rates of the current framework. Since the true state of data available for this research has only two risk levels, the author was not able to test the hypothesis. In addition to that, larger number of data points is needed to calibrate the clusters and the center of the clusters. Increasing the number of clusters from two (safe and dangerous) will also improve the error rates in clustering methodology.

The current methodology in this chapter only considers the events in which pedestrian makes a crossing decision. One of the caveats of dataset is the lack of data on those supposedly risky decisions that pedestrian chose not to cross. In other words, the number of unsafe crossing decisions in the dataset is much lower than the number of safe crossing decisions. it is possible that not all unsafe crossing decision possibilities can be found in dataset.

3 CONTROLLED FIELD STUDY: DRIVER YIELDING BEHAVIOR TO PEDESTRIANS AT TWO-LANE ROUNDABOUT APPROACHES

3.1 Introduction

Availability of sufficient crossing opportunity is one of the components of accessibility framework introduced by Schroeder et al. (2011a) in NCHRP report 674. Crossing opportunity is in the form of crossable gaps or driver yields. The focus of this chapter is to study the factors that impact the likelihood of driver yielding. The type of controlled field study described in this chapter is a proxy method to understand driver yielding behavior and its contributing factors. This type of study also attempts to eliminate “pedestrian behavioral differences” and “differences across sites” as the two sources of error in study of blind pedestrian crossing by controlling for pedestrian behavior and study locations.

The rate of driver yielding to pedestrians at (multi-lane) roundabouts varies across locations (Rodegerdts et al. 2010), but in nearly all cases is less than 100%. A range of treatments exist that are intended to increase the rate of driver yielding (Rodegerdts et al. 2010), and yielding behavior has been linked in research to operational characteristics such as vehicle speeds (Geruschat and Hassan 2005), as well as geometric characteristics including the entry versus exit leg at a roundabout (Rodegerdts et al. 2010,Ashmead et al. 2005). But to date, these isolated studies of driver yielding behavior at roundabouts have largely been descriptive, with little insight gained towards predicting driver yielding at modern roundabouts.

This section of research studies the factors that may influence the propensity of driver yielding to pedestrians at two-lane roundabout approaches. The research is based on controlled observations of driver yielding behavior at entry and exit legs of six multi-lane roundabouts across the United States, and seeks to develop predictive models for yielding. The research rests on the premise that yielding is a critical component of pedestrian accessibility and pedestrian safety, and that an improved understanding of yielding behavior may be of great value to researchers and agencies.

3.2 Background and Literature

Due to multiple-threat situations and being exposed to two conflicting lanes of traffic, pedestrians crossing at two-lane approaches are generally more challenging and risky than single-lanes (Schroeder et al. 2001a, Harkey and Zegeer, 2004).The results of NCHRP Report 674 (Schroeder et al. 2011a) suggest that pedestrians who are visually impaired experience more delay crossing the two-lane approaches of the roundabout since they take longer to utilize crossing opportunities in the form of yields or gaps. Participants also made more risky crossing decisions at two-lane roundabout approaches compared to single-lane roundabouts (Schroeder et al. 2011a). Research has found that the likelihood of blind pedestrians making a risky crossing decision is 2.5 times higher than sighted pedestrians (Ashmead et al. 2005,Guth et al. 2005). Blind pedestrians required more time (on average 3 to 5 seconds longer) to detect a crossing opportunity (Schroeder et al. 2009).The studies also show that drivers tend to yield to blind pedestrians more often than sighted pedestrians (Geruschat and Hassan 2005,Ashmead et al. 2005,Schroeder et al. 2011a)

Findings of pedestrian operations at roundabouts by NCHRP report 572 (Rodegerdts et al. 2010) show that 43% of the drivers at two-lane approaches of the roundabout do not yield to pedestrians. The lack of yielding is only 17% for single-lane roundabouts. Lack of yielding is also higher at exit (54%) compared to 33% not yielding at the entry. Based on these findings, the number of lanes and crosswalk location (entry or exit) are two important design elements that affect pedestrian accessibility at roundabouts.

Schroeder and Rouphail (2011b) formulated a pedestrian delay model at single lane roundabouts as a function of “probability of crossing” and “probability of encountering a yield”. Alternatively, the 2010 Highway Capacity Manual (TRB 2010) suggests the use of a methodology for calculating pedestrian delay at the major street of two-way stop-controlled intersections for calculating pedestrian delay at roundabouts. Such crossings do not have control for pedestrians and therefore pedestrian crossing delay is based on availability of gaps or driver yields. The methodology in chapter 19 of HCM2010 (TRB 2010) defines delay as a function of probability that the i^{th} crossing event is either a driver yield or produces a crossable gap. It further describes the probability of driver yielding as a function of motorist yield rate. The model in HCM 2010 (TRB 2010) is not calibrated from field data and does not take into account behavioral factors. This research explores P(Yi), the probability that a motorist yields to a pedestrian on a crossing event and attempts to calibrate the model taking into account microscopic traffic parameters related to pedestrian crossing. The methodology in this chapter is adopted and modified from similar research approach by Schroeder and Rouphail (2011b) for midblock crosswalks. The methodology uses an "event-based predictive model" to predict driver yielding behavior from observations of pedestrian and vehicle interactions at crosswalks.

A study at two two-lane roundabouts in Maryland by Geruschat and Hassan (2005) shows that the speed of the vehicle at the entry and exit of roundabouts significantly influences the driver yielding rate. The authors found that 65% of the variability of driver yielding rate can be explained by speed. Based on their study, they estimated that the driver yielding rate with speeds lower than 15 miles per hour is about 75% as opposed to 50% with speeds higher than 20 miles per hour. In addition to the speed of the vehicle, they found that drivers yield to pedestrians at the entry 79% of the time as opposed to only 37% of the time at exit. The authors observed that pedestrian behavior influences the driver yielding rate. Based on their study, the pedestrian behavior affects the driver yielding behavior. For example if a pedestrian is standing one foot from the curb, at the curb or in the crosswalk, the driver yielding rates are different. The further the pedestrian is standing into the crosswalk the higher the likelihood of driver yielding. Drivers are almost twice as likely to yield to a pedestrian standing one foot in the crosswalk as one foot from the curb. Their study also shows that drivers have significantly higher yielding rates to pedestrians carrying a white cane (2.1 times higher at entry and 4.4 times higher at exit). Although the study has valuable findings, it only observes the interaction of one pedestrian with one vehicle at a certain distance from the crosswalk under the condition of no vehicle platooning or following. This study is descriptive of driver yielding behavior but not predictive, and does not take into account other traffic factors such as heavy vehicles, multiple pedestrians, platooning, or the lane location of the vehicle with respect to pedestrian. Another study by Schroeder and Rouphail (2011b) takes a more predictive approach to understanding driver yielding behavior to pedestrians. The authors observed pedestrian-driver interaction at two unsignalized midblock crosswalks, and developed logistic regression models to predict driver yielding (Schroeder and Rouphail 2011b), as well as pedestrian gap acceptance (Schroeder and Rouphail 2011c). The data collection methodology involved observing and recording traffic characteristics during the interaction between vehicles and naturally occurring pedestrians crossing the street. Although the research approach takes into account all the factors involved, results are confounded by much variability in (naturally occurring) pedestrian behavior, and is further limited to two midblock crossing sites.

Inspired by the research methodology presented by Schroeder and Rouphail (2011b) and the roundabout-related findings by Geruschat and Hassan (2005) this chapter of research develops logistic regression models to predict the likelihood of driver yielding to pedestrians at the entry and exit legs of six two-lane roundabouts in different states across the United States.

3.3 Methodology

The objective of this chapter is to develop models for predicting driver yielding to pedestrians at two-lane roundabouts and to identify the contributing factors. The methodology is built upon earlier findings of parameters that affect driver yielding behavior, such as vehicle dynamics, pedestrian behavior and other traffic related factors. Accordingly, a data collection methodology was developed to capture a range of observations in these variables, while controlling for some pedestrian behavioral attributes: 1) Use of a white cane, and 2) waiting position relative to the crosswalk curb.

Many states have “White Cane Laws” that emphasize the need to pay attention to pedestrians traveling with a long white cane, and in some cases mandate yielding. This research therefore also seeks to explore the effect of white cane use on driver yielding. Many state laws are written such that vehicles must yield the right of way to pedestrians within the crosswalk, while many pedestrians choose to wait at the crosswalk. The distinction of whether or not a pedestrian physically has a foot in the roadway therefore has certain legal implications, and furthermore may convey different levels of pedestrian assertiveness. Therefore the data collection methodology is designed to include different waiting positions for the pedestrian.

For data collection, special attention is given to the first vehicle. The first vehicle is the closest vehicle to a pedestrian at the crosswalk (in terms of time and distance), but in a key difference to earlier research (Geruschat and Hassan 2005), that first vehicle may be the lead vehicle of a platoon, and the research accounts for the interaction effects between vehicles on the yield response. An experiment is defined as one of the research team members approaching the crosswalk as a (seeded) pedestrian at random intervals. Pedestrian behavior is controlled as either “blind” or “sighted” (either with or without the white cane) and for waiting position (either standing at the curb or one foot in the crosswalk). Therefore we have a total of four conditions in the study: blind pedestrian standing at the crosswalk, blind pedestrian standing one foot in the crosswalk, sighted pedestrian standing at the crosswalk, and sighted pedestrian standing one foot in the crosswalk. An observer records the events related to the experiment. After the pedestrian arrives at the crossing location, the experiment can have three possible outcomes:

1) The subject detects and identifies a crossable gap, he/she then steps back and the experiment is completed. The observer records the crossing attempt as a crossable gap. A crossable gap is defined as enough time for the pedestrian to finish crossing both lanes of the leg completely before the vehicle arrives at the crosswalk, which was about 8 to 10 seconds for our studied locations.

2) A vehicle or a platoon of vehicles is approaching the crosswalk. The first vehicle closest to the pedestrian yields which causes a crossing opportunity (yield event). The pedestrian accepts the yield and crosses (assuming the other lane also has a yield or is free). The observer records all the traffic attributes related to the first vehicle and the first vehicle-pedestrian interaction.

3) A vehicle or platoon of vehicles is approaching the crosswalk. The first vehicle does not yield to the pedestrian (non-yield event). The pedestrian waits at the crosswalk until a crossing opportunity in a form of a yield or crossable gap is presented. The observer records all the traffic attributes related to the first vehicle and the first vehicle-pedestrian interaction. The observer further records the attributes related to the utilized crossing opportunity by pedestrian.

The experiment is repeated 25 times for each of the four pedestrian conditions. This results in 100 controlled pedestrian crossings for each approach, entry and exit, for a total of 200 crossings for each roundabout leg. For the purpose of developing models for likelihood of driver yielding all the yield and non-yield events related to the first vehicle–pedestrian interaction are taken into account, while gap crossing events are ignored.

3.3.1 Field Data Collection and Parameters

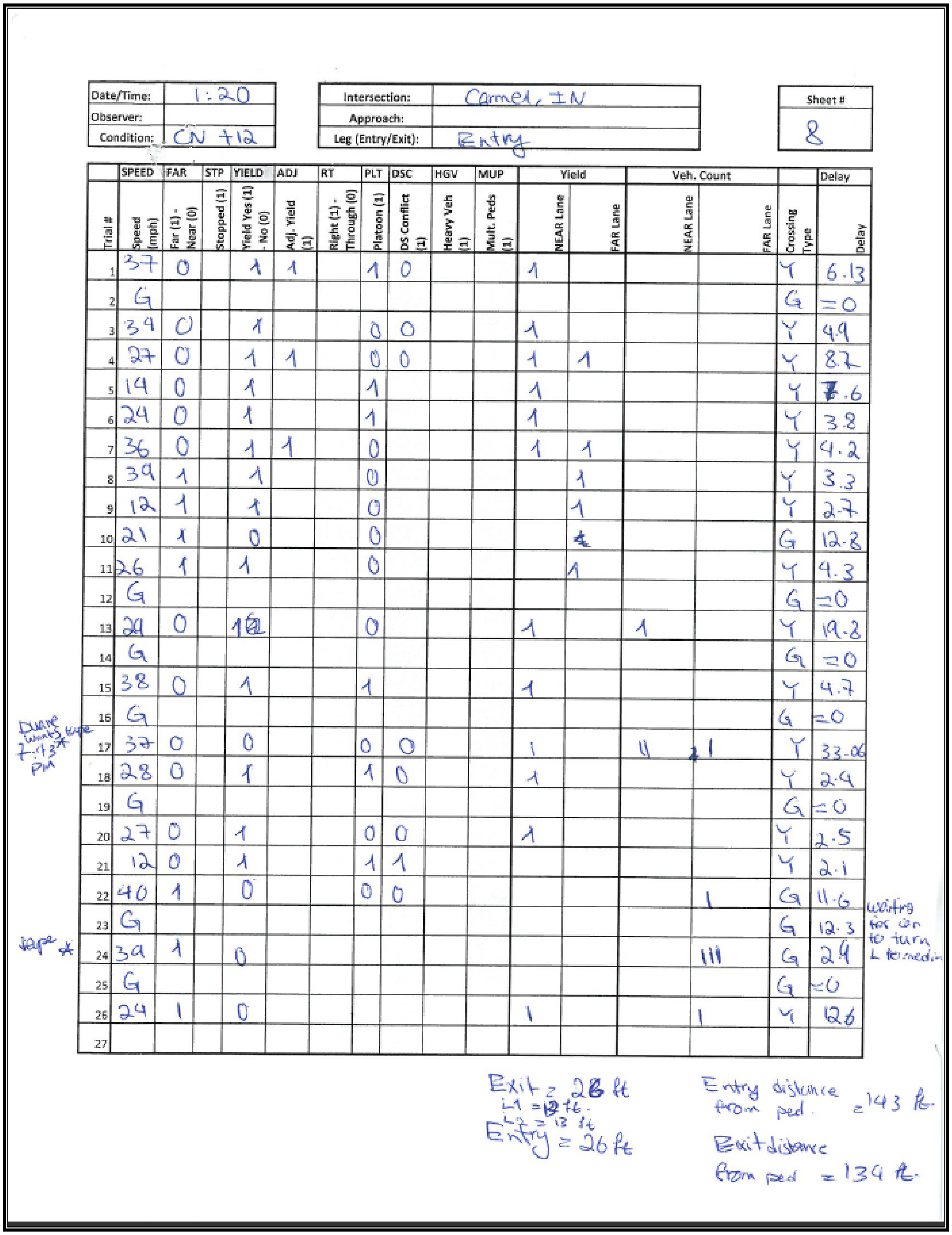
For each experiment a set of variables is collected as shown in Table 15. These variables describe the interaction between the first vehicle and the pedestrian. A Bushnell Speedster speed gun was used to measure the speed of the vehicles. The speed gun was wirelessly connected to an LCD Screen that shows the speed of the vehicles (1.5% error in measurement at an angle of 10 degrees off center) (Bushnell Speedster 2012) and is visible to a video camera (but not to approaching drivers). A ground level video camera was pointed at the crosswalk and approach to capture the pedestrian, oncoming vehicles and speed screen. The video camera is used as a backup for data collection. Figure 11 shows the data collection set up for the study.

Figure 11 Camera, speed measurement system and speed screen set up for studying driver yielding behavior at two-lane roundabout approaches.

Table 15 Traffic Characteristics Collected for Yielding Study

Factor		Description	Value
Condition	EXT	Exit or entry approach of Roundabout	Exit =1, Entry=0
	CN	If the pedestrian was acting to be blind and carried a white cane	CN=1
	FT	Waiting Position; whether the pedestrian was standing at the curb (at curb) or one foot in the crosswalk (in-road)	FT=1(at curb), FT=0 (in-road)
First-Vehicle-Parameters	SPD	The speed of the first vehicle (mph),at the start of the experiment	MPH
	FAR	Lane that first vehicle was driving (near-lane or far-lane with respect to pedestrian),	Far =1, Near=0
	STP	Whether the first vehicle had already stopped at the time that pedestrian arrived	Stopped=1
	YIELD	Whether the first vehicle yielded (Response Variable)	Yield Yes=1, No=0
	PLT	If the first vehicle was in a platoon	Platoon=1
	MUP	If there were other pedestrians present near the crosswalk; if any pedestrian is at either sides of the street or the splitter island and intends to cross	Multiple Pedestrian =1
	HGV	First vehicle type: passenger car or heavy vehicle	Heavy Vehicle= 1
	RT	If first vehicle was turning right from adjacent leg of roundabout (only applicable to exit leg)	Right=1, Through=0
	DSC	If there were any downstream conflicts present (only applicable to the entry leg of roundabouts); downstream conflict happens when there is queuing at the entry to enter the roundabout or the circulating traffic is congested	DS Conflict=1

The observer (research team member) used a data sheet to record the variables exhibited in Table 15. All the variables, expect for speed, are binary variables. Speed is a continuous variable recorded from the speed gun screen. The response variable is yield and is a binary variable (first vehicle yielded=1, first vehicle did not yield=0). Figure 12 shows a sample data collection sheet used for collecting data at the roundabout located in Carmel Indiana. Each sheet is used for one condition. Figure 12 shows the condition roundabout entry approach/blind pedestrian with white cane/ standing 1 ft. in the crosswalk.



Date/Time:	1:20
Observer:	
Condition:	CN +12

Intersection:	Carmel, IN
Approach:	
Leg (Entry/Exit):	Entry

Sheet #
8

	SPEED	FAR	STP	YIELD	ADJ	RT	PLT	DSC	HGV	MUP	Yield		Veh. Count			Delay
Trial #	Speed (mph)	Far (1) - Near (0)	Stopped (1)	Yield Yes (1) - No (0)	Adj. Yield (1)	Right (1) - Through (0)	Platoon (1)	DS Conflict (1)	Heavy Veh (1)	Mult. Peds (1)	NEAR Lane	FAR Lane	NEAR Lane	FAR Lane	Crossing Type	Delay
1	37	0		1	1		1	0			1				Y	6.13
2	G														G	=0
3	34	0		1			0	0			1				Y	4.9
4	27	0		1	1		0	0			1	1			Y	8.7
5	14	0		1			1				1				Y	7.6
6	24	0		1			1				1				Y	3.8
7	36	0		1	1		0				1	1			Y	4.2
8	39	1		1			0					1			Y	3.3
9	12	1		1			0					1			Y	2.7
10	21	1		0			0					~~1~~			G	12.8
11	26	1		1			0					1			Y	4.3
12	G														G	=0
13	24	0		12			0				1		1		Y	19.8
14	G														G	=0
15	38	0		1			1				1				Y	4.7
16	G														G	=0
17	37	0		0			0	0			1		ll	21	Y	33.06
18	28	0		1			1	0			1				Y	2.9
19	G														G	=0
20	27	0		1			0	0			1				Y	2.5
21	12	0		1			1	1							Y	2.1
22	40	1		0			0	0						1	G	11.6
23	G														G	12.3
24	39	1		0										lll	G	29
25	G														G	=0
26	24	1		0							1			1	Y	126
27																

Duane wants tape 7:43* PM

tape *

waiting for car to turn L to median

Exit = 28 ft
L1 = 13 ft.
L2 = 13 ft
Entry = 26 ft

Entry distance from ped. = 143 ft.

Exit distance from ped = 134 ft.

Figure 12 Sample data collection Sheet for yielding study

3.3.2 Site Description

The data collection methodology was applied to six multilane roundabouts in four different states; Maryland, North Carolina, Indiana and Tennessee. One two-lane entry and one two-lane exit approach of each of these six roundabouts were studied. All these roundabouts are located in relatively urban areas, and drivers have a general expectation of (some) pedestrian activity. All sites are equipped with pedestrian sidewalks, crosswalks, and have some naturally occurring pedestrian traffic. The list of roundabouts studied is displayed in Table 16.

Table 16 List of the Roundabouts Studied for Driver Yielding Behavior

Site ID	City, State	Intersection	Approach	Approach Speed Limit (mph)	type	X-W. Dist.
ST_NASH	Nashville, TN	Music Square/ Division St./ 16th Ave./ Demonbreun St.	Eastbound Exit and Westbound Entry at Demonbreun St.	25	Suburban	20 ft.
ST_TSN	Towson, MD	MD 45/Dulaney Valley Rd./Joppa Rd./Allegheny Ave.	Northbound Entry and Southbound Exit on Dulaney Valley Rd.	25	Urban	40 ft.
ST_ANN	Annapolis, MD	MD 450 (West St.)/Taylor Ave./Spa Rd.	Eastbound Exit and Westbound Entry	25	Urban	20 ft.
ST_IND	Carmel, IN	Old Meridian St./ Guilford Ave.	Eastbound Entry and Westbound Exit at Old Meridian St.	25	Suburban	40 ft.
ST_RAL	Raleigh, NC	Hillsborough St./ Pullen Rd.	Northbound Entry and Southbound Exit at Pullen Rd.	25	Suburban	20 ft.
ST_SLM	Winston-Salem, NC	Old Salem Rd./ S. Main St./ Salem Ave.	Southbound Entry and Southbound Exit at Old Salem Rd.	25	Suburban	25 ft.

A review of the state right-of-way laws in the four states (North Carolina, Maryland, Tennessee and Indiana) suggests that traffic laws in these states give the right-of-way to pedestrians crossing within the crosswalk. They also state that drivers should yield the right of way to pedestrians carrying a while cane or guide dog (NCDOT 2012, MDOT 2012, Tennessee Traffic Safety Resource Services Agency 2012, Indiana Legislative Services Agency 2012).

3.4 Data Analysis

Data on 200 simulated crossing attempts were collected from five of the roundabout approaches (Nashville TN, Annapolis MD, Carmel IN, Raleigh NC and Winston-Salem NC). For Towson, MD 150 crossings were recorded, which resulted in a total of 1150 data points for all six roundabouts. For the purpose of developing yielding models, only the data points that described an interaction between the pedestrian and first vehicle were considered. The YIELD event is a binary indicator explaining whether the first vehicle yielded or not, and serves as the dependent variable. Other factors defined in Table 15 are explanatory variables and are used to develop a model to describe the YIELD response variable.

3.4.1 Descriptive Statistics

Based on previous research (Geruschat and Hassan 2005) three factors were shown to have an effect on driver yielding behavior, speed of the vehicle (SPD) , whether the pedestrian is standing at the entry or exit leg of the roundabout (EXT) and whether the pedestrian is carrying a white cane or not (CN). Table 17 shows the yielding rate for each of the study locations based on these three factors (SPD, EXT and CN).

Table 17 Yielding Rates and Speed Measurements for Each Site

Site, (n=25 for each condition)		Entry (EXT=0)				Exit (EXT=1)			
		Sighted (CN=0)		Blind (CN=1)		Sighted (CN=0)		Blind (CN=1)	
		Passive	Aggressive	Passive	Aggressive	Passive	Aggressive	Passive	Aggressive
Carmel, IN	Yield Rate	16%	18%	80%	70%	0%	0%	6%	13%
	Overall	**46%**				**5%**			
	Speed	Average = 30 mph, Max= 44 mph				Average = 19 mph, Max= 31 mph			
Nashville, TN	Yield Rate	39%	23%	75%	82%	0%	0%	0%	20%
	Overall	**55%**				**5%**			
	Speed	Average = 19 mph, Max= 31 mph				Average = 17 mph, Max= 25 mph			
Raleigh, NC	Yield Rate	17%	20%	21%	50%	16%	5%	17%	16%
	Overall	**27%**				**13%**			
	Speed	Average = 19 mph, Max= 31 mph				Average = 17 mph, Max= 26 mph			
Winston-Salem, NC	Yield Rate	0%	10%	19%	20%	0%	0%	12%	26%
	Overall	**12%**				**10%**			
	Speed	Average = 27 mph, Max= 44 mph				Average = 17 mph, Max= 24 mph			
Towson, MD	Yield Rate	30%	59%	57%	79%	48%	N/A	N/A	64%
	Overall	**56%**				**56%**			
	Speed	Average = 20 mph, Max= 31 mph				Average = 15 mph, Max= 21 mph			
Annapolis, MD	Yield Rate	40%	78%	94%	85%	29%	13%	41%	40%
	Overall	**74%**				**31%**			
	Speed	Average = 22 mph, Max= 31 mph				Average = 15 mph, Max= 26 mph			

The results of Table 17 show significant variability in driver yielding behavior among the different sites and entry and exit approaches of the roundabout for different pedestrian behavior. Overall the yielding rates are higher at the entry than exit leg of the roundabouts with maximum yielding rate of 85% in Annapolis, MD to a pedestrian carrying a white cane while they are waiting “at curb”. On the other extreme, Winston-Salem has 0% yielding rate at the entry (to sighted pedestrian waiting “in road”). At the exit approaches of roundabouts in Carmel IN, Nashville, TN and Winston-Salem, NC the yielding rate to sighted pedestrian (crossing behavior) similarly was 0%. The study of the exit legs at the six roundabouts shows that drivers overall yield more often to a blind pedestrian than sighted pedestrian. However the effect of pedestrian waiting position on driver yielding behavior changes among sites.

The speed results show generally higher speeds at entry legs, which is intuitive. Average and maximum speeds are largely consistent across sites, with exception of higher entering speeds at the Winston-Salem, NC site.

The model development section of this chapter applies logistic regression models to these factors and other factors explained in Table 15 to determine which factors significantly contribute to driver yielding behavior. Table 18 shows the average and standard deviation for the traffic attribute variables collected at the study locations for entry and exit.

Table 18 Descriptive Statistics for Each Site- a) Entry, b) Exit

Entry	Carmel, IN		Nashville, TN		Raleigh, NC		Winston-Salem, NC		Towson, MD		Annapolis, MD	
	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev
sample size	71		54		68		83		79		58	
Response Variable												
YIELD	0.451	0.501	0.519	0.504	0.265	0.444	0.120	0.328	0.557	0.500	0.776	0.421
Binary Factors												
FAR	0.366	0.485	0.630	0.487	0.750	0.436	0.723	0.450	0.468	0.502	0.276	0.451
RT	-	-	-	-	-	-	-	-	-	-	-	-
PLT	0.324	0.471	0.630	0.487	0.103	0.306	0.133	0.341	0.405	0.494	0.328	0.473
DSC	0.085	0.280	0.278	0.452	0.118	0.325	0.048	0.215	0.241	0.430	0.224	0.421
HGV	0.000	0.000	0.000	0.000	0.015	0.121	0.048	0.215	0.051	0.221	0.034	0.184
MUP	0.000	0.000	0.093	0.293	0.088	0.286	0.012	0.110	0.076	0.267	0.000	0.000
Continuous Factor												
SPD (mph)	29.746	7.653	18.593	6.227	18.765	4.960	27.133	7.638	19.696	4.797	21.707	6.170

Exit	Carmel, IN		Nashville, TN		Raleigh, NC		Winston-Salem, NC		Towson, MD		Annapolis, MD	
	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev	Ave.	StdDev
sample size	64		79		81		75		50		91	
Response Variable												
YIELD	0.047	0.213	0.051	0.221	0.136	0.345	0.107	0.311	0.560	0.501	0.308	0.464
Binary Factors												
FAR	0.500	0.535	0.481	0.503	0.728	0.448	0.480	0.503	0.340	0.479	0.385	0.489
RT	0.141	0.350	0.152	0.361	0.247	0.434	0.000	0.000	0.400	0.495	0.176	0.383
PLT	0.297	0.460	0.430	0.498	0.062	0.242	0.027	0.162	0.340	0.479	0.198	0.401
DSC	-	-	-	-	-	-	-	-	-	-	-	-
HGV	0.000	0.000	0.051	0.221	0.037	0.190	0.027	0.162	0.020	0.141	0.022	0.147
MUP	0.000	0.000	0.165	0.373	0.099	0.300	0.013	0.115	0.060	0.240	0.033	0.180
Continuous Factor												
SPD (mph)	18.703	4.108	16.582	3.112	17.074	3.308	17.480	3.351	14.780	2.444	15.495	2.639

Table 18 assists in characterizing the sites based on the data collected. For example for Raleigh NC, on average 75% and 73% of the first vehicle events occurred on the far lane at the entry and exit respectively, which are the highest numbers among all sites. Nashville TN has the highest rate of vehicle platooning both at entry and exit (63% and 43% respectively). Downstream conflict (DSC), which only applies to the entry leg, was observed for all study locations, however; Nashville TN has the highest (28%) and Winston-Salem NC (4%) has the lowest rate of DSC among all sites. Right turning vehicle (RT) only applies to the exit leg. Table 12 shows that Towson, MD has the highest (41%) and Winston-Salem NC has the lowest (0.0%) rate of right turning vehicles from the upstream adjacent leg. No heavy vehicles (HGV) or multiple pedestrian (MUP) events were observed in Carmel IN, on either entry or exit legs. There were no multiple pedestrian events (MUP) while studying the entry leg of the roundabout in Annapolis, MD. However on average, 3% of the data collected at exit had multiple pedestrians involved.

3.5 Model Development

3.5.1 Modeling Approach

The driver yielding response is a nominal parameter with a binary outcome (1=yield, 0=non-yield) (Schroeder and Rouphail 2011b,Schroeder 2008) Therefore a binary logistic regression model is used to predict the propensity of driver yielding behavior. The form of logistic regression model for yield behavior is (Equation 4):

Equation 4

$$Logit\ [P = (Y = 1)] = \log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \sum_{i=1}^{m} \beta_i\, x_i$$

Where:

β0: Intercept

βi : Parameter describing the effects of m explanatory variables xi on the yield response

Therefore the probability estimate of yield response can be calculated using Equation 5.

Equation 5

$$P(Y=1) = \frac{e^{\alpha+\sum_{i=1}^{m}\beta_i x_i}}{1+e^{\alpha+\sum_{i=1}^{m}\beta_i x_i}} = \frac{1}{1+e^{-\left(\alpha+\sum_{i=1}^{m}\beta_i x_i\right)}}$$

Based on Equation 5, if the values of all variables expect one xi are kept constant, one unit increase in the value of xi will increase the odds of response variable Y with a multiplicative effect of $e^{\beta i}$ (called the Odds Ratio). The R^2 statistic is generally used in regression models to describe how much variability of the data is explained by the model. For logistic regression models, the variability of the model can be evaluated by max-rescaled R^2. Higher max-rescaled R^2 is an indication of a better fit of the model to the data and the proportion of the data that can be explained by the model. Further fit statistics such as -2LogL and Akaike Information Criterion (AIC) are also used to explain the overall fit of the model.

The data from all sites are analyzed using the SAS Logistic regression model to develop the yielding probability models (SAS 2012). From all the factors described in Table 1, the events where a vehicle was already stopped when the pedestrian approaches the crosswalk (STP=1), and the events where the first vehicle was a heavy vehicle (HGV=1) were discarded. Stopped vehicles did not contribute to the yielding model since no other traffic characteristics such as speed or platoon, could be associated them. During the experiments in Raleigh, Winston-Salem in NC, Towson and Annapolis in MD, a few heavy vehicles were observed, which varied from school buses, campus university buses, transit buses or heavy commercial trucks. There was a variability observed in driver yielding behavior of different types of heavy vehicles. School buses and campus university buses yielded all the times to pedestrian while the yielding rate was much lower with transit buses and trucks. Therefore the authors decided to eliminate the crossing events that were associated with a heavy vehicle as the first vehicle event (HGV=1). The authors first used all the variables, DSC, SPD, FAR, RT, MUP, CN, FT and EXT in a SAS logit regression model using the forward selection algorithm with a threshold p=0.05 . In order to capture the effect of different sites in each model the authors also used five dummy variables to include the six study locations. These dummy variables are shown in Table 16. The effect of the site in Carmel IN (ST_IND) will be captured in the intercept of the model. The authors chose Carmel IN to be presented in the base model after carefully investigating and testing other sites. Carmel IN has moderate yielding rate and speed compared to other sites.

It is further hypothesized that entry and exit have different effects on the yielding probability model, as will the speed of the approaching vehicle. DSC is a variable that is defined only for entry since it indicates whether queue of vehicles was already present at the entrance of the roundabout when the first vehicle approaches the crosswalk. RT is a variable that is defined only for the exit, indicating whether the exiting vehicle was a right-turning vehicle from the adjacent lane or was coming from a different direction. In order to capture the effect of these variables in the yield probability model, the authors separated the entry and exit events and developed separate models for them.

3.6 Results

Table 19 and Table 20 demonstrate the results of the SAS logistic regression model development for all sites. Initially, entry and exit are modeled jointly, followed by separate entry and exit models. Table 19 shows the parameter estimate for each explanatory variable, as well as the odds ratio. The parameter significance level is indicated by superscripts. Table 19 does not take into account the effect of sites. This table shows that the factors: presence of white cane (CN), vehicle lane position (FAR), and vehicle speed (SPD) as well as entry and exit (EXT) are significant in the model with p-value<0.001. The presence of multiple pedestrians (MUP) is significant with p-value<0.05 in the combined entry and exit model and in the entry model, but it is not significant in the exit model. Pedestrian waiting position (FT) is only significant in the combined model with p-value<0.1. The value for Max-rescaled R^2 are 0.35, 0.35 and 0.28 for all, entry and exit model respectively.

Table 20 shows the SAS logistic regression model for all variables with the addition of the site variables. As noted before, after careful examination of the effect of each site on the regression model Carmel IN (ST_IND) was chosen be described by the effect of intercept. The first observation in Table 20 is that the overall fit is improved for the models relative to the values in Table 19 (Max-rescaled R^2 ; all=0.44,entry=0.47 and exit=0.44). In addition to the significant factors identified in Table 5a, sites Raleigh (ST_RAL), Winston-Salem (ST_SLM), Annapolis (ST_ANN) and Towson (ST_TSN) showed significance in three models as well as right turning vehicle (RT) for exit model.

Table 19 Results of Logistic Regression for All Sites:

	P(Yield)-All		P(Yield)-Entry		P(Yield)- Exit	
	Estimate	Odds Ratio	Estimate	Odds Ratio	Estimate	Odds Ratio
Intercept	2.06	-	1.62	-	3.45	-
DSC	0.29	1.33	0.43	1.54	-	-
SPD	**-0.11**[a]	0.90	**-0.09**[a]	0.92	**-0.33**[a]	0.72
FAR	**-1.46**[a]	0.23	**-1.65**[a]	0.19	**-1.16**[a]	0.31
RT	-0.09	0.91	-	-	-0.44	0.64
PLT	0.13	1.13	0.13	1.14	0.02	1.02
MUP	-0.79	0.45	-1.07	0.34	-0.52	0.59
CN	**1.28**[a]	3.59	**1.41**[a]	4.09	**1.10**[a]	3.01
FT	**0.36**[b]	1.44	0.31	1.37	0.45	1.57
EXT	**-2.14**[a]	0.12	-	-	-	-
AIC	796.782		442.652		408.410	
-2logL	776.782		426.652		327.158	
R^2	0.2501		0.2622		0.169	
Max-rescaled R^2	0.354		0.352		0.276	

[a] $p<0.001$ [b] $p<0.05$

Table 20 Results of Logistic Regression for All Sites: With Site Dummy Variables

	P(Yield)-All		P(Yield)-Entry		P(Yield)- Exit	
	Estimate	Odds Ratio	Estimate	Odds Ratio	Estimate	Odds Ratio
Intercept	2.07	-	2.52	-	2.18	-
DSC	0.22	1.25	0.29	1.33	-	-
SPD	**-0.11**[a]	0.90	**-0.11**[a]	0.90	**-0.32**[a]	0.73
FAR	**-1.21**[a]	0.30	**-1.25**[a]	0.29	**-1.26**[a]	0.29
RT	-0.34	0.71	-	-	**-1.28**[a]	0.28
PLT	-0.15	0.86	-0.36	0.70	0.17	1.19
MUP	-0.79	0.46	-1.06	0.35	0.03	1.03
CN	**1.40**[a]	4.05	**1.61**[a]	5.03	**1.31**[a]	3.70
FT	0.33	1.40	0.41	1.51	-0.34	0.71
ST_RAL	**-0.89**[b]	0.41	**-1.79**[a]	0.17	**1.28**[c]	3.62
ST_NASH	-0.34	0.72	-0.27	0.77	-0.47	0.63
ST_SLM	**-1.37**[a]	0.25	**-2.36**[a]	0.10	0.34	1.40
ST_ANN	**0.89**[a]	2.44	**0.82**[c]	2.28	**1.95**[a]	7.01
ST_TSN	**0.74**[b]	2.09	-0.41	0.67	**3.38**[a]	29.29
EXT	**-2.26**[a]	0.10	-	-	-	-
AIC	738.015		399.424		297.674	
-2logL	708.015		373.424		271.674	
R^2	0.3098		0.3537		0.2701	
Max-rescaled R^2	0.439		0.475		0.441	

[a] *$p<0.001$* [b] *$p<0.05$*

The final iteration of the analysis uses SAS forward selection with a p=0.05 threshold on all variables, including site dummy variables and is illustrated in Table 21. Since not all the variables were statistically significant as shown in Table 19 and Table 20, the forward selection procedure was used in SAS to only select the variables that are significant with p=0.05 threshold. Similar to previous findings CN, FAR, SPD, EXT (for only the combined "All" model) and RT (for only "Exit" model) have significant effect in likelihood of driver yielding to pedestrian (p<0.001). In addition to these factors, each studied site has a different effect on probability of yielding. As noted before the author tried different set of dummy variables to ensure the same results about the site variables (dummies) that are significant. Therefore site-specific differences exist that impact yielding beyond the effects of traffic attributes (such as CN, SPD, FAR). These site specific differences are addressed as the site name itself for simplicity. Nashville TN does not show up as significant in all three models which suggest that its yielding model is similar to Carmel IN. For “Entry” model Towson, MD and for “Exit” model Winston-Salem, NC are not significant at 95% confidence level, which suggests similar yielding models as Nashville TN and Carmel IN.

Table 21 Results of Forward Selection Logistic Regression Model (Final Models)

	P(Yield)-All		P(Yield)-Entry		P(Yield)- Exit	
	Estimate	Odds Ratio	Estimate	Odds Ratio	Estimate	Odds Ratio
Intercept	1.74	-	2.00	-	2.18	-
DSC	-	-	-	-	-	-
SPD	-0.10[a]	0.91	-0.10[a]	0.91	-0.32[a]	0.73
FAR	-1.22[a]	0.30	-1.31[a]	0.27	-1.31[a]	0.27
RT	-	-	-	-	-1.33[a]	0.26
PLT	-	-	-	-	-	-
MUP	-	-	-	-	-	-
CN	1.41[a]	4.09	1.62[a]	5.06	1.32[a]	3.74
FT	-	-	-	-	-	-
ST_RAL	-0.66[b]	0.52	-1.35[a]	0.26	1.31[c]	3.70
ST_NASH	-	-	-	-	-	-
ST_SLM	-1.10[a]	0.34	-1.93[a]	0.15	-	-
ST_ANN	1.22[a]	3.07	1.14[a]	3.13	1.94[a]	6.94
ST_TSN	0.94[a]	2.57	-	-	3.23[a]	25.27
EXT	-2.27[a]	0.10	-	-	-	-
AIC	734.606		395.837		289.639	
-2logL	716.606		381.837		273.639	
R^2	0.3026		0.34		0.2667	
Max-rescaled R^2	0.429		0.457		0.435	

[a] $p<0.001$ [b] $p<0.05$

Among all factors, entry and exit (EXT) has the largest impact on model with estimate of -2.27 and odds ratio of 0.1. The odds ratio suggest that for each study location, if all the other variables (CN, FAR, SPD) are kept at the same value, moving from entry to exit reduces the probability of yielding by a multiplication of 0.1.Overall, the roundabout located in Annapolis MD had the highest yielding rate among all other studied locations. The model estimate for Annapolis is 1.22 and the odds ratio is 3.07. The odds ratio indicates that with the same conditions of speed, pedestrian, lane location, and roundabout approach, the probability of a drive yielding in Annapolis MD is 3 times higher than a driver in Carmel, Indiana.

3.7 Discussion

The statistical tests for the three models (likelihood ratio, Wald and Score tests) are significant at p=0.0001 for all three models. The Max-rescaled R^2 varies from 0.43 to 0.46 which is fairly good for the fit of the models and better than yielding models for midblock crossings developed in prior research (Schroeder and Rouphail 2011b). The Akaike Information Criterion AIC for the "Entry" (AIC= 399.95) and for "Exit" (AIC = 289.64) have both lower values than the AIC for the "All" model (AIC= 734.10) which shows less information were lost during modeling entry and exit and these two models are better fits for the data than the "All" model.

The logistic regression modeling of driver yielding behavior to pedestrians at two-lane roundabouts shows there are few factors that have significant effect in the likelihood of yielding. Drivers that exit the roundabout have lower likelihood of yielding to a pedestrian than drivers entering the roundabout. At the exit leg of the roundabout drivers who are turning right, from the adjacent leg to the approach that pedestrian is standing, have lower propensity of yielding to pedestrian than drivers who are exiting from other directions. Drivers tend to yield more often to a pedestrian who is carrying a white cane compared to a sighted pedestrian. Drivers located in the far lane relative to the pedestrian location have lower likelihood of yielding to a pedestrian standing at the curb than driver located in near lane. As the speed of the vehicle entering or exiting the roundabout increases the likelihood of driver yielding decreases.

Other factors such as vehicle platooning, multiple pedestrians and downstream conflict (for entry approaches) did not significantly influence yielding rate at 95% confidence level in the final model (Table 21).

Previous research on midblock crossings by Schroeder and Rouphail (2011b) found a significantly reduced probability of yielding for vehicles traveling in a platoon; this is seemingly related to the perceived risk of rear-end collisions. Presumably, there is a greater expectation of pedestrians and reductions in speeds at roundabouts, which may explain why drivers are possibly less sensitive to being part of a platoon in deciding whether or not to yield.

Pedestrian waiting position (FT: in crosswalk versus at curb) also did not have a significant impact on yielding at 95% confidence level. This is important to note, given the fact that there is a debate about pedestrian right-of-way laws and the distinction between “in” versus “at” the crosswalk. State laws imply that drivers yield the right of way to pedestrians “in” the crosswalk (NCDOT 2012, MDOT 2012, Tennessee Traffic Safety Resource Services Agency 2012, and Indiana Legislative Services Agency 2012).

Figure 13 and Figure 14 show the effect of varying speed on probability of yielding with different conditions (CN=1, 0 and FAR=1,0). For the exit approach assumed the vehicle is not a right turning vehicle. The diagrams are plotted for the base model (Carmel, IN) with all the other site variables at zero level. Comparing the plots in Figure 13 and Figure 14 shows that probability of yielding is more sensitive to variability in speed at entry than exit. At 25 mph speed at the exit the likelihood of driver yielding is near to zero (for Carmel, IN) for different conditions (CN and FAR). However for speed of 25 mph at entry the likelihood of driver yielding is still greater than zero.

For both entry and exit the probability graphs are highest for an encounter with a blind pedestrian with vehicle in near lane (CN=1, FAR=0). The probability graph for sighted pedestrians and vehicle in the near lane (CN=0, FAR=0) are very close to the probability graph for blind pedestrian and vehicle in far lane (CN=1, FAR=1) for both entry and exit. The effect of blind pedestrian and a vehicle in far lane (CN=1, FAR=1) generates a slightly higher likelihood of yielding at entry. However the impacts of these two variables for exit are very similar such that both graphs overwrite each other. The encounter of a sighted pedestrian with a vehicle in the far lane (CN=0, FAR=1) is predicted to have the lowest yielding rates for both entry and exit. For a speed of 15 mph at the entry the probability of yielding changes from 65% (CN=1, FAR=0) , 35% (CN=1, FAR=1) to 27% (CN=0, FAR=0) and to only 10% (CN=0, FAR=1)

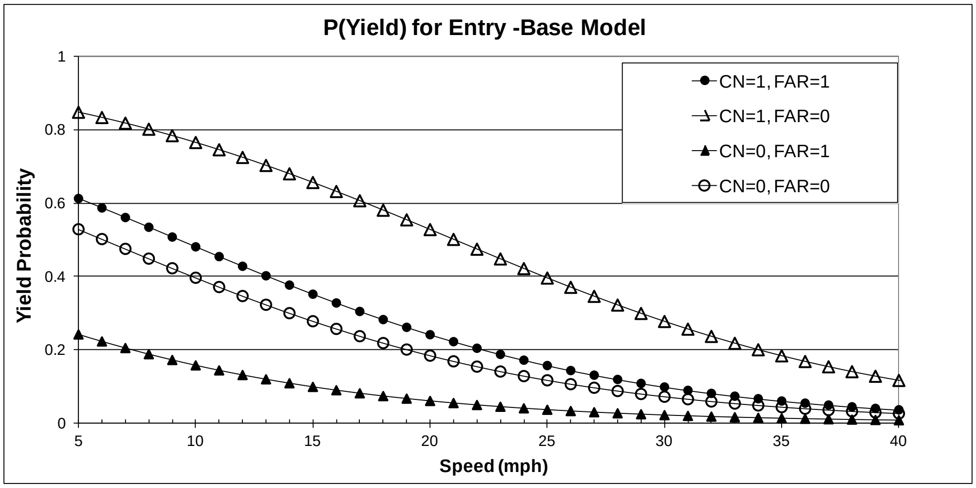


Figure 13 Model Probability Plots for the Base Case with No Site Variable, Entry Only

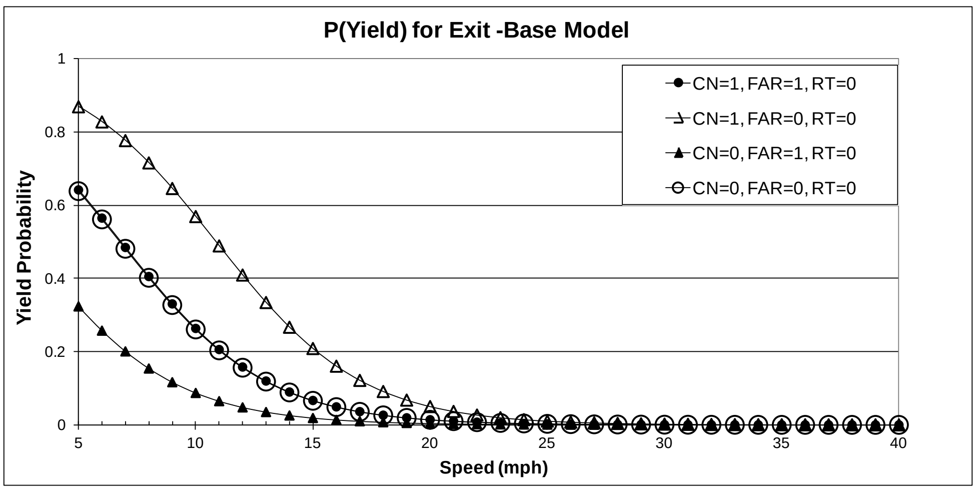


Figure 14 Model Probability Plots for the Base Case with No Site Variable, Exit Only

Figure 15 and Figure 16 plot the likelihood of predicted yielding rates by comparing all sites for a certain condition; no cane (CN=0) and vehicles located in near lane (FAR=0). The graphs in Figure 15 and Figure 16 illustrate how the yielding rate varies among sites. For the entry approach Annapolis MD has the highest and Winston-Salem has the lowest yielding rate among all sites (Figure 15). The curvature of graphs in

Figure 15 suggest that the probability of yielding in sites with overall lower yielding (Raleigh and Winston-Salem NC) drops less rapidly as the entry speed increases.

Figure 16 shows that Towson, MD has the highest yielding rate at exit among all sites. The base model for Carmel IN, which is also the suggested model for Nashville TN and Winston-Salem NC illustrates the lowest yielding rate among all sites. The graphs in Figure 16 emphasize the effect of study locations. Further analysis is needed to understand what the site-specific variables are and how they can be incorporated into the model. Some factors such as cultural driver behavior, the severity of right-of-way enforcement by police officers in each area, driver courtesy or driver urgency may not be quantified into the regression models as variables but can always be described as a general site variable. The modeling approach showed the importance of calibration for each study location and how driver behavior varies from one area to another.

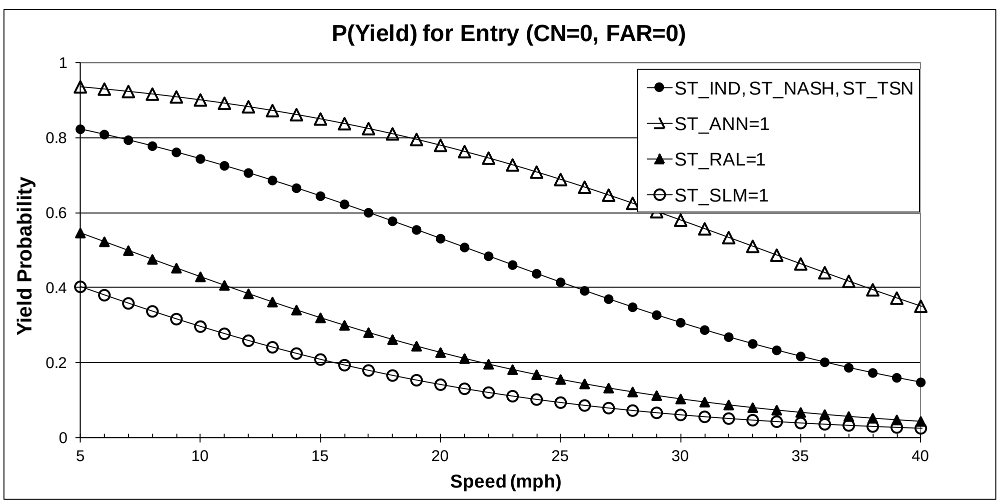


Figure 15 Model Probability Plots for Across All Sites for, Entry

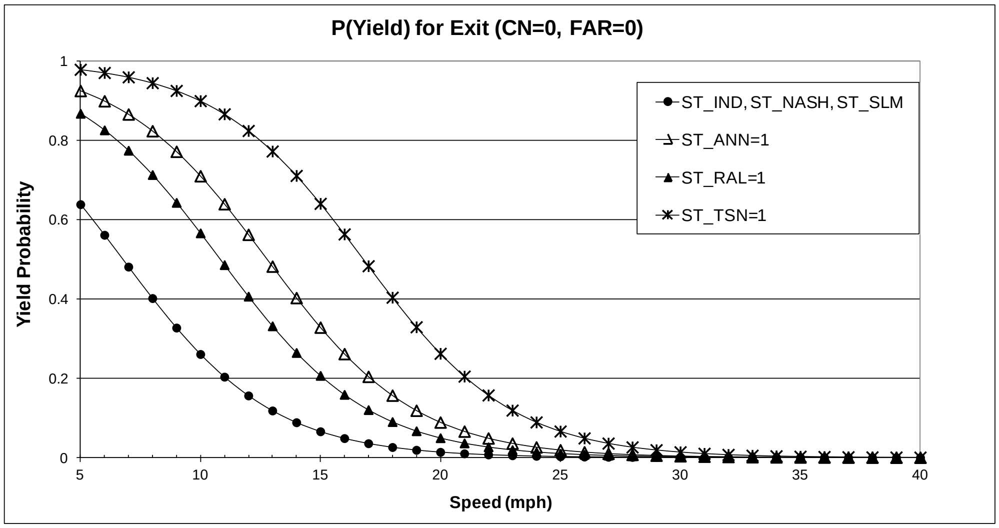


Figure 16 Model Probability Plots for Across All Sites for Exit

The models can be implemented in stochastic micro-simulation systems. The models are microscopic in nature and therefore capable of incorporating a discrete decision outcome of yielding for drivers and crossing for pedestrians. These models are based on probability functions and therefore the outcome of the model would vary by randomizing the input variables to the model. The models contain speed which describes the vehicle dynamics in car following algorithms. It also includes vehicle lane position and movement (RT for exit model) which are related to vehicle attributes in simulation modeling. It also includes variables related to pedestrian attributes (CN). In the simulation environment variables such as pedestrian attribute and site are global attributes that will have a certain value throughout the simulation. Variable speed (SPD) will vary by time in simulation since the nature of simulation software is such that variables are dynamically updated at every simulation time step (0.1 second for most software). Therefore the logistic yielding models can be incorporated as core algorithms in simulation software to predict driver decision of yielding at roundabouts. The site dummy variables in the model further help to calibrate the model for each region.

3.8 Conclusion and Future Work

This chapter aimed to identify and quantify the contributing factors affecting the likelihood of driver yielding. Availability of driver yielding as a crossing opportunity for pedestrians is one of the components of accessibility framework. The methodology described in this chapter as a form of controlled filed study and utilizing statistical regression models quantify probability of driver yielding is the proxy method for evaluating pedestrian accessibility. Pedestrian behavioral differences and site differences as the two sources of error in study of blind pedestrian crossing are controlled and accounted for with the use of this methodology.

This chapter attempted to identify the contributing factors affecting the likelihood of driver yielding to pedestrians at two-lane roundabouts. It further tried to model the likelihood of driver yielding based on these factors using logistic regression modeling. The results show that the likelihood of driver yielding at the entry leg of two-lane roundabouts is higher than the exit. This is consistent with findings at single-lane roundabouts (Schroeder et al. 2011, Geruschat and Hassan 2005). Drivers tend to yield to pedestrians with a white cane more often than sighted pedestrians. Drivers traveling in the far lane, relative to the pedestrian crossing location, have a lower probability of yielding to a pedestrian than drivers in the near lane. As the speed increases the probability of driver yielding decreases. At the exit leg of the roundabout drivers turning right from the adjacent lane have a lower propensity of yielding than drivers coming from other directions.

The results further show that factors such as vehicle platooning, downstream conflict (for only entry leg of the roundabout) and pedestrian waiting position, “at curb” versus “in crosswalk” do not have a significant impact (with 95% confidence level) on the probability of a driver yielding to pedestrian. It is important to note that all the right-of-way laws to pedestrians have been reviewed for these six study locations. The laws imply that drivers yield the right of way to a pedestrian crossing “in” the crosswalk. However none of the models show the effect of pedestrian waiting position as significant.

The modeling approach also explored the effect of model calibration methods for different study locations. For the six studied roundabouts, three sites showed significant intercept terms (or site dummy variables) that suggest a significantly different yielding performance. In other words, even when controlling for vehicular speed, pedestrian behavior, vehicle platooning, and other factors, this research showed that other site-specific variables and/or driver culture explain a significant portion of yield differences. For example for similar pedestrian and vehicle conditions a driver in Towson MD at the exit approach is 25 times more likely to yield to a pedestrian than a driver in Carmel IN. At the entry leg and with same conditions a driver in Winston-Salem NC is 1.9 times less likely to yield to a pedestrian than a driver in Carmel IN.

Future work includes explaining and identifying the site-specific factors that contribute to different yielding rates in different regions (while keeping all the other variables with the same value).It is also required to expand the data set to other two-lane roundabouts across the country. With further expansion of these models to other sites, the methodology and analysis approach presented here can provide valuable insights into geometric and cultural differences in driver yielding.

Crossable gaps in addition to yields are crossing opportunities that impact the accessibility of street crossings. Future work is needed to define proxy methods to identify and quantify contributing factors to increase availability of crossable gaps.

4 CONTROLLED LABORATORY STUDY WITH DRIVING SIMULATOR

4.1 Introduction

Availability of crossing opportunity in forms of crossable gaps and yields is one of the components of accessibility framework (Schroeder et al. 2011a). Previous chapter focused on contributing factors that impact the likelihood of driver yielding and attempted to quantify these factors. This section of the research aims at exploring the treatments that could increase the driver yielding rates and utilizes the use of a driving simulator to test the effect of the treatments. The proxy method described in this chapter is controlled laboratory study with driving simulator which allows the researchers to control for three sources of error in study of blind pedestrian crossings exhibited in Figure 2, driver behavioral differences, different treatments and random arrivals of traffic and pedestrians. Driving simulator allows testing particular treatments on certain driver population expose all subjects to the same environment. It also controls the traffic attributes of each scenario such as arrival of pedestrians, traffic volume, changes in signal phases and allows testing the reaction of different drivers in the same environment hence controls for these three sources of error.

The driving simulator is tested to study different pedestrian treatments at the exit leg of two-lane roundabout approaches. The studies show exit legs have lower yielding rates compare to entry leg of multilane roundabouts (Ashmead et al. 2005, Geruschat and Hassan 2005, Fitzpatrick et al. 2006). In order to test different treatments, for pedestrian crossings in a controlled environment, a driving simulator was used. Using a driving simulator for this purpose allows controlling factors such as speed; traffic and pedestrian volumes and other characteristics, and only test the effect of different treatments.

Three different treatments are assessed in terms of their propensity for increasing driver yielding rate at the exit leg of roundabouts. These are stop bar and crosswalk relocation away from the roundabout, and two types of beacons: a Pedestrian Hybrid Beacon (PHB) and a Rectangular Rapid Flashing Beacon (RRFB)..

4.2 Literature Review

The TRB Roundabout Informational Guide (Rodegerdts et al. 2010) suggests roundabout signalization may be beneficial under three conditions, *high vehicular volume, high pedestrian volume, and accessibility at more complex crossing situations*. This recommendation is related to a recently released Notice of Proposed Rule-Making by the US Access Board that call for the use of accessible pedestrian signals at newly constructed roundabouts with multilane approaches (US Access Board, 2011).To avoid the cost and uncertain effectiveness of full signalization schemes, non-signalization treatments have been put forward to improve accessibility at complex roundabouts (Schroeder et al. 2011a).

The Manual on Uniform Traffic Control Devices (MUTCD, 2009) has authorized the use of a new pedestrian crossing treatment, the Pedestrian Hybrid Beacon (PHB, also known as a HAWK) as a device intended to “warn and control traffic at signalized locations” and help pedestrians cross the street by having a red signal indication. Fitzpatrick et al. (2006) conducted research on the safety effects of PHB beacons installed at uncontrolled midblock pedestrian crossings and showed an 86% decrease in pedestrian crashes. A separate study of PHBs indicated that the number of pedestrian crashes had decreased compared to reference sites with no PHB (Hunter and Srinivasan 2009). They also reported high rates of driver compliance with PHBs, which resulted in higher driver yielding rate to pedestrians at the crossing location. NCHRP 674 tested a system of PHBs at a two lane roundabout in Golden, Colorado to increase accessibility for blind and visually impaired pedestrians (Schroeder et al. 20111a). The report concluded that the average (blind) pedestrian delay while trying to cross the street dropped from 16.0 seconds to 5.9 seconds, and more importantly, reduced the occurrence of potential vehicle-pedestrian collisions from 2.8% to 0.0%. As with other previous studies, NCHRP 674 indicated that driver compliance rate is not 100% with the installation of PHB at a two-lane roundabout and reports a 12.6% red light running rate (Schroeder et al. 2011a). Regardless of the findings on PHBs, they are supported as an equivalent to signalization by the US Access Board (RCOC 2011).

Another type of beacon sanctioned in the MUTCD is the Rectangular Rapid Flashing Beacon (RRFB). Shurbutt et al. (2010) studied the effect of RRFB on yielding rate and found that installation of side-mounted RRFB's at multilane uncontrolled midblock crosswalk locations increased driver yielding rate, on average from 18.2 to 87.8 percent. Hunter et al. (2009) evaluated the effect of a RRFB at a trail crossing in Florida and reported driver yielding to cyclists and pedestrians increased significantly compared to the no beacon condition. However the report mentions that "*…the device is not fail safe, and communities employing the device, especially at trail crossings, should take note of this…*" and suggests additional effort on educating the drivers and residents about the RRFB device (Shurbutt et al. 2010).The RRFB system is being considered as a potential treatment for improving accessibility in upcoming research by FHWA, but at the present time, is not mentioned explicitly as an alternative to pedestrian signals by the US Access Board (US Access Board 2011).

4.3 Methodology

The research consists of a controlled study environment in a driving simulator, equipped with an eye tracker device. Using a driving simulator is cost-effective compared to field studies. It also allowed the author to conduct a controlled experiment in terms of the location of crosswalk, pedestrians, traffic volume, and type of treatment. The driving simulator software also simplifies the data collection process for the experiment in the sense that all participants are exposed to exactly the same stimulus conditions (although in a randomized order). It also enabled the author to collect different types of data related to driver behavior and driver attentiveness through the use of an eye tracker system. The eye tracker provided valuable information about drivers' eye movement and gaze pattern in the process of yielding (or not yielding) to the pedestrian while exiting the roundabout.

The use of the driving simulator study and eye tracker helps to understand:

a) If the presence of either beacon improves driver yielding rates over a regular crosswalk base scenario.
b) Which type of beacon produces a higher driver yielding rate?
c) If the location of the crosswalk relative to the circulating lane affects driver yielding rate.

d) If yielding behavior (or lack therefore) is related to drivers consciously ignoring the pedestrian at the crosswalk, or to a lack of awareness.

The last objective aims to distinguish between drivers that saw the pedestrian and/or the treatment, but decided (consciously) not to yield, and those that didn't notice the pedestrian and/or the treatment. It is important to note that relocating the crosswalk farther away from the roundabout has some disadvantages including adding walking distance for the pedestrians and potentials for higher speeds for the vehicles when exiting.

4.3.1 Driving Simulator Study

The following sections discuss the equipment used to conduct the study, the experimental design, and the measures used to test the effectiveness of the simulated treatments.

4.3.1.1 The Driving Simulator

A STISIM Drive™ M400 driving simulator (System Technology Inc.) located in the Ergonomics Lab of Industrial Engineering department (North Carolina State University) was used for the study. The driving simulator is interactive and has a modular steering unit with full-sized steering wheel, semi-adjustable car seat, turn indicator, speedometer, modular accelerator and brake pedal unit, adjustable speed-sensitive steering force-feel system, horn and audio system. Three 37 inch HDTV monitors provide a 135 degree field of view for the driving environment. Drivers can see the rear view and side mirrors through the animation provided on the screens, as well as a button to do shoulder check for blind spots. STISIM Drive™ software allows the logging of various types of data for each trial such as speed of the drivers at any time and point, acceleration, deceleration, lane changing, etc.

4.3.1.2 The Eye Tracker

An eye-tracker is mounted on the participants' head to track their pupil movement on the screen (Zhang and Kaber, 2010). An H6 Head Mounted Optics Eye Tracking System can accurately track the pupil diameter and eye position relative to the person's head. The eye tracker provided valuable information about the drivers' gaze pattern during driving as they enter and exit the roundabouts. Figure 17 shows a screen shot of the driving simulator. Figure 18 shows the eye tracker device mounted on participants head to track their eye movement.

Figure 17 Driving Simulator Screen Shot PHB20 Scenario

Figure 18 Eye Tracker Device Source (http://www.ise.ncsu.edu/ergolab/)

4.3.2 Experimental Design

The author designed an experiment with the driving simulator to test side-mounted RRFB and overhead-mounted PHB compared to a standard crosswalk base scenario at the exit legs of multilane roundabouts. In addition, the author tested two offset distances from the circulating lane to the crosswalk, measured at 20 and 60 feet from the beginning of exit leg. The pedestrian crosswalk and beacons were installed with reference to the location of stop bar according to MUTCD guidelines.

The simulator experiment was designed as a full factorial experiment with two factors, the stop bar distance measured upstream of the exit leg and the type of beacon. The type of beacon factor has three levels PHB, RRFB, and control (no beacon) condition (CTRL). The full factorial combination generates 6 unique scenarios (CTRL20, PHB20, RRFB20, CTRL60, PHB60, and RRFB60). Each scenario simulates an urban corridor of eight roundabouts located at a constant spacing of 2000 feet. Four of the roundabouts have one pedestrian standing at the crosswalk with one foot on the crosswalk. This design thus allows for within subject replication. The location of the roundabouts with a pedestrian is randomized across each of the scenarios. The use of buildings, trees, pedestrians walking along the sidewalk, and traffic assisted in creating a realistic urban environment. The roundabouts were modeled with an hourly flow rate of approximately 200 vehicles per hour for the subject approach, to assure operations well below capacity. Modeling of a congested roundabout and the associated gap acceptance rules for simulated vehicles (other than the subject driver) was not possible with the available simulator technology. The roundabouts have two entering and exiting lanes in each approach, each 12 feet wide, and two circulating lanes in the circle. The center islands have diameter of 100 feet and the speed limit is 35 mph.

Each participant was asked to drive all six scenarios. The author decided not to advise the participants about the true purpose of the study as to not bias their yielding behavior in the experiment. Instead drivers were told that the experiment was geared at studying roundabout corridors, and to drive the scenarios as they would naturally drive while observing the traffic rules and regulations to the best of their knowledge. A Latin Square design for 6x6 experiments (Montgomery 2005) is used to randomize the order of scenarios for each subject. In order account for any learning effects, each driver was asked to drive one additional scenario at the end of the experiment, which is a repetition of the 1st scenario. This should allow the author to test for any learning effects during the experiment. Table 22 shows the 6 different patterns for the order of scenarios. For the purpose of this research, the results of orders 2 through 7 are presented, treating the first scenario as a pilot run.

Table 22 Latin Square Design for Randomizing the Order of Trials

	Randomized Order of scenarios						
Pattern	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
1	CTRL20	CTRL60	RRFB20	PHB60	PHB20	RRFB60	CTRL20
2	PHB20	CTRL20	PHB60	RRFB20	RRFB60	CTRL60	PHB20
3	RRFB20	PHB60	CTRL60	RRFB60	CTRL20	PHB20	RRFB20
4	CTRL60	RRFB20	RRFB60	PHB20	PHB60	CTRL20	CTRL60
5	RRFB60	PHB20	CTRL20	CTRL60	RRFB20	PHB60	RRFB60
6	PHB60	RRFB60	PHB20	CTRL20	CTRL60	RRFB20	PHB60

Each participant is randomly assigned one of the six patterns, while assuring that overall an equal number of scenarios is achieved across all subjects. For example, a participant assigned to pattern 2 would start with the PHB20 case (treated as a practice run), followed by CTRL20, PHB60, RRFB20, RRFB60, CTRL60, and PHB20. The randomization of scenarios is intended to account for any learning effects or changes in driver behavior over time. With four pedestrians present in each scenario, a total of 24 usable data points for each participant were generated, with four within-subject replications of each of the six scenarios.

4.3.2.1 Sample Size Calculation

Since the goal is to report whether drivers yield to a pedestrian at the crosswalk exit leg, the experiments result in a success or failure. Therefore the binomial distribution is used to calculate the required sample size. There are not any published results on the prevailing yielding rates at roundabout exits for RRFB. However, NCHRP 674 reported a 22% yielding rate to pedestrians at a channelized turn lane with a flashing beacon installed (Schroeder et al. 2011a). The same source also cites an approximately 87.4% yielding rate in both lanes of a two-lane roundabout, entry and exit, with PHB installed (Schroeder et al. 2011a).

NCHRP 572 reports an average yielding rate of 29% for roundabouts across the United States (Rodegerdts et al. 2010). These values were chosen to calculate the sample size for the base scenario and each beacon scenario. The significance value (alpha) is chosen to be 0.05 and the power at 0.8. By carrying, out a two-sided test and with the approximate success rates discussed above, the resulting sample size was estimated at 70 (Montgomery 2005). The data was collected from 45 subjects, with 4 pedestrian crossings in each scenario. Consequently the sample size adds up to 180. The equation below is used for sample size calculations (Flesis et al. 1980).

Equation 6

$$n = \frac{(z_a\sqrt{(2PQ)} + z_\beta\sqrt{P_1\ Q_1 + P_2\ Q_2})^2}{\delta^2}$$

where:

Z_α= *Upper 100(1-α) is the percentile of the standard normal distribution,*

Z_β= *Upper 100(1-β) is the percentile of the standard normal distribution,*

$\sigma = P_2 - P_1 : P_2 > P_1$ *is the sample size standard deviation,*

$P = ½ (P_2 + P_1)$ *is the success rate, and*

$Q = ½(Q_1+Q_2)$, $Q = 1-P$, *is the failure rate.*

4.3.3 Driving Simulator Measures of Effectiveness

The Driving simulator has the ability to store numerous microscopic variables with regard to driver performance on the simulator. This enables the author to evaluate the performance of drivers while entering and exiting the roundabout and yielding or not yielding to the pedestrian standing at the exit leg of roundabout. In spite of that, it is important to note that simulator has its own limitations. Although it will give a general understanding about the driver performance, it cannot be compared with real world driving in roundabout.

So far, the measure of effectiveness extracted from the driving simulator study is the driver yield rate to pedestrians in each scenario. The yielding rate was analyzed based on different subject attributes (for example, their driving experience average weekly encounter with pedestrians, etc.) and is demonstrated in the next section.

4.3.4 Eye Tracker Measures of Effectiveness

The performance measures extracted from the eye tracker are the pupil fixation duration, and the frequency of pupil fixations on each type of beacon and (or) pedestrians, as well as the percentage of fixations on different objects on the scene.

Fixation is defined as “those eye movements that best indicate the locations of the viewer’s (overt) visual attention” (Duchowski 2007). The author defined a threshold fixation duration, which is used to infer that the driver’s visual attention was in fact focused on the object in question (pedestrian or beacon). The proper threshold for fixation duration found in literature is 67 milliseconds (0.067 seconds) (Duchowski 2007). For the purpose of this study the author used the same threshold*)*. Therefore, any fixation duration less than 0.067 seconds was eliminated from the data. The initial result from analyzing eye tracker output is presented in the next section.

4.4 Experiment Results

4.4.1 Yielding Rate Results

Each of the 45 subjects was exposed to 4 pedestrian crossings in each scenario yielding a sample size of 180. Table 23 shows the yielding rate for each scenario. Taking the CTRL20 scenario as the base case, the table shows the increase in yielding percentage (% Increase), the results of a z-test (Z-Score) to test the significance difference of each scenario relative to the base scenario, along with the associated p-value to see if results were significant at the 95-percentile confidence level.

Table 23 Yielding Rate Results for Each Scenario Compared to the Base (CTRL20) scenario

	CTRL20	**CTRL60**	**PHB20**	**PHB60**	**RRFb20**	**RRFB60**
Yielding Rate	36.7%	46.7%	68.3%	85.6%	51.7%	73.9%
% Increase	Base	27.3%	86.4%	133.3%	40.9%	101.5%
Z-Score	Base	1.92	6.02	9.51	2.87	7.10
P-value	Base	0.054	<0.0001	<0.0001	0.0042	<0.0001

The results of the z-test shows statistically significant differences between the base case (CTRL20) and scenarios with beacon installments, (α=0.05, β=0.8). Although not significant at the 95 percentile confidence level, it should also be noted that the CTRL60 scenario also showed positive signs of improvement over the base condition (p=0.054), with an estimated 27.3% improvement. While smaller than the beacon effects, this represents a potential low-cost modification to the roundabout that may help improve yielding propensity.

The pattern of improved yielding with re-locating the crosswalk was also observed for the PHB60 and RRFB60, which resulted in the two highest overall yielding rates. In fact, relocating the PHB from 20 to 60 feet increased yielding from 68.3% to 85.6% (p-value =0.00010), and relocating the RRFB from 20 to 60 feet resulted in an increase from 51.7% to 73.9% (p-value =0.00001). The combined effects of higher yielding at an increased off-set distance is an important finding, especially since higher off-set distances have previously been linked by research to improved operational performance for vehicle (Schroeder et al. 2008), resulting in lower pedestrian-induced impacts on vehicular delay over the standard crosswalk location.

In a comparison of the RRFB and PHB treatments, the PHB generally resulted in somewhat higher yielding rates. At the 20-foot distance the PHB yielding rate of 68.3% exceed the RRFB rate of 51.7% (p =0.00125). Similarly, the PHB and RRFB yielding rates at 60 feet were 85.6% and 73.9%, respectively, (p-value =0.00591). Therefore, the PHB generally resulted in improved yielding behavior and the differences to the RRFB were statistically significant at the 95-percentile confidence level.

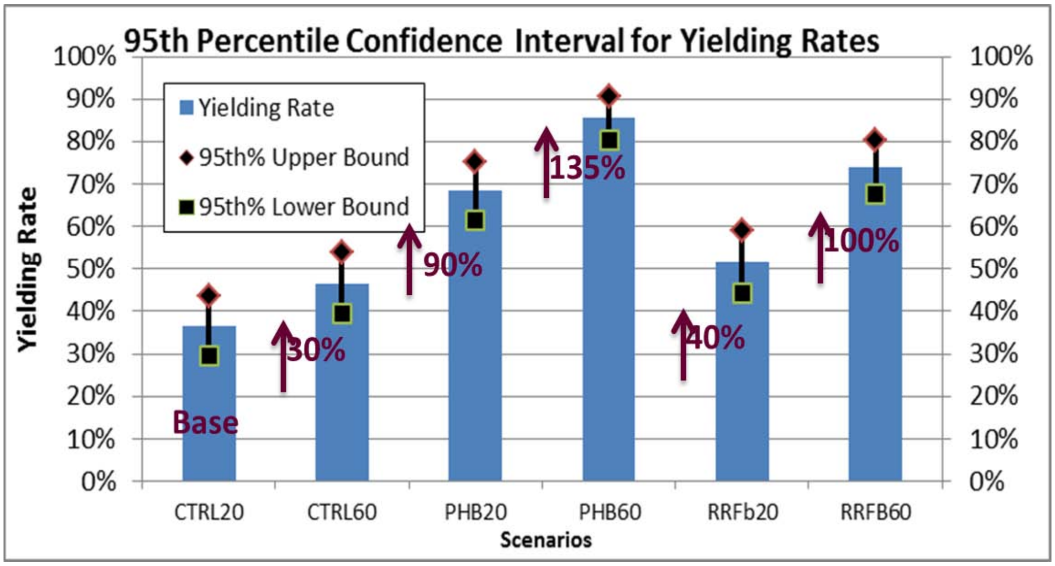


Figure 19 Average Driver Yielding Rate for each Scenario and Comparison with Base Scenario (No Beacon, Crosswalk at 20 ft.)

Figure 19 plots the average driver yielding rate described in Table 23 and the comparison with base case scenario which is no beacon/crosswalk at 20ft.

4.4.2 Participant Questionnaire Results

Further analysis has been done to show the effect of different subject attributes on yielding rates. After completing the experiments each participant was asked a set of questions about his/her driving background, their comprehension of the treatments and how they would rank the safety of each scenario. Based on the responses, the team divided the subjects in to two groups (i.e. less than or more than 10 years of driving experience) based on their *Duration of driving in US with driving license (Experience), Average hours of driving per week (Driving), Average count of passes through a roundabout per week (Roundabout), and Average count of passes through intersections with pedestrian crossings (Pedestrians).* The z-test is used to study if there is a significant difference in yielding rates between the two groups for each of the above subject attributes. The results are summarized in Table 24 and discussed below. Effects with a p-value less than 0.05 are highlighted in bold.

Table 24. Subject Attributes Effect on Drivers Yielding Behavior

	CTRL20	CTRL60	PHB20	PHB60	RRFb20	RRFB60
Experince≤10 Yrs (n=68)	30.9%	30.9%	52.9%	73.5%	45.6%	63.2%
Experience>10 Yrs (n=112)	40.2%	56.3%	77.7%	92.9%	55.4%	80.4%
Z-Score	1.25	3.31	3.46	3.58	1.27	2.54
P-value	0.2095	***0.0009***	***0.0005***	***0.0003***	0.2035	***0.0112***
Driving≤7 hr/wk (n=92)	31.5%	47.8%	65.2%	80.4%	46.7%	68.5%
Driving>7 hr/wk (n=88)	42.0%	45.5%	71.6%	90.9%	56.8%	79.5%
Z-Score	1.46	0.32	0.92	2.00	1.35	1.69
P-value	0.143	0.750	0.358	**0.046**	0.176	0.091
Roundabout≤1 per wk (n=72)	28.7%	42.6%	67.6%	85.2%	48.1%	68.5%
Roundabout>1 per wk (n=108)	47.2%	52.8%	68.1%	86.1%	56.9%	80.6%
Z-Score	2.65	1.37	0.06	0.13	1.17	1.62
P-value	***0.0080***	0.1697	0.9511	0.8930	0.2430	0.1046
Pedestrian≤5 per wk (n=100)	26.0%	43.0%	63.0%	84.0%	44.0%	68.0%
Pedestrian>5 per wk (n=80)	50.0%	51.3%	75.0%	87.5%	61.3%	81.3%
Z-Score	3.32	1.10	1.72	0.66	2.30	2.01
P-value	***0.0009***	0.2703	0.0855	0.5069	***0.0214***	***0.0443***

- **Duration of Driving in United States with Driving License (Exposure)**

The sample population was divided into two groups, drivers with less than and more than 10 years of driving experience in the United States. Using a confidence level of 95%, the results of z-test shows there is no significant difference in yielding behavior between the two groups of drivers in the base scenario (CTRL20) and RRFB20. However, more driving experience resulted in significantly more yielding to pedestrians in the rest of the scenarios.

- **Average Hours of Driving per Week (Driving)**

The yielding rate in each scenario appears to be higher for subjects who, on average, drive more than 7 hours a week. However, there is no significant difference between yielding rate in each scenario except for the PHB60 scenario. It appears that drivers with longer driving hours during the week are more responsive to the red indication of the PHB when the crosswalk and stop bar are re-located further away from the roundabout (p=0.046). The same behavior is observed for RRFB with a confidence level of 90%.

- **Average Count of Passes Through a Roundabout per Week (Roundabout)**

Table 24 shows interesting results of yielding behavior for drivers based on their weekly count of passing through roundabouts. Drivers who pass through roundabouts more than once a week have higher yielding rates than drivers with fewer passes. However, the difference is only significant in the base scenario. These results suggest that drivers with more exposure in navigating roundabout are more likely to yield to pedestrians. They may further suggest that the effects of the tested treatments are independent of driver experience with roundabouts, as both categories end up with comparable yielding rates, on average. These results imply that the tested treatments will have more significant relative effect on increasing yielding rate for drivers with less roundabout experience.

- **Average Count of Passes Through Intersections with Pedestrian Crossings (Pedestrians)**

Drivers who have higher number of encounters with pedestrians in intersections tend to have higher yielding rates at roundabouts, across all scenarios. However, the difference is significant only in the base scenario and in the scenarios with RRFB installation. However when a PHB is installed or the crosswalk is relocated, although the yielding rate increases for both categories of drivers, there is no significant difference between the two populations. Therefore, drivers with more weekly pedestrian encounters are likely more responsive to yield to pedestrians with the existence of an RRFB signal. However, these results of the questionnaire are self-reported and it doesn't take into account the possibility that some drivers don't know when they don't notice pedestrians.

4.4.3 Eye Tracker Results

The results of this experiment can assist in understanding whether the drivers were aware of the presence of the beacons and pedestrians along the road and whether or not they comprehended the implication of their presence. Drivers essentially must negotiate traffic from three different directions in the roundabout while their main focus is to drive out of the circulating lane toward the exit leg. Therefore, they will tend to pay less attention toward objects along the road or the sidewalk along the way.

Table 25 shows the results from the eye tracker experiments. For the scenarios with no beacon installations, fixations on pedestrians and for scenarios with PHB and RRFB the fixations on pedestrians and beacons were extracted and analyzed. Since the

RRFB system was modeled in the form of side-mounted beacons, the eye tracker data is not able to do depth analysis and distinguish between the pedestrian and RRFB. Therefore, for RRFB the fixation is both on pedestrians and beacon. PHBs were overhead beacons and therefore fixations on pedestrian and beacon could be distinguished in the analysis.

Table 25. Eye Tracker Results

		Number of Fixations		t-test	% Fixation on Object		t-test	Fixation Duration(sec.)			t-test
	Object	Average	St. dev.	α=0.05	Average	St. dev.	α=0.05	Average	St. dev.	Max	α=0.05
CTRL20	Ped.	3.1	1.6	Base	8%	6.40%	Base	0.201	0.105	0.683	Base
CTRL60	Ped.	3.8	1.9	p=0.76	10%	6.30%	p=0.82	0.222	0.144	0.842	p=0.13
RRFB20	Ped&Beacon	5.9	2.6	***p=0.009***	32%	5.80%	***p=0.030***	0.301	0.292	2.758	***p=0.031***
RRFB60	Ped&Beacon	6.1	2.6	***P<0.001***	65%	7.20%	***P<0.001***	0.329	0.248	2.075	***P<0.001***
PHB20	Ped.	5.4	2.4	p=0.057	20%	8.20%	p=0.060	0.242	0.276	2.518	p=0.051
	Beacon	6.2	2.3	-	32%	6.50%	-	0.272	0.304	2.700	-
PHB60	Ped.	7.3	2.5	***P<0.001***	26%	6.10%	***p=0.022***	0.275	0.315	3.814	***P<0.001***
	Beacon	7.8	2.3	-	51%	7.30%	-	0.385	0.345	5.375	-

Table 26 Regression Models to test the Effectiveness of Each Treatment

Regression Models					
Models	*Intercept*	*Coefficient for x_1 (=1 if Crosswalk at 60 ft.)*	*Coefficient for x_2 (=1 if beacon is PHB)*	*Coefficient for x_3 (=1 if beacon is RRFB)*	*Regression Model*
Number of Fixations	3.1	0.89	2.73	1.61	0.56
% Fixation on Object	0.09	0.20	0.68	0.49	0.43
Fixation Duration	0.198	0.11	0.83	0.72	0.51

The results show that the *number of fixations* is highest in the PHB60 scenario at an average of 7.8 fixations, relative to the base case of 3.1. The result of a t-test on the difference between the number of fixations on the pedestrian in each scenario compared to base scenario shows that installing any kind of beacon will significantly increase the number of fixations on the pedestrian, or in general the objects along the road. Therefore the presence of a beacon tended to increase drivers’ attention to the presence of pedestrians on their path. It should be mentioned that for PHB20 scenario the increase in number of fixations is not significant at 95% confidence level. The authors hypothesize that in the 20 feet scenario; the PHB is located too close to the roundabout and makes it difficult for drivers to make eye contact. The comparative values of percent fixation on objects and fixation duration also support that hypothesis.

Relocating the crosswalk and stop bar to 60 feet does not have a significant increase in the number of fixations on the pedestrian for the base case. For the RRFB and PHB, the relocation of the crosswalk to 60 ft does suggest a slight increase in the number of fixations on the pedestrian over the equivalent 20 ft scenario, but these increases are not statistically significant. The p-values for 20 versus 60 feet for a RRFB and PHB are 0.306 and 0.101 respectively.

The t-test on the *percentage of fixations* on the pedestrian, and both pedestrian and RRFB in the scenarios show the same trend observed in the number of fixations. Table 25 shows no significant difference between base scenario and CTRL60, but more significant difference between the rest of the scenarios and base case. At a 95-confidence level, there is no significant difference between the base case and PHB20, which suggests against installing a PHB close to roundabouts.

A t-test on the values of *fixation durations* shows there is not a significant difference in the duration of drivers' fixations on pedestrians in the CTRL60 and base (CTRL20) scenarios. It also supports the results of number of fixations and percentage of fixation on pedestrians. Overall, the three measures of effectiveness discussed in Table 5 suggest that relocating the crosswalk does not have a significant increase on drivers' gaze pattern on the pedestrians by itself. Although having an overhead PHB beacon 20 feet from the stop bar increases the fixation time, it is not significant at the 95-confidence level.

Table 26 shoes the regression models developed for the eye tracker measures of effectiveness. x_1, x_2 and x_3 are binary factors (0 or 1) and they define the crosswalk relocation to 60 ft., PHB and RRFB respectively (when equal to 1). The coefficients show how much the measures of effectiveness (*number of fixations*, *percentage of fixations* and *fixation duration*) will be changed with any of these conditions. Note that x_2 and x_3 cannot equal to 1 at the same time.

4.4.4 Debriefing Questionnaire on Treatment Effectiveness

A series of debriefing questions was asked pertaining to the drivers' experience with roundabouts and their perception of the different treatments installed in each of the scenarios. The results indicated that 91% of the subjects were aware of the presence of both types of beacons at the roundabout. This means that 9% (or 4 drivers) did not even notice the RRFB or PHB at the crosswalk. Nearly 80% of the drivers understood the purpose of both beacons at the roundabouts. However about 9% didn't associate the PHBs with pedestrian crossings and 11% of the drivers were seemingly unaware of the RRFB's purpose. Overall, 76% of the drivers felt safer with the stop bars located at 60 feet while 7% didn't notice the differences. The rest of the drivers (18%) felt the stop bar should be moved even further away from the roundabout.

Each driver was also asked to rank the perceived safety of each treatment scenario from 1 to 5, with 1 being the least safe and 5 being the safest condition that will promote nearly 100% yielding to the pedestrians. The results of the safety scores with each scenario and their 96 percentile confidence level are shown in Figure 20. The results show that participants felt the safest with the PHB or RRFB, having stop bars located 60 feet downstream, of the roundabout. The safety score of PHB60 is significantly higher than other scenarios; however, when it comes to stop bars located at 20 feet from the roundabouts they prefer to have RRFB compared to overhead PHB. One possible explanation is that with a stop bar at 20 feet drivers do not feel safe enough to yield to pedestrians. Therefore they prefer to have RRFB which implies caution and does not show a red indication to stop. The RRFB gives the option to drivers (with yellow flashing lights) of whether to yield or not, while the solid red location at the RRFB requires a driver to stop. The safety score of the base scenario (CTRL20) and crosswalk relocation scenario (CTRL60) are not significantly different.

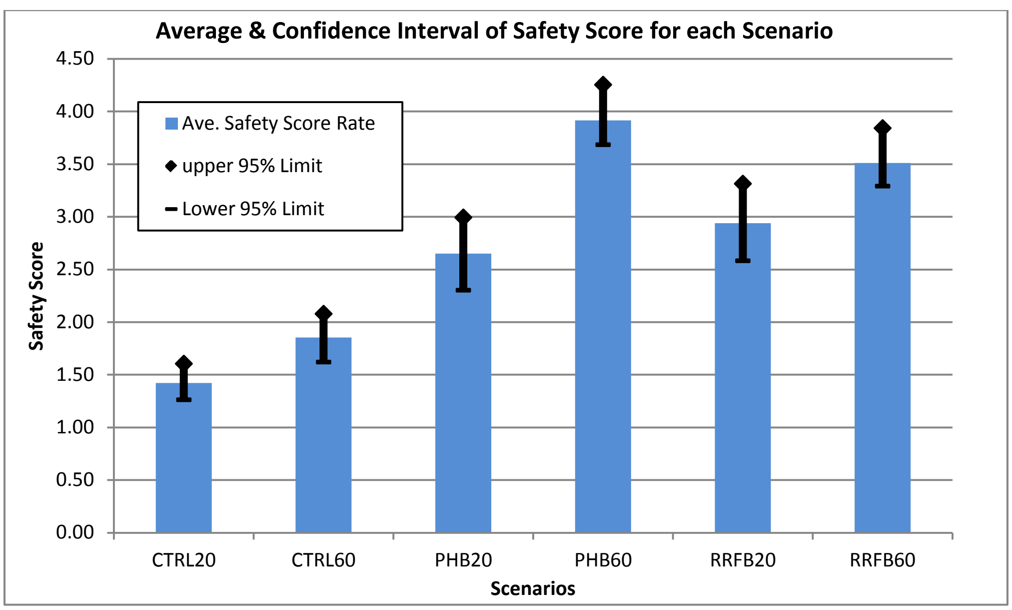


Figure 20 Participants' Safety Score for each Scenario

4.5 Discussion and Future Work

This chapter introduced a proxy methodology to test the effectiveness of different pedestrian treatments. These treatments may increase the availability of crossing opportunity in form of driver yielding in study of blind pedestrian accessibility. Driving simulator allows the researchers to control for three sources of error which are driver behavioral differences, treatment differences and random arrival of traffic and pedestrians.

The chapter aimed to test three different pedestrian crosswalk treatments at the exit leg of multilane roundabouts using a driving simulator and eye tracker. Six unique scenarios were developed based on the combination of crosswalk distance and type of beacon (or no beacon at all). The three treatments studied were the base scenario (CTRL), Pedestrian Hybrid Beacon (PHB), and Rectangular-rapid Flashing Beacon (RRFB). Each treatment was tested using two crosswalk locations (stop bar located at 20 and 60 feet). Drivers were asked to drive a simulated corridor of eight roundabouts, four of which had pedestrian crossings. The driver yielding rate to the pedestrians in each scenario showed that existence of any kind of beacon increases driver yielding rate significantly ($\alpha = 0.05$). Among the treatment options, the use of PHB signal with a stop bar located at 60 feet, appeared to have the highest increase in the yielding rate.

Further analysis on the effect of subject population attributes show some effects on yielding rate. In general, longer driving experience has a significant effect on increasing yielding rate when it comes to installation of beacons as treatments. Other attributes, such has the average driving hours per week, average pedestrian encounters, or average weekly passes through roundabouts do not show conclusive effects on increasing the propensity to yield.

The eye tracker provided valuable information about the gaze patterns of drivers while exiting the roundabouts. Three performance measures including the number of fixations, the percentage of fixation on objects of interest, and mean fixation duration were investigated. Overall, the existence of any type of beacon at roundabout increased the drivers' attention to the pedestrians waiting to cross.

For future analysis, a more detailed study of the results of eye tracker data to analyze gaze pattern for each yielding or non-yielding event for drivers in different scenarios is planned. Future research will also explore the relationship between drivers' speed at exit and their yielding.

The findings in this research imply that the use of RRFB or PHB systems successfully increased the rate of driver yielding at the exit leg of multilane roundabouts. For both beacon treatments, the yield rate was further increased when relocating the treatment to a distance of 60 feet, instead of the 20-foot standard crosswalk location. This low-cost modification to the crosswalk therefore warrants additional consideration, especially since it has been linked in prior research to lower pedestrian-induced vehicular delay impacts of the installed signal.

Finally, the yielding rate resulting from the PHB (with solid red indication) was significantly higher than that of the RRFB, which only has a flashing yellow beacon. While care should be taken to draw broad conclusions from this simulator to engineering practice, the yielding rate of only 85.6% is disconcerting. Even the highest yield percentage of 90.7% is well below the full compliance that one might expect from a solid red indication. This is comparable to findings at a field installation of a PHB at a two-lane roundabout, where red-light running occurred 12.6% of the time (RCOC 2011), which is actually quite similar to the 14.4% observed, and within the lower bound of the 95 percent confidence interval of 80.4% (19.6% non-compliance). The 85.6% average compliance rate is furthermore for the PHB60 location, while the rate for the more standard 20-foot crosswalk is only 68.3%. While not statistically significant, the yielding rate at a 60-foot distance RRFB was higher than for a 20-foot distance PHB. These results call for a careful exploration of any future installations of PHB or other beaconing systems at multilane roundabout exits, as some compliance issues are expected.

Future work with the driving simulator and eye tracker is needed to understand why certain pedestrian treatments, for example PHB at 60 ft., are more effective that other treatments, such as RRFB at 20 ft. One of the hypotheses is that drivers have a fear of being rear-ended while exiting the roundabout if they stop to yield to a pedestrian. The analysis of driver eye movement, such as frequency of looking at the rear mirror or they speed and deceleration rate may help to provide proof for or against the hypothesis. More detailed analysis of eye tracker and driving simulator will help to understand the reasons that drivers choose not to yield to pedestrians. The reasons could be the limitation of the vehicle dynamics such as vehicle speed, unsure of pedestrian intention to cross, not understanding the purpose of the beacon (RRFB or PHB); or simply the driver does not acknowledge the pedestrian standing at the crosswalk. One should also accept the limitations of the driving simulator and the fact that the results should not be perceived as or compared with the real world results.

5 CONCLUSIONS AND RECOMMENDATIONS

This chapter contains recommendations based on the primary analysis chapters. The following sections detail the overall accomplishments of the research effort described in this dissertation. The research generated three empirical contributions which are listed separately, followed by overarching conclusions and recommendations.

5.1 Research Motivation and Objectives

This research aims to develop objective and reproducible proxy methodologies to quantify pedestrian accessibility at complex unsignalized crossings such as multilane roundabouts. The three methodologies presented here attempt to address two of the four components of an "Accessibility Framework" (Schroeder et al. 2011a), which are the *crossing opportunity criterion* and *safety criterion*, while controlling or eliminating the sources of error in study of blind pedestrian crossing. The status quo approach for the study of blind pedestrian access to complex crossings involves actual field trials with blind participants in effort to quantitatively describe the crossing performance and thereby quantify accessibility. However this research identified five sources of variability and/or error in this study of blind pedestrian crossings including variability in pedestrian behavior, driver behavior, traffic patterns, site geometric attributes, and presence of crossing treatments.

The research offers three principal contributions in the form of different methodological approaches for studying pedestrian accessibility and for overcoming one of more of these sources of variability:

4. Field observational studies of vehicle-pedestrian interaction for pedestrian crossings at multilane roundabouts and development of a conflict-based assessment of pedestrian safety (CAPS) framework. This field study explores the dynamics of the pedestrian decision-making process for choosing a safe crossing opportunity at multilane roundabouts. It addresses the fourth component of the accessibility framework which is "degree of risk associated with each crossing decision" and attempts to control for the error originated from "subjectivity by O&M specialist". The goal of CAPS is to present a consistent framework that quantifies the level of risk for each pedestrian crossing decision based on the characteristics of pedestrian-vehicle interaction and aims to control for subjectivity of O&M decision by introducing a formulized and objective risk assessment metric.
5. Controlled field experiment for evaluating driver yielding behavior to pedestrians at multilane roundabouts. This study explores the dynamics of the driver decision making process to yield to pedestrians at multilane roundabouts. The approach attempts to address the first component of the accessibility framework which is the availability of crossing opportunities. However this study only focuses on driver yielding as a form of crossing opportunity. Availability of crossable gaps is not discussed in this document but is well covered in the traffic literature. The methodology attempts to control for pedestrian behavioral differences and differences across sites.

1. Laboratory based study that explores different pedestrian treatments at the exit leg of roundabouts to increase driver yielding rate, in a driving simulator environment. This study aims to address the first component of the accessibility framework which is availability of crossing opportunity by testing different treatments which would provide more crossing opportunities for pedestrians. The driving simulator study enables the research to control for different treatments and random arrival of pedestrians and traffic. It also controls for driver behavioral differences by enabling the researchers to test the study on a particular cohort of drivers as needed.

5.2 Summary of Findings

1) Field observational study of vehicle pedestrian interactions for pedestrian crossings at multilane roundabouts and development of a conflict-based assessment framework: This research developed and implemented a pedestrian-vehicle conflict framework, CAPS (Conflict-based Assessment of Pedestrian Safety) to assess pedestrian accessibility at complex intersections, with the emphasis on the crossings of visually impaired pedestrians. The goal is to evaluate pedestrian crossing decisions and quantify the risk that pedestrians encounter at a particular crossing. CAPS is based on measuring five factors, A (time-to-collision), B (deceleration rate), C (complexity of evasive action), D (distance-to-collision) and E (lane condition factor) to define microscopic traffic attributes of pedestrian-vehicle interaction at the time the pedestrian makes the crossing decision. The CAPS was applied to blind and sighted pedestrian street crossings at two-lane and three-lane roundabout approaches. For each of the crossing decisions an Orientation and Mobility (O&M) specialist evaluated the risk level and ranked the crossing as safe or dangerous (intervention by O&M). By identifying the values of each of the five CAPS factors (A, B, C, D and E) and using the CAPS conflict matrix the author was able to arrive at risk levels similar to what O&M has ranked before. For two-lane and three-lane street crossings the framework was able to correctly associate all the intervention events as dangerous (0% false negative rate). However the framework falsely associated 4% of the crossing events in two-lane as dangerous in spite the fact that they were ranked as safe by O&M (4% false positive for two-lane and 9% for three-lane)

In an attempt to further improve the method, the author used a clustering approach (k-mode, k-means and k-median) with various combinations of the five factors to classify the data into clusters that have similar attributes and arrive at an overall risk score. The results showed that the best match is to apply the k-means methodology to the combination of three factors A, B and E. This model omits the use of the arguably subjective factor C and factor D for less data collection efforts. However the application of clustering methods results in higher error rates compared to the CAPS.

Although the CAPS framework and the optimized CAPS framework are in progress of eliminating the error of “subjectivity by O&M specialist” shown in Figure 2, the result is not ready for implementation. One caveat of the framework is the number of risk levels. The current framework has only two categories of safe and dangerous (intervention worthy) for the state of each crossing event. However more risk levels are needed to cover the events which are not completely safe neither completely dangerous.

The hypothesis is that more risk levels may reduce the false positive and false negative rates of the current framework. Since the true state of data available for this research has only two risk levels, the author was not able to test the hypothesis. In addition to that, larger number of data points is needed to calibrate the clusters and the center of the clusters. Increasing the number of clusters from two (safe and dangerous) will also improve the error rates in clustering methodology.

The current methodology in this chapter only considers the events in which pedestrian makes a crossing decision. One of the caveats of dataset is the lack of data on those supposedly risky decisions that pedestrian chose not to cross. In other words, the number of unsafe crossing decisions in the dataset is much lower than the number of safe crossing decisions. it is possible that not all unsafe crossing decision possibilities can be found in dataset.

2) Controlled field experiment evaluating driver yielding behavior to pedestrians at two-lane roundabout approaches: This study aimed to identify the contributing factors affecting the likelihood of driver yielding to pedestrians at two-lane roundabouts. These factors are approach of the roundabout (entry or exit), pedestrian condition (blind or sighted), pedestrian waiting location (at the curb or in the crosswalk), present of multiple pedestrians as well as some vehicle dynamics such as speed, lane location, heavy vehicle, downstream conflict (queuing at the entry), right turning vehicle (at the exit), etc. The results show that the likelihood of driver yielding at the entry leg of roundabouts is higher than at the exit. Among all factors, entry and exit has the largest impact on model with estimate of -2.27 and odds ratio of 0.1. The odds ratio suggest that for each study location, if all the other variables (cane, speed and vehicle lane location) are kept at the same value, moving from entry to exit reduces the probability of yielding by ten folds. Drivers tend to yield to pedestrians with white cane more often than sighted pedestrians (odds ratio 4.09). Drivers traveling in the far lane, relative to pedestrian location, have lower probability of yielding to a pedestrian than drivers in the near lane (odds ratio 0.30). As the speed increases the probability of driver yielding decreases (odds ratio 0.91). At the exit leg of the roundabout drivers turning right from the adjacent lane have lower propensity of yielding than drivers coming from other directions (odds ratio 0.26).

The results further show that factors such as vehicle platooning, downstream conflict (for only entry leg of the roundabout) and pedestrian waiting position, "at curb" versus "in crosswalk" do not have a significant impact (with 95% confidence level) on the probability of a driver yielding to pedestrian. It is important to note that all the right-of-way laws to pedestrians have been reviewed for these six study locations. The laws imply that drivers yield the right of way to a pedestrian crossing "in" the crosswalk. However none of the models show the effect of pedestrian waiting position as significant.

The modeling approach also explored the effect of model calibration for different study locations. For the six studied roundabouts, three sites showed significant intercept terms (or dummy variables) that suggest a significantly different yielding performance. In other words, even when controlling for vehicular speed, pedestrian behavior, vehicle platooning, and other factors, this research showed that other site-specific variables and/or driver culture explain a significant portion of yield differences.

The type of controlled field study described in this chapter is a proxy method to understand and quantify driver yielding behavior and its contributing factors. This type of study also attempts to eliminate “pedestrian behavioral differences” and “differences across sites” as two of the sources of error in study of blind pedestrian crossing by controlling for pedestrian behavior and accounting for the impact of different study locations. The research methodology and findings of this chapter show that the availability of crossing opportunities in the form of yields is not only impacted by site specific attributes and driver’s culture at each location, but also by factors such as pedestrian behavior and vehicle dynamics. These results are important for future research on how to increase driver yielding in order to provide more crossing opportunities for pedestrians, and to enhance accessibility.

3) Laboratory study of effect of different pedestrian treatments at the exit leg of a roundabout in order to increase driver yielding rate. This chapter aimed to test three different pedestrian crosswalk treatments at the exit leg of multilane roundabouts using a driving simulator and eye tracker. Six unique scenarios were developed based on the combination of crosswalk distance and type of beacon (or no beacon at all). The three treatments studied were the base scenario (CTRL), Pedestrian Hybrid Beacon (PHB), and Rectangular-rapid Flashing Beacon (RRFB). Each treatment was tested using two crosswalk locations (stop bar located at 20 and 60 feet). Drivers were asked to drive a simulated corridor of eight roundabouts, four of which had pedestrian crossings. The driver yielding rate to the pedestrians in each scenario showed that existence of any kind of beacon increases driver yielding rate significantly ($\alpha = 0.05$).

The findings in this research imply that the use of RRFB or PHB systems successfully increased the rate of driver yielding at the exit leg of multilane roundabouts. For both beacon treatments, the yield rate was further increased when relocating the treatment to a distance of 60 feet, instead of the 20-foot standard crosswalk location. This low-cost modification to the crosswalk therefore warrants additional consideration, especially since it has been linked in prior research to lower pedestrian-induced vehicular delay impacts of the installed signal (Schroeder et al. 2011a). Among the treatment options, the use of a PHB with a stop bar located at 60 feet, appeared to have the highest increase in the yielding rate.

The eye tracker provided valuable information about the gaze patterns of drivers while exiting the roundabouts. Three performance measures including the number of fixations, the percentage of fixation on objects of interest, and mean fixation duration were investigated. Overall, the existence of any type of beacon at roundabout increased the drivers' attention to the pedestrians waiting to cross.

The yielding rate resulting from the PHB (with solid red indication) was significantly higher than that of the RRFB, which only has a flashing yellow beacon. While care should be taken to not draw broad conclusions to engineering practice, even the highest yield percentage of 90.7% is below the full compliance that one might expect from a solid red indication. This compliance finding is comparable to findings at a field installation of a PHB at a two-lane roundabout, where red-light running occurred 12.6% of the time (Schroeder et al. 2011a) in one study, and 8.8% in another study (average across entry and exit) (RCOC, 2011). The 85.6% average compliance rate is furthermore for the PHB60 location, while the rate for the more standard 20-foot crosswalk is only 68.3%. While not statistically significant, the yielding rate at a 60-foot distance RRFB was higher than for a 20-foot distance PHB. These results call for a careful exploration of any future installations of PHB or other beaconing systems at multilane roundabout exits, as some compliance issues are expected.

The proxy methodology using the laboratory study with driving simulator allows testing the effect of different treatments on increasing crossing opportunities for pedestrians. Although driving simulator study has its own limitations, the methodology enables the researchers to control for three sources of variability in study of blind pedestrian crossing including random arrivals of vehicles and pedestrians, driver behavior and different treatments.

5.3 Contrast and comparison of the three methods

Each of three proxy methods for quantifying pedestrian accessibility offers its own advantages and shortcomings. This research demonstrated that each of the three methods can be applied to the study of (blind) pedestrian access to complex street crossing principals, targeting crossing opportunity criterion and safety criterion, which are components of a documents framework of pedestrian accessibility.

The conflict-based framework (CAPS) focuses on the “pedestrian decision-making process” as study participants respond to traffic patterns at the crosswalk and base their crossing decisions on perceived risk level of their interaction with approaching vehicles. The CAPS framework enables the researchers to objectively and consistently quantify the safe and risky crossing decisions that pedestrians make at the crosswalk, with some margin of error. It can be applied to the collection of data on the interaction between pedestrian and vehicle using three explanatory factors: time-to-collision, deceleration rate, and lane condition factor. The CAPS framework is also compatible with an indicator study approach, a proxy methodology that is safe for (blind) pedestrian study, as it does not require the pedestrians to cross the street and be exposed to traffic.

Through a clustering optimization approach, this research was able to derive risk performance thresholds, calibrated from field-observed O&M interventions. However, an application of the calibrated model to an independent data set only matched some of the observation, attributed to high variability in the underlying decision-making of blind study participants. One of the key conclusions of this method thus is that the inter-subject variability in decision-making is high, which poses significant challenges in calibrating a risk performance assessment model like CAPS. The weakness of the CAPS framework is that given the available datasets it was not able to correctly classify all the safe and dangerous crossing events. The framework has some error in sorting dangerous crossing decisions as safe (false negative rate) and vice versa (false positive rate). The framework also has only two risk levels (safe and dangerous) which may not be adequate to accurately address the conflict level of interaction between a pedestrian and a vehicle. Lager datasets are needed to properly calibrate CAPS and reduce the error rates, as well as introducing other more risk levels.

These findings suggest that an assessment of other factors associated with accessibility, namely driver behavior and treatment presence, are best evaluated independent of pedestrian behavior, due to aforementioned inter-subject variability. The main limitation of CAPS is that it only concentrates on the pedestrian decision in a pedestrian-vehicle conflict event. Another limitation is that it only takes into account the events that pedestrian chose to cross (go decisions). The current settings in CAPS framework does not account for (no-go decisions) which might be a missed safe crossing opportunity or a correctly-rejected unsafe conflict with vehicle. Since vehicular traffic movement and driver behavior have major parts in affecting pedestrian accessibility, two different types of driver behavior studies have been studied and tested.

The controlled field study of driver yielding behavior focuses on the understanding of *the driver decision-making process*, by controlling pedestrian behavior and evaluating drivers' response in the form of yielding to pedestrians. The outcome of this study are regression models that describe the likelihood of driver yielding as a function of microscopic traffic attributes. By identifying the factors that impact yielding rate, researchers will be able to find and apply treatments that focus more on the variables which increase the probability of yielding. For example, the models indentified vehicle speed to have a key impact on yielding, which suggests that treatments like speed bumps may prove effective in improving accessibility. It will also enable them to find ways to reduce the effect of factors that decrease the probability of yielding. For example higher vehicle speeds result in lower probability of yielding. Therefore research needs to implement treatments that moderate the speed of a vehicle as it approaches the crosswalk.

One of the limitations of the regression models is the need for site-specific calibration. The study of six multilane roundabout approaches across the country shows that driver behavior is diverse across study locations. There are some factors that significantly impact driver yielding rate at some study locations, but showed no significant effect at others for example existence of multiple pedestrians at the crosswalk was a factor in Nashville Tennessee but not a significant factor in Raleigh NC.

Although this study quantifies the driver decision-making process at the instance of interaction with a pedestrian, there are still some factors that are not accounted for as explained by a low overall model fit. This methodology also does not test the effect of different pedestrian treatments on yielding in a controlled environment. Mainly because installation of these treatments is expensive and it is hard to come by study locations that already have the treatments installed. Even if such sites are found, other variables such as driver culture, traffic patterns etc.. might affect the outcome of the results. Therefore, there was a need to test driver yielding in a more controlled environment such as a driver simulator, which can control pedestrian behavior and traffic patterns and hence isolate the driver's response to a treatment.

The third study in this research thus introduced further control in the form of a driving simulator study, geared at testing and comparing infrastructure-based treatments that are aimed at improving accessibility. A key theme in this research therefore is the isolation of various factors contributing to pedestrian accessibility, under the premise that different types of studies are needed to evaluate different aspects of pedestrian access. The use of a driving simulator enabled the author to control for pedestrian behavior, traffic pattern and type of treatments, and by exposing multiple drivers to the same test scenarios.

It further allowed for the testing of different pedestrian treatments with the same population of drivers. The use of an eye tracker also allowed for more in-depth analysis of how drivers perceive the environment around them when driving, and how they react to a pedestrian standing at the crosswalk or a type of a beacon aiming to convey a traffic message to them.

The strength of this third study, providing a controlled environment for research purposes, can also be its weakness and limitation of this type of study. A driving simulator can never completely match driving in the real world. Aside from the interface, some real world distractions and stimuli are not present. Therefore, caution should be exercised while reporting the results of a study done using a driving simulator. It is most feasible to compare the relative effectiveness of different scenarios within the driving simulator environment relative to each other and avoid any absolute comparisons with presumed real world conditions.

5.4 Recommendations for Application

Traditional evaluation methods for pedestrian accessibility focused on field-based studies with blind pedestrians using either a crossing or indicator study protocol. These methods continue to provide important empirical performance data, but do not control for the different sources of variability in components of the study, such as pedestrian, vehicle, traffic, environment and study location. The status quo methods for studying blind pedestrian accessibility can therefore be greatly enhanced in areas of availability of crossing opportunity and safe crossing decisions, more specifically, by the application of one or more of the proxy methods presented in this document. The methods may be particularly useful for (a) pre-screening different treatments alternatives and configurations, (b) evaluating a range of sites without the need to recruit blind participants, (c) provide an unbiased quantifiable assessment of risk, and most importantly (d) arriving at more generalized results by controlling for one or more sources of variability and/or error.

The CAPS framework is applicable to any pedestrian crossing where the level of risk associated with a crossing decision is unknown. By measuring time-to-collision, vehicle deceleration rate and lane condition for each crossing, the researcher is able to arrive at an overall evaluation of how safe or dangerous the crossings are. The framework allows researchers to take an unbiased approach on evaluating the safety of crossing decision and eliminate the variability of human judgments among different O&M professionals. However, caution should be taken while applying this framework. One of the caveats of the CAPS calibration is the lack of data on those supposedly risky decisions that pedestrian correctly chose not to cross in. In other words, the number of unsafe crossing decisions in the dataset is much lower than the number of safe crossing decisions. It is therefore possible that not all unsafe crossing decision possibilities can be found in dataset. The method also needs improvement to correctly classify safe and dangerous events. But despite these limitation, the CAPS method is viable to understand the risk level of conflict between pedestrian and vehicle, where it is too expensive and sometimes infeasible to rely on collision data, instead the researcher shall implement the CAPS framework, as a proxy method,.

The controlled field study of driver yielding behavior focuses on one component of accessibility and that is the availability of crossing opportunities in the form of driver yielding. In addition, this methodology is applicable to any study location to quantify the factors that increase driver yielding rate. It gives the researchers perspective on what microscopic vehicle dynamics and pedestrian behavior factors play significant roles in driver yielding. By implementing this proxy method, researchers will be able to design an experiment that controls for variability in pedestrian behavior and account for the effect of study location. The controlled field study is an effective and economically efficient proxy method to arrive at a quantitative understanding of driver yielding, which further guides the researchers in this decision whether to suggest any treatments or take further actions for improving driver behavior.

The application of a controlled laboratory study is limited to the conditions where different scenarios in terms of accessibility need to be tested in a controlled environment. These scenarios can be in form of infrastructure treatments, design treatments or various traffic control devices. The use of a driving simulator is economically more feasible in testing various scenarios compared to installing actual treatments in real world. The controlled environment of the driving simulator allows containing the sources of variability in driver behavior, traffic patterns. However, one should be aware of the limitations of the driving simulator and interpretation of the results.

The key finding in this research is that control is essential when designing experiences and studies, especially when there would be variability in behavior. Without control, even a well-planned and executed study may lead to inclusive results due to inter-subject variability in driver behavior or other sources of error. The status quo of a field-based study remains useful for case studies and for final testing under real world conditions. But to achieve statistically significant and generalized results, consideration of the presented proxy methods is strongly encouraged.

5.5 Future Research

In general the proxy methods presented here only focused on studying two components of the pedestrian accessibility framework, which are availability of crossing opportunity in form of driver yielding, and safety of crossing decisions made by pedestrians. The availability of crossable gaps as a crossing opportunity and its contributing factors are not discussed here. Pedestrian utilization of an available crossing opportunity, and the delay that pedestrian faces while making a crossing decision are also not addressed in this document, and should be the subject of future research. Each of the three proxy methods described has also room for improvement which is discussed below.

The current CAPS framework only classifies the pedestrian crossing decision into two levels: safe and dangerous or potential intervention by the O&M. Future research for the field observational study is needed to calibrate the safe and dangerous clusters identified by the clustering algorithms and possibly increase the number of clusters from safe and dangerous to safe, risky and dangerous. Research is needed to validate the approach with more crossings and to test the transferability of the approach to other sites and geometries. The ultimate goal of this approach is to present a framework which is simple to apply, efficient, and economically feasible for data collection purposes. The framework should be able to accurately rank the safety (or risk level) of pedestrian crossings.

Future work should also focus on explaining and identifying the site-specific factors that contribute to different yielding rates in different regions. It is also desirable to expand the data set to other two-lane roundabouts across the country. With further expansion of these models to other sites, and especially sites with varying geometries or treatments, the methodology and analysis approach presented here can provide valuable insights into geometric and cultural differences in driver yielding as well as treatment effects. Crossable gaps in addition to yields are crossing opportunities that impact the accessibility of street crossings. Future work is needed to define proxy methods to identify and quantify contributing factors to increase availability and utilization of crossable gaps.

With further expansion of these models to other sites, the methodology and analysis approach presented here can provide valuable insights into geometric and cultural differences in driver yielding

Future work with the driving simulator and eye tracker is needed to understand why certain pedestrian treatments, for example PHB at 60 ft., are more effective that other treatments, such as RRFB at 20 ft. One of the hypotheses is that drivers have a fear of being rear-ended while exiting the roundabout if they stop to yield to a pedestrian. The analysis of driver eye movement, such as frequency of looking at the rear mirror or they speed and deceleration rate may help to provide proof for or against the hypothesis. More detailed analysis of eye tracker and driving simulator will help to understand the reasons that drivers choose not to yield to pedestrians. The reasons could be the limitation of the vehicle dynamics such as vehicle speed, uncertainty about pedestrian intention to cross, misunderstanding the purpose of the beacon (RRFB or PHB); or not acknowledging the pedestrian standing at the crosswalk.

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APPENDIX

APPENDIX A: CONTROLLED FIELD STUDY DATA COLLECTION PROCEDURE AND PHOTOS

Figure 21 Observer records the traffic dynamics and vehicle behavior in each trial during yielding study

Figure 22 Seeded pedestrian carrying a white cane standing at the crosswalk, yielding study

APPENDIX B: REGRESSION MODELS DEVELOPED FOR EACH SITE AND THE CORRELATION RABLES

Table 27 Yield models for entry and exit approach for Carmel Indiana

Indiana

	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Square	Odds Ratio
Intercept	-0.348	0.809	-	57.003	0.645	-
DSC	2.214	0.145	9.149	-	-	-
SPD	-0.034	0.424	0.966	-6.036	0.366	-
FAR	-1.914	0.020	0.148	8.212	0.920	-
STP	0.000	-	-	0.000	-	-
PLT	-0.231	0.804	0.794	27.889	0.759	-
HGV	0.000	-	-	0.000	-	-
MUP	0.000	-	-	0.000	-	-
CN	3.448	<.0001	31.443	12.624	0.730	-
FT	-0.187	0.774	0.829	-9.950	0.762	-
RT	-	-	-	-1.062	0.992	-
AIC	76.477			14.206		
-2logL	62.477			0.206		
R^2	0.391			0.313		
Max-rescaled R^2	0.524			0.690		

Table 28 Correlation table for yielding study variables, Indiana Entry

Indiana Entry:Pearson Correlation Coefficients, N = 71 Prob > |r| under H0: Rho=0								
	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	0.09929 0.4101	-0.1983 0.0974	0.03985 0.7414	-0.1228 0.3075	. .	. .	0.01071 0.9294
FT	0.09929 0.4101	1	-0.1142 0.3429	-0.0594 0.6227	-0.0134 0.9115	. .	. .	-0.0322 0.7901
DSC	-0.19829 0.0974	-0.1142 0.3429	1	0.43891 0.0001	-0.2298 0.0539	. .	. .	0.08438 0.4841
PLT	0.03985 0.7414	-0.0594 0.6227	0.43891 0.0001	1	0.04686 0.698	. .	. .	-0.2763 0.0197
SPD	-0.12282 0.3075	-0.0134 0.9115	-0.2298 0.0539	0.04686 0.698	1	. .	. .	-0.1555 0.1954
HGV	. .	. .	. .	. .	. .	. .	. .	. .
MUP	. .	. .	. .	. .	. .	. .	. .	. .
FAR	0.01071 0.9294	-0.0322 0.7901	0.08438 0.4841	-0.2763 0.0197	-0.1555 0.1954	. .	. .	1

Table 29 Correlation table for yielding study variables, Indiana Exit

Indiana Exit: Pearson Correlation Coefficients, N = 64
Prob > |r| under H0: Rho=0

	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	0.03139	-0.0342	-0.2568	.	.	0.04495	0.11785
		0.8055	0.7885	0.0405	.	.	0.7243	0.3537
FT	0.03139	1	0.16424	-0.2032	.	.	0.17353	0.14797
	0.8055		0.1947	0.1073	.	.	0.1703	0.2433
PLT	-0.0342	0.16424	1	-0.2379	.	.	-0.26285	-0.35468
	0.7885	0.1947		0.0583	.	.	0.0359	0.004
SPD	-0.25683	-0.20322	-0.23794	1	.	.	-0.09183	-0.04698
	0.0405	0.1073	0.0583		.	.	0.4705	0.7124
HGV	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
MUP	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
RT	0.04495	0.17353	-0.26285	-0.0918	.	.	1	0.21188
	0.7243	0.1703	0.0359	0.4705	.	.		0.0928
FAR	0.11785	.	.	.	.	.	.	.
	0.3537	.	.	.	.	.	.	.

Table 30 Yield models for entry and exit approach for Nashville Tennessee

Nashville Tennessee	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Square	Odds Ratio
Intercept	1.465	0.307	-	-13.839	0.915	-
DSC	-0.077	0.934	0.926	-	-	-
SPD	-0.086	0.173	0.918	0.100	0.684	-
FAR	-0.942	0.264	0.390	-2.366	0.172	-
STP	0.000	-	-	0.000	.	-
PLT	-0.207	0.794	-	0.031	0.984	-
HGV	0.000	-	-	-11.109	0.972	-
MUP	-14.710	0.959	<0.001	-8.116	0.971	-
CN	2.811	0.005	16.625	12.122	0.034	>0.999.99
FT	0.292	0.708	1.340	-10.945	0.045	<0.001
RT	-	-	-	-0.139	1.000	-
AIC	66.107			33.659		
-2logL	50.107			31.659		
R^2	0.367			0.179		
Max-rescaled R^2	0.489			0.542		

Table 31 Correlation table for yielding study variables, Nashville Tennessee Entry

Nashville Tennessee

NASH Entry: Pearson Correlation Coefficients, N = 54 Prob > |r| under H0: Rho=0								
	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	0.05862	-0.19974	0.11776	-0.1738	.	-0.01675	0.42797
		0.6737	0.1476	0.3964	0.2088	.	0.9043	0.0012
FT	0.05862	1	-0.05547	0.0686	0.3128	.	-0.02857	-0.00857
	0.6737		0.6903	0.6221	0.0213	.	0.8375	0.9509
DSC	-0.19974	-0.05547	1	0.30442	-0.30085	.	0.08717	-0.12367
	0.1476	0.6903		0.0252	0.0271	.	0.5308	0.373
PLT	0.11776	0.0686	0.30442	1	-0.13146	.	-0.0196	-0.03235
	0.3964	0.6221	0.0252		0.3433	.	0.8881	0.8163
SPD	-0.1738	0.3128	-0.30085	-0.13146	1	.	-0.10318	-0.08173
	0.2088	0.0213	0.0271	0.3433		.	0.4578	0.5568
HGV	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
MUP	-0.01675	-0.02857	0.08717	-0.0196	-0.10318	.	1	-0.0196
	0.9043	0.8375	0.5308	0.8881	0.4578	.		0.8881
FAR	0.42797	-0.00857	-0.12367	-0.03235	-0.08173	.	-0.0196	1
	0.0012	0.9509	0.373	0.8163	0.5568	.	0.8881	

Table 32 Correlation table for yielding study variables, Nashville Tennessee Exit

Nashville Tennessee

NASH Exit: Pearson Correlation Coefficients, N = 79 Prob > |r| under H0: Rho=0								
	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	0.05939	0.26059	-0.11225	0.20597	0.18965	0.09346	0.34862
		0.6031	0.0204	0.3246	0.0686	0.0941	0.4126	0.0016
FT	0.05939	1	-0.2377	0.11575	0.10678	0.15395	0.33684	0.06483
	0.6031		0.0349	0.3097	0.349	0.1755	0.0024	0.5703
PLT	0.26059	-0.2377	1	-0.08101	0.03247	0.09688	-0.01172	0.0842
	0.0204	0.0349		0.4779	0.7763	0.3957	0.9183	0.4607
SPD	-0.11225	0.11575	-0.08101	1	-0.13686	-0.09462	-0.06829	0.02354
	0.3246	0.3097	0.4779		0.2291	0.4068	0.5498	0.8368
HGV	0.20597	0.10678	0.03247	-0.13686	1	-0.10249	0.22398	0.00878
	0.0686	0.349	0.7763	0.2291		0.3687	0.0472	0.9388
MUP	0.18965	0.15395	0.09688	-0.09462	-0.10249	1	0.09752	0.05103
	0.0941	0.1755	0.3957	0.4068	0.3687		0.3925	0.6551
RT	0.09346	0.33684	-0.01172	-0.06829	0.22398	0.09752	1	0.15725
	0.4126	0.0024	0.9183	0.5498	0.0472	0.3925		0.1663
FAR	0.34862	0.06483	0.0842	0.02354	0.00878	0.05103	0.15725	1
	0.0016	0.5703	0.4607	0.8368	0.9388	0.6551	0.1663	

Table 33 Yield models for entry and exit approach for Raleigh North Carolina

Raleigh North Carolina	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Square	Odds Ratio
Intercept	6.037	0.008	-	5.798	0.001	-
DSC	1.594	0.238	-	-	-	-
SPD	-0.354	0.001	0.702	-0.597	0.005	0.550
FAR	-1.914	0.039	0.147	-0.125	0.363	-
STP	0.000	-	-	0.000	-	-
PLT	-12.136	0.964	-	-0.003	0.835	-
HGV	-13.175	0.988	-	15.875	0.972	-
MUP	-10.986	0.969	-	0.874	0.854	-
CN	-0.020	0.979	-	2.103	0.041	8.194
FT	1.132	0.149	-	1.340	0.214	-
RT	-	-	-	0.075	0.691	-
AIC	62.157			66.358		
-2logL	44.157			64.358		
R^2	0.397			0.146		
Max-rescaled R^2	0.580			0.266		

Table 34 Correlation table for yielding study variables, Raleigh North Carolina Entry

Raleigh North Carolina

RAL Entry: Pearson Correlation Coefficients, N = 68
Prob > |r| under H0: Rho=0

	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	0.00261	-0.1934	-0.34887	-0.27352	0.11863	-0.11289	-0.15289
		0.9832	0.1141	0.0035	0.024	0.3353	0.3593	0.2132
FT	0.00261	1	-0.0593	-0.21291	0.06774	-0.11183	-0.07654	-0.08524
	0.9832		0.631	0.0813	0.5831	0.3639	0.535	0.4895
DSC	-0.1934	-0.0593	1	0.47711	-0.22359	-0.04461	0.04733	0.21082
	0.1141	0.631		<.0001	0.0668	0.7179	0.7015	0.0844
PLT	-0.34887	-0.21291	0.47711	1	-0.00347	-0.04139	0.23585	0.19558
	0.0035	0.0813	<.0001		0.9776	0.7376	0.0528	0.11
SPD	-0.27352	0.06774	-0.22359	-0.00347	1	-0.01898	0.04646	-0.14486
	0.024	0.5831	0.0668	0.9776		0.8779	0.7067	0.2385
HGV	0.11863	-0.11183	-0.04461	-0.04139	-0.01898	1	-0.03801	-0.2116
	0.3353	0.3639	0.7179	0.7376	0.8779		0.7583	0.0832
MUP	-0.11289	-0.07654	0.04733	0.23585	0.04646	-0.03801	1	0.17961
	0.3593	0.535	0.7015	0.0528	0.7067	0.7583		0.1428
FAR	-0.15289	-0.08524	0.21082	0.19558	-0.14486	-0.2116	0.17961	1
	0.2132	0.4895	0.0844	0.11	0.2385	0.0832	0.1428	

Table 35 Correlation table for yielding study variables, Raleigh North Carolina Exit

Raleigh North Carolina

RAL Exit: Pearson Correlation Coefficients, N = 81 Prob > |r| under H0: Rho=0								
	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	-0.06044	-0.26618	0.18705	-0.07269	-0.01227	-0.07852	0.02263
		0.592	0.0163	0.0945	0.519	0.9134	0.4859	0.8411
FT	-0.06044	1	-0.04183	0.10605	0.07269	0.01227	-0.09338	0.08847
	0.592		0.7108	0.3461	0.519	0.9134	0.407	0.4322
PLT	-0.26618	-0.04183	1	-0.20862	-0.0503	-0.08491	0.09106	0.04129
	0.0163	0.7108		0.0616	0.6556	0.451	0.4188	0.7144
SPD	0.18705	0.10605	-0.20862	1	-0.18337	0.09323	-0.28285	0.01376
	0.0945	0.3461	0.0616		0.1013	0.4078	0.0105	0.903
HGV	-0.07269	0.07269	-0.0503	-0.18337	1	-0.06492	0.0393	-0.02722
	0.519	0.519	0.6556	0.1013		0.5647	0.7276	0.8094
MUP	-0.01227	0.01227	-0.08491	0.09323	-0.06492	1	-0.09359	0.01608
	0.9134	0.9134	0.451	0.4078	0.5647		0.4059	0.8867
RT	-0.07852	-0.09338	0.09106	-0.28285	0.0393	-0.09359	1	-0.42276
	0.4859	0.407	0.4188	0.0105	0.7276	0.4059		<.0001
FAR	0.02263	0.08847	0.04129	0.01376	-0.02722	0.01608	-0.42276	1
	0.8411	0.4322	0.7144	0.903	0.8094	0.8867	<.0001	

Table 36 Yield models for entry and exit approach for Winston-Salem North Carolina

Winston-Salem North Carolina	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Square	Odds Ratio
Intercept	7.578	0.021	-	-9.048	0.932	-
DSC	-12.299	0.959	-	-	-	-
SPD	-0.313	0.003	0.898	-0.229	0.235	-
FAR	-1.014	0.326	-	-2.719	0.026	0.791
STP	0.000	-	-	0.000	-	-
PLT	-10.144	0.951	-	-1.101	0.998	-
HGV	-11.541	0.964	-	2.121	0.382	-
MUP	-12.667	0.986	-	-10.851	0.989	-
CN	-1.900	0.251	-	11.606	0.913	-
FT	-0.183	0.847	-	1.138	0.301	-
RT	-	-	-	0.000	-	-
AIC	50.149			52.923		
-2logL	32.149			50.923		
R^2	0.294			0.295		
Max-rescaled R^2	0.565			0.599		

Table 37 Correlation table for yielding study variables, Winston-Salem North Carolina Entry

Winston-Salem, North Carolina

SLM Entry: Pearson Correlation Coefficients, N = 83 Prob > |r| under H0: Rho=0								
	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	0.036 0.7466	-0.10981 0.3231	-0.31511 0.0037	-0.65211 <.0001	0.00271 0.9806	0.11177 0.3144	0.18099 0.1015
FT	0.036 0.7466	1	-0.22232 0.0434	-0.17297 0.1179	-0.04899 0.6601	0.00271 0.9806	0.11177 0.3144	-0.03438 0.7577
DSC	-0.10981 0.3231	-0.22232 0.0434	1	0.24387 0.0263	-0.06321 0.5702	-0.05063 0.6494	-0.02485 0.8235	0.01363 0.9027
PLT	-0.31511 0.0037	-0.17297 0.1179	0.24387 0.0263	1	0.17572 0.1121	0.07796 0.4836	-0.04316 0.6984	-0.07557 0.4972
SPD	-0.65211 <.0001	-0.04899 0.6601	-0.06321 0.5702	0.17572 0.1121	1	-0.0558 0.6164	-0.16194 0.1436	-0.0282 0.8002
HGV	0.00271 0.9806	0.00271 0.9806	-0.05063 0.6494	0.07796 0.4836	-0.0558 0.6164	1	-0.02485 0.8235	0.01363 0.9027
MUP	0.11177 0.3144	0.11177 0.3144	-0.02485 0.8235	-0.04316 0.6984	-0.16194 0.1436	-0.02485 0.8235	1	0.06837 0.5391
FAR	0.18099 0.1015	-0.03438 0.7577	0.01363 0.9027	-0.07557 0.4972	-0.0282 0.8002	0.01363 0.9027	0.06837 0.5391	1

Table 38 Correlation table for yielding study variables, Winston-Salem North Carolina Exit

Winston-Salem, North Carolina

SLM Exit: Pearson Correlation Coefficients, N = 75 Prob > |r| under H0: Rho=0								
	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	-0.02533	-0.17695	-0.34691	0.15483	0.10874	.	0.36377
		0.8292	0.1288	0.0023	0.1847	0.3531	.	0.0013
FT	-0.02533	1	-0.1972	0.22682	-0.02913	0.09758	.	0.15609
	0.8292		0.0899	0.0504	0.8041	0.4049	.	0.1811
PLT	-0.17695	-0.1972	1	-0.17308	-0.0274	-0.01924	.	-0.15903
	0.1288	0.0899		0.1376	0.8155	0.8698	.	0.173
SPD	-0.34691	0.22682	-0.17308	1	-0.02387	-0.08662	.	0.13408
	0.0023	0.0504	0.1376		0.8389	0.4599	.	0.2515
HGV	0.15483	-0.02913	-0.0274	-0.02387	1	-0.01924	.	0.00663
	0.1847	0.8041	0.8155	0.8389		0.8698	.	0.955
MUP	0.10874	0.09758	-0.01924	-0.08662	-0.01924	1	.	0.12099
	0.3531	0.4049	0.8698	0.4599	0.8698		.	0.3011
RT	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
FAR	0.36377	0.15609	-0.15903	0.13408	0.00663	0.12099	.	1
	0.0013	0.1811	0.173	0.2515	0.955	0.3011	.	

Table 39 Yield models for entry and exit approach for Towson Maryland

Towson Maryland	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Square	Odds Ratio
Intercept	1.593	0.372	-	8.023	0.009	-
DSC	0.817	0.307	-	-	-	-
SPD	-0.076	0.302	-	-0.465	0.009	-
FAR	-1.717	0.002	0.543	-1.272	0.153	0.892
STP	0.000	-	-	0.000	-	-
PLT	-0.612	0.343	-	-0.046	0.948	-
HGV	1.694	0.260	-	-13.472	0.986	-
MUP	1.434	0.254	-	-0.340	0.817	-
CN	0.846	0.139	-	0.309	0.650	-
FT	1.086	0.058	9.116	0.000	-	-
RT	-	-	-	-1.328	0.137	-
AIC	110.490			70.593		
-2logL	108.490			68.593		
R^2	0.314			0.225		
Max-rescaled R^2	0.421			0.302		

Table 40 Correlation table for yielding study variables, Towson, Maryland Entry

Towson Maryland

TSN Entry: Pearson Correlation Coefficients, N = 79 Prob > |r| under H0: Rho=0								
	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	-0.0071	0.23141	-0.05233	0.004	0.1011	-0.01818	-0.13578
		0.9505	0.0402	0.6469	0.9718	0.3755	0.8736	0.2328
FT	-0.00709	1	0.07979	0.02163	-0.1283	0.0205	-0.07044	-0.14571
	0.9505		0.4845	0.8499	0.2597	0.8574	0.5373	0.2001
DSC	0.23141	0.0798	1	-0.16267	-0.281	-0.13	-0.04953	-0.23141
	0.0402	0.4845		0.152	0.0121	0.2537	0.6647	0.0402
PLT	-0.05233	0.0216	-0.1627	1	-0.2828	0.1623	-0.13923	0.05233
	0.6469	0.8499	0.152		0.0116	0.1531	0.2211	0.6469
SPD	0.00404	-0.1283	-0.281	-0.28282	1	-0.01	-0.12208	0.12901
	0.9718	0.2597	0.0121	0.0116		0.9337	0.2838	0.2571
HGV	0.10106	0.0205	-0.13	0.16227	-0.0095	1	-0.06621	0.01465
	0.3755	0.8574	0.2537	0.1531	0.9337		0.5621	0.8981
MUP	-0.01818	-0.0704	-0.0495	-0.13923	-0.1221	-0.066	1	-0.07757
	0.8736	0.5373	0.6647	0.2211	0.2838	0.5621		0.4968
FAR	-0.13578	-0.1457	-0.2314	0.05233	0.129	0.0147	-0.07757	1
	0.2328	0.2001	0.0402	0.6469	0.2571	0.8981	0.4968	

Table 41 Correlation table for yielding study variables, Towson Maryland Exit

Towson Maryland

TSN Exit: Pearson Correlation Coefficients, N = 50 Prob > |r| under H0: Rho=0								
	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	.	0.12666	-0.04134	-0.1429	-0.084	0	-0.29554
		.	0.3808	0.7756	0.3223	0.5609	1	0.0372
FT	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
PLT	0.12666	.	1	0.03037	-0.1025	-0.181	0.01724	-0.15865
	0.3808	.		0.8342	0.4786	0.2076	0.9054	0.2712
SPD	-0.04134	.	0.03037	1	-0.0461	-0.221	-0.39829	0.15254
	0.7756	.	0.8342		0.7508	0.1235	0.0042	0.2903
HGV	-0.14286	.	-0.1025	-0.04606	1	-0.036	-0.11664	0.19904
	0.3223	.	0.4786	0.7508		0.8035	0.4198	0.1658
MUP	-0.08422	.	-0.1813	-0.22072	-0.0361	1	-0.03438	-0.00356
	0.5609	.	0.2076	0.1235	0.8035		0.8126	0.9804
RT	0	.	0.01724	-0.39829	-0.1166	-0.034	1	-0.49985
	1	.	0.9054	0.0042	0.4198	0.8126		0.0002
FAR	-0.29554	.	-0.1587	0.15254	0.199	-0.004	-0.49985	1
	0.0372	.	0.2712	0.2903	0.1658	0.9804	0.0002	

Table 42 Yield models for entry and exit approach for Annapolis Maryland

Annapolis Maryland

	P(Yield)-Entry			P(Yield)-Exit		
	Estimate	Chi-Square	Odds Ratio	Estimate	Chi-Squar	Odds Ratio
Intercept	5.493	0.046	-	1.226	0.530	-
DSC	10.605	0.938	-			-
SPD	-0.185	0.071	1.016	-0.1258	0.2748	-
FAR	-0.798	0.336	-	-0.842	0.146	-
STP	0.000	.	-	0.000	-	-
PLT	-1.216	0.209	-	0.107	0.873	-
HGV	10.276	0.979	-	-14.162	0.980	-
MUP	0.000	.	-	1.826	0.176	-
CN	1.491	0.076	23.010	1.084	0.042	-
FT	-0.281	0.741	-	-0.449	0.391	-
RT	-	-	-	-1.471	0.090	-
AIC	63.723			114.338		
-2logL	61.723			112.338		
R^2	0.280			0.154		
Max-rescaled R^2	0.428			0.217		

Table 43 Correlation table for yielding study variables, Annapolis Maryland Entry

Annapolis Maryland

ANN Entry: Pearson Correlation Coefficients, N = 58 Prob > |r| under H0: Rho=0								
	CN	FT	DSC	PLT	SPD	HGV	MUP	FAR
CN	1	-0.2099	0.1883	0.01268	-0.08578	0.18257	.	0.0559
		0.1138	0.1569	0.9248	0.522	0.1701	.	0.6768
FT	-0.2099	1	0.25295	0.06222	-0.32162	0.17637	.	-0.27468
	0.1138		0.0554	0.6427	0.0138	0.1854	.	0.0369
DSC	0.1883	0.25295	1	0.32959	-0.46768	-0.10157	.	-0.33174
	0.1569	0.0554		0.0115	0.0002	0.448	.	0.011
PLT	0.01268	0.06222	0.32959	1	-0.429	0.06942	.	-0.18423
	0.9248	0.6427	0.0115		0.0008	0.6046	.	0.1662
SPD	-0.0858	-0.32162	-0.46768	-0.429	1	-0.12998	.	0.23769
	0.522	0.0138	0.0002	0.0008		0.3308	.	0.0724
HGV	0.18257	0.17637	-0.10157	0.06942	-0.12998	1	.	0.09477
	0.1701	0.1854	0.448	0.6046	0.3308		.	0.4792
MUP	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
FAR	0.0559	-0.27468	-0.33174	-0.18423	0.23769	0.09477	.	1
	0.6768	0.0369	0.011	0.1662	0.0724	0.4792	.	

Table 44 Correlation table for yielding study variables, Annapolis Maryland Exit

Annapolis Maryland

ANN Exit: Pearson Correlation Coefficients, N = 91 Prob > |r| under H0: Rho=0								
	CN	FT	PLT	SPD	HGV	MUP	RT	FAR
CN	1	-0.05462	0.14923	-0.03554	0.14504	-0.06767	-0.1885	0.13212
		0.6071	0.158	0.738	0.1701	0.5239	0.0735	0.2119
FT	-0.0546	1	0.22617	-0.08587	-0.14827	0.06358	0.06281	0.07646
	0.6071		0.0311	0.4183	0.1607	0.5494	0.5542	0.4713
PLT	0.14923	0.22617	1	-0.15664	-0.07444	-0.09168	-0.012	-0.16575
	0.158	0.0311		0.1381	0.4831	0.3874	0.9105	0.1164
SPD	-0.0355	-0.08587	-0.15664	1	-0.17105	-0.08169	-0.087	-0.18339
	0.738	0.4183	0.1381		0.105	0.4414	0.412	0.0818
HGV	0.14504	-0.14827	-0.07444	-0.17105	1	-0.02768	-0.0692	-0.11851
	0.1701	0.1607	0.4831	0.105		0.7945	0.5143	0.2632
MUP	-0.0677	0.06358	-0.09168	-0.08169	-0.02768	1	-0.0853	0.10704
	0.5239	0.5494	0.3874	0.4414	0.7945		0.4215	0.3125
RT	-0.1885	0.06281	-0.01195	-0.08703	-0.06924	-0.08528	1	-0.30581
	0.0735	0.5542	0.9105	0.412	0.5143	0.4215		0.0032
FAR	0.13212	0.07646	-0.16575	-0.18339	-0.11851	0.10704	-0.3058	1
	0.2119	0.4713	0.1164	0.0818	0.2632	0.3125	0.0032	

APPENDIX C: SIMULATOR STUDY DEBRIEFING QUESTIONNAIRE

North Carolina State University

Roundabout Corridor Study, May- July 2011

Date:__________ **Subject:__________**

Study#: ________ **Analyst: __________**

Driver Information:

1) How long have you had a driving license?
2) How many hours do you drive on average?
3) How often do you pass through intersections with pedestrian crossings?
4) How often do you pass through roundabouts?
5) How often do you yield to pedestrians?

Study Related Questions:

1) How many types of signals have you noticed in the scenarios?
2) How many pedestrians have you noticed in each scenario?
3) Which type of signal caught your attention more?
4) Have you had difficulty understanding the stages of signals?
5) What did you notice different about the environment?
6) Did you notice that in difference scenarios the signals are located in different distances from roundabout?

APPENDIX D: STISIM DRIVING SIMULATOR

STISIM includes three desktop computers. Each computer is connected to the Uninterruptible Power Source (UPS). Since the desktop is very sensitive to electric shock, all system should be connected to UPS. All input and output cables from each computer (i.e., monitor, keyboard and mouse cables) are connected to the USB switcher (STARTVEW SWITCH) since the switcher can control all three computers with one monitor, keyboard and mouse at another location. the switch has four channels. Since we have three computer systems, we use three channels from 1 to 3. A Steering Box and a speaker system are connected to the center computer (PC2) since the center computer has the main program (Source: www.ise.ncsu.edu/ergolab). Figure 23 shows the driving simulator equipment in NCSU ergonomics lab used for the experiment. Figure 24 through Figure 29 show the views of driving simulator environment for different scenarios and treatments tested for the experiment.

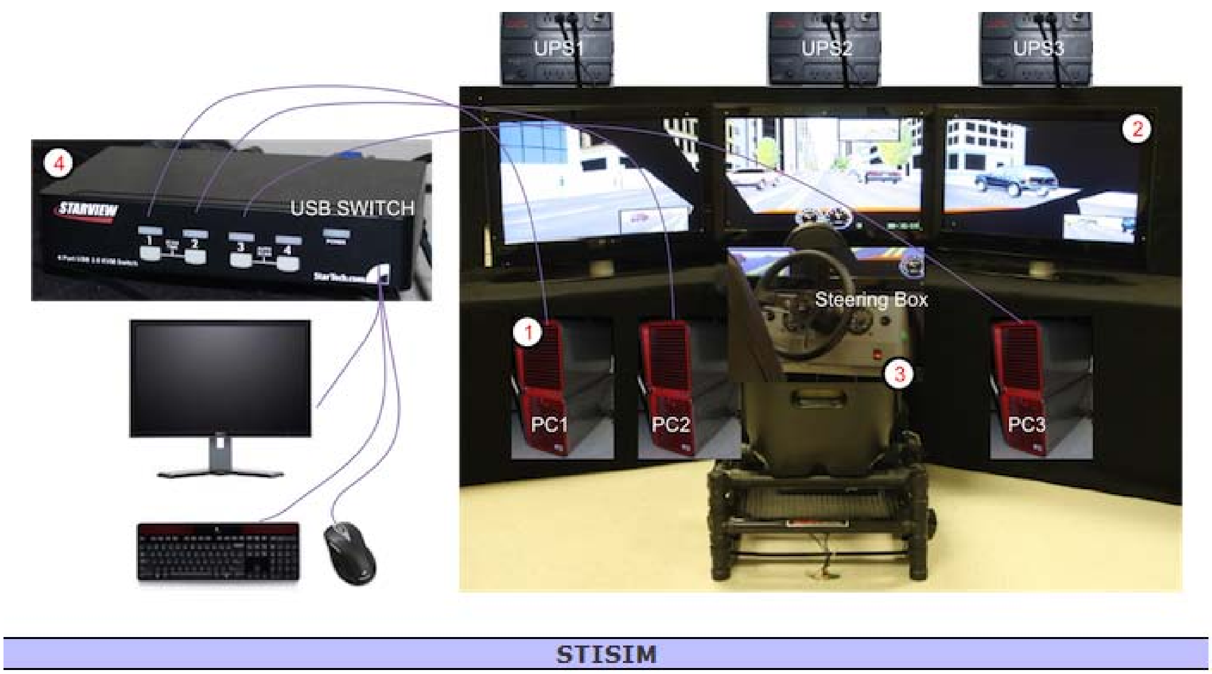


Figure 23 Driving Simulator STISIM Equipment (Photo Source: WWW.ise.ncsu.edu/ergolab)

Figure 24 View of driving simulator environment, no treatment (CTRL20) scenario

Figure 25 View of driving simulator environment, entry to the roundabout, PHB20 scenario

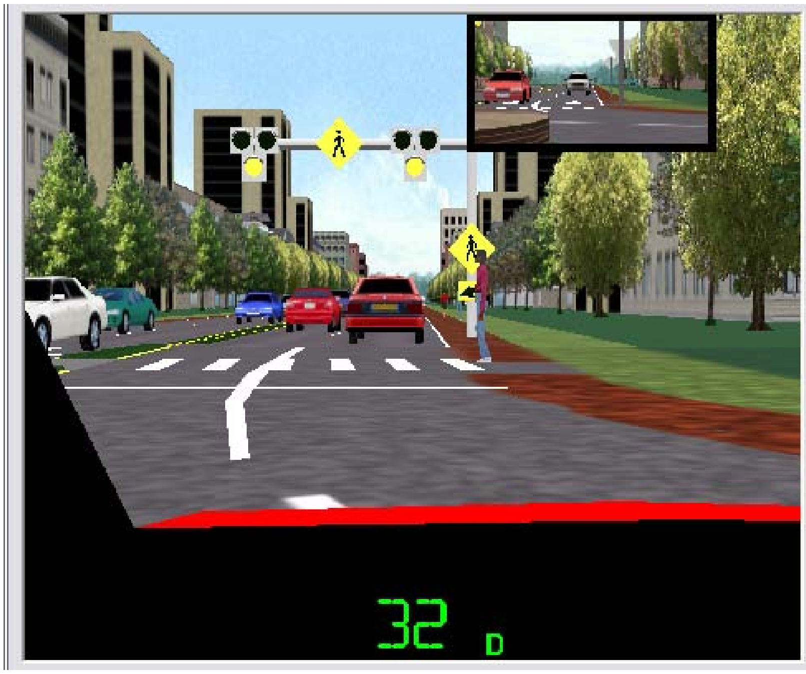


Figure 26 View of driving simulator environment PHB20 scenario, beacon turning yellow while driver approaching the exit crosswalk and pedestrian

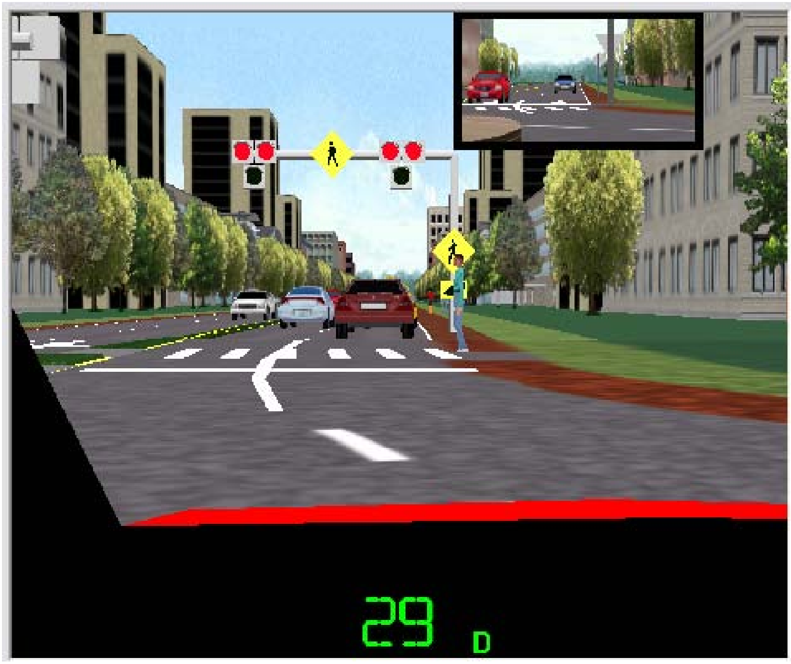


Figure 27 View of driving simulator environment PHB20 scenario, beacon turning red while driver approaching the exit crosswalk and pedestrian

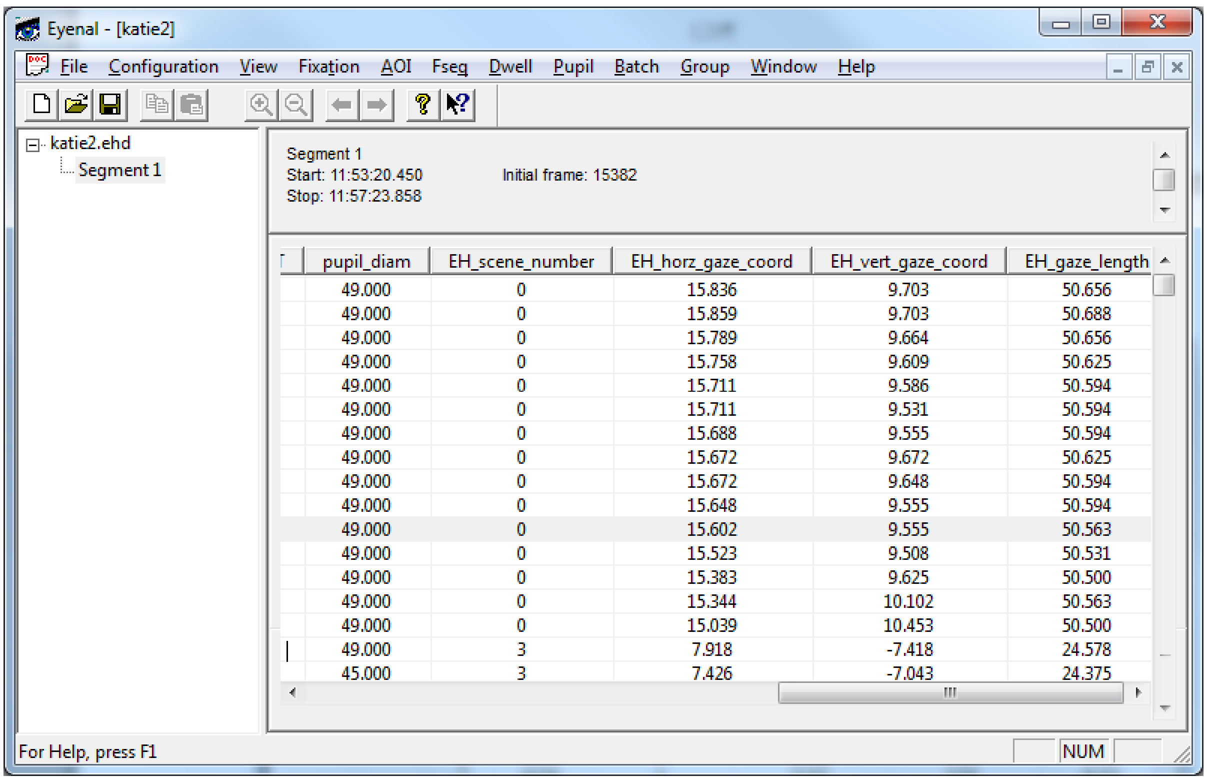
Figure 28 View of driving simulator environment entry approach, RRFB20 scenario, RRFB in dark mode

Figure 29 View of driving simulator environment, exit approach, RRFB20 scenario, RRFB activated for pedestrian crossing

APPENDIX E: EYE TRACKER SOFTWARE

The ASL Eye Tracker owned by the Ergonomics Lab (Figure 18) uses a camera and infrared light sources fixed on a head-mounted unit to capture an image of a participants' pupil in real time. This allows an integrated computer system and software to identify where the eyes fixate or gaze direction. The eye tracker does not touch the eyes and poses no harm to a participants' vision. However, wearing the head-mounted unit can cause fatigue in the neck and shoulders and sweating due to the heat of the camera. Both of these effects are normal for use and are reversible.

Figure 30 ASL Eye tracking System (Source: http://www.s-oliver-associates.com)



pupil_diam	EH_scene_number	EH_horz_gaze_coord	EH_vert_gaze_coord	EH_gaze_length
49.000	0	15.836	9.703	50.656
49.000	0	15.859	9.703	50.688
49.000	0	15.789	9.664	50.656
49.000	0	15.758	9.609	50.625
49.000	0	15.711	9.586	50.594
49.000	0	15.711	9.531	50.594
49.000	0	15.688	9.555	50.594
49.000	0	15.672	9.672	50.625
49.000	0	15.672	9.648	50.594
49.000	0	15.648	9.555	50.594
49.000	0	15.602	9.555	50.563
49.000	0	15.523	9.508	50.531
49.000	0	15.383	9.625	50.500
49.000	0	15.344	10.102	50.563
49.000	0	15.039	10.453	50.500
49.000	3	7.918	-7.418	24.578
45.000	3	7.426	-7.043	24.375

Figure 31 (Eyenal (Eye-Analysis) software interface for ASL series 5000 eye tracking system, sample of a data set collected during the driving simulator experiment

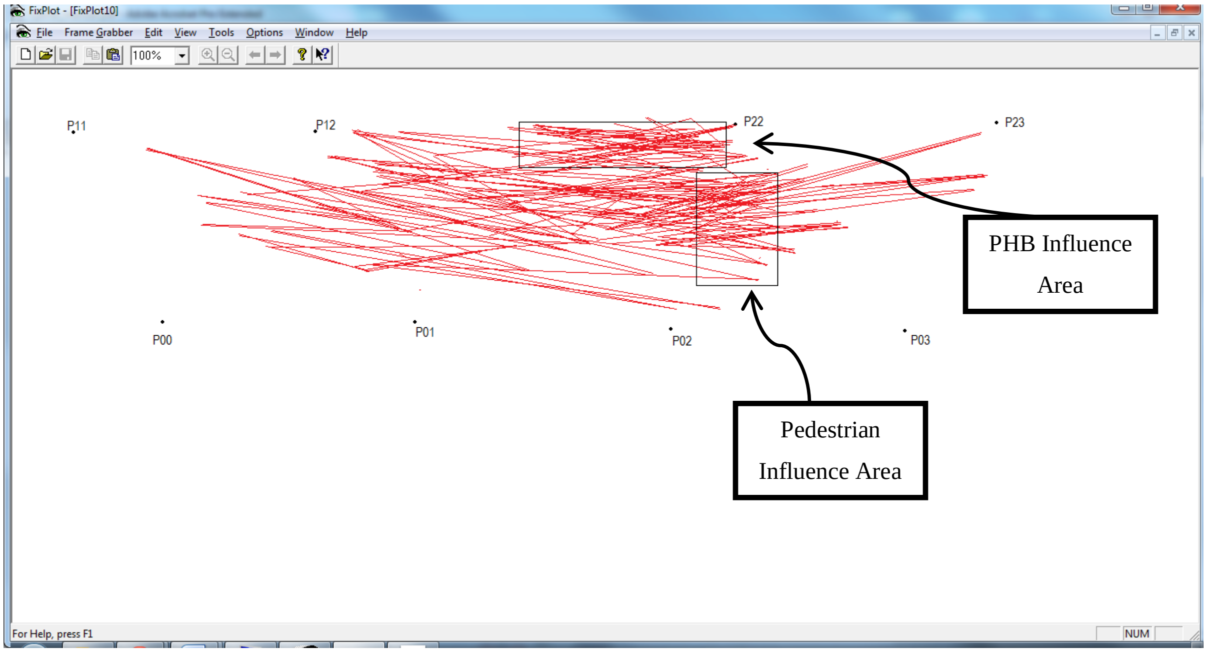


Figure 32 Screen Shut of a Fix Plot (eye movement trajectory from the time vehicle enters the circulating lane to the time that crosses the crosswalk, PHB20)