Assessing Potential(s) of Mini-Roundabout Designs From a User's Perspective: A Case Study Using a High-Fidelity Driving Simulator

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Abstract

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Assessing Potential(s) of Mini-Roundabout Designs From a User's Perspective: A Case Study Using a High-Fidelity Driving Simulator

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In recent years, the US has recognized roundabouts as a viable solution for mitigating traffic congestion challenges. While traditional stop-controlled intersections are effective under conditions of moderate congestion, they are less suitable for urban and suburban areas where traffic density and safety concerns lead to frequent crashes. Roundabouts offer significant safety improvements and enhance traffic flow, particularly in rapidly urbanizing cities. However, the construction of traditional roundabouts often incurs high costs and typically necessitates additional right-of-way (ROW), making them a less feasible option in many cases. This has led to increased interest in mini-roundabouts among engineers in the US, as they require minimal design modifications for installation within existing intersections and are seen as a cost-effective alternative for managing traffic congestion and improving road safety.

Through a driving simulator-based analysis, this research compares navigability across different mini-roundabout designs to derive actionable insights on design specifications and operational improvements. Findings indicate that mini-roundabouts, particularly those with an Inscribed Circle Diameter (ICD) between 60 and 90 feet, exhibit speed patterns comparable to single-lane roundabouts with a 120-feet ICD but with significantly reduced entry, circulatory, and exit speeds. These outcomes suggest

that carefully considered mini-roundabout implementations can enhance traffic flow and safety without the extensive demands of traditional roundabouts.

The insights gained from this study enhance our understanding of driver behavior and offer valuable perspectives on how drivers interact with mini-roundabouts. By integrating these findings on driver performance, opinions, and preferences into future design considerations, transportation authorities can make informed decisions to optimize the implementation of mini-roundabouts across the US, ensuring they meet the needs and expectations of road users.

Dedication

To my mother and my wife for their endless love and support, and to my late father, whose memory fuels my aspirations.

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I am deeply thankful to God for His endless blessings and guidance throughout my journey. I extend my heartfelt thanks to Dr. Bhaven Naik, whose unwavering support and guidance have been instrumental in my journey through my master's degree. His mentorship has been a cornerstone of my development as a Transportation Engineer, and for that, I am deeply grateful. My gratitude also extends to Dr. Deborah McAvoy, Dr. Daniel Che, and Dr. Gaurav Sinha for their invaluable feedback and for serving on my committee. I cherish the memories and learning experiences with my peers in Stocker 308 – the Safety and Human Factors Lab, whose collective wisdom and unique characters have greatly enriched my journey. Additionally, I extend my thanks to the undergraduate and graduate students of Russ College, who shared this academic path with me, for their friendship and support.

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Chapter 1: Introduction

Background

Over the past two decades in the US, roundabouts have increasingly become recognized as a more suitable intersection control alternative. Converting traditional intersections (i.e., stop-controlled and also signalized) into modern roundabouts has been shown to reduce fatalities by 90% and crash frequency by 35% (Persaud et al., 2001). The reduced risk of vehicle crashes along with the aesthetic appearance of intersections increased the acceptance of roundabouts substantially (Hu et al., 2014).

While there are safety, congestion-based, and aesthetic benefits associated to traditional roundabouts – single-lane and multi-lane; there are some concerns associated with their usage including, high construction costs, the need for additional right-of-way (ROW); and a lack of navigational skills amongst users and public disapproval. It is due to these negative reasons – high construction costs, need for ROW, etc. –that the concept of mini-roundabouts has drawn the attention of engineers in the US. Mini-roundabouts (and their modular counterparts) are relatively easier to adopt within the existing intersection ROW with very minimal geometric design modifications required; thus giving them a much smaller footprint than traditional single or multi-lane roundabouts. The total cost of a mini-roundabout is around $250,000 on average whereas a traditional multi-lane roundabout costs around $2.05 million on average (Pochowski et al., 2016). Given mini-roundabouts can be constructed at relatively a fraction of the costs of traditional roundabouts and also using the existing ROW whilst providing similar benefits with traditional roundabouts; these mini-roundabouts have become an attractive intersection modification option for practitioners in jurisdictions with limited monetary budgets.

Study Rationale

Most of the roundabouts constructed in the US over the past few decades are single-lane and multi-lane (2x2) roundabouts. One of the most essential reasons for choosing roundabouts over other type of intersection control (e.g., two or four-way stop and signalization) is the reduced rate of motor vehicle fatalities and crashes. In 2008, about 40% percent of the crashes that occurred in the US were intersection related crashes (Choi, 2010). This percentage can be reduced with some geometric modifications to the existing intersections. As stated before, many countries started converting stop-controlled and signalized intersections to roundabouts where it is required and compatible. While the adoption of mini-roundabouts in the US is relatively recent, they have been a longstanding element in the transportation infrastructure of many countries within the roundabout community (Lochrane et al., 2013a). For this reason, these countries have specific guidelines on the design and implementation of mini-roundabouts. However, the use of the mini-roundabouts in the US has been limited and there have not been too many studies and/or pilot projects.

The most useful information regarding the design guidelines of the US mini-roundabouts can be found in the “Mini-Roundabouts Technical Summary” and “NCHRP Report 672 Roundabouts: An Informational Guide” published by Federal Highway Administration (FHWA) (Rice, 2010; Rodegerdts et al., 2010a) However, these resources are not enough for the local transportation officials for implementing mini-roundabouts in their local jurisdictions. There is a need for more specific and context-sensitive design guidelines for mini-roundabouts.

Previous studies on mini-roundabouts have demonstrated their effectiveness in improving traffic flow, reducing speeds, and lowering both accident rates and costs (Delbosc et al., 2017; Lochrane et al., 2012; Waddell & Albertson, 2005; Zhang et al., 2010). However, there has been only a single study dedicated to estimating the critical gap associated with mini-roundabouts (Lochrane et al., 2013b). This indicates a notable lack of comprehensive research into critical gap measurements, pointing to a need for more extensive study to develop dependable critical gap standards for mini-roundabouts.

While numerous studies have confirmed the benefits of mini-roundabouts, there is a noticeable lack of experimentation involving driving simulators within the research literature. Such simulations are essential for evaluating driver responses to mini-roundabouts, especially for those who are encountering them for the first time. Simulators can assess drivers' comfort, their hesitation, and any possible misunderstandings—all of which are key to determining the efficiency and safety of mini-roundabouts. Despite the recognized importance of these tools, past research has not ventured extensively into simulation-based studies for mini-roundabouts.

The performance of mini-roundabouts in the US remains a topic with many unanswered questions, particularly from the perspective of human factors. Previous studies have indicated that both the age and gender of drivers play significant roles in influencing driving patterns around roundabouts. On average, younger and male drivers approach and leave roundabouts at higher speeds compared to their older and female counterparts (Raiyn & Weidl, 2023). Additionally, the time of day, specifically daylight presence, significantly impacts driving behaviors (Owens et al., 2007). There is a lack of in-depth statistical and comparative research into these variables affect driver behavior within mini-roundabouts. These gaps in the existing literature motivated the undertaking of the research work detailed in this thesis.

Research Objectives and Hypotheses

The primary objective of this thesis work is to assess the potential(s) of mini-roundabout designs from a user's perspective using a high-fidelity driving simulator. More specifically, this thesis focuses on evaluating drivers' familiarity with mini-roundabouts and investigating the factors influencing driver behavior within mini-roundabouts. Additionally, this thesis presents a comprehensive review of existing research, pilot projects, and practices related to the design, installation and implementation of mini-roundabouts. Accordingly, the study is designed to fulfill the following research objectives:

1. Determine the optimal design specifications for mini-roundabouts using a driving simulator.
2. Evaluate driver familiarity with, and behaviors within, mini-roundabouts.
3. Identify the critical gap necessary for efficient traffic flow in mini-roundabouts.
4. Explore the factors that affect driver behavior in mini-roundabouts.

Thesis Outline

The succeeding chapters of this thesis are organized as follows:

- Chapter 2 presents a comprehensive overview on the history and developments of the mini-roundabouts, detailed design guidelines from different countries and a comparison among them, current practical use of mini-roundabouts in the US, safety, operational, economical and other benefits of min-roundabouts.
- Chapter 3 provides an elaborated description of the simulation study methodology developed and implemented for this research.
- Chapter 4 presents the results obtained from the simulation study and analyzed data and discusses them.
- Chapter 5 presents the conclusions on all the findings, study limitations and provides recommendations for future works.

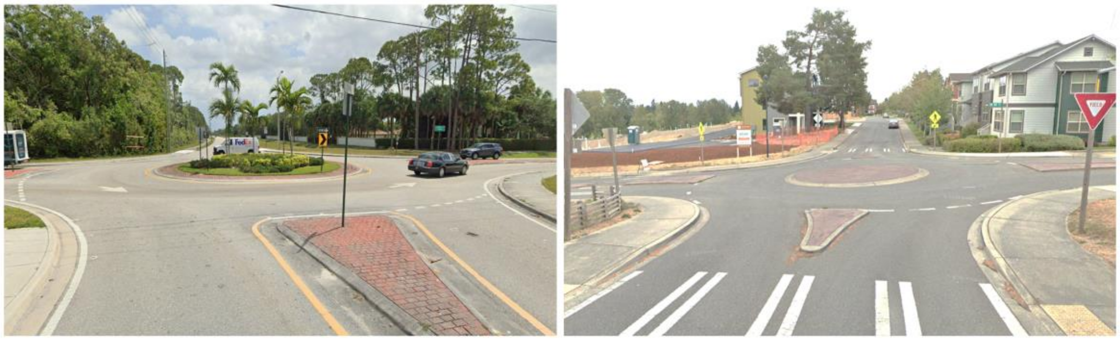
Chapter 2: Literature Review

The Concept of Mini-Roundabouts

A mini-roundabout is a type of roundabout which is distinguished by a its compact inscribed circular diameter (ICD) and traversable central and splitter islands (Naik et al., 2021; W. Zhang et al., 2012). Typically, their ICD ranges from 50 to 90 feet (approximately 15 to 27 meters), which is considerably smaller than the 90 to 180 feet (27 to 55 meters) ICD of standard single-lane roundabouts (W. Zhang et al., 2012). The advantage of a small ICD is that the mini-roundabouts occupy lesser space than single lane roundabouts. Additionally, their fully traversable central and splitter islands are designed to accommodate large vehicles (W. Zhang et al., 2012). Figure 1 shows examples of a single lane roundabout and a mini-roundabout.

Figure 1

Examples of (a) Single Lane Roundabout and (b) Mini-Roundabout



Mini roundabouts have been implemented in many places around the world. These roundabouts are designed for low-volume urban and rural roads, where the approach speeds do not exceed 30 miles per hour (mph) (Rice, 2010). Mini-roundabouts can reduce delay at peak hours and also improve safety while encouraging slower speeds. The past decade has seen a surge in the interest and implementation of mini-roundabouts, leading to numerous exploratory projects. However, there is an ongoing need to aggregate research findings and develop comprehensive guidelines to aid decision-making in the design, material selection, costing, and installation of mini-roundabouts.

Definitions According to Different Guidelines

Definitions found in different design guidelines provide a clear idea about the concept of mini-roundabouts. According to “Roundabouts: An Informational Guide” by the US Federal Highway Administration (FHWA), mini-roundabouts are compact roundabouts with fully traversable central islands, designed for use in low-speed urban settings (Robinson & Rodegerdts, 2000).

Whereas FHWA has put importance on the function of the central islands, the UK guidelines have given more emphasis on the dimension of the central island. According to “Mini-Roundabouts: Enabling Good Practice”, a mini-roundabout is a type or form of junction control where vehicles navigate around a central circular road marking, which is white and reflectorized, with a diameter ranging between one and four meters (Bodé & Maunsell, 2006).

According to “Understanding Safety and Driver Behavior Impacts of Mini-Roundabouts on Local Roads”, a paper highlighting Australian roundabouts, mini-roundabouts are small, either flush or slightly raised (up to 6 millimeters), and completely mountable roundabouts designed for traversing by larger vehicles (Delbosc et al., 2017).

All these definitions are similar in that a mini-roundabout will contain a small traversable central island that can be used to accommodate large vehicles.

Design Guidelines

Over the last few years, mini-roundabouts have been gaining interest in the US and several pilot projects have been undertaken. However, there is a lack of comprehensive guidance to support decision-making processes. Therefore, it is essential to synthesize different design guidelines for installing mini-roundabouts based on the central island dimension, speed limit and average daily traffic. The following design guidelines have been specifically developed for the design, installation, operation, and maintenance of mini-roundabouts.

US Guidelines

US Guidelines prefer mini-roundabouts over stop-controlled or signalized intersections to reduce delay and enhance safety. The main advantage of mini-roundabouts is that it can be constructed within the existing right–of–way constraints. These are suitable for roadways with maximum approach speed of 30 mph (Rice, 2010). Mini-roundabouts are not recommended for intersections with high truck traffic volumes or low minor street traffic volumes. They are also unsuitable for intersections expecting U-turn truck movements and those with five or more approaches (Rice, 2010).

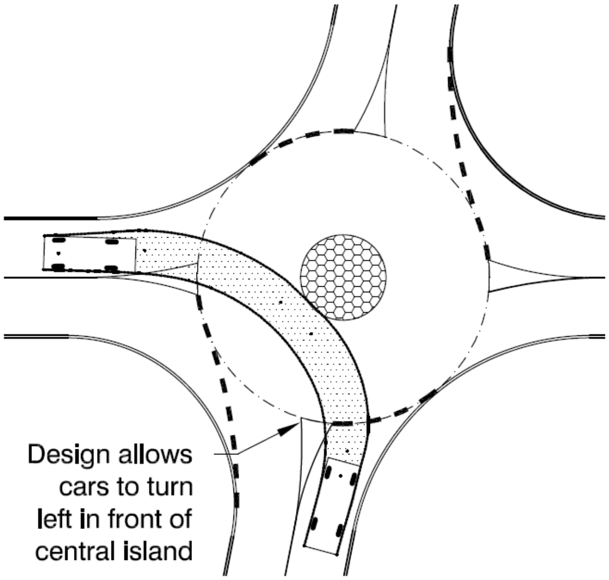
The total daily traffic volume entering a mini-roundabout should not exceed 15,000 vehicles (Naik et al., 2021). For higher volume, single-lane roundabouts are preferred. There have been some use of multi-lane mini-roundabouts in the UK but these are rare in the US (Rice, 2010). The diameter of the inscribed circle for a mini-roundabout should not exceed 90 feet. For larger areas, single-lane roundabouts should be used as these have raised central-islands to provide physical channelization and control vehicle speeds (Rice, 2010).

The diameter and location of a mini-roundabout can be determined by passenger car swept paths which is required space when a vehicle traverses a curve or makes a turn (Gkoutzini et al., 2021). Mini-roundabouts can accommodate heavy vehicles (bus, truck etc.) along with passenger cars within the circulatory roadway. However, the heavy vehicles have a larger turning radius which might be problematic for navigating in a mini-roundabout with a small, inscribed circle diameter. The central island of a mini-roundabout is designed to be traversable, enabling heavy vehicles to travel over it (Rice, 2010). The central island can be flush or raised but raised islands are more preferred. The maximum height of the central island must not exceed 5 inches, and it should feature a domed shape with a cross slope between 5% and 6% (Rice, 2010).

One of the design improvements that is provided in the US guidelines is the correct positioning of the entrance line. The placement of the entrance line is crucial in the geometric design of a mini-roundabout, as incorrect positioning can lead to undesirable driver behavior. Figure 2 shows how a small central island with an excessively large inscribed circle diameter persuades drivers to make a left turn without circulating the central island (Rice, 2010).

Figure 2

Undesirable Design Allowing Drivers to Make a Left-Turn in Front of the Central Island (Rice, 2010).



The possible design improvements which can be effective in this type of cases are either to move the entrance line forward or to enlarge the central island to reduce the circulatory roadway width. The entrance line, if moved forward, should be located at least 2 feet outside of the vehicle paths (Rice, 2010). Figure 3 and Figure 4 illustrate the two types of possible design improvements.

Figure 3

Possible Design Improvement by Moving Entrance Line Forward (Rice, 2010)

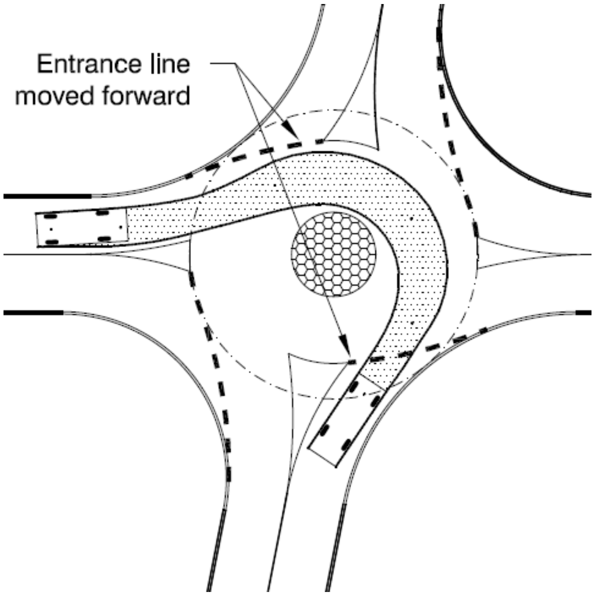
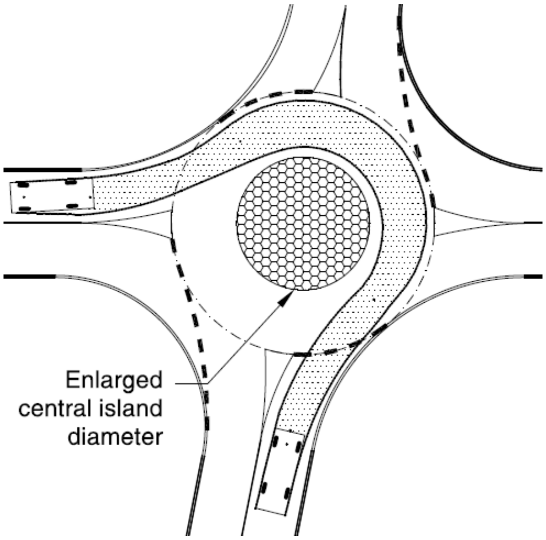


Figure 4

Possible Design Improvement by Enlarging Central Island (Rice, 2010)



The total costs of a mini-roundabout starts from $50,000 including all pavement markings and signage. It can be increased up to $250,000 or more when raised islands and pedestrian improvements are included (Rice, 2010).

UK Guidelines

United Kingdom (UK) guidelines provide geometric design requirements for mini–roundabouts and also safety regulations. Mini-roundabouts should be installed on roads with a speed limit not exceeding 30 mph (Bodé & Maunsell, 2006). Roadways that have higher design speed should be provided with a single lane roundabout. Mini-roundabouts are not suitable for use at new junctions, direct accesses, or on dual carriageways. Additionally, they should not be employed at intersections where the anticipated traffic flow or two-way AADT on any arm falls below 500 vehicles per day (vpd) and when there are five or more arms (Merron & Allister, 2006)

The maximum inscribed circle diameter (ICD) of a mini-roundabout recommended by the UK guidelines is 28 meters (90 feet). The central island of a mini-roundabout can be delineated by a white circle, ideally ranging from 1 meter to 4 meters in diameter (or 4 feet to 13 feet). This circle is typically defined by the inside of the swept path of vehicles (DMRB, 2023). Figure **5**5, Figure **6**6 and Figure **7**7 show the way of determining the white circle location and the design vehicle path (UK traffics are left-handed).

Figure 5

Determination of White Circle Location and Vehicle Path Using Swept Paths (3-Arm Mini-Roundabout) (DMRB,2023)

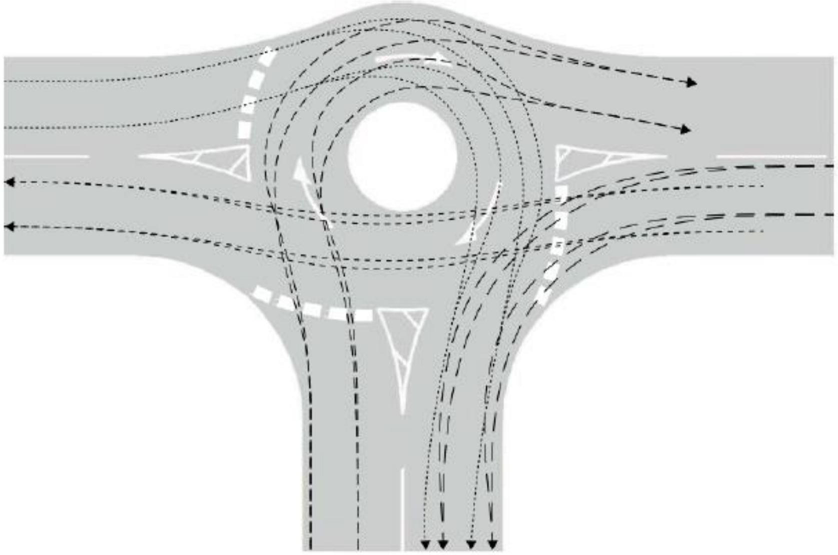


Figure 6

Determination of White Circle Location and Vehicle Path Using Swept Paths (4-Arm Mini-Roundabout) (DMRB, 2023)

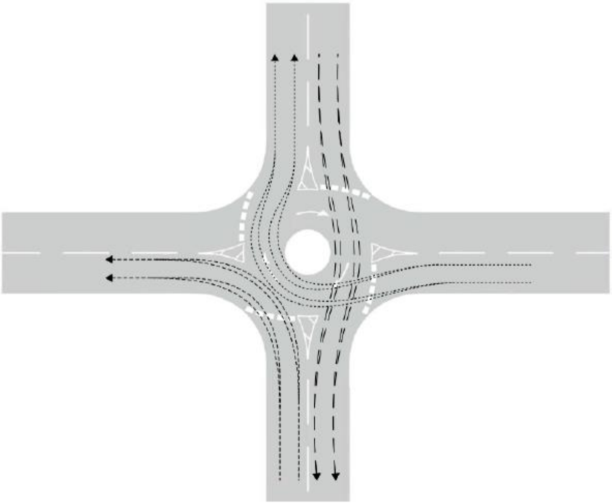
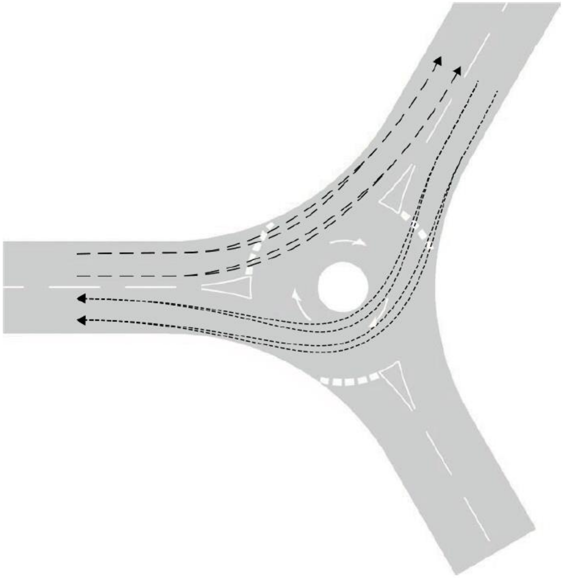


Figure 7

Determination of White Circle Location and Vehicle Path Using Swept Paths (3-Arm Y-Junction) (DMRB, 2023)



The center of the mini-roundabout may be domed up to 100 mm (4 inch) for a four-meter diameter marking and it should be formed using white reflectorized materials. An overrun area can be incorporated to enhance deflection, with a maximum diameter typically set at 7.5 meters (25 feet) (DMRB, 2023). Traffic islands are preferred to separate the opposing flow of vehicles and to provide the location for pedestrian crossing. The entry lane width should not be more than 3-4 m (10-13 feet). It can be reduced to 2.5 m (8 feet) for two-lane mini-roundabouts (Šurdonja et al., 2012). The total cost for 3-arm mini-roundabouts is £10,000-£30,000 ($12,450-$37,350) and for 4-arm mini-roundabouts is £15,000-£50,000 ($18,650-$62,250) according to 2003 outturn prices (Merron & Allister, 2006).

South African Guidelines

South Africa Department of Transport provided a preliminary version of design guidelines for mini-roundabouts in 1997 (Emslie, 1997). These guidelines include detailed criteria, constraints, and design requirements for the implementation and operation of mini-roundabouts (Table 1). The inscribed central diameter should be 14 meters (~46 feet) minimum for a single lane approach and 28 meters (~92 feet) for a double lane approach. The diameter of the central island should be 4 meters, but must not be less than 3 meters (Naik et al., 2021). The use of flush painted central islands is not recommended, suggesting instead that the central island's height should range from 75 to 100 millimeters (approximately 2.95 to 3.95 inches) (Emslie, 1997). Mini-roundabouts should be implemented as a part of a broader traffic calming strategy, rather than being installed on a standalone basis (Naik et al., 2021).

Table 1

Recommended major/minor proportional split

Number of approaches	Intersection volume (mph)	Split (%)
3	<1500	70/30
	>1500	60/40
4	<2000	70/30
	>2000	60/40

Several conditions should be met before implementing a mini-roundabout. For intersections with three legs, the traffic volume should not surpass 3000 vehicles per hour. In the case of four-leg intersections, the limit is set at 4000 vehicles per hour (Emslie, 1997; Naik et al., 2021). The traffic should have a recommended ratio between major and minor flows. Furthermore, the dominant straight-on traffic flow on a major approach should constitute 50% to 80% of that approach's traffic, and also account for 25% to 40% of the overall intersection traffic (Emslie, 1997). Finally, if the intersection experiences significant delays over 15 seconds per vehicle for right-turning traffic, which exceeds 25% of the flow, or there's a high occurrence of right-angle collisions, a mini-roundabout may be warranted (Emslie, 1997).

Also, there are several warrants which determine the required traffic calming measure to be implemented. If all conditions and warrants are met for a specific intersection, mini-roundabout is recommended. Otherwise, different traffic calming measures are taken.

Swiss Guidelines

Swiss guidelines prefer the installation of mini-roundabouts primarily within urban settings and in certain situations where alternative intersection designs are not feasible (Šurdonja et al., 2012). The construction of mini-roundabouts is not recommended in cases where the minimum design criteria cannot be met. Moreover, in areas where it is feasible to construct a small (but not mini) roundabout, the installation of a mini-roundabout is not advised. Average Daily Traffic **(**ADT) should not be more than 15,000 vehicles per day and the combined traffic volume entering the roundabout and circulating within it should not exceed 1,200 vehicles per hour. Mini-roundabouts should not be installed where pedestrian traffic is dense (Šurdonja et al., 2012).

The outer diameter of mini roundabouts should not be less than 14 meters (45 feet) and should not be more than 26 meters (85 feet). The minimum diameter should be 14 meters (45 feet) if there is a central transit island and 18 meters (60 feet) if there is a partially central transit island (Šurdonja et al., 2012). The central island should be positioned at the intersection of all arms. The arms and the center should be placed in such a way that prevents passing without turning. A suitable entrance angle is required to prevent vehicles from entering the roundabout in a straight, or tangent, line. The minimal angle between any two arms of the roundabout should be at least 30 degrees to facilitate safer and more effective navigation (Naik et al., 2021; Šurdonja et al., 2012).

German Guidelines

German guidelines recommend that the inscribed circle diameter of a mini-roundabout should be between 13 meters (43 feet) and 24 meters (79 feet) (Brilon, 2011). For accommodating larger vehicles, the central island of a mini-roundabout should be designed to allow for the potential override by these vehicles. The central island should be positioned using the design vehicle's swept path (Naik et al., 2021; Šurdonja et al., 2012). Mini-roundabouts are advised to be placed exclusively in urban areas where the speed limit does not exceed 50 km/h (approximately 31 mph) (Naik et al., 2021; Šurdonja et al., 2012). The circular roadway width should be between 4.5 meters (15 feet) and 6 meters (20 feet). The maximum height of the central island should be 12 centimeters (or 4.7 inches) above the level of the circular roadway, featuring a cross slope of 2.5% inclined to the outside (Naik et al., 2021; Šurdonja et al., 2012). Mini-roundabouts are suitable for areas where the traffic capacity does not exceed 20,000 vehicles per day. The design should avoid flaring at the entries, and it is recommended that entries and exits consist of only single lanes.

A comparison of different design guidelines for mini-roundabouts is shown in Table 2.

Table 2

Comparison of Different Design Guidelines for Mini-Roundabouts

Design Parameters	**Inscribed Central Diameter (feet)**		**Central Island Height (inch)**	**Central Island**	**Splitter Islands**	**Speed Limit (mph)**	**ADT (vpd)**
	Max	**Min**		**Treatment**	**Treatment**		
US Guidelines	90	50	5	Fully traversable	Raised, traversable, or flush	30-35	15000
UK Guidelines	80	-	3.9	Flush or slightly domed	Curbed or flush	31	-
Swiss Guidelines	85	46	-	Fully traversable / Non-traversable + truck apron	-	-	15000
German Guidelines	80	43	4.7	Domed	-	31	20000
French Guidelines	80	50	5.9	Domed	Curbed or flush	31	-
Italian Guidelines	82	46	-	Fully traversable / Non-traversable + truck apron	-	-	-
South African Guidelines	46	92	2.95-3.95	Domed	-	-	-

Comparison of Guidance Between US State DOTs

A survey of the geometric design guidelines from various state Departments of Transportation (DOTs) shows that at least 27 out of the 50 states (54%) have incorporated guidelines from NCHRP 672, titled "Roundabouts: An Informational Guide," as well as from the "Mini-Roundabouts: Technical Summary." In addition to utilizing these resources, 17 of these states have also integrated additional requirements tailored to the design of mini-roundabouts into their manuals (Naik et al., 2021). Table 3 provides a detailed list of these state DOTs, outlining the NCHRP guidance specific to mini-roundabouts included in their manuals, along with any additional state-specific design criteria.

Table 3

State Specific Mini-Roundabouts Guidelines (Naik et al., 2021)

State Agency	State Design Manual Includes NCHRP 672 Guidance?	Additional Criteria/Deviations
Alabama	Yes	Truck Volume < 3% (study)
Alaska	Yes	Circulating roadway width (CRW) >= 15 feet
Arizona	Yes	Inscribed Circle Diameter (ICD) 50-90 feet
Arkansas	Yes	
California	Yes	
Colorado	Yes	
Connecticut	Yes	
Delaware	Yes	
Georgia	Yes	ICD 70-90 feet, Truck Volume < 5% (study), operating speed < 35 mph
Illinois	Yes	Central island diameter < 13 feet
Indiana	Yes	ICD 45-110 feet
Iowa	Yes	Minimum 10% side street volume, detailed dimensions
Kansas	Yes	ICD 50-90 feet, Central island diameter 16-45 feet, operating speed < 35 mph
Maryland	Yes	
Massachusetts	Yes	Circulating roadway width (CRW) 14-16 feet
Michigan	Yes	CRW 14.5-16 feet, Central island diameter 20-50 feet, Entry lane width 13-15 feet, operating speed < 35 mph
Minnesota	Yes	ICD 50-80 feet, Central island diameter 16-45 feet, Entry lane width 10-11 feet, Peak all entering traffic demand < 1600 vph, Truck Volume < 5%, Operating speed 35 mph, at some places 45 mph
Montana	Yes	
Nevada	Yes	
Ohio	Yes	CRW 14-16 feet
Oregon	Yes	Central island diameter < 13 feet
Pennsylvania	Yes	ADT 12250-15500 vpd, operating speed < 35 mph
South Carolina	Yes	
Tennessee	Yes	ADT 10000 vpd
Texas	Yes	
Virginia	Yes	Central island diameter 25-50 feet, Peak all entering traffic demand 900-1600 vph, CRW 14-16 feet, crosswalk 25 feet before yield line, Splitter islands width >= 4ft, Approach lanes 10-11 feet (to reduce speeds), Truck Volume < 5% (study)
Washington	Yes	ICD 50-85 feet, CRW 16-18 feet, ADT 10000 vpd, Entry lane width 14-15 feet

Practical Implementations in the US

In 2009, the Federal Highway Administration (FHWA) initiated the first study to evaluate the feasibility of mini-roundabouts in the US. Since that time, over 100 additional sites within the US have implemented this alternative roundabout type as a cost-effective method for enhancing operations, capacity, and safety at intersections without requiring extra right-of-way (Naik et al., 2021). The findings are the result of an extensive examination of current literature, which encompasses presentations and web-based resources, alongside a detailed evaluation of a national roundabout database hosted by Kittelson and Associates. This database, found at roundabouts.kittelson.com, offers a broad inventory of roundabouts throughout the US and Canada, with its scope recently expanding to include additional countries. This comprehensive approach ensures a well-rounded understanding of roundabout usage, characteristics, and their impact on traffic dynamics and safety (Kittelson & Associates, Inc., 2020). A list of all mini-roundabouts in the US along with their design characteristics has been provided in Appendix A and B. These tables also provide details related to the design characteristics, cost of installation, and the conditions of the sites both before and following the installation of these roundabouts.

Site Specific Considerations for Placement

The following is a summary of site conditions commonly found at many mini-roundabout locations in the US, which influenced the decision to consider the adoption of a mini-roundabouts.

Traffic Conditions. Mini-roundabouts in the US adhere to specific traffic conditions set by the Federal Highway Administration (FHWA), with the total entering Average Daily Traffic (ADT) typically not exceeding 15,000 vehicles per day, aligning with FHWA's recommendations (Naik et al., 2021). The ADT at these mini-roundabouts varies, with the lowest observed around 1,500 vehicles per day and the highest reaching 18,500 vehicles per day, though most hover between the median range of 10,000 to 12,000 vehicles per day. During peak hours, traffic volumes often lie between 1,150 and 1,400 vehicles per hour, with a distinguishable volume split of approximately 60/40 between major and minor approaches, suggesting higher traffic on major approaches. Despite minimal large vehicle activity, truck volumes have been reported to be between 3% to 4%. Pedestrian and bike volumes were not a primary concern in the design phase, indicating a minimal impact on mini-roundabout operations (Naik et al., 2021).

Roadway Conditions. Regarding roadway conditions, mini-roundabouts are typically found at intersections of minor arterials and/or collectors and mostly feature 2-lane configurations, with rare instances of 3-lane setups. Speed limits across these sites vary from 15 to 40 mph, based on the 85th percentile observed speed. Before mini-roundabout installations, intersections were commonly controlled by stop signs, with some previously managed by yield signs or signalized controls. Most intersections have a standard 90-degree approach layout and are designed to accommodate four approaches, with limited instances of T-intersections having only three approaches. These installations often occur at sites with limited available right-of-way, influencing design considerations (Naik et al., 2021).

Design Criteria and Specific Considerations for Mini-Roundabouts

Mini-roundabouts' design criteria are meticulously outlined, with Inscribed Circle Diameter (ICD) typically ranging between 70 to 80 feet, though some extend up to 90 feet. The central islands, varying in diameter from 45 to 55 feet, are designed to be traversable for heavy goods vehicles and emergency services, ensuring minimal disruption in traffic flow. Circulating and entry lane widths are optimally set between 12 to 20 feet to accommodate various vehicle sizes. Splitter islands, crucial for traffic management and pedestrian safety, vary in length and width, adapted to the specific needs of the intersection. The approach speeds to these roundabouts are generally set between 15 to 20 mph to ensure safety and efficiency (Naik et al., 2021).

Benefits of Mini-Roundabouts Versus Other Traffic Control

Over the years, numerous studies have been performed to determine the effectiveness of mini-roundabouts in improving traffic flow and safety (Candappa, 2015; W. Zhang et al., 2012). These studies and a few pilot projects from the US highlight the operational and safety benefits of mini-roundabouts over other traffic controls. The primary areas of operational improvement identified in these studies include enhanced traffic operations (focusing on delays and congestion) and traffic calming measures to reduce speeding.

Operational Benefits

Traffic Parameter Benefits. One of the most significant advantages of mini-roundabouts is the facilitation of a smoother and more continuous traffic flow. Unlike traditional intersections with stop signs or traffic signals, mini-roundabouts keep traffic moving, which is especially beneficial during peak traffic hours (Pratelli et al., 2020). The conversion of traditional four-way stop controlled intersections to mini/modular roundabouts, which function on a yield system, results in increased intersection capacity (Naik et al., 2021; W. Zhang et al., 2010). Also, it notably reduces the dominance of traffic from one direction, leading to decreased directional delays and improved traffic flow, especially from lesser-used streets. (Merron & Allister, 2006). One example of successful implementation was found in Jackson County, GA where a persistent problem of a 50-vehicle queue on a minor street was effectively eliminated following the installation of a mini-roundabout (W. Zhang et al., 2012).

A critical feature of mini-roundabouts is the traversable center island, which facilitates the smooth passage of large vehicles like trucks. This allows for the efficient movement of heavy vehicles or long trucks through the intersection, ensuring they pass with little to no delay to other traffic. However, for most efficient use, mini-roundabouts should be recommended at intersections with less than 3% truck traffic. (Merron & Allister, 2006; Naik et al., 2021).

Traffic Calming Benefits. Implementing mini-roundabouts is also aimed at reducing speeding along roadways. The transformation of an intersection from a straight path to a circular layout of a mini-roundabout necessitates that drivers reduce their speed for navigation and yield to approaching traffic. Unlike traditional roundabouts, the mini-roundabouts effectively slows down traffic without significantly impacting overall travel time due to its smaller inscribed diameter (Rice, 2010). There are several examples where mini-roundabouts were successfully implemented as a traffic calming solution. In Dimondale, MI, the implementation of a mini-roundabout led to a decrease in the 85th percentile of speeds from 32 mph to 24 mph (Waddell & Albertson, 2005). An Australian study observed a significant reduction in average speeds at mini-roundabout sites than traditional roundabout sites, from about 31.3 kmh (~20 mph) to between 22.17-23.78 kmh (~14-15 mph). This speed reduction not only improves the smooth flow and efficiency of vehicle movement but also enhances the overall navigability of the intersection (Candappa, 2015; Naik et al., 2021).

Safety Benefits

Research has extensively studied the safety advantages of mini-roundabouts (e.g. Zhang et al., 2010). The design of mini-roundabouts naturally slows down traffic, which reduces the likelihood and severity of accidents. Therefore, mini-roundabouts can play a crucial role in improving road safety (Pratelli et al., 2020). Specific safety enhancements include the reduction in crash frequency and severity, improved safety and mobility for pedestrians and cyclists, and driver/public comfortability.

Crash Frequency and Severity Benefits. The integration of mini-roundabouts as traffic calming structures has been shown to significantly decrease both the frequency and severity of vehicular crashes. The transition from traditional four-way stops to mini-roundabouts inherently changes the traffic flow from linear to circular, reduces the ability of a driver to speed and the propensity for accidents (Naik et al., 2021). Moreover, compared to traditional intersections, mini-roundabouts have fewer conflict points. This reduction in conflict points plays a vital role in decreasing the potential for accidents. The circular design means that all traffic is moving in the same direction, which minimizes the risk of head-on and side-impact collisions.

A comprehensive study in Germany evaluated various roundabout types and discovered that mini-roundabouts were substantially safer, with accident rates plummeting from 0.79 to 0.56 accidents per million vehicles (Brilon, 2005). This study also used the accident cost rate as a metric for crash severity, revealing that mini-roundabouts were far more cost-effective in terms of safety compared to unsignalized and signalized intersections. Another pilot study in Monash, Australia, observed a dramatic 78.9% reduction in all crash types over three years at intersections converted to mini-roundabouts, with severe crashes dropping from six (6) incidents to none (Delbosc et al., 2017). In Dimondale, MI, an analysis of crash data three years before and after the installation of a mini-roundabout indicated a 3.9% reduction in the average annual cost of crashes at the site (Waddell & Albertson, 2005). Post-installation, alcohol involvement emerged as the primary factor in recorded crashes, suggesting that the roundabouts themselves significantly mitigate other common causes of accidents.

Pedestrian/Cyclist Safety and Mobility Benefits. Mini-roundabouts are optimally designed for use at intersections characterized by lower traffic volumes and speed limits of approximately around 30 mph. In urban areas, where there is a higher density of pedestrians and cyclists, these roundabouts play a crucial role in ensuring the safe movement of these road users. Most mini-roundabouts feature a splitter island, which plays a dual role: directing vehicular traffic around the central island and acting as a refuge island for pedestrians crossing the street, significantly enhancing their safety and comfort (Rice, 2010). The ideal placement of pedestrian crossings is recommended to be about 20 feet from the entry of the mini-roundabout, a safe distance where vehicles already have reduced speed. A notable implementation in Scott County, Michigan, near a school, demonstrated the effectiveness of these roundabouts in improving pedestrian safety, especially for children going to school. This installation led to a noticeable reduction in conflicts between pedestrians and vehicles at the intersection (Naik et al., 2021; W. Zhang et al., 2017).

In terms of cyclist safety, mini-roundabouts create a more secure environment due to the inherently lower speed of traffic. The Federal Highway Administration (FHWA) advises the use of tapering bike lanes, starting between 200 to 50 feet before the roundabout, to facilitate safe merging of cyclists with vehicular traffic (Rice, 2010). This design consideration is crucial in allowing cyclists ample time to merge, and for drivers to adjust their speed accordingly. Research has highlighted the positive impact of mini-roundabouts on cyclist safety, particularly due to the reduced vehicle speeds and the reconfiguration of intersections (Sawers, 2009). A study from Denmark focused on roundabout designs and their influence on cyclist safety, identifying the height of the central island as a critical factor. The higher the central island, the safer it is for cyclists, suggesting a design where the island is elevated enough to prevent cars from crossing over while allowing safe passage for trucks (Jensen, 2017).

Driver/Public Comfortability Benefits. One of the primary challenges in the adoption of any roundabout, including mini-roundabouts, lies in the public's perception and attitude towards them. A driver's comfort and confidence in navigating a roundabout are crucial for ensuring not only their own safety but also that of others on the road (Naik et al., 2021). The design of mini-roundabouts typically offers better visibility for drivers. With a clear view of all approaching traffic, drivers can make safer decisions about entering and navigating the roundabout. The simplicity and ease of navigation associated with mini/modular roundabouts, attributable to lower traffic volumes and speeds, plays a significant role in enhancing driver comfort over time.

Research has shown that there are age-related differences in how drivers perceive and adapt to roundabouts. Studies highlighted that younger drivers tend to be more adept and quicker in understanding how to navigate roundabouts compared to their older counterparts (Toussant, 2016). This finding suggests that as the younger, more adaptable drivers age and as the prevalence of mini-roundabouts increases, the overall anxiety and unfamiliarity associated with driving through roundabouts are likely to diminish across the driver population (Naik et al., 2021).

A comprehensive study conducted in Australia examined the behavioral changes in drivers before and after the installation of two mini-roundabouts. Post-installation, there was a noticeable decrease in risky driving behaviors and an increase in compliance with traffic rules, such as stopping and yielding at intersections (Delbosc et al., 2017).

The introduction of new roundabouts often encounters initial public hesitation. However, experience and familiarity tend to improve attitudes over time. For instance, a community feedback initiative on Facebook regarding a new roundabout in Newark, OH, revealed initial resistance from residents. Yet, after personally experiencing the roundabout, many expressed increased comfort and appreciation for it (Naik et al., 2021).

Environmental Benefits

The integration of mini-roundabouts at intersections not only enhances efficiency and operation but also offers significant environmental benefits, primarily through the reduction of vehicle emissions. The smoother traffic flow facilitated by a mini-roundabout effectively minimizes delays, subsequently leading to lower emissions (Rice, 2010). Traditional four-way stop-controlled intersections often create longer queues, resulting in vehicles idling for extended periods. This idling contributes to increased emissions, including carbon monoxide, sulfur, and nitrous oxides. In contrast, the design of mini-roundabouts reduces the length of vehicle queues and, as a result, cuts down on emissions (Waddell & Albertson, 2005).

Moreover, the construction process of mini-roundabouts presents further environmental advantages over traditional roundabouts. Owing to their smaller size, mini-roundabouts require less additional right-of-way. This factor, coupled with their rapid construction time, leads to minimized disruption to traffic flow and, consequently, less environmental impact during the construction phase (W. Zhang et al., 2010).

In terms of air quality, converting signalized intersections to roundabouts, including mini-roundabouts, has been shown to lower particulate matter ($PM_{2.5}$) levels by as much as 40% in specific areas. This indicates a significant potential for air quality improvements in urban settings (Garceau, 2018). These aspects of mini-roundabouts make them not only a traffic-efficient solution but also a more environmentally friendly option compared to their larger counterparts.

Economic Benefits

The installation of mini-roundabouts is typically less expensive and demands less routine maintenance compared to traditional roundabouts. As reported by the Federal Highway Administration (FHWA) in 2010, the cost for a basic mini-roundabout installation, consisting primarily of pavement markings and signage, starts at around $50,000 (Naik et al., 2021). This cost can rise to $250,000 or more for more complex installations that include features like raised islands and enhancements for pedestrian safety. Another study by Zhang (2010) found that the cost of constructing mini-roundabouts can range from $25,000 to $50,000 (W. Zhang et al., 2010). In contrast, the average cost for a traditional roundabout is around $250,000 (Rice & Niederhauser, 2010). Construction of a mini-roundabout in Jackson County, GA, incurred a total cost of $63,353, covering curbing, labor, equipment, and materials (Lochrane et al., 2012).

In the United Kingdom, estimates from local authority consultants indicate that the cost for constructing a mini-RAB with three approaches ranges from £10,000 to £30,000, which equates to approximately $13,000 to $39,000 in 2023 dollars. For mini-RABs with four approaches, the cost is estimated to be between £15,000 and £50,000, or about $20,000 to $65,000 in 2023 dollars (Merron & Allister, 2006). These figures encompass the comprehensive process of planning, designing, and constructing the mini-roundabouts.

The lower installation and maintenance costs, coupled with the enhanced operational and safety benefits, position mini-roundabouts as a highly valuable investment in terms of return on investment. A pilot study in Dimondale, MI, highlighted this by reporting a benefit-to-cost ratio of 14.5:1 for mini-roundabouts (Waddell & Albertson, 2005). Moreover, another significant area of cost savings with mini/modular roundabouts is the reduction in crash-related expenses. The decreased frequency and severity of crashes at these installations lead to lower societal and economic costs, further underscoring their overall cost-effectiveness (Delbosc et al., 2017).

Another key financial benefit of mini-roundabouts is their limited right-of-way requirements, often eliminating the need for costly land acquisition (Naik et al., 2021). These can be particularly beneficial in urban areas where land value is high. The shorter construction period for mini-roundabouts not only reduces direct construction costs but also minimizes disruption to local businesses and residents, thereby mitigating economic losses that can occur due to prolonged construction activities.

Gap Acceptance Behavior in Roundabouts

Critical gap is the shortest time interval that an incoming driver considers acceptable to enter the circulating lane without disrupting flow (D. Lee et al., 2018). It plays a vital role in determining the capacity of a mini-roundabout. Drivers will generally not merge into the roundabout if the available gap is less than the critical gap, whereas gaps exceeding critical gap are typically accepted (D. Lee et al., 2018; Naik et al., 2021). Analysis of critical gaps is crucial to optimize roundabout dimensions and signage to enhance traffic flow, reduce congestion, and minimize collision risks, making roundabouts safer and more effective for all road users.

Several methodologies including Raff's method, Ashworth Method, Troubeck Method, Wu Method etc. have been formulated to estimate the critical gap (D. Lee et al., 2018). Originally, Raff's method was developed to calculate the critical lag by analyzing both accepted and rejected lags. However, as Miller indicated, this original method showed a bias largely influenced by the distribution of lags presented to drivers (Naik et al., 2021; Troutbeck, 2016). To address this, Miller adapted Raff's method to incorporate gap data, creating a more refined approach known as the revised Raff's method. The revised Raff's method is depicted in Figure 7 illustrating the determination of the critical gap through the intersection point of two functions (Naik et al., 2021; Shaaban & Hamad, 2018):

$$1 - F(t_r), F(t_a) \tag{1}$$

Here,

$\mathrm{t_a} = \text{accepted gap}$

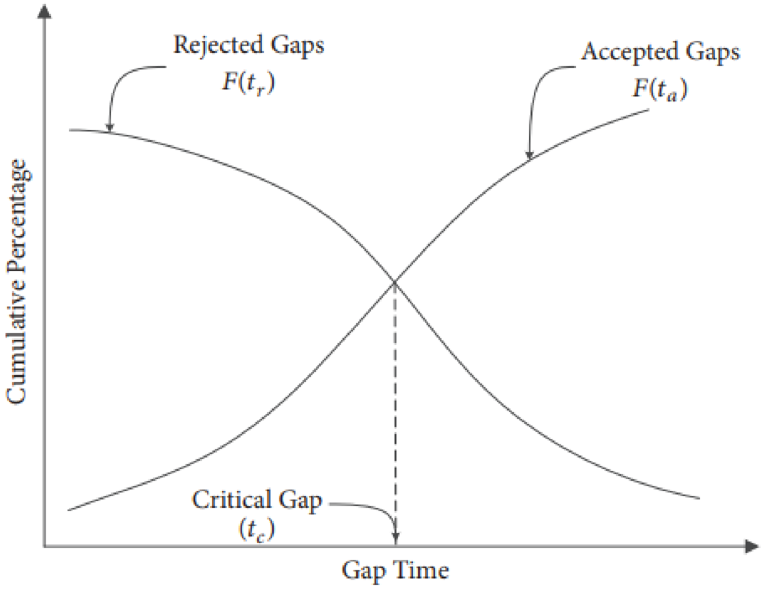
$\mathrm{t_r} = \text{rejected gap}$

$\mathrm{F(t_r)} = \text{cumulative distribuition function of the rejected gap}$

$\mathrm{F(t_a)} = \text{cumulative distribuition function of the accepted gap}$

Figure 8

Critical Gap Based on Revised Raff's Method (Shaaban & Hamad, 2018)



The critical gap is identified at the intersection point on the cumulative distribution function curves, as shown in Figure 8. The value on the horizontal axis at this intersection denotes the critical gap, signifying the minimum gap size that is typically accepted by drivers, with smaller gaps being rejected (Naik et al., 2021; Shaaban & Hamad, 2018).

Previous studies of gap acceptance maneuver have been conducted through two approaches (D. Lee et al., 2018). One approach is recording gap data of the roundabout vehicles for a certain time and estimating critical gap and follow-up time. These are the two main parameters for gap acceptance. Another approach is developing gap acceptance behavior models (D. Lee et al., 2018). Xu and Tian estimated critical gaps and follow-up headways at eight single-lane roundabouts in California, US. The estimated critical gaps were 4.5-5.3 seconds and the follow-up headways were 2.3-2.8 seconds (Xu & Tian, 2008). The NCHRP Report 672, Roundabouts: An Informational Guide developed by the Federal Highway Administration (FHWA) estimated the critical gaps for roundabouts which was 4.2-5.9 seconds (Rodegerdts et al., 2010b). The Highway Capacity Manual estimated the critical gaps for roundabouts as 4.1 seconds (*Highway Capacity Manual 2010 (HCM2010) | Blurbs New | Blurbs | Main*, 2010).

Lochrane et al. conducted a study to estimate the critical gap and the capacity of a mini-roundabout (Lochrane et al., 2013b). A mini-roundabout located in Stevensville, Maryland, was chosen for collecting field data on critical gap and headway acceptance in order to calibrate a simulation. This mini-roundabout has an ICD of 80-feet and it conforms closely to the basic design of a mini-roundabout. The gap data were collected along three legs of the mini-roundabout (west, north, and south legs) and the critical gap was estimated to be in the range of 3.5 to 5.5 seconds (Lochrane et al., 2013b).

Estimating Capacity of Mini-Roundabouts

Introducing a new traffic design like the mini-roundabout into areas unfamiliar with such configurations raised concerns about how it would affect operational performance. A study (Brilon, 2005) in Germany evaluated the effects of transforming 13 non-signalized intersections into mini-roundabouts. The findings indicated that the introduction of mini-roundabouts did not result in significant delays, even with traffic volumes reaching around 17,000 vehicles per day (Brilon, 2005).

Furthermore, there's only one empirical-based capacity model dedicated to the analysis of mini-roundabouts. This model emerged from research conducted in the United Kingdom, part of a program named ARCADY, developed by the Transport Research Laboratory. A key equation from ARCADY used for calculating the capacity of 4-way mini-roundabouts in Europe is as follows (Cicu et al., 2011):

$$Q_E = 1200 - Q_C \tag{2}$$

where

$Q_E = entry\ flow\ (veh/hr)$

$Q_C = circulating\ flow\ (veh/hr)$

Additionally, the NCHRP Report 572, titled "Roundabouts in the US," includes capacity equations for both single and multi-lane roundabouts (National Cooperative Highway Research Program et al., 2007). One of the equations for a single-lane roundabout from NCHRP-572, which is also referenced in the HCM 2010, details the calculations specific to the capacity analysis of single-lane roundabout:

$$c = 1130.exp^{(-0.0010.V_c)} \tag{3}$$

where

$c = q_{e,max} = entry\ capacity\ (veh/hr)$

$v_c = q_c = conflicting\ circulating\ traffic\ (veh/hr)$

These equations were used to develop design guidelines and capacity models of mini-roundabouts from US data (Lochrane et al., 2013a). Two roundabouts were selected that have an Inscribed Circle Diameter (ICD) of 50 feet and 75 feet. A mini-roundabout located in Stevensville, Maryland, was chosen for collecting field data on Critical Gap and Headway acceptance in order to calibrate a simulation. This mini-roundabout has an ICD of 80 feet and it closely matches the essential design characteristics of a mini-roundabout, setting it apart from other mini-roundabouts constructed in the US.

The VISSIM simulation software, known for its detailed microscopic, time-step, and behavior-based approach to traffic flow modeling, was employed to simulate the capacity of the 50 feet and 75 feet ICD mini-roundabouts. This software is adept at simulating urban traffic operations, making it an ideal tool for this analysis (Cicu et al., 2011). The capacity models were then formulated based on a calibrated micro-simulation that incorporates gap-acceptance modeling to mimic drivers' yielding behaviors at mini-roundabouts (Lochrane et al., 2013a).

Equations 3 and 4 provide the basis for estimating approach capacities under varying circulating volumes (Lochrane et al., 2013a). The capacity is influenced by different factors such as approach volumes from conflicting directions, the percentage of heavy vehicles (% HVs), and the proportions of left and right turns. Simulation outcomes revealed that the capacity of a 50 feet mini-roundabout is generally lower than that of a 75 feet mini-roundabout. The coefficient values of -1.025 for the 50 feet and -0.944 for the 75 feet mini-roundabouts indicate how an increase in conflicting vehicle volumes negatively impacts the capacity of the smaller mini-roundabouts more than the larger ones.

$$C_{50ICD} = 1009 - 1.025 * V_C \; ; \; R^2 = 0.978 \tag{4}$$

$$C_{75ICD} = 1020 - 0.944 * V_C \; ; \; R^2 = 0.967 \tag{5}$$

where V_C denotes the conflicting vehicles in passenger car equivalent per hour.

The comparative analysis of the capacity of mini-roundabouts with other intersection types, such as all-way stop-controlled (AWSC) intersections and single-lane modern roundabouts, reveals insightful findings. Mini-roundabouts exhibit a higher capacity than AWSC intersections but lower than the capacity offered by single-lane modern roundabouts (Lochrane et al., 2013a). This variance is attributed to the more complex vehicle interactions occurring at mini-roundabouts compared to modern roundabouts. The simulations based on the NCHRP-572 equation further confirm that single-lane roundabouts possess a higher capacity than mini-roundabouts, as per the model discussed in this study (Lochrane et al., 2013a).

Despite these findings, mini-roundabouts have distinct advantages, especially in terms of land utilization. Unlike single-lane roundabouts, mini-roundabouts do not require additional right-of-way, making them a space-efficient option for intersection upgrades or constructions. The results indicated that the entry capacity per area for the 50 feet and 75 feet ICD mini-roundabouts is higher than that of the single lane roundabout (Lochrane et al., 2013a). This efficiency indicates that mini-roundabouts make better use of the available space in terms of accommodating entry demand.

Furthermore, when converting an AWSC intersection to a mini-roundabout, an increase in capacity can be expected. The analysis shows that the 50 feet mini-roundabout, in particular, offers a higher capacity per square foot up to a circulating volume of more than 800 vehicles per hour, beyond which the single-lane roundabout becomes more efficient (Lochrane et al., 2013a).

Mini-roundabouts can be implemented as a viable design solution for enhancing capacity and optimizing land use in urban settings. The capacity model used in the ARCADY program suggests mini-roundabouts have a higher capacity per unit area compared to single-lane roundabouts and stop-controlled intersections. However, since this is the only available capacity model for mini-roundabouts to date, there is a pressing need for further validation of this model and the development of a multi-criteria analysis-based decision-making process tailored for the selection of mini-roundabout designs that are specific to location requirements.

Utilizing Driving Simulators for Human Factors Research

A driving simulator is a machine which is used to examine various driving behavior factors for training and research purposes (Y. Zhang et al., 2020). . It can replicate properties and characteristics of a real vehicle in a controlled virtual environment. The virtual world of the simulator enables researchers to investigate a broad range of experiments regarding roadway safety and driving behavior without posing significant risks to participants. The adoption of driving simulators has gained widespread acceptance among researchers in health, clinical and educational fields, as well as professionals in automotive and transportation sectors. A wide range of studies (Casutt et al., 2014; Chan et al., 2010; Just et al., 2008; Lewis et al., 2016; Michaels et al., 2017; Papantoniou et al., 2015) have made use of driving simulators for clinical research purposes, while other researchers have utilized them in transportation-focused .studies (Ali et al., 2020; Antonson et al., 2009; Calvi et al., 2012; Coeckelbergh et al., 2002; de

Groot et al., 2012; de Winter et al., 2014; Rendon-Velez et al., 2016; Risto & Martens, 2014).

Driving simulators have been extensively used in various research studies to explore a wide range of questions related to driver behavior, vehicle design, road safety, and transportation planning. Simulators provide a highly controlled environment where variables can be manipulated precisely, allowing researchers to isolate and study specific factors affecting driving behavior. One study by Strayer & Johnston, 2001 investigated the influence of talking on a cellphone on driving performance. Utilizing a driving simulator, they found that drivers talking on cellphones exhibited slower reaction times and were more likely to miss traffic signals compared to when they were not distracted. In another study, a driving simulator was used to understand how drivers adapt to driving among automated vehicles, providing insights into car-following behaviors, lane changes, and speed adaptations under varying traffic conditions (Aramrattana et al., 2022). In another research, a driving simulator was utilized to explore the impact of geometric design of roadways on drivers' speed profiles (Dols et al., 2016).

Driving simulators enable the study of risky driving behaviors and scenarios (e.g., near-crashes, extreme weather conditions) without putting participants or others at risk. Experiments in driving simulators can be repeated with exactly the same conditions, which is crucial for scientific reliability and for studying rare or dangerous driving situations that are difficult or unethical to replicate in real life. A recent simulation study explores how different weather conditions affect driver behavior and subsequently, the flow of traffic by simulating scenarios like rain, snow, and fog within the driving simulator (Chen et al., 2019). Another study used driving simulator to examine the effects of collision warning timing and driver distraction on responses to impending rear-end collisions (J. D. Lee et al., 2002).

Simulators facilitate the collection of detailed data on driver behavior, vehicle performance, and physiological responses (e.g., eye tracking, heart rate), which might be challenging or intrusive to gather in real-world studies. A study by Bortkiewicz et al., 2019 used a high-tech bus driving simulator to determine if a driver's visual strategy influences their ability to avoid crashes in high-risk situations. Another study by Gable et al., 2015 explores the effectiveness of heart rate and pupil size as objective measures to assess workload in driving scenarios, contrasting with traditional subjective measures utilizing a high-fidelity driving simulator.

While driving simulators offer numerous advantages for research and training, they also have some limitations. Some participants may experience simulation sickness (akin to motion sickness), which includes symptoms like nausea, disorientation, and headaches, potentially affecting their performance and the study's outcomes (Aykent et al., 2014; Smyth et al., 2019). Research indicates that older drivers (≥65 years) are more susceptible to experiencing motion sickness in these simulators (Classen et al., 2021; Domeyer et al., 2013). Despite advances in technology, simulators still cannot fully replicate the complexity and unpredictability of real-world driving. This limitation can affect the external validity of the findings, as drivers may behave differently in a simulator than on actual roads. The availability of driving simulators is often limited to certain locations (e.g., universities, research institutions), which might lead to a selection bias in participant recruitment, affecting the generalizability of the results. Another key constraint is that participants may require time to adapt to the simulator, which could affect their initial performance. This adaptation or learning effect needs to be accounted for in the study design (Ronen & Yair, 2013).

Literature Review Summary

In recent decades, roundabouts have emerged as a viable solution for addressing traffic congestion in the US. While traditional stop-control methods are effective for moderately congested intersections, they fall short in urban and suburban areas plagued by severe traffic jams and safety issues, often leading to crashes. However, constructing traditional roundabouts can be expensive and often requires additional right-of-way (ROW). This has brought mini-roundabouts into the spotlight in the US Mini-roundabouts, which require minimal design modifications and have a smaller footprint, are more easily integrated within existing intersections. They are particularly accommodating for larger vehicles due to their traversable central islands. For these reasons, mini-roundabouts have started to gain popularity and have been implemented worldwide, particularly on urban and rural roads where speeds do not exceed 30 mph (Rice, 2010). Several countries including US developed specific guidelines containing design criteria, location and material selection for the effective installation of mini-roundabouts. However, these guidelines are not comprehensive enough to rely on for proper guidance in planning and implementing this type of roundabouts.

Below listed are the key takeaways from different mini-roundabout guidelines:

- As per US guidelines, the Average Daily Traffic (ADT) for a mini-roundabout should not be more than 15,000 vehicles, and the ICD should not exceed 90 feet. Maximum approach speed should be 30 mph. Truck volumes should not exceed 3% (Rice, 2010).
- According to U.K. guidelines, mini-roundabouts are recommended where traffic flow on any arm is below 500 vehicles per day (vpd) and posted speed limit is 30 mph or less (Merron & Allister, 2006).
- South Africa guidelines provided a more specific warrant-based determination for implementation of a mini-roundabout. Intersection volume should be less than 3000 vph for 3-legged and less than 4000 vph for 4-legged intersection.
- As per Swiss guidelines, the ADT at the location intended for a mini-roundabout should not exceed 15,000 vehicles per day. Additionally, the combined traffic load at the entry lane and within the roundabout itself should not surpass 1,200 vehicles per hour. Locations with high pedestrian traffic density are not recommended for installing mini-roundabouts (Šurdonja et al., 2012).
- According to German guidelines, mini-roundabouts are recommended for areas where the ADT does not exceed 20,000 vehicles per day. Installation of mini-roundabouts is recommended only in urban areas, and the maximum allowed speed in these areas should be around 50 km/h (~31 mph) (Brilon, 2011; Šurdonja et al., 2012).

A review of US state DOTs indicates that 27 out of the 50 states have incorporated NCHRP 672 guidelines into their manuals, with several states adding specific criteria for mini-roundabouts. Since 2009, over 100 additional sites in the US have adopted mini-roundabouts. This growth is underpinned by studies evaluating their feasibility, costs, and benefits, as detailed in a national database maintained by Kittelson and Associates. Common site conditions for mini-roundabout implementation in the US include:

- ADT not exceeding 15,000 vpd, with a median range of 10,000-12,000 vpd.
- Peak hour volumes between 1,150 and 1,400 vph.
- A major/minor approach volume split of about 60/40.
- Minimal large vehicle (truck) activity.
- Pedestrian and bike volumes not a primary concern, with some areas reporting high pedestrian traffic but without specific figures.

Key design aspects for mini-roundabouts include:

- ICD typically between 70 and 80 feet, but not more than 90 feet.
- Central island diameters ranging from 45 to 55 feet, with a minimum of 15 feet.
- Circulating and entry lane widths falling within specific ranges to accommodate different traffic volumes and vehicle sizes.
- Splitter islands designed to manage traffic flow and pedestrian safety, with lengths and widths varying based on approach type and traffic needs.

- Smallest intersection angle commonly at 90 degrees to facilitate smooth traffic flow.
- Optional flared entries based on specific intersection requirements.
- Posted approach speeds generally between 15 and 20 mph, with a maximum of 25 mph.
- Pedestrian crosswalks, if present, are usually 8 to 10 feet wide.

Critical gap is a vital metric for determining the capacity of a mini-roundabout. It represents the minimum time gap an approaching driver needs to safely merge into the circulating lane of a mini-roundabout. Previous studies on gap acceptance have taken two main approaches: recording roundabout gap data to estimate critical gap and follow-up time, and developing gap acceptance behavior models (D. Lee et al., 2018). Xu and Tian's study on single-lane roundabouts in California found critical gaps ranging from 4.5 to 5.3 seconds and follow-up headways between 2.3 to 2.8 seconds (Xu & Tian, 2008). The NCHRP Report 672 by FHWA estimated critical gaps for roundabouts to be between 4.2 and 5.9 seconds, and the Highway Capacity Manual (2010) estimated them to be around 4.1 seconds.

Mini-roundabouts, compared to other intersection controls, show significant operational and safety benefits. They facilitate smoother traffic flow, especially during peak hours, and contribute to traffic calming by necessitating slower speeds. Safety improvements include reduced crash frequency and severity, better pedestrian and cyclist safety, and enhanced driver comfort. Key environmental advantages of mini-roundabouts include a significant reduction in vehicle emissions, such as carbon monoxide, sulfur, and nitrous oxides, due to less idling. The construction of mini-roundabouts also has a smaller environmental footprint, requiring less additional right-of-way and causing minimal disruption during construction. Mini-roundabouts are less costly to install and maintain than traditional roundabouts.

The literature review on mini-roundabouts discussed above is comprehensive in many aspects. However, these studies tend to offer a wide range of design parameters, such as inscribed circle diameters, splitter island dimensions, and entry widths, without specifying optimal values or conditions under which certain specifications are most effective. This lack of specificity can lead to ambiguity and challenges in applying these guidelines in practical scenarios. There is a clear need for more specific, detailed, and context-sensitive design guidelines that can guide practitioners in decision making for the implementation of effective, safe, and efficient mini-roundabouts.

A significant gap in the literature review of mini-roundabouts is the absence of driving simulation-based experiments. Simulations can effectively gauge how drivers adapt to mini-roundabouts, particularly those unfamiliar with this type of intersection. They can measure comfort levels, hesitations, and misunderstandings that might occur, which are crucial for assessing the overall effectiveness and safety of these roundabouts. Driving simulators allow for the experimentation with various mini-roundabout designs under controlled conditions. Researchers can modify factors like the size of the roundabout, or the presence of pedestrian crossings to see how these changes impact driver behavior.

Several studies discussed above provide insights on different traffic parameters like critical gap, average speed, capacity etc. However, detailed statistical and comparative analysis and also the impact of factors like gender, age, and time of day (day/night) on critical gap acceptance and speed at mini-roundabouts is an often overlooked area in these studies. This is another area where driving simulator-based experiments can play a vital role. Driving simulators can mimic the conditions of a mini-roundabout, allowing researchers to study how drivers judge and respond to gaps in traffic. Also, simulators can accurately track the speed at which drivers approach and navigate through mini-roundabouts. Researchers can use driving simulators to create a variety of traffic conditions to see how these impact driver behavior at mini-roundabouts. Use of statistical analysis software e.g. SPSS can be crucial for creating a logistic regression model, differentiating between factors on driver behavior at mini-roundabouts and determining the prevalent factors which influence critical gap acceptance, speed decision, and overall driving behavior.

Chapter 3: Study Methodology

Introduction

The focal point of this study was to investigate mini-roundabout designs from the perspective of the user. Essentially to adopt a high-fidelity driving simulator to investigate the navigation patterns and understand how driver behavior is affected by the physical dimension(s) of mini-roundabouts. This chapter highlights the methodology adopted and provides essential details on the driving simulator, the driving simulation scenarios, the participant recruitment procedure, participant demographics, and the experimental procedure.

High Fidelity Driving Simulator

A driving simulator is a machine which is used to examine various driving behavior factors for training and research purposes. It can replicate properties and characteristics of a real vehicle in a controlled virtual environment. The virtual world of the simulator enables researchers to investigate a broad range of experiments regarding roadway safety and driving behavior without causing a significant harm to the participant. A driving simulator was used to create multiple scenarios containing different sizes of mini-roundabouts.

The driving simulator used for this study is located in the Safety and Human Factors Facility at Stocker Center, Ohio University. The simulator, manufactured by DriveSafety, is a regular width Ford Focus car, which was recovered from a traffic crash. It is built with automatic transmission, and it acquires all the realistic features of an actual car. The car is equipped with steering wheel, blinkers, gear shift, accelerator and brake pedal. The car is also equipped with DriveSafety's Q-Motion platform, which provides real time motion simulation. It is a unique feature of the simulator which makes the car shift forward when the driver presses the brake pedal and backward when the driver presses the accelerator. This also helps the car to shift in response to roadway curbs, sidewalk, grade and other roadway elements. The rear-view mirror and the side mirrors are replaced by three computer monitors to assist the driver look backwards. The simulator also consists of three 9-foot-wide display screens which are used to display traffic scenes within the virtual environment. A speaker is located behind the gearshift to provide the sound of the car engine and the surrounding vehicles in the simulation. Figure 9 show the operational simulator car.

Figure 9

Simulator Car (While Running)

The simulator car has a dashboard and a gearshift similar to an actual car. The dashboard consists of speedometer, fuel gauge and temperature gauge. The steering wheel also replicates a real car, comprising turn-indicators and headlights.

The driving simulator comprises of eight computers, which are used to control different aspects of the simulation system. The Hyperdrive Computer is the primary one, which is used to create and run scenarios. It also gathers data from the drivers while the simulation is running. The three projector screens display views from three different computers, labeled as Left, Center or Right. The Rear Mirror Computer is used to control the rearview mirror which is replaced by an 8-inch monitor. The Dual Mirror Computer controls the side mirrors which are replaced by two 6-inch monitors. The combined images from the three projectors, the rearview mirror and the side mirrors provide the participants with a 360 degree virtual driving scenario. The host computer creates a network of all the computers used for the simulator.

Driving scenarios were created in the Hyperdrive Computer using DriveSafety's Hyperdrive software. Hyperdrive Authoring Suite has a wide range of environments, roadways, vehicles, pedestrians, animals, roadway entities and signs to replicate a real-time scenario. The roadways, intersections and the interchanges were inserted into Hyperdrive as tiles. The dimension of each tile is 656 x 656 feet (200 x 200 meters). The tiles can be connected one after another to create continuous roadway systems. Roadway elements including road signs, roadway markers, vehicles, pedestrians were inserted as entities. Road signs, roadway markers, bus stops, buildings, trees, bushes were added as static entities. Vehicles, pedestrians, animals can be entitled to a specific speed and acceleration in the simulator, and these were added as dynamic entities. Additionally, customized road signs and billboards were added at required locations.

The roundabouts in the simulation scenario were placed in an urban scenario. The simulator has a wide range of elements to replicate an urban area. Diverse types of commercial buildings, schools and office buildings were added to create the urban environment. Also, wide-range of vehicles including cars, SUVs, trucks, buses, motorcycles were added as dynamic entities. The ambient traffic in the simulator was entitled to a speed according to the speed limit of that roadway. Finally, some pedestrians, pedestrian crossings, and bicycles were also added in the simulation scenario.

Hyperdrive Authoring Suite has a unique way of using scripting commands to control the ambient traffic and the simulation conditions. The scripting commands can also be used to trigger one or more specific vehicles to respond as commanded. In this way, researchers are able create various types of events within the virtual environment. Triggered vehicles were entitled to scripting commands to bring a change in their speed or go to a specific location. Triggers were also put on pedestrians to move them to specific locations. All triggered vehicles and pedestrians had specific start point and end point which were also created using the commands. Finally the physical characteristics of the simulator car such as headlight brightness, steering calibration, braking intensity, the weather conditions, daylight conditions, visibility were also established using the scripting commands.

Experimental Design

Institutional Review Board Approval

All human subjects related research at Ohio University requires prior review and approval by the Institutional Review Board (IRB) – an administrative committee within the Office of Research Compliance. The IRB is charged with providing ethical and regulatory oversight on research that involves human subjects including the assurance that the research will be conducted in a risk-free environment and the personal privacy of human subjects will be protected. Moreover, an informed consent has to be obtained from each participant before starting any experiment according to the IRB. For this study IRB approval was obtained under IRB protocol 19-X-166 (included in Appendix C).

Participant Recruitment

Participants for this study were recruited in using a recruitment script that was developed and provided for reference in Appendix C. A set of criteria were used to screen participants including; participants must be 18 years and older, must have a valid US driver's license, and have driving experience of no less than two years.

In order to determine an appropriate number of participants to recruit, a suitable power of the statistical analyses was adopted. Based on statistical power of 0.8 and 0.9, an appropriate sample of 32 to 52 participants was calculated as shown by the calculations presented below. The assumed confidence interval was 95% and the effect size was 0.5 for a large effect (Sullivan, 2018; Zint, 2018)

$$\mathrm{N} = \left(\frac{z_{1-\alpha/2} + z_{1-\beta}}{\mathrm{ES}}\right)^2 \tag{1}$$

Where:

N = sample size

$1-\frac{\alpha}{2} = \text{confidence interval} = 0.95$

$1-\beta = \text{selected power} = 0.9 \text{ or } 0.8$

$z_{1-\alpha/2}$ = z-score for 95% CI = 1.96

$z_{1-\beta/2}$= z-score for 0.90 power = 1.645; z-score for 0.80 power = 0.84

ES (effect size) = 0.5

Therefore, for a power of 0.8, the appropriate sample size was calculated as:

$$N = \left(\frac{z_{1-\frac{\alpha}{2}} + z_{1-\beta}}{ES}\right)^2 = \left(\frac{1.96 + 0.84}{0.5}\right)^2 = 32 \text{ participants}$$

And similarly, for a power of 0.9, the appropriate sample size was calculated as:

$$N = \left(\frac{z_{1-\frac{\alpha}{2}} + z_{1-\beta}}{ES}\right)^2 = \left(\frac{1.96 + 1.645}{0.5}\right)^2 = 52 \text{ participants.}$$

Based on the sample size calculations, a total of 51 participants were recruited for this simulation study. However, one (1) participant, after completing the pre-test questionnaire, was unable to proceed with the experimental scenarios due to motion sickness and was subsequently excluded from further data analysis. Of these 50 participants, only 40 of them completed the two different scenarios (i.e., Day and Night) while the other 10 completed only one scenario (i.e., either Day or Night). The remaining 10 participants were unable to complete both scenarios due to motion sickness.

The participants were separated into three age groups: 18-25 years, 26-40 years and 41-65 years. The thresholds were established to categorize drivers based on their level of driving experience. The 18-25 years age group typically represents young adults, who have limited driving experience compared to older age groups (Matthews & Moran, 1986). The 26-40 years age group contains individuals who are likely to be in the workforce and have more driving experience compared to younger age groups (Hakamies-Blomqvist et al., 2002). The 41-65 years age group represents older drivers who are often considered experienced drivers, yet their responses to driving conditions may differ based on individual factors (Ouellette et al., 2023).

Given the driving simulator was located on the Ohio University campus, most participants were either students or staff from the university. Consequently, the number of participants from the 18-25 years and 26-40 years were substantially higher than the 41-65 years. As well, older drivers have a higher risk of demonstrating motion sickness (Classen et al., 2021; Domeyer et al., 2013), and therefore it was not possible to recruit many older participants.

As per the demographic of participants, 50% (N=25) of the participants are from the 18-25 years age group, 40% (N=20) from the 26-40 years age group, and 10% (N=5) are from 41-65 year age group.

The study aimed to represent Ohio's gender distribution among drivers - that is, 49.05% male drivers and 50.95% female drivers (FHWA, 2020). Of the recruited participants, 78% (N=39) were male and 22% (N=11) were female, deviating from the initial goal. This discrepancy is due to a higher ratio of male to female students, faculty, and staff within the engineering department, influencing the participant demographics.

The participant demographics are presented in Table 4.

Table 4

Participant Demographics

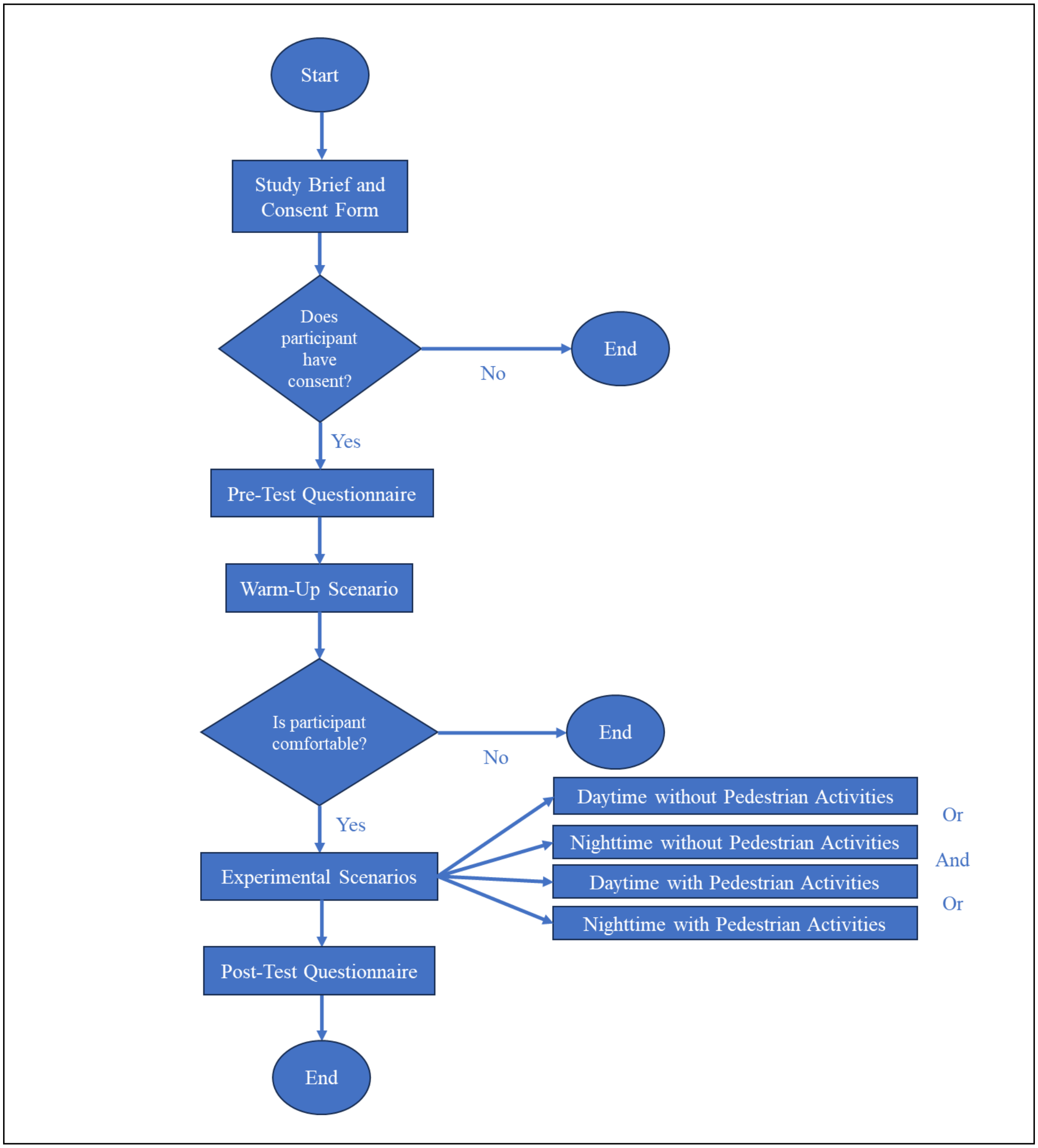
Participant Characteristics		N	Percent of Total
Age	18-25	25	50%
	26-40	20	40%
	41-65	5	10%
Total		50	100%
Gender	Male	39	78%
	Female	11	22%
Total		51	100%

Experimental Procedure

Figure 10 presents the complete set of activities that each participant was expected to undertake including signing an IRB-approved consent form, completing a pre-test questionnaire, driving a warm-up scenario, driving the main experimental scenarios, and completing a post-test questionnaire. This section will provide detailed discussions on each of these components.

Figure 10

Experimental Procedure



Study Brief and Consent Form

After receiving IRB approval and setting up the simulation environments for the experiments, participant sessions were arranged for the driving simulation test using an online scheduling system. Prospective participants were invited to choose from the available slots on weekdays or weekends, spanning from 8 a.m. to 6 p.m., for their session. Upon their arrival at the designated time at the Safety and Human Factors lab located in Stocker Center 308, they were provided an overview of the study. Following this briefing, participants were required to fill out the IRB consent form before proceeding with the test. The IRB consent form consisted of the summary and explanation of the study, risks and discomforts related to the simulation test and the benefits of the study. The consent form was given to ensure that the participants were well-informed about the research and had full consent to participate in the study. Participants who did not sign the IRB consent form were excluded from taking part in the simulation study. The IRB consent form is attached in Appendix D.

Pre-Test Questionnaire

After signing the IRB consent form, the participants were asked to complete a pre-test questionnaire. The pre-test questionnaire included inquiries about participants' age, gender and their average driving frequency. The pre-test questionnaire also included questions about participants' familiarity with roundabouts and mini-roundabouts, experience driving through mini-roundabouts and previous receipt of navigation instructions for roundabout. The participants were also asked their preferred information sources for learning about roundabout navigation, and opinions on the most helpful type of roundabout signage through the pre-test questionnaire. This information helps in understanding how these factors might influence participants' performance in the driving simulation. It also provides insights into the participants' knowledge and perceptions of roundabouts, which can be critical for assessing the effectiveness of different roundabout designs and signage in the simulations. Additionally, the questionnaire can identify gaps in public knowledge or education about roundabouts, informing future educational campaigns or modifications to roundabout design and signage. The pre-test questionnaire is attached in Appendix E.

Simulation Setup and Warm-Up Scenario

After completing the pre-simulation questionnaire, the participants were taken to the simulator car; where they were asked to make themselves comfortable (i.e., wearing the seat belt, adjusting the seat). The drivers were briefly instructed about the simulation environment and any questions regarding the simulation were answered. The drivers were advised to take the simulation seriously drive as realistically as possible.

Participants were provided with a warm-up scenario prior to any data collection. The warm-up scenario was essential for the participants to adapt with the simulation environment. The warm-up scenario was 5-6 minutes long. During the scenario, it was ensured that the participants can see all the projector screens, rear mirror and side mirrors and identify any incoming vehicles, pedestrians or other objects in the simulation scenario. The warm-up scenario was important to make participants comfortable with the speed limits, brake and acceleration, maneuvering, parking, lane changing and turning. Also, it was useful for the participants to understand and decide if they are comfortable with the simulation environment and if they are willing to go forward with the main scenarios. If the participants were not feeling uneasy and if they agreed to participate in the main scenarios, they were allowed to continue with the study. Conversely, those who felt uncomfortable were not required to proceed with the main scenarios. If any participant had any questions or needed a break, they were answered or provided with the required facilities. No driving data was recorded from the warm-up scenario.

Simulation Scenario Specific

Roundabout Designs. Each experimental scenario featured four mini-roundabouts and one single-lane roundabout. The single-lane roundabout was included to provide base conditions that can be used for comparisons. The mini-roundabouts were designed based on a review of different state and federal guidelines. The speed limit for approaching the roundabouts was set at 25 miles per hour (mph), while the speed limit for navigating within the roundabouts was 15 mph. Key design aspects for the mini-roundabouts, as well as the single-lane roundabout are presented in Table 5 below:

Table 5

Roundabout Key Design Aspects

Roundabout ID	Inscribed Central Diameter (ICD) (feet)	Central Island Diameter (feet)	Circulating Lane Width (feet)	Splitter Island Width (feet)
Mini-Roundabout 1	45	15	15	8
Mini-Roundabout 2	60	28	16	8
Mini-Roundabout 3	75	45	15	10
Mini-Roundabout 4	90	58	16	10
Single Lane Roundabout	120	90	15	10

A sample mini-roundabout tile (ICD 75 feet) and the single-lane roundabout tile (ICD 120 feet) are shown in Figure 11 and 12.

Figure 11

Mini-Roundabout (ICD 75 feet)

Figure 12

Single-Lane Roundabout (ICD 120 feet)

To evaluate drivers' performance whilst navigating the mini-roundabout designs , four unique scenarios were developed. Each scenario was 13-15 minutes long, depending on a participant's driving speed. The significant difference between the scenarios were the driving conditions – day versus night and also the inclusion for pedestrian crossings at the entry of the roundabouts. Each participant's specific driving data including speed, brake force, acceleration, lane position, headway. were recorded as they drove their randomly assigned driving simulation scenarios. Figure 13 and 14 shows the simulation environment at daytime and nighttime conditions.

Figure 13

Simulation Scenario (Daytime Condition)

Figure 14

Simulation Scenario (Nighttime Condition)

Simulation Scenario Specifics: Without Pedestrian Activities. As depicted in Figure 10, the first two simulation scenarios featured the roundabouts with no pedestrian crossings, one was in daytime condition and the other was in nighttime condition. The gap data collected from these scenarios were utilized to determine the critical gap. As the participant drives towards a roundabout in the simulation, a series of vehicles approach from the left side of the roundabout. The simulation vehicles have different headways varying from 1 second to 8 seconds and more. While the simulation vehicles continue to enter into the roundabout, the participant waits and makes a decision to take the most suitable gap for him and exits the roundabout. The gap data in five roundabouts for each participant has been recorded. The participant's speed, acceleration, brake force, collision data have also been recorded while he/she navigates in the roundabouts. After collecting gap data from all participants, the revised Raff's method is used to plot a graph for the cumulative percentage of accepted gaps and rejected gaps. The gap acceptance theory used in this study is illustrated in Figure 15. An image from a simulation scenario without pedestrian activities is shown in Figure 16.

Figure 15

Gap Acceptance Theory

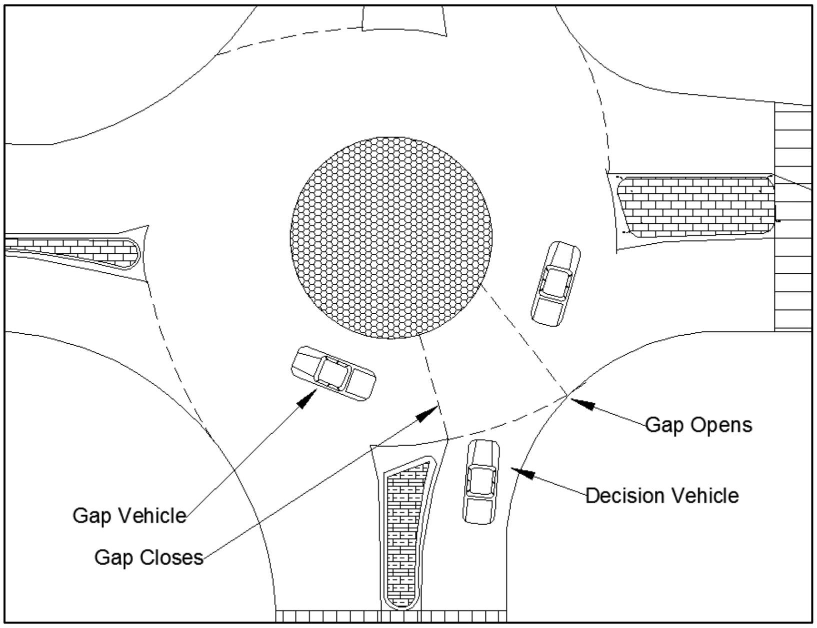


Figure 16

Simulation Scenario (Roundabout Without Pedestrian Activities)

Simulation Scenario Specifics: With Pedestrian Activities. As shown in Figure 10, the next two simulation scenarios featured pedestrian activities at the roundabouts, one was in daytime condition and the other was in nighttime condition. In these simulation scenarios, the roundabouts had pedestrian crossings at the entry of the roundabouts. The pedestrian crossings were 20 feet away from the entry of the roundabouts. The width of the pedestrian crossings was 10 feet. As the participants approached towards the roundabouts, few pedestrians and bicycles from different directions started crossing the road, which caused the participants to slow down or come to a complete stop i.e., react in a different way than the scenarios with no pedestrian crossings. This resulted in a significant difference in the speed, brake force and eye movement of the drivers which was significant for the analysis. Critical gap data was not taken in these scenarios. An image from a simulation scenario with pedestrian activities is shown in Figure 17.

Figure 17

Simulation Scenario (Roundabout With Pedestrian Activities)

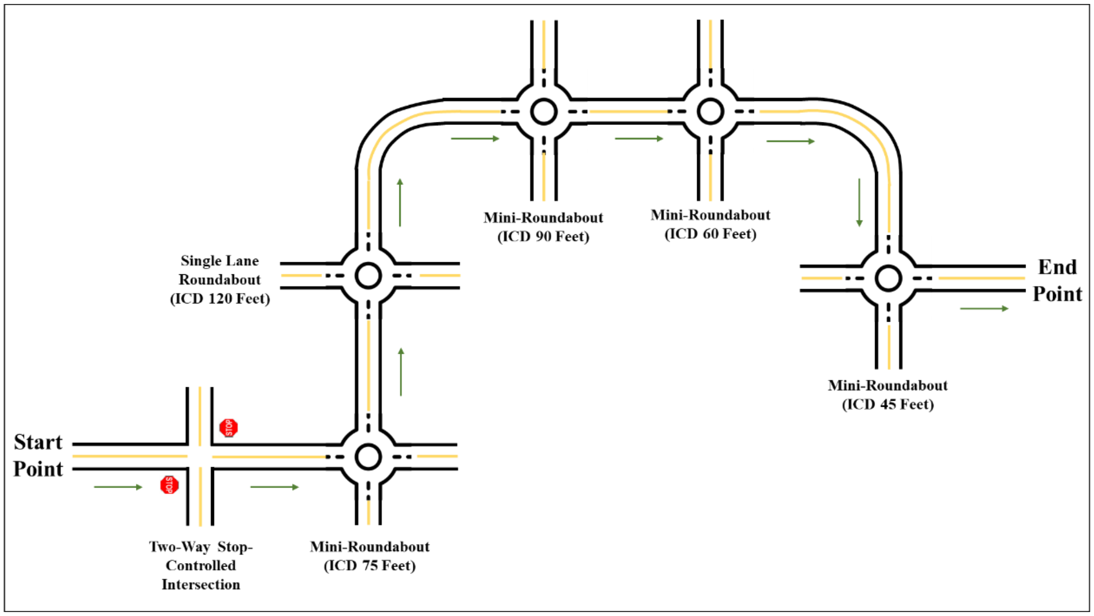
Participants Experimental Driving Path

Each participant, regardless of the assigned simulations scenarios, followed the driving path depicted in Figure 18. As such, during each simulation scenario, a participant experienced the following common events:

- Started driving from a common start point (i.e., a parallel parking space) on a two-lane roadway in an urban setting and drove for approximately 2 miles.
- After that, the participants went through a stop-controlled intersection.
- Next, after around 2 miles they approached to a mini-roundabout with an inscribed circular diameter (ICD) of 75 feet. Participants were told to take the third exit (left-turn) from the mini-roundabout.
- After that, the participants approached to a traditional single-lane roundabout and advised to take the second exit (straight) from there.
- Then, they exited the urban area and entered a two-lane sub-urban roadway and drove for approximately 5 miles.
- Next, they again entered a two-lane urban roadway and approached to a mini-roundabout with an inscribed circular diameter (ICD) of 90 feet. Participants were told to take the second exit (straight) from the mini-roundabout.
- After 2 more miles, the participants approached to a mini-roundabout with an ICD of 60 feet and were advised to take the second exit (straight) from there.
- Then, they exited the urban area and again entered a two-lane sub-urban roadway and drove for 4 to 5 miles.

Figure 18

Simulation Study Route



- After that, the participants entered a two-lane urban roadway and approached a mini-roundabout with an ICD of 45 feet. The participants were advised to take the third exit (left-turn) from there.
- After exiting the last mini-roundabout, the participants drove for another mile and parked the car at a residential parking space. The simulation then comes to an end.

Post-Simulation Questionnaire

Once a participant completed the driving, they were asked to complete the post-simulation questionnaire and provide responses based on their driving simulation experience. The post-test questionnaire aimed to gather subjective feedback on the drivers' experiences navigating the different mini/single-lane roundabout configurations within the simulation. Questions were designed to identify perceived differences between roundabouts, assess comfort levels, and gauge preferences for features like pedestrian crosswalks and bicycle lanes. This feedback helps to understand drivers' comfort and preferences, which can inform future roundabout design and implementation strategies. The post-test questionnaire is attached in Appendix E.

Data Collection

The simulation data were collected by two different means: the driving simulator, and the pre/post questionnaires. The data extraction process was kept identical for each of the four test scenarios.

Driving Simulation Data Collection

The Hyperdrive software has programs to record the participant’s driving data including speed, acceleration, brake force, collision, headway, speed limit, time of the day and many other things. The data were collected for all main four scenarios at a rate of 10 Hertz. Each participant’s data was stored separately as a text file and then converted to an excel document under a unique identification code. A sample of the raw simulation data for an arbitrary participant is attached in Appendix F.

After extracting the raw data for each participant into excel files, the data were transformed and filtered into summary data tables. The simulation software records the speed data as meters per seconds (m/s) and this data were converted to miles per hour (mph). The speed data were taken at 500 feet, 400 feet, 300 feet, 100 feet, 0 feet (yield line) from the entry of the roundabouts and also from the exit of the roundabouts. Two speed data inside the roundabout have been taken as the circulating speed. The acceleration and brake force data were represented on a scale of 0.0 to 1.0 where 0.0 represents no force and 1.0 represents the maximum force. A sample of the raw data summary table for speed at 500 feet from the entry of the roundabouts for 18 participants is attached in Appendix F.

Survey Questionnaire Data Collection

The participants responses from the pre- and post-test questionnaire were stored in a separate file for using in the analysis. The data then was summarized and examined to gauge drivers' preferences, perceptions, and comfort levels concerning roundabouts and mini-roundabouts. Furthermore, participants provided qualitative feedback on their experiences navigating different roundabouts under various conditions. Observations on driving behavior and speed were also noted during the simulations.

Chapter 4: Results And Discussion

Introduction

This chapter presents and discusses the findings from the study, including analyses of the pre-test and post-test questionnaires, critical gap, speed data, and brake force measurements. The analysis considers overall trends and examines variations based on factors such as gender, age group, and daylight conditions. Additionally, a logistic regression analysis has been conducted to explore the influence of these factors on driving behavior within the simulation scenarios.

Analysis of Pre-Test Questionnaire

Public perception is crucial in the success of transportation projects. The pre-test questionnaire serves to gauge how various factors could affect participants' driving simulation performance. It offers a window into their understanding and attitudes towards roundabouts, vital for evaluating the impact of diverse roundabout designs and signage within the simulation. The analysis of the pre-test questionnaire concentrates on evaluating drivers' opinions, attitudes, preferences, and perceptions towards roundabouts and mini-roundabouts. Specifically, the analysis includes the following:

- Drivers' familiarity with roundabouts
- Drivers' navigational knowledge related to roundabouts
- Drivers' preferences regarding roundabout signage

Driving Experience and Familiarity with Roundabouts

The first two questions on the pre-test questionnaire pertained to participant demographics, details of which are presented in Table 4. Questions 3 to 6 (on the pre-test questionnaire) were presented to each participant in order to understand his/her driving habits and also the familiarity with not only roundabouts – in general, but also with mini-roundabouts. The aggregated responses to questions 3 to 5 are presented in Table 6 and 7. Among the participants, 8% (N=4) drove 0 to 1 day per week, 60% (N=30) drove 2 to 4 days per week, and 32% (N=16) drove 5 to 7 days in a week.

Table 6

Responses to Pre-Questionnaire Question 3

Question 3	**Responses**		
	0-1 days	**2-4 days**	**5-7 days**
How much would you say you drive on average?	8%	60%	32%

The responses indicated that all recruited participants were familiar with the concept of a roundabout (in general) – in fact, Table 9 depicts that 76% (N=38) were very familiar and 24% (N=12) were somewhat familiar. With respect to the mini-roundabout concept, only 20% (N=10) of participants responded to being very familiar. whereas 40% (N=20) reported to being somewhat familiar, and 40% (N=20) were not familiar with mini-roundabouts. From the responses to question 6, approximately 52% (N=26) of participants reported to have driven through a mini roundabout previously, whereas 48% (N=24) reported to have not driven through a mini-roundabout.

Table 7

Responses to Pre-Questionnaire Questions 4 and 5

Questions	**Responses**		
	Not familiar	**Somewhat familiar**	**Very familiar**
Question 4: How familiar are you with the concept of a roundabout?	0%	24%	76%
Question 5: How familiar are you with the concept of a mini-roundabout?	40%	42%	20%

Drivers' Navigational Knowledge Related to Roundabouts

In order to get an idea about a participant's awareness of navigational knowledge relating to roundabouts and his/her source of this navigational knowledge; questions 7 to 8 were included in the pre-test questionnaire. As depicted in Figure 19, a large proportion of participants (84%, N=42) had received navigation information on roundabouts (in general) while only 16% (N=8) had not received any prior navigational knowledge of roundabouts. More specifically 80% (N=41) reported to having received navigational information about traditional roundabouts, 16% (N=8) about mini-roundabouts, and 2% (N=1) about turbo-roundabouts. Note that participants had the option to select multiple responses for question 7.

Based on the participant pool that was recruited for this study, the preferred means of receiving navigational information pertaining to roundabouts (in general) was video and/or animation – 61% (N=31) responses. As seen from Figure 20, physical demonstrations and the Ohio driver's manual where the next preferred sources for navigational information with responses of 49% (N=25) and 29% (N=15), respectively.

The sources of navigational that were least preferred included brochures and/or websites, presentations, and other sources. Similar to question 7, participants could choose multiple answers for question 8 as well.

Figure 19

Pre-Questionnaire Question 7: When you think of roundabouts, have you ever received any information on how to navigate through the following?

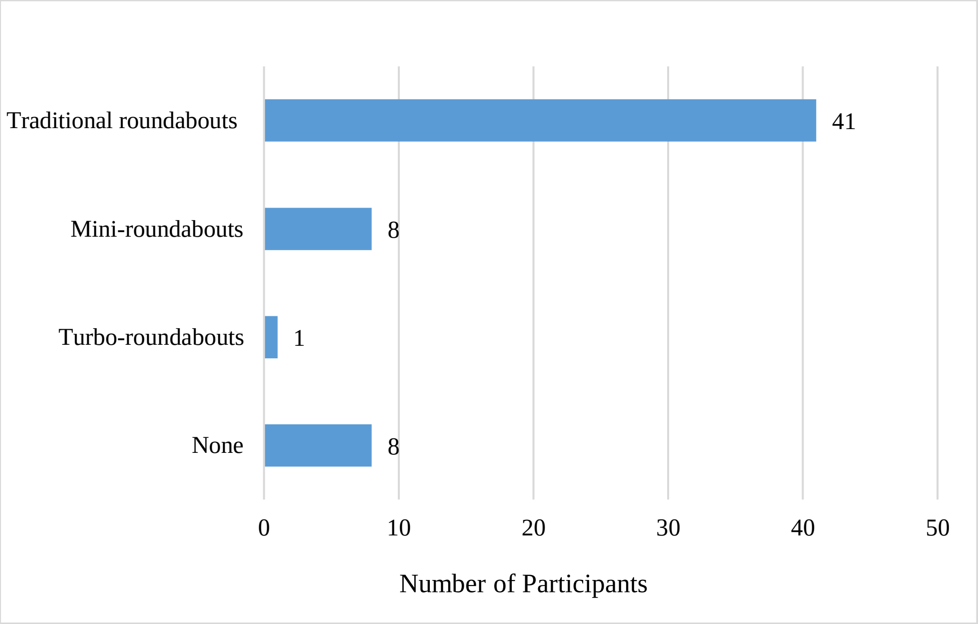
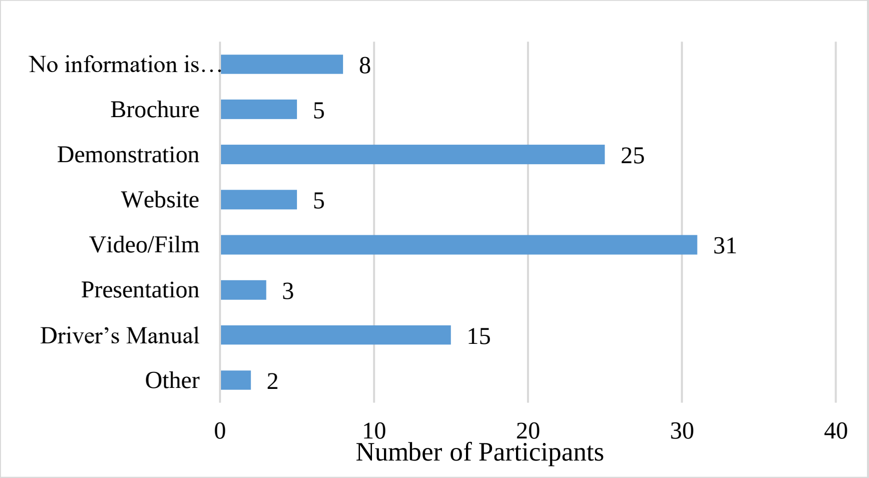


Figure 20

Pre-Questionnaire Question 8: What type of information source would be most helpful to you to understand how to navigate through a Roundabout?

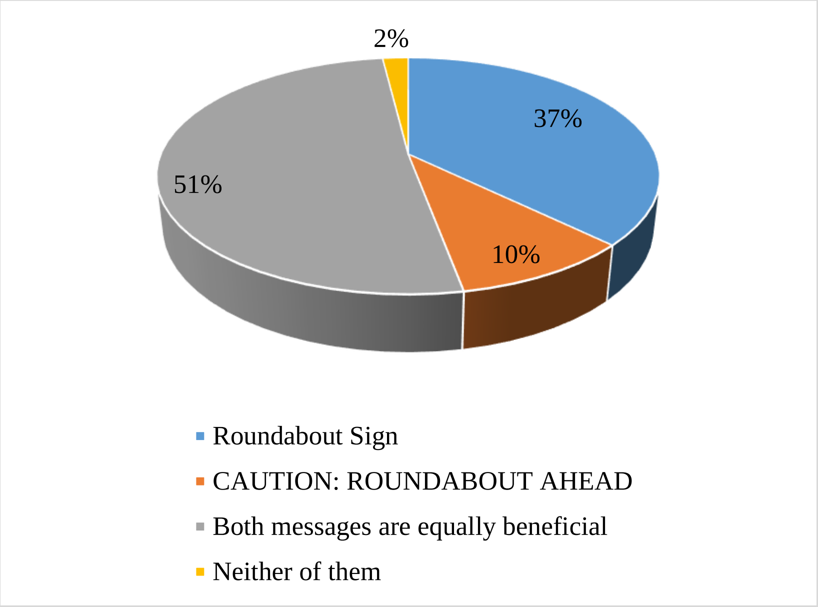


Drivers' Preferences Regarding Roundabout Signage

Question 9 was crucial for assessing the effectiveness of different signs in improving drivers' understanding and safety when approaching and driving through roundabouts. Figure 21 depicts the participants preferences regarding the type of roundabout sign they found beneficial. Notably, 37% responded for the Roundabout sign, 10% preferred the CAUTION: ROUNDABOUT AHEAD sign, 51% preferred any of them and only 2% responded neither of them.

Figure 21

Pre-Questionnaire Question 9: Which type of roundabout sign is more beneficial for you to drive through a mini-roundabout?



Analysis of Post-Test Questionnaire

The post-test questionnaire was designed to capture participants' personal experiences with different roundabout layouts in the simulator. The objective was to identify any noticeable differences among the roundabout designs, assess participants' comfort levels, and identify their preferences for incorporating pedestrian crosswalks and bicycle paths. The analysis of the post-test questionnaire encompasses the following:

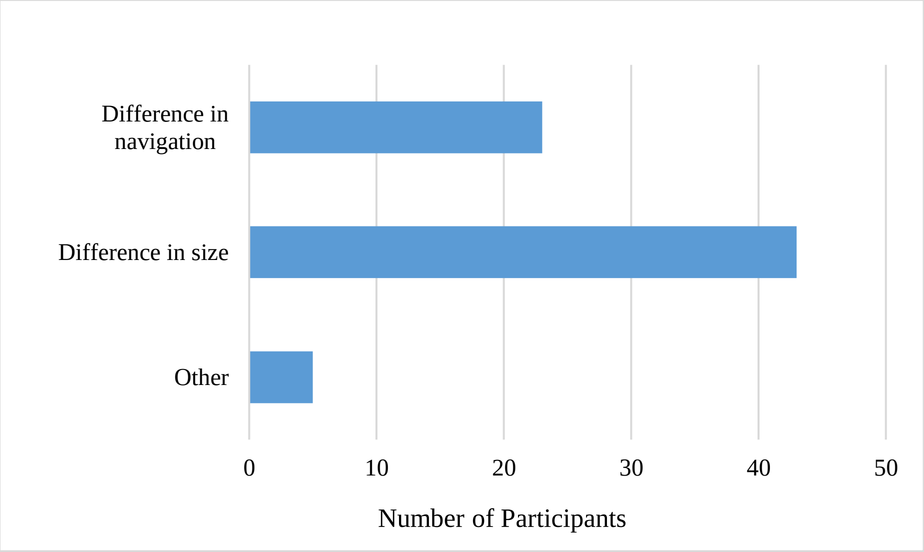
- Drivers' perceptions of differences between the roundabouts
- Drivers' comfort levels while navigating the roundabouts
- Drivers' preferences regarding non-motorists movements

Drivers' Perceptions of Differences Between the Roundabouts

Question 1 was included in the post-test questionnaire in order to understand participants' subjective experiences and perceptions of the roundabouts in the simulation. Responses to question 1 on the post-questionnaire are shown in Figure 22 below. Participants were asked if they notice/feel any differences while navigating the roundabouts and the nature of these differences (i.e. by size, navigation etc). A significant majority, 90% of participants (N=45) reported perceiving differences. Among them, 43 participants (84%) responded they find difference in size, 22 participants (43%) identified differences in navigation, and 5 participants (10%) responded other reasons for the distinctions. Participants had the option to select multiple responses for question 1.

Figure 22

Post-Questionnaire Question 1: If YES, did you observe differences such as navigation, size, other.



Drivers' Comfort Levels While Navigating the Roundabouts

In order to understand participants' subjective comfort levels while navigating various intersection configurations, questions 2 and 3 were included in the post-test questionnaire. Participants were asked to rank their comfort level while maneuvering on a scale of 1 to 5; with 1 being the lowest level of comfort and 5 being the highest. Figure 23 shows that participants' overall comfort level at the beginning of simulation was 3.33. Participants reported the highest comfort level, averaging 3.86, when navigating STOP-controlled intersections, followed by an average of 3.61 for traditional roundabouts, and the lowest average comfort level of 3.12 for mini-roundabouts. The probable reason mini roundabouts received the lowest comfort rating could be due to their compact size, necessitating faster decision-making and maneuvering by drivers. Additionally, the novelty of these designs may contribute to the discomfort, as drivers might be less familiar with the operational dynamics of mini roundabouts compared to more traditional intersections. Responses to question 3, the preference of participants in terms of comfort while navigating the simulator are illustrated in Table 8. Aligned with the findings from the first question, Table 8 indicates that 51% of participants (N=26) showed a preference for STOP-controlled intersections, marking it as the most favored among all types of intersections surveyed. However, when focusing specifically on roundabouts, 33% of participants (N=17) showed a preference for mini roundabouts, while 16% (N=8) preferred traditional roundabouts.

Figure 23

Post-Questionnaire Question 2: Please rank your comfort level while you were navigating/maneuvering through different situations in the simulator.

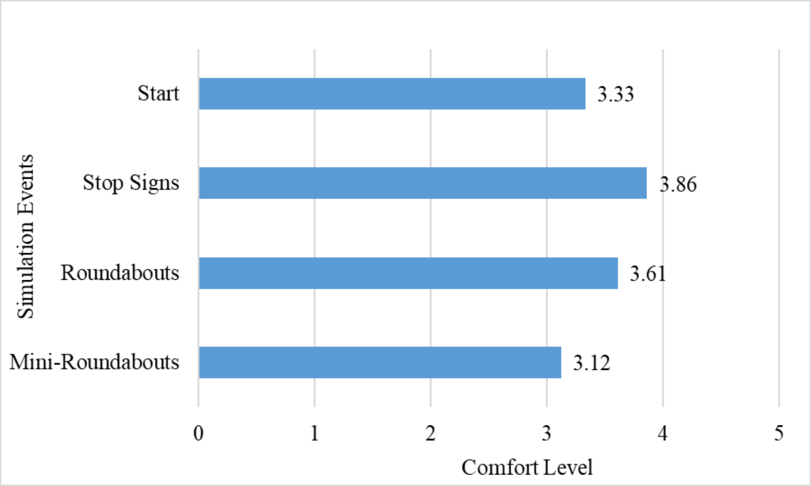


Table 8

Responses to Post-Questionnaire Question 3

Question 3	Responses		
	Stop Signs	**Mini-Roundabouts**	**Roundabouts**
Recall the intersections you just experienced in the simulation and indicate your order of preference based on comfort of navigating them.	49%	16%	33%

Drivers' Preferences Regarding Non-Motorists Movements

The post-test questionnaire also aimed to gauge participants' comfort levels with pedestrian crosswalks and bicycle movements within roundabouts. Questions 4 to 6 in the post-test questionnaire were specifically designed to assess this. Table 9 illustrates participants' comfort levels when navigating roundabouts featuring pedestrian crosswalks, revealing that 48% of respondents (N=24) felt comfortable, whereas 52% (N=26) expressed discomfort. Moreover, Table 9 detail participants' comfort levels regarding bicycles in and around roundabouts. 36% (N=18) reported comfort with bicycles. Of those 18 participants, 56% (N=10) preferred bicycles in pedestrian crossings, while 44% (N=8) were comfortable with bicycles sharing the road with vehicles.

Table 9

Responses to Post-Questionnaire Questions 4 and 5

Questions	**Responses**	
	Yes	**No**
Question 4: In general, will you be more comfortable driving through roundabouts with pedestrian crosswalks?	48%	52%
Question 5: In general, will you be more comfortable driving through roundabouts with bicycles?	36%	64%

Analysis of Critical Gaps

Introduction

As described previously in the literature review (chapter 2), it was important to study the critical gaps for enhancing traffic flow, decreasing congestion, and reducing collision risk. As such, critical gaps for both a single-lane roundabout and also for the different mini-roundabouts were determined using the revised Raff’s method (Naik et al., 2021; Shaaban & Hamad, 2018) as described in the literature. Once critical gap information was extracted from the data, a series of statistical analysis were performed.

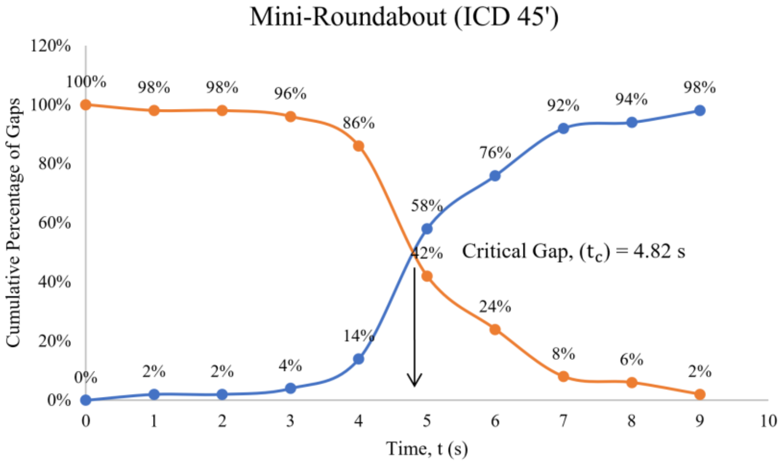
These analyses extended to calculating critical gap values with considerations for the driver's age, gender, and the time of day (daylight conditions), aiming to evaluate how these human factors might influence critical gap estimations.

Sample Critical Gap Calculation (45-Feet ICD Mini-Roundabout)

The critical gap for mini-roundabouts was determined by analyzing the cumulative distribution functions (CDFs) of accepted and rejected gaps from data collected from 50 participants. According to the revised Raff's method, the horizontal axis value of the intersection between the CDFs of accepted and rejected gaps represents the critical gap (Shaaban & Hamad, 2018). For a mini-roundabout with an inscribed circular diameter (ICD) of 45 feet, the combined critical gap estimated from the participants was found to be 4.82 seconds. The critical gap calculation is illustrated in Figure 24.

Figure 24

Combined Critical Gap for 45-Feet ICD Mini-Roundabout



The critical gap calculations for mini-roundabouts with ICDs of 60 feet, 75 feet, 90 feet, and for the single-lane roundabout, as well as the critical gap calculations based on age, gender, and daylight conditions, are detailed in Appendix G. The gap acceptance data is also included in Appendix G.

Discussion on Critical Gap Related Findings

The combined critical gap values and critical gap values from different categories are summarized in Table 10.

Table 10

Summary of Critical Gaps

Critical Gap (s)	**Mini-Roundabouts ICD**				**Single Lane Roundabout**
	45-feet	**60-feet**	**75-feet**	**90-feet**	**120-feet**
Combined	4.82	4.22	4.50	4.53	4.11
Daytime	4.83	5.06	3.94	4.58	4.25
Nighttime	4.81	4.56	4.59	4.50	3.83
Male	4.71	4.08	4.43	4.50	4.05
Female	4.38	4.50	4.62	4.62	4.50
Age Group 18-25 years	4.86	4.88	4.43	4.50	4.05
Age Group 26-40 years	4.60	3.67	3.71	4.38	4.33
Age Group 41+ years	5.50	4.50	4.50	5.25	5.25

The following key insights can be derived from the summary of critical gap values estimated from the study:

- Combined critical gap values ranged from 4.22 to 4.82 seconds regardless of the ICD size or type. The critical gap values align with the critical gap range of 4.2 to 5.9 seconds recommended by NCHRP Report 672.
- The critical gap value determined for the single lane roundabout was 4.11 seconds which matches with the critical gap value of 4.1 seconds, as utilized by the Highway Capacity Manual (HCM) for roundabouts. This suggests that the driving behavior observed in the simulation scenarios closely replicates real-world driving.
- Daytime critical gap values ranged from 3.94 to 5.06 seconds and nighttime critical gap values ranged from 3.83 to 4.81 seconds. Contrary to expectations that daytime driving would have shorter critical gaps than nighttime driving (Dissanayake et al., 2002) due to better visibility, the findings show that critical gaps were actually shorter at night.
- Male participants critical gap values ranged from 4.05 to 4.71 seconds and female participants critical gap values ranged from 4.38 to 4.62 seconds.
- Critical gap values for age group 18-25 years ranged from 4.05 to 4.88 seconds. For age group 26-40 years, the range was 3.67 to 4.60 seconds and for age group 41+ years, the range was 4.50 to 5.50 seconds. It can be observed that drivers over 41 years of age displayed longer critical gaps, aligning with the assumption that this age group tends to be more cautious. In contrast, the critical gaps for drivers aged 26-40 were the shortest, indicating more aggressive driving tendencies. The 18-25 age group showed larger

critical gaps than 26-40 age group, likely reflecting their limited driving experience (Matthews & Moran, 1986).

- The 45-feet mini-roundabouts had the longest critical gaps (4.82 seconds overall) across all categories, suggesting that drivers were more cautious when merging, which could potentially influence the flow and safety of the roundabout traffic (Jamal et al., 2022).

These observations underscore the importance of considering various factors, such as time of day, driver age, and specific design attributes of roundabouts, in understanding and optimizing roundabout design and usage. The varied critical gap times suggest that drivers perceptions and behaviors change under different conditions, which can have significant implications for the design and operational strategies of roundabouts to enhance safety and efficiency across diverse user groups.

Analysis of Speed at Roundabouts With No Pedestrian Crossing

Introduction

In this section, an examination of how drivers' speeds varied across different mini-roundabout designs is performed. The examination includes findings in varying forms including without pedestrian crossings, analyzing overall speeds and the impact of factors such as age, gender, and daylight conditions through several statistical analyses. The primary objective is to assess whether variations in roundabout diameters significantly influence drivers' average travel speeds.

Analysis of Overall Speed Data

As a participant driver traversed the route (shown in Figure 24) for the scenario presented to them, their speed was collected at the entry, within the circulatory section, and also at the exit of each roundabout they encountered. More specifically, speed data were collected along approach to roundabout (i.e., at 500 feet, 400 feet, 300 feet, 200 feet, 100 feet, 0 feet (yield line)), two locations within the circulatory area of roundabout, and along approach from roundabout (i.e., 0 feet (exit line), 100 feet, 200 feet, 300 feet, 400 feet, and 500 feet). Test for normality has been performed for all of the speed data using SPSS. The test for normality is conducted to check if the speed data collected from participants follow a normal distribution, which is a prerequisite for many statistical analyses. Ensuring that the data are normally distributed validates the use of parametric statistical tests, which assume that the data come from a population that follows a normal distribution. The speed data at every location were found to be normal.

Test of homogeneity of variances have been performed for all of the speed data as showed in Table 11. The test of homogeneity is conducted to verify that the spread or variability of speed data across different locations around the roundabout is consistent for all groups of participants. The speed data from 500 feet to 100 feet from the entry and the speed data at 100 feet to 400 feet from the exit (highlighted in green) of the roundabout were homogenous. The speed data at entry yield line, the circulating speed and the speed data at 0 feet and 500 feet from the exit (highlighted in red) of the roundabout were not homogenous.

Table 11

Test of Homogeneity of Variances

Location	Levene Statistic	Sig.
Entry speed at 500 feet	0.548	0.701
Entry speed at 400 feet	0.087	0.986
Entry speed at 300 feet	0.476	0.754
Entry speed at 200 feet	1.631	0.167
Entry speed at 100 feet	2.335	0.056
Entry speed at yield line	6.968	0
Circulating Speed	3.896	0.004
Exit speed at 0 feet	5.998	0
Exit speed at 100 feet	0.989	0.414
Exit speed at 200 feet	0.797	0.528
Exit speed at 300 feet	1.763	0.137
Exit speed at 400 feet	2.342	0.056
Exit speed at 500 feet	4.552	0.001

An ANOVA test was conducted to identify specific locations where significant variations in speed occurred among participants. This statistical analysis allows researchers to determine if there are any meaningful differences in speed at various points approaching, within, and exiting the roundabout. Table 12 shows the summary of the ANOVA test. The ANOVA test indicated that speeds at all studied locations significantly differed (highlighted in red). To identify locations of significant speed variation among drivers, their mean speed profiles at different roundabouts were plotted, as illustrated in Figure 25. The analysis of the mean speed profile of drivers, led to the selection of entry speed at 500 feet, 200 feet, 100 feet and 0 feet, one circulating speed, and the exit speed at 0 feet, 100 feet and 500 feet.

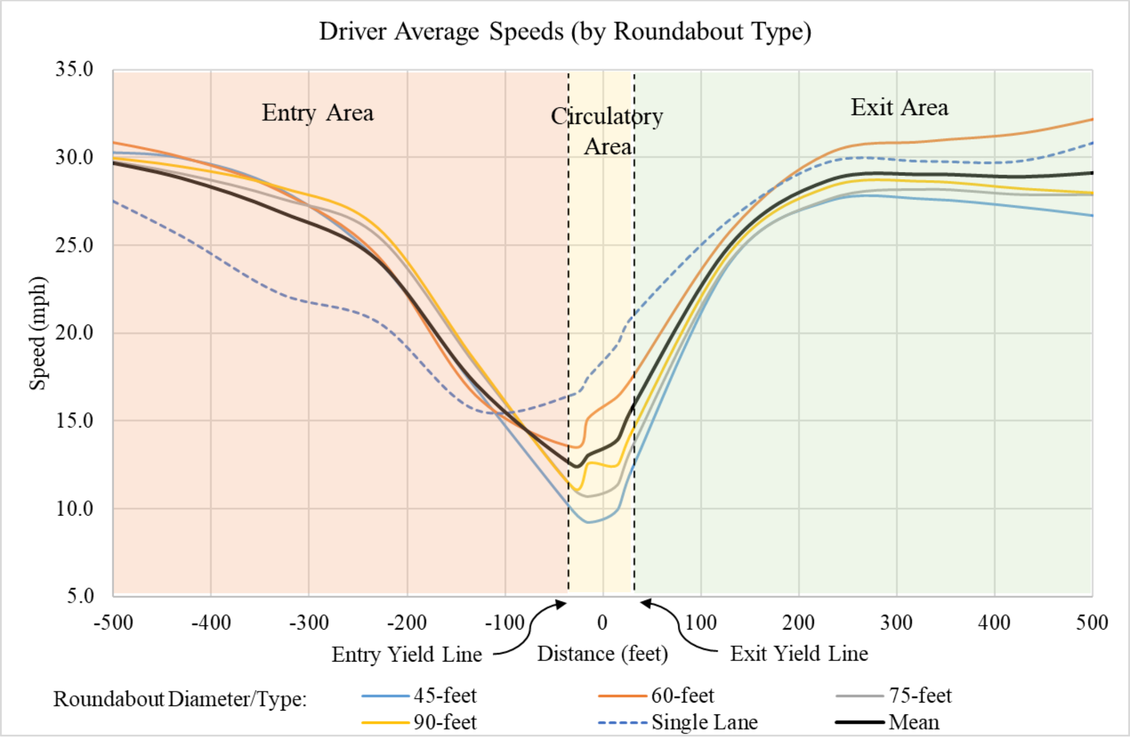
Table 12

ANOVA Test

Location	**F**	**Sig.**	**Eta-squared**
Entry speed at 500 feet	15.604	0.007	0.208
Entry speed at 200 feet	11.936	0	0.167
Entry speed at 100 feet	3.795	0.005	0.06
Entry speed at yield line	24.421	0	0.291
Circulating speed	37.68	0	0.388
Exit speed at 0 feet	42.108	0	0.414
Exit speed at 100 feet	3.744	0.006	0.059
Exit speed at 500 feet	11.591	0	0.163

Figure 25

Mean Speed Variation



From the ANOVA test results, the following conclusions can be made:

- The entry speeds at 500 feet and 200 feet show significant differences ($p<0.05$) with large effect sizes ($\eta^2 > 0.14$). This suggests a strong influence of these locations on driver behavior and speed choice as they approach the roundabout.
- The entry speed at 100 feet shows significant differences ($p<0.05$) with moderate effect size ($\eta^2 = 0.06$).
- The entry speed at the yield line and circulating speed demonstrate significant differences ($p<0.05$), accompanied by large effect sizes ($\eta^2 > 0.14$). This indicates

a substantial influence of these specific locations on the variability of driver speeds within the roundabout.

- The exit speeds at 0 feet and 500 feet show significant differences ($p<0.05$) with large effect sizes ($\eta^2 > 0.14$). This indicates that these specific locations significantly impact the variability of exit speeds.

The descriptive statistics for the entry speed at the selected locations have been presented in Table 13. The descriptive statistics for the circulatory speed and exit speed at the selected locations have been presented in Table 14.

Table 13

Descriptive Statistics for the Entry Speed at Different Roundabouts

Location	**Roundabout Diameter (feet)**	**N**	**Mean Speed (mph)**	**Std. Deviation (mph)**	**Std. Error**
Entry speed at 500 feet	45	46	30.363	5.391	0.795
	60	47	31.185	4.379	0.639
	75	50	30.070	4.165	0.589
	90	50	30.144	4.607	0.652
	Single Lane	50	28.346	4.703	0.665
	Total	243	30.002	4.712	0.302
Entry speed at 200 feet	45	46	24.146	4.267	0.629
	60	47	24.406	4.028	0.587
	75	50	25.546	4.986	0.705
	90	50	25.992	4.455	0.630
	Single Lane	50	20.640	3.675	0.520
	Total	243	24.143	4.681	0.300
Entry speed at 100 feet	45	46	16.883	4.080	0.602
	60	47	16.460	3.713	0.542
	75	50	18.184	4.682	0.662
	90	50	18.394	3.560	0.503
	Single Lane	50	15.644	4.847	0.685
	Total	243	17.125	4.312	0.277
Entry speed at 0 feet	45	46	9.841	2.943	0.434
	60	47	13.526	3.361	0.490
	75	50	11.152	3.753	0.531
	90	50	11.206	2.946	0.417
	Single Lane	50	16.534	5.142	0.727
	Total	243	12.482	4.399	0.282

Table 14

Descriptive Statistics for Circulatory and Exit Speed at Different Roundabouts

Location	**Roundabout Diameter (feet)**	**N**	**Mean Speed (mph)**	**Std. Deviation (mph)**	**Std. Error**
Circulating speed	45	46	9.220	2.970	0.438
	60	47	15.170	4.028	0.588
	75	50	10.720	3.519	0.498
	90	50	12.594	3.238	0.458
	Single Lane	50	17.512	4.848	0.686
	Total	243	13.080	4.802	0.308
Exit speed at 0 feet	45	46	12.294	2.498	0.368
	60	47	17.475	4.787	0.698
	75	50	13.536	2.836	0.401
	90	50	14.450	3.490	0.494
	Single Lane	50	20.944	4.562	0.645
	Total	243	15.775	4.859	0.312
Exit speed at 100 feet	45	46	24.046	3.985	0.587
	60	47	25.806	4.276	0.624
	75	50	24.144	3.191	0.451
	90	50	24.612	3.411	0.482
	Single Lane	50	26.484	4.464	0.631
	Total	243	25.025	3.977	0.255
Exit speed at 500 feet	45	46	26.504	4.728	0.697
	60	47	32.534	6.871	1.002
	75	50	27.934	4.070	0.576
	90	50	27.900	3.926	0.555
	Single Lane	50	31.324	5.809	0.822
	Total	243	29.244	5.620	0.361

Post-hoc tests have been performed among the speed data at the mini-roundabouts with ICD 45 feet, 60 feet, 75 feet, 90 feet and the single-lane roundabout. These analyses aimed to identify any significant differences in the participants' speeds between these various roundabout configurations. For the homogenous speed data, the Tukey HSD (Honestly Significant Difference) test was employed and for the speed data which were not homogenous, the Games-Howell test was used (Frost, 2019). The post-hoc tests have been shown in Table 15.

Table 15

Post-Hoc Test

Location	Post-Hoc Test	(I) Roundabout Diameter (ft)	(J) Roundabout Diameter (ft)	Mean Speed Difference (I-J)	Std. Error	Sig.
Entry500	Tukey HSD	60	Single Lane	2.839*	0.946	0.025
Entry200	Tukey HSD	45	Single Lane	-3.505*	0.880	0.001
			60	-3.766*	0.875	0
			75	-4.906*	0.862	0
			90	-5.352*	0.862	0
Entry100	Tukey HSD	75	Single Lane	-2.540*	0.843	0.024
			90	-2.750*	0.843	0.011
Entry0	Games-Howell	45	60	-3.684*	0.655	0
			Single Lane	-6.692*	0.847	0
		60	45	3.684*	0.655	0
			75	2.373*	0.723	0.012
			90	2.319*	0.643	0.005
			Single Lane	-3.008*	0.877	0.008
		75	Single Lane	-5.382*	0.900	0
		90	Single Lane	-5.328*	0.838	0
Circulating	Games-Howell	45	60	-5.950*	0.733	0
			90	-3.374*	0.634	0
			Single Lane	-8.292*	0.814	0
		60	75	4.450*	0.770	0
			90	2.576*	0.745	0.007
		75	Single Lane	-6.792*	0.847	0
		90	Single Lane	-4.918*	0.825	0
Exit0	Games-Howell	45	60	-5.180*	0.789	0
			90	-2.156*	0.616	0.006
			Single Lane	-8.650*	0.743	0
		60	75	3.938*	0.805	0
			90	3.024*	0.855	0.006
			Single Lane	-3.469*	0.951	0.004
		75	Single Lane	-7.408*	0.760	0
		90	Single Lane	-6.494*	0.812	0
Exit100	Tukey HSD	45	Single Lane	-2.438*	0.795	0.02
		75	Single Lane	-2.340*	0.778	0.024
Exit500	Games-Howell	45	60	-6.029*	1.221	0
			Single Lane	-4.819*	1.077	0
		60	75	4.600*	1.156	0.001
			90	4.634*	1.146	0.001
		75	Single Lane	-3.390*	1.003	0.009
		90	Single Lane	-3.424*	0.992	0.007

* The mean difference is significant at the 0.05 level.

Based on the descriptive statistics and the ANOVA results, the roundabouts that showed significant differences in mean speeds can be determined. As discussed in literature review, the installation of a mini-roundabout in Dimondale, Michigan, led to an 8 mph decrease in the 85th percentile speeds, from 32 mph down to 24 mph (Waddell & Albertson, 2005). Considering the mean differences which are higher than 5 mph (highlighted in green), the following conclusions can be made:

- The entry speed at 200 feet distance from the entry of the ICD 90 feet mini-roundabout (M = 25.992) is 5.35 mph higher than the entry speed at 200 feet distance from the entry of the ICD 45 feet mini-roundabout (M = 24.146). This difference is statistically significant ($p < 0.05$). The partial eta squared value of 0.167 for the entry speed at 200 feet indicates a large effect, showing that entry speed at 200 feet accounts for approximately 16.7% of the variance in speeds. The effect sizes for the entry speeds at 500 feet and yield line also indicate large effect of these locations on drivers' speed ($\eta^2 > 0.14$).
- The entry speed at the yield line of the single-lane roundabout (M = 16.534) is 6.69 mph higher than the entry speed at the yield line of the ICD 45 feet mini-roundabout (M = 9.841). This difference is statistically significant ($p = 0.00 < 0.05$) with large effect size ($\eta^2 > 0.14$). The entry speed at the yield line of the single-lane roundabout (M = 16.534) is also significantly higher than the entry speed at the yield line of the ICD 75 feet (M = 11.152) and ICD 90 feet mini-roundabout (M = 11.206).

- The circulating speed of the ICD 60 feet mini-roundabout (M = 15.17) is 5.95 mph higher than the circulating speed of the ICD 45 feet mini-roundabout (M = 9.22). This difference is statistically significant ($p = 0.00 < 0.05$). The partial eta squared value of 0.388 for the circulating speed indicates a large effect, showing that circulating speed accounts for approximately 38.8% of the variance in speed.
- The circulating speed of the single-lane roundabout (M = 17.51) is significantly higher than the circulating speed of the ICD 45 feet and ICD 75 feet mini-roundabout.
- The exit speed at 0 feet of the ICD 60 feet mini-roundabout (M = 17.47) is 5.18 mph higher than the exit speed at 0 feet of the ICD 45 feet mini-roundabout (M = 12.293). This difference is statistically significant ($p = 0.00 < 0.05$). The partial eta squared value of 0.414 indicates a large effect, showing that exit speed at 0 feet accounts for approximately 41.4% of the variance in speeds.
- The exit speed at 0 feet of the single-lane roundabout (M = 20.944) is significantly higher than the exit speed 0 feet of the ICD 45 feet (M = 12.293), ICD 75 feet (M = 12.293) and ICD 90 feet mini-roundabout (M = 12.293).
- The exit speed at 500 feet distance from the exit of the ICD 60 feet mini-roundabout (M = 32.53) is 6.03 mph higher than the entry speed at 200 feet distance from the entry of the ICD 45 feet mini-roundabout (M = 26.504). This difference is statistically significant ($p = 0.00 < 0.05$) with large effect size ($\eta^2 > 0.14$).

From the descriptive statistics and the ANOVA tests, it can be seen that the mean speed at the ICD 60 feet mini-roundabout higher than the mean speeds at the other roundabouts. Overall, there is an observed similarity in the general trend with mean speed across roundabout designs – that is, approach speeds are higher as vehicle approaches roundabout, there is a speed reduction upon entry into roundabout, and then an increase in speed upon exit of the roundabout. This observed trend was expected.

The above graph shows that the mean speed at the mini-roundabouts is significantly higher at the approach of the mini-roundabouts than the single-lane roundabout. The average speeds within the circulatory area and upon exiting the mini-roundabouts were found to be lower than those observed at the single-lane roundabout.

Mini-roundabouts, particularly those with Inscribed Circle Diameters (ICD) of 60, 75, and 90 feet, showed speed patterns akin to those of single-lane roundabouts with a 120-feet ICD. This similarity suggests that, despite their reduced dimensions, mini-roundabouts are capable of effectively regulating vehicle speeds, mirroring the performance of traditional roundabout configurations. Therefore, for the implementation of mini-roundabouts, it is recommended to consider an ICD within the range of 60 to 90 feet.

Analysis of Speed by Age Group

The participants' speed data was categorized based on age group and then the speeds at various locations within the five roundabouts were examined to assess if a participant's age influences their driving speed. For this test, Repeated Measures ANOVA has been conducted as the variables are subjected to repeated observations i.e., same specific locations at five different roundabouts. To determine the effect of age, the participants have been separated into three age groups: 18-25 years, 26-40 years, and 41-65 years.

Table 16 shows the Tests of Between-Subjects Effects for the variable age group. Table 17 shows the pairwise comparisons.

Table 16

Tests of Between-Subjects Effects: Age Group

Location	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Entry speed at 500 feet	257.862	2	128.931	2.159	0.128	0.091
Entry speed at 200 feet	200.886	2	100.443	1.914	0.16	0.082
Entry speed at 100 feet	129.266	2	64.633	1.281	0.288	0.056
Entry speed at yield line	110.708	2	55.354	1.498	0.235	0.065
Circulating speed	166.84	2	83.42	2.106	0.134	0.089
Exit speed at 0 feet	424.042	2	212.021	5.002	0.011	0.189
Exit speed at 100 feet	363.543	2	181.772	3.523	0.038	0.141
Exit speed at 500 feet	562.727	2	281.364	4.039	0.025	0.158

Table 17

Pairwise Comparisons: Age Group

Location	(I) Age	(J) Age	Mean Speed Difference (I-J)	Std. Error	Sig.b
Exit speed at 0 feet	18-25	26-40	1.531	0.931	0.322
		41-65	4.095	1.335	0.011
Exit speed at 100 feet	18-25	26-40	1.346	1.027	0.591
		41-65	3.819	1.473	0.039
Exit speed at 500 feet	26-40	18-25	2.006	1.194	0.3
		41-65	4.899	1.772	0.025

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusions can be made:

- The age group is a significant factor for the drivers exit speeds at the 0 feet, 100 feet and 500 feet from the exit of the roundabouts ($p < 0.05$). The partial eta squared value of 0.189 for the exit speed at 0 feet indicates a large effect of the age group on drivers' exit speeds, showing that age accounts for approximately 18.9% of the variance in exit speeds. The effect sizes for the exit speeds at 100 feet and 500 feet also indicate large effect of the age group on drivers' exit speed ($\eta^2 > 0.14$).
- The mean speed is significantly higher for the drivers from age group 18-25 years than the drivers from age group 41-65 years at 0 feet and 100 feet from the exit of the roundabouts ($p < 0.05$).

- The mean speed is significantly higher for the drivers from age group 26-40 years than the drivers from age group 41-65 years at 500 feet from the exit of the roundabouts ($p < 0.05$).

Analysis of Speed by Gender

The speed data at different roundabouts has also been analyzed based on gender. Table 18 shows the Tests of Between-Subjects Effects for the variable gender. Table 19 shows the pairwise comparisons.

Table 18

Tests of Between-Subjects Effects: Gender

Location	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Entry speed at 500 feet	87.355	1	87.355	1.404	0.242	0.031
Entry speed at 200 feet	244.739	1	244.739	4.865	0.033	0.1
Entry speed at 100 feet	89.215	1	89.215	1.777	0.189	0.039
Entry speed at yield line	22.358	1	22.358	0.586	0.448	0.013
Circulating speed	174.203	1	174.203	4.52	0.039	0.093
Exit speed at 0 feet	214.541	1	214.541	4.645	0.037	0.095
Exit speed at 100 feet	166.74	1	166.74	3.038	0.088	0.065
Exit speed at 500 feet	563.635	1	563.635	8.282	0.006	0.158

Table 19

Pairwise Comparisons: Gender

Location	(I) Gender	(J) Gender	Mean Speed Difference (I-J)	Std. Error	Sig.b
Entry speed at 200 feet	Male	Female	2.600*	1.179	0.033
Circulating speed	Male	Female	2.194*	1.032	0.039
Exit speed at 0 feet	Male	Female	2.435*	1.13	0.037
Exit speed at 500 feet	Male	Female	3.946*	1.371	0.006

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusions can be made:

- Gender is a significant factor for the drivers entry speeds at 200 feet from the entry of the roundabout and for the circulating speed. The gender is a significant factor also for the drivers exit speeds at the exit point, and 500 feet from the exit of the roundabouts ($p<0.05$). The partial eta squared value of 0.1 for the entry speed at 200 feet indicates a moderate effect of gender on drivers' exit speeds, showing that gender accounts for approximately 10% of the variance in entry speeds. The effect sizes for the circulating speed and exit speed at 0 feet also indicate moderate effect of gender on drivers' exit speed ($\eta^2 > 0.06$). The effect size for the exit speed at 500 feet indicate large effect of gender on drivers' exit speed ($\eta^2 > 0.14$).

- The mean speed is significantly higher for the male drivers than the female drivers at 200 feet from the entry of the roundabout, in the circulating area, at 0 feet and 500 feet from the exit of the roundabouts ($p < 0.05$).

Analysis of Speed by Daylight Condition

The speed data at different roundabouts has also been analyzed based on daylight condition. Table 20 shows the Tests of Between-Subjects Effects for the variable daylight condition. Table 21 shows the pairwise comparisons.

Table 20

Tests of Between-Subjects Effects: Daylight Condition

Location	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Entry speed at 500 feet	263.113	1	263.113	4.518	0.039	0.093
Entry speed at 200 feet	282.939	1	282.939	5.724	0.021	0.115
Entry speed at 100 feet	63.657	1	63.657	1.253	0.269	0.028
Entry speed at yield line	77.604	1	77.604	2.104	0.154	0.046
Circulating speed	53.088	1	53.088	1.286	0.263	0.028
Exit speed at 0 feet	56.504	1	56.504	1.135	0.292	0.025
Exit speed at 100 feet	13.538	1	13.538	0.232	0.633	0.005
Exit speed at 500 feet	130.277	1	130.277	1.672	0.203	0.037

Table 21

Pairwise Comparisons: Daylight Condition

Location	**(I) Condition**	**(J) Condition**	**Mean Speed Difference (I-J)**	**Std. Error**	**Sig.b**
Entry speed at 500 feet	Day	Night	-2.139*	1.006	0.039
Entry speed at 200 feet	Day	Night	-2.218*	0.927	0.021

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusions can be made:

- The daylight condition is a significant factor for the drivers entry speeds at 500 feet and 200 feet from the entry of the roundabout ($p < 0.05$). The partial eta squared value of 0.093 for the entry speed at 500 feet indicates a moderate effect of daylight condition on drivers' entry speeds, showing that daylight condition accounts for approximately 9.3% of the variance in entry speeds. The effect size for the entry speed at 200 feet indicates moderate effect of daylight condition on drivers' entry speed ($\eta^2 > 0.06$).
- The mean speed is significantly higher at night conditions than day conditions at 500 feet and 200 feet from the entry of the roundabout ($p < 0.05$).

Summary of Speed Data Analysis (No Pedestrian Crossing Scenarios)

Table 22 shows the summarized vehicle speed comparisons across different mini-roundabout designs with no pedestrian crossings.

Table 22

Comparisons of Speeds Across Mini-Roundabouts with No Pedestrian Crossings

Speed Type	Location at the Roundabout	Roundabout ICDs with Significant Speed Differences?	Average Speed Difference (mph)	Std. Error
Entry Speed	500 feet prior to the yield line	None	-	-
	200 feet prior to the yield line	ICD 90 feet vs. 45 feet	5.35	0.86
	100 feet prior to the yield line	None	-	-
	At the entry yield line	ICD 120 feet vs. 45 feet	6.69	0.84
		ICD 120 feet vs. 75 feet	5.38	0.90
		ICD 120 feet vs. 90 feet	5.32	0.83
Circulating Speed		ICD 60 feet vs. 45 feet	5.95	0.73
		ICD 120 feet vs. 45 feet	8.29	0.81
		ICD 120 feet vs. 75 feet	6.79	0.84
Exit Speed	At the exit yield line	ICD 60 feet vs. 45 feet	5.18	0.80
		ICD 120 feet vs. 45 feet	8.65	0.74
		ICD 120 feet vs. 75 feet	7.41	0.76
		ICD 120 feet vs. 90 feet	6.49	0.81
	100 feet past the yield line	None	-	-
	500 feet past the yield line	ICD 60 feet vs. 45 feet	6.03	1.22

Based on the speed comparisons at mini-roundabouts with no pedestrian crossings, following conclusions can be made:

- In general, mini-roundabout entry speeds are 5.3 to 6.7 mph lower compared to single lane roundabouts. This is consistent with the case study by Waddell & Albertson (2005), which documented an 8 mph reduction in the 85th percentile speeds at a mini-roundabout in Dimondale, Michigan, from 32 mph to 24 mph. The findings from our study align with previous studies, supporting the effectiveness of mini-roundabouts as a traffic calming measure. (Waddell & Albertson, 2005).

- Compared to the single-lane roundabout (ICD = 120-feet), the speed curves for mini-roundabouts exhibit a similar pattern, displaying higher speeds on the approach regardless of the mini-roundabout's ICD size. However, approximately 100 feet before the yield line of the approach, average speed drops by about 5 mph for mini-roundabout options.
- On average, mini-roundabout circulatory speeds are about 6.8 to 8.3 mph lower compared to single lane roundabouts. The exit speeds at mini-roundabouts are about 6.5 to 8.7 mph lower compared to single lane roundabouts.
- Predictably, circulatory speeds and exit speeds are consistently lower for mini-roundabout alternatives than those observed in the single-lane roundabout. Irrespective of their ICD size, mini-roundabouts naturally prompted drivers to reduce their speed both upon entry and within the circulatory zone, effectively serving as a traffic calming measure.
- The analysis of speed curves for mini-roundabouts with different ICDs revealed patterns consistent with those of a single-lane roundabout with a 120-feet ICD. This suggests a positive outcome where drivers were capable of navigating mini-roundabouts in a manner akin to their experience with the more familiar single-lane roundabout design.

Analysis of Speed at Roundabouts With Pedestrian Crossing

Introduction

This analysis focuses on drivers’ speeds at roundabouts with pedestrian crossings, evaluating overall speeds and the effects of variables like age, gender, and daylight conditions using statistical methods. The pedestrian crossing scenarios have pedestrian crossings at 20 feet from the entry of the roundabout. When the drivers are approaching towards the roundabout, some pedestrians crossed the road from random directions which caused the drivers to slow down or come to a complete stop. The main aim is to determine if differences in roundabout diameters notably affect drivers’ average speeds and to investigate how pedestrian crosswalks and activities influence drivers’ speed behavior.

Analysis of Overall Speed Data

Speed data were collected along approach to roundabout (i.e., at 500 feet, 400 feet, 300 feet, 200 feet, 100 feet, 0 feet (yield line)), two locations within the circulatory area of roundabout, and along approach from roundabout (i.e., 0 feet (exit line), 100 feet, 200 feet, 300 feet, 400 feet, and 500 feet). Test for normality has been performed for all of the speed data using SPSS. The test for normality ensures that the speed data from participants adhere to a normal distribution, which is essential for the accuracy of further statistical analyses. The speed data at every location were found to be normal.

Test of homogeneity of variances have been performed for all of the speed data as showed in Table 23. The test of homogeneity ensures the variability or spread of speed data around the roundabout is uniform across all participant groups. The speed data from

500 feet to 100 feet from the entry and the speed data at 100 feet to 500 feet from the exit (highlighted in green) of the roundabout were homogenous. The speed data at entry yield line, the circulating speed and the speed data at 0 feet from the exit (highlighted in red) of the roundabout were not homogenous.

Table 23

Test of Homogeneity of Variances

Location	Levene Statistic	Sig.
Entry speed at 500 feet	0.546	0.702
Entry speed at 400 feet	0.081	0.989
Entry speed at 300 feet	0.472	0.758
Entry speed at 200 feet	0.378	0.824
Entry speed at 100 feet	1.535	0.193
Entry speed at yield line	3.72	0.006
Circulating Speed	5.572	<.001
Exit speed at 0 feet	6.073	<.001
Exit speed at 100 feet	2.129	0.079
Exit speed at 200 feet	0.791	0.538
Exit speed at 300 feet	1.773	0.132
Exit speed at 400 feet	2.348	0.055
Exit speed at 500 feet	1.577	0.182

The ANOVA test is then conducted to identify specific locations where significant speed variations among participants are observed, allowing for a detailed understanding of driving behavior at different points around the roundabouts. Table 24**Error! Reference source not found.** shows the summary of the ANOVA test. The ANOVA test indicated that speeds at all studied locations significantly differed (highlighted in red). To identify locations of significant speed variation among drivers, their mean speed profiles at different roundabouts were plotted, as illustrated in Figure 26. The analysis of the mean speed profile of drivers, led to the selection of entry speed at 200 feet, 100 feet and 0 feet, one circulating speed, and the exit speed at 0 feet, 100 feet and 500 feet.

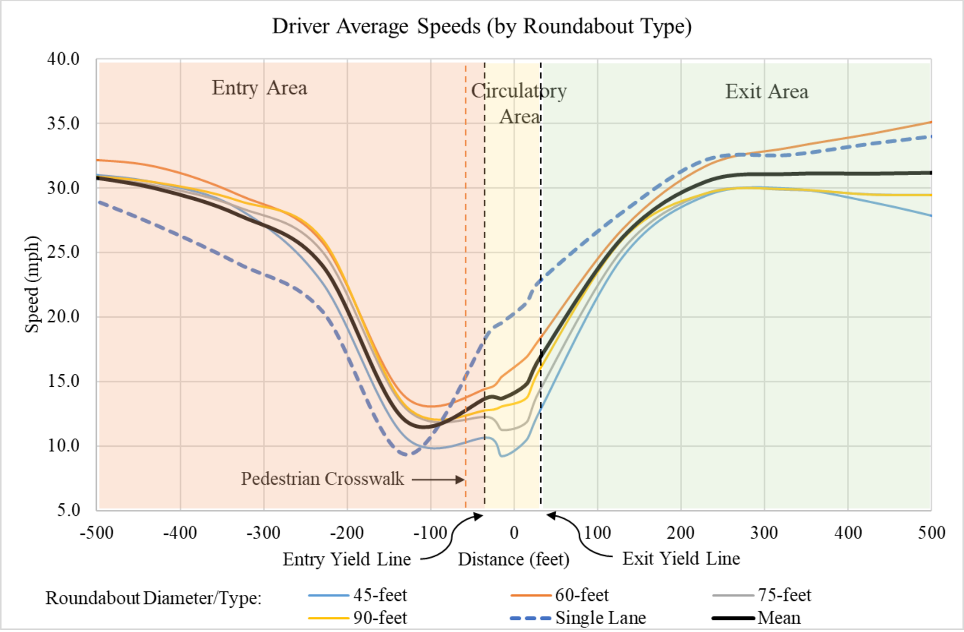
Table 24

ANOVA Test

Location	**F**	**Sig.**	**Eta-squared**
Entry speed at 200 feet	9.281	0.001	0.2
Entry speed at 100 feet	4.086	0.003	0.18
Entry speed at yield line	35.64	0.001	0.32
Circulating speed	55.916	0.001	0.35
Exit speed at 0 feet	52.83	0.001	0.381
Exit speed at 100 feet	6.741	0.001	0.313
Exit speed at 500 feet	20.631	0.001	0.171

Figure 26

Mean Speed Variation



From the ANOVA test results, the following conclusions can be made:

- The entry speeds at 200 feet, 100 feet and yield line show significant differences ($p<0.05$) with large effect sizes ($\eta^2 > 0.14$). This suggests a strong influence of these locations on driver behavior and speed choice as they approach the roundabout.
- The circulating speed demonstrate significant differences ($p<0.05$), accompanied by large effect size ($\eta^2 > 0.14$). This indicates a substantial influence of circulating speed on the variability of driver speeds within the roundabout.

- The exit speeds at 0 feet, 100 feet and 500 feet show significant differences ($p<0.05$) with large effect sizes ($\eta^2 > 0.14$). This indicates that these specific locations significantly impact the variability of exit speeds.

The descriptive statistics for the entry speed at the selected locations have been presented in Table 25. The descriptive statistics for the circulatory speed and exit speed at the selected locations have been presented in Table 26.

Table 25

Descriptive Statistics for the Entry Speed at Different Roundabouts

Location	Roundabout Diameter (feet)	N	Mean Speed (mph)	Std. Deviation (mph)	Std. Error
Entry speed at 200 feet	45	41	22.688	5.244	0.819
	60	41	25.793	4.588	0.717
	75	41	25.054	5.159	0.806
	90	41	26.061	4.808	0.751
	Single Lane	41	20.463	5.121	0.800
	Total	205	24.012	5.385	0.376
Entry speed at 100 feet	45	41	10.690	4.824	0.753
	60	41	13.773	6.269	0.979
	75	41	12.915	6.426	1.004
	90	41	13.110	5.522	0.862
	Single Lane	41	9.342	6.411	1.001
	Total	205	11.966	6.101	0.426
Entry speed at yield line	45	41	10.659	2.741	0.428
	60	41	14.510	3.646	0.569
	75	41	12.239	2.636	0.412
	90	41	12.800	3.167	0.495
	Single Lane	41	18.832	4.298	0.671
	Total	205	13.808	4.347	0.304

Table 26

Descriptive Statistics for Circulatory and Exit Speed at Different Roundabouts

Location	Roundabout Diameter (feet)	N	Mean Speed (mph)	Std. Deviation (mph)	Std. Error
Circulating speed	45	41	9.237	2.876	0.449
	60	41	15.366	3.674	0.574
	75	41	11.251	2.474	0.386
	90	41	13.071	2.943	0.460
	Single Lane	41	19.556	4.642	0.725
	Total	205	13.696	4.912	0.343
Exit speed at 0 feet	45	40	12.678	2.500	0.395
	60	41	18.261	3.812	0.595
	75	41	14.251	2.581	0.403
	90	41	15.905	3.304	0.516
	Single Lane	41	22.771	4.617	0.721
	Total	204	16.793	4.917	0.344
Exit speed at 100 feet	45	40	24.695	3.530	0.558
	60	41	26.817	3.168	0.495
	75	41	25.249	2.743	0.428
	90	41	26.051	3.232	0.505
	Single Lane	41	28.163	3.952	0.617
	Total	204	26.203	3.533	0.247
Exit speed at 500 feet	45	39	27.421	4.388	0.703
	60	41	35.481	5.052	0.789
	75	41	29.454	4.373	0.683
	90	41	29.463	4.565	0.713
	Single Lane	41	34.224	5.664	0.885
	Total	203	31.246	5.701	0.400

Post-hoc tests have been performed among the speed data at the mini-roundabouts with ICD 45 feet, 60 feet, 75 feet, 90 feet and the single-lane roundabout. These analyses aimed to identify any significant differences in the participants' speeds between these various roundabout configurations. The post-hoc tests have been shown in Table 27.

Table 27

Post-Hoc Test

Location	Post-Hoc Test	(I) Roundabout Diameter (ft)	(J) Roundabout Diameter (ft)	Mean Speed Difference (I-J)	Std. Error	Sig.
Entry200	Tukey HSD	45	60	-3.104*	1.102	0.042
		60	Single Lane	5.329*	1.102	<.001
		75	Single Lane	4.590*	1.102	<.001
		90	Single Lane	5.597*	1.102	<.001
Entry100	Tukey HSD	60	Single Lane	4.431*	1.308	0.008
Entry0	Games-Howell	45	60	-3.851*	0.712	<.001
			Single Lane	-8.173*	0.796	<.001
		60	Single Lane	-4.321*	0.880	<.001
		75	Single Lane	-6.592*	0.787	<.001
		90	Single Lane	-6.031*	0.834	<.001
Circulating	Games-Howell	45	60	-6.129*	0.729	<.001
			Single Lane	-10.319*	0.853	<.001
		60	75	4.114*	0.692	<.001
			Single Lane	-4.190*	0.925	<.001
			Single Lane	-8.304*	0.821	<.001
		90	Single Lane	-6.485*	0.858	<.001
Exit0	Games-Howell	45	60	-5.583*	0.715	<.001
			Single Lane	-10.093*	0.822	<.001
		60	75	4.009*	0.719	<.001
			Single Lane	-4.509*	0.935	<.001
		75	Single Lane	-8.519*	0.826	<.001
		90	Single Lane	-6.865*	0.887	<.001
Exit100	Tukey HSD	45	60	-2.122*	0.744	0.038
			Single Lane	-3.468*	0.744	<.001
Exit500	Tukey HSD	45	60	-8.059*	1.082	<.001
			Single Lane	-6.803*	1.082	<.001
		60	75	6.026*	1.069	<.001
			90	6.017*	1.069	<.001
		75	Single Lane	-4.770*	1.069	<.001
		90	Single Lane	-4.760*	1.069	<.001

* The mean difference is significant at the 0.05 level.

From the descriptive statistics and the ANOVA tests, the roundabouts which show significant difference in mean speeds can be found. As discussed in literature review, the installation of a mini-roundabout in Dimondale, Michigan, led to an 8 mph decrease in the 85th percentile speeds, from 32 mph down to 24 mph (Waddell & Albertson, 2005). Considering the mean differences which are higher than 5 mph (highlighted in green), the following conclusions can be made:

- The entry speed at 200 feet distance from the entry of the ICD 60 feet mini-roundabout ($M = 25.79$) is 5.33 mph higher than the entry speed at 200 feet distance from the entry of the single-lane roundabout ($M = 20.46$). The difference is statistically significant ($p = 0.00 < 0.05$). The partial eta squared value of 0.2 for the entry speed at 200 feet indicates a large effect, showing that entry speed at 200 feet accounts for approximately 20% of the variance in speeds. The effect sizes for the entry speeds at 100 feet and yield line also indicate large effect of these locations on drivers' speed ($\eta^2 > 0.14$).
- The entry speed at the yield line of the single-lane roundabout ($M = 18.83$) is 8.17 mph higher than the entry speed at the yield line of the ICD 45 feet mini-roundabout ($M = 10.66$). This difference is statistically significant ($p = 0.00 < 0.05$). The entry speed at the yield line of the single-lane roundabout is also significantly higher than the entry speed at the yield line of the ICD 75 feet and ICD 90 feet mini-roundabout.
- The circulating speed of the ICD 60 feet mini-roundabout ($M = 15.37$) is 6.13 mph higher than the circulating speed of the ICD 45 feet mini-roundabout (M =

9.24). This difference is statistically significant (p = 0.00 < 0.05). The partial eta squared value of 0.35 for the circulating speed indicates a large effect, showing that circulating speed accounts for approximately 35% of the variance in speed.

- The circulating speed of the single-lane roundabout (M = 19.56) is 10.32 mph higher than the circulating speed of the ICD 45 feet mini-roundabout. This difference is statistically significant (p = 0.00 < 0.05). It is also significantly higher than the circulating speed of the ICD 75 feet and ICD 90 feet mini-roundabout.
- The exit speed at 0 feet of the ICD 60 feet mini-roundabout (M = 18.26) is 5.58 mph higher than the exit speed of the ICD 45 feet mini-roundabout (M = 12.68). This difference is statistically significant (p = 0.00 < 0.05). The partial eta squared value of 0.381 indicates a large effect, showing that exit speed at 0 feet accounts for approximately 38.1% of the variance in speeds.
- The exit speed at 0 feet of the single-lane roundabout (M = 22.77) is 10.09 mph higher than the exit speed of the ICD 45 feet mini-roundabout. This difference is statistically significant (p = 0.00 < 0.05). It is also significantly higher than the exit speed at 0 feet of the ICD 75 feet and ICD 90 feet mini-roundabout.
- The exit speed at 500 feet distance from the exit of the ICD 60 feet mini-roundabout (M = 35.48) is 8.06 mph higher than the exit speed at 500 feet distance from the exit of the ICD 45 feet mini-roundabout (M = 27.42). This difference is statistically significant (p = 0.00 < 0.05). It is also significantly

higher than the exit speed at the exit point of the ICD 75 feet and ICD 90 feet mini-roundabout with large effect size ($\eta^2 > 0.14$).

Analysis of Speed by Age Group

The participants' speed data was categorized based on age group and then the speeds at various locations within the five roundabouts were examined to assess if a participant's age influences their driving speed. For this test, Repeated Measures ANOVA has been conducted as the variables are subjected to repeated observations i.e., same specific locations at five different roundabouts. To determine the effect of age, the participants have been separated into three age groups: 18-25 years, 26-40 years, and 41-65 years.

Table 28 shows the Tests of Between-Subjects Effects for the variable age group.

Table 28

Tests of Between-Subjects Effects: Age Group

Location	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Entry speed at 500 feet	86.893	2	43.447	0.513	0.603	0.026
Entry speed at 200 feet	274.528	2	137.264	1.777	0.183	0.086
Entry speed at 100 feet	136.542	2	68.271	0.737	0.485	0.037
Entry speed at yield line	157.021	2	78.51	2.287	0.115	0.107
Circulating speed	170.144	2	85.072	2.678	0.082	0.124
Exit speed at 0 feet	131.484	2	65.742	1.708	0.195	0.085
Exit speed at 100 feet	30.032	2	15.016	0.386	0.682	0.02
Exit speed at 500 feet	254.39	2	127.195	2.032	0.146	0.101

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusion can be made:

- The age group is not a significant factor for the drivers speeds at any location of the roundabouts with pedestrian crosswalks.

Analysis of Speed by Gender

The speed data at different roundabouts has also been analyzed based on gender. Table 29 shows the Tests of Between-Subjects Effects for the variable gender.

Table 29

Tests of Between-Subjects Effects: Gender

Location	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Entry speed at 500 feet	2.467	1	2.467	0.029	0.865	0.001
Entry speed at 200 feet	79.188	1	79.188	0.987	0.327	0.025
Entry speed at 100 feet	4.971	1	4.971	0.053	0.819	0.001
Entry speed at yield line	10.257	1	10.257	0.276	0.603	0.007
Circulating speed	0.131	1	0.131	0.004	0.952	0
Exit speed at 0 feet	25.005	1	25.005	0.621	0.436	0.016
Exit speed at 100 feet	56.08	1	56.08	1.508	0.227	0.038
Exit speed at 500 feet	63.419	1	63.419	0.96	0.334	0.025

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusions can be made:

- Gender is not a significant factor for the drivers speeds at any location of the roundabouts with pedestrian crosswalks.

Analysis of Speed by Daylight Condition

The speed data at different roundabouts has also been analyzed based on daylight condition. Table 30 shows the Tests of Between-Subjects Effects for the variable daylight condition. Table 31 shows the pairwise comparisons.

Table 30

Tests of Between-Subjects Effects: Daylight Condition

Location	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Entry speed at 500 feet	0.157	1	0.157	0.002	0.966	0
Entry speed at 200 feet	110.2	1	110.2	1.387	0.246	0.034
Entry speed at 100 feet	489.954	1	489.954	6.037	0.019	0.134
Entry speed at yield line	0.962	1	0.962	0.026	0.873	0.001
Circulating speed	23.091	1	23.091	0.665	0.42	0.017
Exit speed at 0 feet	23.986	1	23.986	0.595	0.445	0.015
Exit speed at 100 feet	9.656	1	9.656	0.251	0.619	0.007
Exit speed at 500 feet	17.612	1	17.612	0.262	0.612	0.007

Table 31

Pairwise Comparisons: Daylight Condition

Location	**(I) Condition**	**(J) Condition**	**Mean Speed Difference (I-J)**	**Std. Error**	**Sig.b**
Entry speed at 100 feet	Day	Night	-4.218*	1.612	0.013

Based on the Between-Subjects Effects and the pairwise comparisons, the following conclusions can be made:

- The daylight condition is a significant factor for the drivers entry speeds at 100 feet from the entry of the roundabout ($p < 0.05$). The partial eta squared value of 0.134 for the entry speed at 100 feet indicates a moderate effect of daylight condition on drivers' entry speeds, showing that daylight condition accounts for approximately 13.4% of the variance in entry speeds.

- The mean speed is significantly higher at night conditions than day conditions at 100 feet from the entry of the roundabout ($p < 0.05$).

Summary of Speed Data Analysis (Pedestrian Crossing Scenarios)

Table 32 shows the summarized vehicle speed comparisons across different mini-roundabout designs with pedestrian crossings.

Table 32

Comparisons of Speeds Across Mini-Roundabouts with Pedestrian Crossings

Speed Type	**Location at the Roundabout**	**Roundabout ICDs with Significant Speed Differences?**	**Average Speed Difference (mph)**	**Std. Error**
Entry Speed	500 feet prior to the yield line	None	-	-
	200 feet prior to the yield line	ICD 60 feet vs. 120 feet	5.33	1.10
		ICD 90 feet vs. 120 feet	5.60	1.10
	100 feet prior to the yield line	None	-	-
	At the entry yield line	ICD 120 feet vs. 45 feet	8.17	0.80
		ICD 120 feet vs. 75 feet	6.59	0.79
		ICD 120 feet vs. 90 feet	6.03	0.83
Circulating Speed		ICD 60 feet vs. 45 feet	6.13	0.73
		ICD 120 feet vs. 45 feet	10.32	0.85
		ICD 120 feet vs. 75 feet	8.31	0.82
		ICD 120 feet vs. 90 feet	6.49	0.86
Exit Speed	At the exit yield line	ICD 60 feet vs. 45 feet	5.58	0.71
		ICD 120 feet vs. 45 feet	10.09	0.82
		ICD 120 feet vs. 75 feet	8.52	0.83
		ICD 120 feet vs. 90 feet	6.87	0.89
	100 feet past the yield line	None	-	-
	500 feet past the yield line	ICD 60 feet vs. 45 feet	8.06	1.08
		ICD 120 feet vs. 45 feet	6.80	1.08
		ICD 60 feet vs. 75 feet	6.03	1.07
		ICD 60 feet vs. 90 feet	6.02	1.07

Based on the speed comparisons at mini-roundabouts with pedestrian crossings, following conclusions can be made:

- The speed curves for mini-roundabouts with pedestrian crossings also exhibit a similar pattern compared to the single lane roundabout. However, approximately 200 feet before the yield line of the approach, mini-roundabout average speeds were found 5.3 to 5.6 mph higher than the single lane roundabout.
- The entry speeds 100 feet before the roundabouts with pedestrian crossings were generally lower than the roundabouts without pedestrian crossings. The pedestrian crossings were 20 feet before the entry yield line of the roundabouts. Due to the presence of pedestrians, drivers were required to exercise increased caution and, in many instances, come to a complete stop, thereby resulting in reduced average speeds.
- In general, mini-roundabout entry speeds near the entry yield line of the approach are 6.0 to 8.2 mph lower compared to the single lane roundabout. Mini-roundabout circulatory speeds are about 6.5 to 10.3 mph lower compared to single lane roundabouts. The exit speeds at mini-roundabouts are about 6.8 to 10.1 mph lower compared to single lane roundabouts.
- Similar to the mini-roundabouts without pedestrian crossings, circulatory speeds and exit speeds are consistently lower for mini-roundabouts with pedestrian crossings than those observed in the single-lane roundabout.

Analysis of Brake Force (No Pedestrian Crossing Scenarios)

Analyzing brake force helps understand how drivers adjust their speed upon approaching roundabouts. Recording mean brake force at the entry and circulatory areas reveals drivers' reactions to roundabout warning signs, speed limits, and the presence of other vehicles. This data is crucial for evaluating drivers' anticipatory and reactive behaviors, which are key to assessing roundabout safety and design effectiveness.

The mean brake force at the entry and circulatory area of the roundabout has been recorded for each participant. As the participants approached towards the roundabouts, the roundabout warning sign and the 15-mph speed limit became visible to them. Also moving forward, the participants encountered either some pedestrians crossing the road or some cars navigating in the circulatory area of the roundabouts. These events caused the participants to hit the brake pedal to slow down or come to a complete stop. The brake force is measured on a scale of 0 to 1, 0 being no brake force and 1 being the maximum brake force. The maximum break force and also the locations where the brake pedal was pressed were also recorded. The brakes were pressed within the range of 300 feet distance from the entry of the roundabouts to the circulatory area of the roundabouts. That is why break force data have been taken at every 50 feet interval starting from 300 feet from the roundabouts to the yield line and also in the circulatory area.

Table 33 shows the mean break force of the participants in the “No Pedestrian Crossing” scenarios. In the “No Pedestrian Crossing” scenarios, the participants do not confront any pedestrian; however, they had to brake at certain points due to vehicles approaching to the roundabouts from different directions. The mean brake force has been categorized into three groups. Brake force (B) higher than 0.06 is categorized as high (highlighted in red), brake force (B) between 0.03 and 0.06 is categorized as medium (highlighted in yellow) and brake force (B) below 0.03 is categorized as low brake force (highlighted in green).

Table 33

Mean Brake Force (No Pedestrian Crossing Scenarios)

Roundabout Diameter/Type	**75 feet**	**Single Lane**	**90 feet**	**60 feet**	**45 feet**
Brake force at 300 feet	0.004	0.017	0.005	0.007	0.014
Brake force at 250 feet	0.004	0.009	0.008	0.022	0.024
Brake force at 200 feet	0.023	0.011	0.024	0.037	0.044
Brake force at 150 feet	0.048	0.030	0.057	0.037	0.044
Brake force at 100 feet	0.086	0.053	0.080	0.062	0.071
Brake force at 50 feet	0.092	0.021	0.084	0.061	0.072
Brake force at yield line	0.017	0.012	0.006	0.003	0.014
Brake force in the circle	0.037	0.006	0.014	0.007	0.034

Based on the brake force data of the “No Pedestrian Crossing” scenarios, following conclusions can be made:

- High brake forces (B>0.06) predominantly occurred within 100 feet and 50 feet distance from the entry of the mini-roundabouts. This suggests that as drivers near the roundabout, they become more cautious or possibly react to the layout and traffic conditions, prompting them to decelerate significantly to safely navigate the roundabout.

- Majority of the medium brake forces ($0.03<B\leq0.06$) occurred within 200 feet and 100 feet distance from the entry of the mini-roundabouts. This gradual deceleration might be a response to the visibility of the roundabout, traffic signage, or the actions of other vehicles within the roundabout, highlighting the drivers' anticipation of having to yield or adjust speed according to the roundabout's traffic flow.
- The maximum mean brake force is found at 50 feet from the entry of the ICD 75 feet mini-roundabout, with a mean value of 0.092.
- Mini-roundabouts experienced a higher incidence of strong braking compared to single-lane roundabouts, where such intense braking was less common. The design of mini-roundabouts, intended to slow traffic and improve safety through reduced vehicle speeds, appears to effectively influence driver behavior in line with these goals.

Analysis of Brake Force (Pedestrian Crossing Scenarios)

In the “Pedestrian Crossing” scenarios, there are pedestrians crossing the road at 20 feet distance from the entry of the roundabouts. So the participants in average, pressed the brake pedal earlier in these scenarios than in the “No Pedestrian Crossing” scenarios. Table 34 shows the mean break force of the participants in the “Pedestrian Crossing” scenarios. The mean brake force has been categorized into three groups. Brake force (B) higher than 0.06 is categorized as high (highlighted in red), brake force (B) between 0.03 and 0.06 is categorized as medium (highlighted in yellow) and brake force (B) below 0.03 is categorized as low brake force (highlighted in green).

Table 34

Mean Brake Force (Pedestrian Crossing Scenarios)

Roundabout Diameter/Type	75 feet	Single Lane	90 feet	60 feet	45 feet
Brake force at 300 feet	0.006	0.016	0.009	0.017	0.017
Brake force at 250 feet	0.018	0.020	0.016	0.023	0.041
Brake force at 200 feet	0.027	0.019	0.045	0.040	0.070
Brake force at 150 feet	0.071	0.048	0.113	0.045	0.068
Brake force at 100 feet	0.129	0.127	0.084	0.136	0.077
Brake force at 50 feet	0.043	0.010	0.032	0.041	0.021
Brake force at yield line	0.009	0.004	0.009	0.007	0.039
Brake force in the circle	0.022	0.008	0.016	0.003	0.028

Based on the brake force data of the “Pedestrian Crossing” scenarios, following conclusions can be made:

- High brake forces ($B>0.06$) primarily occurred within 150 feet and 100 feet distance from the entry of the mini-roundabouts. This increased caution is likely a response to the potential for pedestrians to cross, necessitating a more immediate and significant reduction in speed to ensure safety.
- Majority of the medium brake forces ($0.03<B\leq0.06$) occurred within 100 feet and 50 feet distance from the entry of the mini-roundabouts.
- The maximum mean brake force is found at 100 feet from the entry of the ICD 60 feet mini-roundabout, with a mean value of 0.136.
- Mean brake forces at different locations are comparatively higher in the “Pedestrian Crossing” scenarios than in the “No Pedestrian Crossing” scenarios. Drivers exhibit a tendency to brake more frequently and intensely, underscoring

the critical role of pedestrian crossings in traffic calming strategies at roundabouts.

- High brake forces occurred more in the mini-roundabouts where these were less frequent in the single-lane roundabout.

Logistic Regression Modeling

Along with statistical comparisons and hypothesis testing based on the collected data, this study also sought to explore any relationships between speeding behavior within mini-roundabouts and human factors. Previous research has consistently indicated that both the age and gender of drivers significantly influence their speeding behavior. Studies have found that younger drivers, particularly males, are more likely to engage in speeding compared to older or female drivers (Familar et al., 2011; Islam & Mannering, 2021). Previous studies have also indicated that daylight conditions have a significant impact on speeding behavior (Bellis et al., 2018; Yuan et al., 2024). Thus, to explore the factors influencing speeding behavior at mini-roundabouts, this study focuses on these three variables - age, gender, and daylight conditions.

In this study, logistic regression was performed to specifically address the binary nature of our research question: whether human factors increase the likelihood of exceeding speed limits. This methodological choice reflects our focus on the binary outcome of speeding behavior (yes/no) rather than the continuous variable of speed itself. Logistic regression is a statistical method used to examine situations where one or more independent variables influence an outcome variable. (Liu, 2018). It is better suited for modeling and interpreting the probabilities associated with binary outcomes, offering more relevant insights into the factors influencing the occurrence of speeding.

In this research, the phenomenon of interest was whether drivers were speeding through mini-roundabouts, a binary outcome coded as speeding (1) or not speeding (0). The posted speed limit for the mini-roundabouts was 15 miles per hour (mph). Drivers exceeding the posted speed limit in the circulatory area by 5 mph or more were classified as speeding. The speed data of all the participants was obtained after the simulation study. Independent variables included in the analysis were gender, age group, and daylight condition, serving as predictors of speeding behavior. Logistic regression was employed to model the relationship between these predictors and the likelihood of speeding. The probability of a driver being categorized as either speeding or not is determined by the logistic function:

$$p(Y) = \frac{e^{z}}{1 + e^{z}} \tag{2}$$

Here, e represents the base of the natural logarithm (approximately 2.71828), and z is a linear combination of the predictor variables, defined as:

$$z = a + b_1X_1 + b_2X_2 + \cdots + b_pX_p \tag{3}$$

The null hypothesis tested in this analysis is that the selected independent variables have no impact on a driver's speeding behavior. Conversely, the alternative hypothesis is that the independent variables significantly predict the speeding behavior, which is the categorical dependent variable.

The results of critical gap, speed and brake force analysis suggest that mini-roundabouts, despite their smaller dimensions, exhibit speed patterns that are consistent with those observed in larger single-lane roundabouts with a 120-feet ICD, effectively controlling vehicle speeds in a manner comparable to these broader configurations. However, a closer analysis of the results reveals that mini-roundabouts with a 45-feet ICD effectively reduce vehicle speeds but potentially impact traffic flow due to longer driver wait times. In contrast, mini-roundabouts with ICDs ranging from 60 to 90 feet demonstrated consistent and efficient traffic management, balancing safety and operational efficiency. Consequently, for the logistic regression analysis, speed data from the 60-feet ICD mini-roundabouts were selected to investigate potential correlations between speeding behavior and various independent variables.

Logistic Regression Variables

Out of 50 participants, 47 successfully completed navigation through the 60-feet ICD mini-roundabout. The remaining 3 participants could not navigate through all roundabouts; hence their speed data was not considered in the Logistic Regression Modeling. The participants represented a diverse mix of age groups, genders, and experienced different daylight conditions. These factors were considered as independent variables, presumed to have a notable influence on the participants' tendencies to speed. Table 35 outlines the variables employed in the logistic regression analysis. Table 36 summarizes the descriptives of the independent variables.

Table 35

Logistic Regression Variables

	Variables	Variable Types	Variable Coding
1	Age Group	Independent	0 = 18-25 Years, 1 = 26-40 Years, 2 = 41 Years or More
2	Gender	Independent	0 = Male, 1 = Female
3	Daylight Condition	Independent	0 = Day, 1 = Night
4	Speeding Behavior	Dependent	0 = Not Speeding, 1 = Speeding

Table 36

Descriptives of the Independent Variables

Variable	Category	Frequency	Percentage
Age Group	18-25 years (= 0)	23	49%
	26-40 years (= 1)	18	38%
	41-65 years (= 2)	6	13%
Gender	Male (= 0)	38	81%
	Female (= 1)	9	19%
Condition	Day (= 0)	24	51%
	Night (= 1)	23	49%

Logistic Regression Results

The outcomes of the logistic regression analysis conducted with SPSS software are outlined in this section. Complete details of the analysis findings are provided in Appendix H: SPSS Logistic Regression Results. As previously mentioned, the posted speed limit for the mini-roundabouts was 15 mph. Drivers traveling over the posted speed limit by 5 mph or more were categorized as speeding. Preliminary analysis indicates that out of the 47 participants, 13 participants (28%) were found to be speeding, while 34 participants (72%) maintained the speed limit. For the logistic regression, all data was retained and no observations were excluded. Table 37 depicts the preliminary analysis results.

Table 37

Preliminary Analysis Results

Variable	**Category**	**Frequency**	**Percentage**
Speeding Behavior	No (= 0)	34	72%
	Yes (= 1)	13	28%

Table 38 shows the SPSS findings for the initial model (constant-only) related to the null hypothesis, which posits that the three predictor variables (age, gender, and condition) do not have a statistically significant impact. The Likelihood Ratio (LR) value is 55.433. Given that the Wald test statistic for the initial model is significant (with p = 0.003 < 0.05), the initial model should be rejected.

Table 38

Initial Model SPSS Output: Variables in the Equation

		B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Step 0	Constant	-0.961	0.326	8.692	1	0.003	0.382

Table 39 highlights the impact of predictor variables not present in the initial model on the dependent variable. The result shows that the daylight condition variable significantly contributes to predicting whether a driver speeds in the mini-roundabout (chi-square value = 0.018 < 0.05).

Table 39

Initial Model SPSS Output: Variables Not in the Equation

			Score	**df**	**Sig.**
Step 0	Variables	Gender	0.16	1	0.685
		Age Group	0.13	2	0.939
		Age Group (1)	0.00	1	0.989
		Age Group (2)	0.11	1	0.739
		Condition	5.63	1	0.018
	Overall Statistics		6.33	4	0.176

Table 40 presents the final model incorporating all three predictor variables. This model yielded a likelihood ratio (LR) of 48.643, which is lower than the LR of 55.433 observed for the initial model. A higher LR value suggests a poorer fit of the statistical model. The Cox & Snell R Square value of 0.135 and the Nagelkerke R Square value of 0.194 indicate that 13.5% and 19.4%, respectively, of the variance in the dependent variable is explained by the predictor variables.

Table 40

Final Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	48.643	0.135	0.194

Table 41 shows that the final model, which incorporates the three predictor variables, accurately classified all 34 drivers who were not speeding in the mini-roundabouts. However, it incorrectly classified the 13 drivers who were speeding as not speeding. This results in an overall classification accuracy of 72.3% (34 out of 47).

Table 41

Final Model Classification Table

Observed			Predicted		
			Speeding?		Percentage Correct
			No	Yes	
Step 1	Speeding?	No	34	0	100.0
		Yes	13	0	0.0
	Overall Percentage				72.3

Table 42 displays the coefficients calculated for the predictor variables: gender (-1.146), age group (-0.300) and condition (1.756). The results reveal that among the predictor variables, (gender, age group, and condition) only the daylight condition variable holds a statistically significant relationship ($p = 0.023 < 0.05$) with the prediction of speeding behavior among drivers. This suggests that the time of day, whether it's daylight or nighttime, significantly influences drivers' speeding tendencies, with a higher likelihood of speeding at night due to less traffic. Age group and gender, with p-values of 0.670 and 0.442 respectively, did not significantly predict speeding behavior.

Table 42

Final Logistic Regression Model Outputs

		B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Step 1	Gender	-1.146	1.493	0.590	1	0.442	0.318
	Age Group			0.802	2	0.670	
	Age Group (1)	-0.300	0.775	0.149	1	0.699	0.741
	Age Group (2)	1.099	1.567	0.492	1	0.483	3.002
	Condition	1.756	0.773	5.164	1	0.023	5.791
	Constant	-2.440	1.961	1.548	1	0.213	0.087

The odds ratio (OR) or Exp (B) for the condition variable is reported as 5.791, according to the SPSS output, indicating that drivers are approximately 5.8 times more likely to speed at night compared to during the day. The result is statistically significant ($p = 0.023 < 0.05$).

According to the SPSS output, the odds ratio (OR) or Exp (B) for the gender variable is 0.318. This suggests that male drivers are about 3.1 times as likely to engage in speeding compared to female drivers. However, the result is not statistically significant ($p = 0.442$).

The SPSS output shows that the odds ratio (OR) or Exp (B) for the age group variable is 0.741, indicating that drivers aged 26-40 years are approximately 1.4 times more likely to speed compared to those aged 16-25 years. However, this finding is not statistically significant (p = 0.699).

Final Logistic Regression Function

The following logistic regression function can be obtained using the calculated coefficients for the predictor variables:

$$p(Y) = \frac{e^{-2.44-(1.146*gender)-0.3*age\ group+1.756*condition}}{1 + e^{-2.44-(1.146*gender)-0.3*age\ group+1.756*condition}} \qquad (4)$$

Interaction Effect of Gender, Age Group and Condition

To investigate the possibility of interaction effects between variables, a further logistic regression analysis was carried out. Yet, none of the interaction terms met the inclusion criteria for the logistic regression model. The outcomes of this secondary analysis are detailed in Table 43.

Table 43

Logistic Regression Model Using Variable Interaction Effects

	B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Gender*Condition	-1.073	1.581	0.461	1	0.497	0.342
Age Group*Condition	-0.191	0.686	0.077	1	0.781	0.826
Age Group*Gender	-2.895	2.151	1.811	1	0.178	0.055
Age Group*Gender*Condition	1.837	1.557	1.392	1	0.238	6.275
Constant	1.139	2.865	0.158	1	0.691	3.125

Chapter 5: Conclusion and Recommendations

This chapter provides a discussion of the conclusions, limitations, and future recommendations derived from the data analysis. The primary goal of this study was to assess navigational differences across various mini-roundabout designs using a driving simulator. Moreover, the study aimed to compile an extensive overview of current research and pilot projects related to the design, implementation, and maintenance of mini-roundabouts. In recent years, mini-roundabouts have attracted increasing attention in the US, leading to several pilot initiatives. Despite this growing interest, there remains a notable absence of in-depth guidelines to support decision-making processes. Thus, this research sought to consolidate various design standards for mini-roundabouts, considering factors such as the size of the central island, speed limits, and average daily traffic. The insights gained from this study aim to highlight design standards and operational improvements for mini-roundabouts.

Research Summary

A methodology employing a driving simulator to gather data on driver behavior, along with a pre/post-simulation survey aimed at understanding drivers' experiences with mini-roundabouts, was executed. This approach facilitated the collection and analysis of a diverse set of data from 50 participants. The chosen methodology was designed to fulfill the following research objectives:

1. Determine the optimal design specifications for mini-roundabouts using a driving simulator.
2. Evaluate driver familiarity with, and behaviors within, mini-roundabouts.

3. Identify the critical gap necessary for efficient traffic flow in mini-roundabouts.
4. Explore the factors that affect driver behavior in mini-roundabouts.

Specific Conclusions

Based on the findings of this study, specific conclusions can be drawn in relation to the previously mentioned questions:

Objective 1: Determine the optimal design specifications for mini-roundabouts using a driving simulator.

Findings: The driving simulation study utilized mini-roundabouts that were modeled following US practices for mini-roundabouts. The most significant difference was in their ICD spanning from 45 to 90 feet. Compared to single-lane roundabouts with a 120-feet ICD, mini-roundabouts displayed similar trends in speed patterns, indicating that despite their smaller size, they effectively manage vehicle speeds in a way that aligns with the larger roundabout configurations.

However, extensive research indicates that speeds at 45-feet ICD mini-roundabouts are significantly lower than at other ICD mini-roundabouts. While this reduced speed is beneficial for traffic calming, it may adversely affect traffic flow and operations if it becomes excessively low. The observation that critical gaps were highest in 45-feet ICD mini-roundabouts supports the argument that while these configurations effectively calm traffic, they may also introduce inefficiencies in traffic flow by necessitating longer wait times for drivers to enter the mini-roundabout (Cambridge Systematics, 2005).

On the other hand, the mini-roundabouts with ICD of 60, 75 and 90 feet exhibited similar patterns in terms of speed, critical gap, and brake force, indicating a more consistent and predictable behavior across these configurations. This suggests that larger ICD mini-roundabouts maintain a balance between safety and operational efficiency, allowing for smoother traffic flow without significantly compromising on traffic calming benefits. Therefore, for the successful implementation of a mini-roundabout, it is recommended to consider an Inscribed Circle Diameter (ICD) between 60 and 90 feet. The other design specifications, such as central island diameter, circulating roadway width, and splitter island dimensions, should be aligned with practical implementations observed in the US.

Objective 2: Evaluate driver familiarity with, and behaviors within, mini-roundabouts.

Findings: The pre-test questionnaire results highlighted varied levels of familiarity with mini-roundabouts among participants: only 20% reported being very familiar, 41% somewhat familiar, and 39% not familiar. Over half (51%) had experience driving through a mini-roundabout, while the rest had not. Most participants (84%) had been informed on how to navigate roundabouts in general, with the majority educated on traditional roundabouts (80%), fewer on mini-roundabouts (16%), and very few on turbo-roundabouts (2%).

Post-test feedback revealed that 90% of the participants observed differences in roundabout designs, mainly regarding size and navigation, with a preference for the familiarity and comfort provided by STOP-controlled intersections and traditional roundabouts over mini-roundabouts. The discomfort with mini-roundabouts was attributed to less familiarity with their operational dynamics.

Speed studies comparing mini-roundabouts to single-lane roundabouts with a 120-feet ICD showed lower speeds at entry, circulation, and exit for mini-roundabouts. This suggests that despite lower familiarity, driving patterns at mini-roundabouts mimic those at single-lane roundabouts, indicating that with increased training and familiarity, mini-roundabouts could be effectively integrated into areas with limited space, cost, or right-of-way concerns.

Objective 3: Identify the critical gap necessary for efficient traffic flow in mini-roundabouts.

Findings: Findings from the analysis of critical gaps show that the combined critical gap values for mini-roundabouts ranged from 4.22 to 4.82 seconds regardless of the ICD size or type. This outcome is consistent with the critical gap range of 4.2 to 5.9 seconds outlined in the NCHRP Report 672, "Roundabouts: An Informational Guide," developed by the FHWA as discussed in the literature review (Rodegerdts et al., 2010b).

In this study, the estimated critical gap for the 75-feet ICD mini-roundabout was 4.5 seconds. This finding aligns well with the critical gap range of 3.5 to 5.5 seconds that Lochrane et al. estimated for a 80-feet ICD mini-roundabout in Stevensville, Maryland (Lochrane et al., 2013b). This match indicates consistency in critical gap measurements across mini-roundabouts of similar sizes, suggesting a degree of reliability in these estimations.

Objective 4: Explore the factors that affect driver behavior in mini-roundabouts.

Findings: In the study, driver age significantly impacted gap acceptance and driving speed, particularly at mini-roundabout exits. Younger drivers (18-25 years) demonstrated critical gap times ranging from 4.05 to 4.88 seconds, young to middle-aged drivers (26-40 years) showed the shortest gaps between 3.67 to 4.60 seconds indicating more aggressive driving, and older drivers (over 41 years) had the longest gaps from 4.50 to 5.50 seconds, suggesting increased caution. Additionally, younger drivers exhibited higher exit speeds than their older counterparts, with the 26-40 age group maintaining higher speeds at 500 feet after exiting the mini-roundabouts compared to drivers aged 41-65 years. The logistic regression analysis showed an odds ratio of 0.741 for the 26-40 age group, suggesting they are about 1.4 times more likely to speed than the 16-25 age group, although this was not statistically significant, highlighting age as a pivotal factor in driving behaviors at mini-roundabouts.

The study's findings on critical gap values, which varied from 3.94 to 5.06 seconds during the day and from 3.83 to 4.81 seconds at night, present an intriguing insight into driver behavior at mini-roundabouts. Contrary to the expected outcome that better visibility during the day would lead to shorter critical gaps due to increased confidence in gap acceptance (Dissanayake et al., 2002), the results indicated that drivers actually accepted shorter gaps at night. Additionally, speed analysis revealed higher entry speeds at night compared to daytime at 500 and 200 feet before the mini-roundabout. Logistic regression analysis further highlighted this nocturnal tendency to speed, with a significant odds ratio of 5.791, suggesting drivers are nearly 6 times more likely to speed at night than in the day.

The research indicated no significant gender differences in critical gap acceptance, with male participants choosing gaps from 4.05 to 4.71 seconds and females selecting gaps from 4.38 to 4.62 seconds. Nonetheless, gender significantly influenced driving speed, particularly 200 feet before entering, throughout the circulating zone, and upon exiting the mini-roundabout, with male drivers generally driving faster than female drivers at these points. The odds ratio from logistic regression analysis, at 0.318, implies males are approximately 3.1 times more inclined to exceed speed limits than females, though this result didn't reach statistical significance, showcasing distinct driving behaviors between genders without a notable impact on gap acceptance.

Study Limitations

The comprehensive analysis of driver behavior in response to mini-roundabouts provides valuable insights. However, like any research, this study faces several limitations that should be acknowledged to understand the context and scope of the findings better. Recognizing these limitations also helps in identifying areas for future research to further refine our understanding of traffic dynamics at mini-roundabouts.

- The participant pool, while diverse in age, had a higher representation of males and a specific age distribution, primarily within the 18-25 and 26-40 age ranges. This demographic distribution may not fully represent the broader driving population, particularly the older age groups who might exhibit different driving behaviors, especially in terms of risk perception and reaction times at roundabouts. Additionally, the sample was drawn from a university setting, which could influence the generalizability of the findings to other populations and geographic locations.

- The research study's reliance on participants' honesty in responding to pre-questionnaire and post-questionnaire surveys introduces potential error, as it is impossible for the researcher to verify the accuracy of these responses. This means that if participants were not honest or accurate in their answers, or if they guessed on pre-questionnaire questions, it could have influenced the outcomes of the statistical analysis. Such factors might skew the findings, impacting the study's reliability and validity in understanding the effects or perceptions investigated.
- The study's design, focused on short-term interactions with mini-roundabouts, does not account for the potential adaptation of driver behavior over time. Drivers' initial responses to roundabout configurations may evolve as they become more familiar with the layout and operational characteristics of these intersections. Longitudinal studies are needed to understand how driver behavior adapts over time and the long-term safety and efficiency implications of mini-roundabouts.

Future Recommendations

Future studies should incorporate more dynamic and realistic simulation models that better replicate the diversity of driving behaviors and urban traffic conditions. Integrating real-world traffic data and driver behavior studies could refine the accuracy of simulation outcomes. As the participant pool of this study highly represents male participants, people from age group 18-25 and 26-40 years and mostly university students, more extensive study should be conducted to encompass equal representation of genders, a broader age range, and participants from different backgrounds. Long-term impact studies on mini-roundabouts are also required, which could provide insights into their durability, maintenance needs, and evolving effectiveness as urban traffic patterns change. Such studies would also contribute to understanding the long-term environmental and safety benefits.

To address the public's limited understanding of mini-roundabouts and their proper navigation techniques, it is essential to enhance awareness and education. Despite the observation that drivers familiar with single-lane roundabouts adapt more easily to mini-roundabouts, the overall unfamiliarity with this newer intersection design remains a challenge. As the implementation of mini-RABs increases, there should be a concentrated effort to highlight their benefits and operational advantages. Education campaigns, targeted driver training programs, and focused media outreach are recommended to make mini-roundabouts more familiar to the public.

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APPENDIX A: Current In-Service Mini-Roundabouts in the US

	City, State County Country	Intersection (Lat, Lng)	Control Type / Other Control Type	Approaches / Driveways	Year Completed	Inscribed Central Diameter (ft)	Central Island Diameter (ft)	Circulating Lane Width (ft)	Entry Lane Width (ft)	Splitter Island Length (Major) (ft)	Splitter Island Length (Minor) (ft)	Splitter Island Width (ft)	Smallest Angle of Intersection	Flare	Daily Traffic (veh/ day)	Speed Limit (mph)	Pedestrian Crosswalk Width (ft)
1.	**Soldotna, AK** **Kenai Peninsula** **United States**	N Binkley St./W Redoubt Ave. (60.48781, -151.07231)	All-Way Yield None	4 Approaches 0 Driveways	2014	75	30	22	14	72	50	10	90	No	8060	25*	10
2.	**Soldotna, AK** **Kenai Peninsula** **United States**	S Binkley St./Wilson Ln. (60.48344, -151.07215)	All-Way Yield None	3 Approaches 1 Driveways	2014	75	25	25	16	72	50	10	65, skewed 35	No	6590*	25*	10
3.	**Conway, AR** **Faulkner Co.** **United States**	Van Ronkle St./Markham St./Chestnut St. (35.09176, -92.44000)	All-Way Yield Rectangular Rapid Flashing Beacon (RRFB)	4 Approaches 0 Driveways	2019	76	36	20	13.5	20	20	10	Skewed	Yes			10
4.	**San Luis, AZ** **Yuma Co.** **United States**	Main St./Urtuzuastegui St. (32.48698, -114.78233)	All-Way Yield None	3 Approaches 0 Driveways	2015	70	24, not raised	23	14	50	50	12	90	Yes	18484*	15	10
5.	**Grass Valley, CA** **Nevada Co.** **United States**	Olympia Park Cir./(parking lot) (39.23248, -121.03766)	All-Way Yield None	2 Approaches 1 Driveways	2014	74	40, not raised	17	17	35, not raised	25, not raised	10, not raised	85	No		15	None
6.	**Redding, CA** **Shasta Co.** **United States**	Shasta St./Olive Ave. (40.58343, -122.40524)	All-Way Yield None	4 Approaches 0 Driveways	2006	50	25	12	14	30, not raised	30, not raised	8, not raised	90	No	1875	None	None
7.	**Arcata, CA** **Humboldt Co.** **United States**	Sunset Ave./Foster Ave./Jay St. (40.87972, -124.08482)	All-Way Yield None	4 Approaches 0 Driveways	2014	84	46	18	14	45	35	10	70, skewed	Yes		25*	8
8.	**Loveland, CO** **Larimer Co.** **United States**	Aries Dr./Saint John Pl. (40.39440, -105.03312)	All-Way Yield None	3 Approaches 0 Driveways	2013	75	50	12	12	50	30	15	90	No			10
9.	**Loveland, CO** **Larimer Co.** **United States**	N Garfield Ave./W 7th St. (40.39864, -105.07792)	All-Way Yield None	4 Approaches 0 Driveways	2016	60	34	13	14	25	25	10	90	No	7335	20, school zone	10
10.	**Golden, CO** **Jefferson Co.**	Heritage Rd./W 4th Ave.	All-Way Yield Unknown	4 Approaches 0 Driveways	2015	60	36	12	10	20	15	6	90	Yes	14083	25*	10

United States	(39.72190, -105.21004)															
11. Snowmass Village, CO Pitkin Co. United States	Wood Rd./Carriage Way (39.21000, -106.94756)	All-Way Yield Unknown	3 Approaches 0 Driveways	2016	50	20	15	13	100	40	6	120, skewed	Yes		15*	10
12. Kissimmee, FL Osceola Co. United States	E Monument Ave./Lakeview Dr. (28.29192, -81.40460)	All-Way Yield None	4 Approaches 0 Driveways	2010	80	50	15	10	45	22	8	90	No	8049*	15	8
13. Kissimmee, FL Osceola Co. United States	Lakeshore Blvd./(parking lot) (28.28792, -81.40889)	All-Way Yield None	4 Approaches 0 Driveways	2011	80	50	15	10	50	50	8	80	No		15	8
14. Port St Lucie, FL St. Lucie Co. United States	SW Tulip Blvd./SW College Park Rd. (27.25803, -80.37393)	All-Way Yield None	4 Approaches 0 Driveways	2019											15*	
15. McDonough, GA Henry Co. United States	GA 81/Snapping Shoals Rd./Jackson Lake Rd. (33.46282, -83.96860)	All-Way Yield None	4 Approaches 0 Driveways	2017	85	50	18	11	80, not raised	45, not raised	20, not raised	60, skewed	Yes	5410	25	None
16. Macon, GA Bibb Co. United States	US 32 (Riverside Dr.)/Bass Rd./Arkwright Rd. (32.93662, -83.71736)	All-Way Yield None	4 Approaches 0 Driveways	2017	85	50	18	13	40	12	10	65, skewed	No	14065	25	None
17. Jackson, GA Butts Co. United States	Keys Ferry Rd./Barnetts Bridge Rd./Hwy 36 (33.38354, -83.90331)	All-Way Yield None	4 Approaches 0 Driveways	2017	90	50						90, Modular, Rapid-Install Roundabout	No	6510	25	10
18. Kealakekua, HI Hawaii Co. United States	Halekii St./Mamao St. (19.51783, -155.92400)	Two-Way Stop Unknown, Traffic Circle	4 Approaches 0 Driveways		45	20, not raised	13	14	None	None	None	75, skewed	No		15	10
19. Kealakekua, HI Hawaii Co. United States	Halekii St./Muli St. (19.51673, -155.92736)	Two-Way Stop Unknown, Traffic Circle	4 Approaches 0 Driveways		45	20, not raised	15	14	None	None	None	90	No		15	10

20. Coralville, IA Johnson Co. United States	12th Av./ Holiday Rd. (41.69491, -91.58287)	All-Way Yield None	4 Approaches 0 Driveways	2015	60	35	13	11	50	50	8	90	No	13557	15	8
21. Marion, IA Linn Co. United States	29th Ave./35th St. (42.05043, -91.57448)	All-Way Yield Unknown	4 Approaches 0 Driveways	2016	80	50	15	12	95	50	13	90	Yes	8325	15	10
22. Millbury, MA Worcester Co. United States	Elm St/Elm Ct/Rte 146 Ramps (42.18783, -71.76618)	All-Way Yield None	4 Approaches 0 Driveways	2018	80	50	15	12				80, skewed	No	15100*	15*	10
23. Fitchburg, MA Worcester Co. United States	Main St./River St. (42.58718, -71.80861)	All-Way Yield None	3 Approaches 0 Driveways	2017	55	28	14	12	50	12	12	60, skewed	Yes	17500	15	10
24. Bel Air, MD Harford Co. United States	Tollgate & MacPhail Rd (39.51916, -76.35227)	All-Way Yield None	4 Approaches 0 Driveways	2012	60	30	15	12	55	25	12	90	Yes	13056	15	10
25. Columbia, MD Howard United States	Golden Straw Ln./Davis Rd. (39.21597, -76.81084)	All-Way Yield None	4 Approaches 0 Driveways	2000	45	20	13	11	15	15	10	90	No		15*	None
26. Baltimore, MD Baltimore United States	Canterbury Rd./W 39th St. (39.33569, -76.62047)	All-Way Yield None	4 Approaches 0 Driveways	2013	64	32	16	13	45	45	10	60, skewed	Yes	6350*	15	10
27. Baltimore, MD Baltimore City United States	Guilford Ave./22nd St. (39.31441, -76.61263)	All-Way Yield None	4 Approaches 0 Driveways	2012	40	15	13	10	None	None	None	90	No	1440*	15*	10
28. Baltimore, MD Baltimore City United States	Guilford Ave./E 24th St. (39.31650, -76.61276)	All-Way Yield None	4 Approaches 0 Driveways	2012	40	15	13	10	None	None	None	90	No	2510*	15*	10
29. Baltimore, MD Baltimore City United States	Guilford Ave./E 32nd St. (39.32703, -76.61345)	All-Way Yield None	4 Approaches 0 Driveways	2012	40	15	13	10	None	None	None	90	No	1440*	15*	10
30. Stevensville, MD	Thompson Creek Rd./US	All-Way Yield None	4 Approaches 0 Driveways	2007	75	40	18	14	90, not raised	30, not raised	12, not raised	120, skewed	Yes	5154*	15	None

Queen Annes United States	50 EB Ramps (38.97599, -76.31046)															
31. Ypsilanti, MI Washtenaw Co. United States	Textile Rd./Hitchingham Rd. (42.20169, -83.62088)	All-Way Yield None	4 Approaches 0 Driveways	2015	90	50	20	14	150	30	15	85	Yes	12917	15	None
32. Ypsilanti, MI Washtenaw Co. United States	Textile Rd./Stony Creek Rd. (42.20172, -83.62311)	All-Way Yield None	4 Approaches 0 Driveways	2016	90	50	20	15	230	20	15	50, skewed	Yes	10850	15	None
33. Saline, MI Washtenaw Co. United States	Ann Arbor-Saline Rd./Textile Rd. (42.19859, -83.79691)	All-Way Yield None	4 Approaches 0 Driveways	2016	90	45	22	15	185	100	14	90	Yes	11670	15	None
34. Shakopee, MN Scott Co. United States	CR 79 (Spencer St. S)/Vierling Dr. (44.78335, -93.52016)	All-Way Yield None	4 Approaches 0 Driveways	2014	75	45	15	15	180	150	12	90	Yes	12400	15	10
35. Elk River, MN Sherburne Co. United States	Railroad Dr & Thrid St & Irving Ave (45.30450, -93.56572)	All-Way Yield None	4 Approaches 0 Driveways	2013	85	50			35	15		30, skewed	No	1695	15*	10
36. St James, MN Watonwan Co. United States	1st Ave. S/Armstrong Blvd. N (43.98198, -94.62838)	All-Way Yield Unknown	4 Approaches 0 Driveways	2017								90		12252	15*	10
37. St James, MN Watonwan Co. United States	1st Ave. S/7th St. S (43.98246, -94.62703)	All-Way Yield Unknown	4 Approaches 0 Driveways	2017								90		10241	15*	10
38. Anoka, MN Anoka Co. United States	S 4th Ave./Washington St./Military Rd. (45.19165, -93.38535)	All-Way Yield None	5 Approaches 0 Driveways	2017	90	65	13	13	25	25	10	60, skewed	Yes	4700	15*	10
39. Lakeland, MO Miller Co. United States	US 54 Business/N Shore Dr. (38.21423, -92.62436)	All-Way Yield None	3 Approaches 0 Driveways	2014	80	30	25	18	None	None	None	75, skewed	Yes	12576	15	None

40. Midtown, MO Greene Co. United States	Commercial St./Washington Ave. (37.23001, -93.28546)	All-Way Yield None	4 Approaches 0 Driveways	2016	75	40	17	13	None	None	None	95, skewed	Yes	13870	15*	8
41. Colonial Gardens, MO Boone Co. United States	Rollins Rd./S Fairview Rd. (38.94681, -92.38090)	All-Way Yield Unknown	4 Approaches 0 Driveways	2013	60	30	15	12	80	40	10	85, skewed	No	10500	15*	10
42. Columbia, MO Boone Co. United States	Grant Ln./Trailside Dr./Post Oak Dr. (38.92438, -92.39510)	All-Way Yield Unknown	4 Approaches 0 Driveways	1995	70	40	15	14	60, not traversable	35, not traversable	10, not traversable	85, skewed	No	251*	15	10
43. Jackson, MS Hinds Co. United States	E Capitol St./West St. (32.29975, -90.18412)	All-Way Yield None	4 Approaches 0 Driveways	2014	70	45	12	13	55	35	10	90	No	11750		10
44. Jackson, MS Hinds Co. United States	E Capitol St./Lamar St. (32.30000, -90.18602)	All-Way Yield None	4 Approaches 0 Driveways	2014	70	45	12	13	60	50	10	90	No	12250		10
45. Jackson, MS Hinds Co. United States	Capitol St./Farish St. (32.30034, -90.18851)	All-Way Yield None	4 Approaches 0 Driveways	2014	70	45	12	13	40	40	10	80, skewed	Yes	9590		10
46. Missoula, MT Missoula Co. United States	Scott St./Toole Ave. (46.87803, -114.00632)	All-Way Yield None	4 Approaches 0 Driveways	2014	75	45	15	13	50	50	12	80, skewed	No	7161	15	10
47. Wilmington, NC, New Hanover Co. United States	Tanbridge Rd./Wells Rd. (34.24406, -77.83776)	All-Way Yield None	4 Approaches 0 Driveways	2009	55	18	18	11	15	8	8	90	No		10	None
48. Wilmington, NC New Hanover Co. United States	Windemere Rd./Camberly Dr. (34.24265, -77.84314)	All-Way Yield None	4 Approaches 0 Driveways	2009	60	25	18	10	12	12	8	90	No		10	None
49. Durham, NC Durham Co. United States	Broad St./Carver St./Kenan Rd. (36.04004, -78.90837)	All-Way Yield Unknown	4 Approaches 0 Driveways	2016	65	35	15	12	45	45	8	85	No	10395	15	None
50. Cary, NC Wake Co. United States	Wellingborough Dr./Forest Park Way (35.74966, -	All-Way Yield None	3 Approaches 0 Driveways	2009	65	30	16	12	40	30	14	130, skewed	Yes		15	8

		78.76117)															
51.	**Fayetteville, NC Cumberland Co. United States**	Augusta Dr./Commerce St. (35.04725, -78.89901)	All-Way Yield None	4 Approaches 0 Driveways	2009	60	30	15	14	20, not raised	20, not raised	10, not raised	90	No		15*	None
52.	**Mooresville, NC Iredell Co. United States**	College St./S Church St. (35.57668, -80.81736)	All-Way Yield None	4 Approaches 0 Driveways	2014	50	27	12	10	10, not raised	10, not raised	5, not raised	90	No		15	7
53.	**North Wilkesboro, NC Wilkes Co. United States**	Fairplains Rd./Reynolds Rd. (36.19561, -81.14437)	All-Way Yield Unknown	3 Approaches 0 Driveways	2017	40	15	13	10	20, not raised	20, not raised	8, not raised	90	No	2680*	10	None
54.	**Lincoln, NE Lancaster Co. United States**	S 11th St./D St. (40.80254, -96.70560)	All-Way Yield Unknown	4 Approaches 0 Driveways	2013	60	30	15	10	20	20	10	90	No	5440	15*	10
55.	**Omaha, NE Douglas Co. United States**	S 63rd St./Shirley St. (41.24148, -96.00960)	All-Way Yield None	4 Approaches 0 Driveways	2017	70	35	17	12	50, not raised	30, not raised	10, not raised	90	Yes	3813	15	7
56.	**Elmira, NY Chemung Co. United States**	Maple Ave./Caldwell Ave. (42.08399, -76.79589)	All-Way Yield Unknown	4 Approaches 0 Driveways	2012	60	30	15	10	65, not raised	30, not raised	12, not raised	90	No		15	7
57.	**Elmira, NY Chemung Co. United States**	Maple Ave./Horner St. (42.08282, -76.79445)	All-Way Yield Unknown	4 Approaches 0 Driveways	2012	55	30	13	10	65, not raised	30, not raised	12, not raised	90	Yes		15	7
58.	**Newark, OH Licking Co. United States**	N 3rd St./N Park Pl. (40.05829, -82.40281)	All-Way Yield None	3 Approaches 0 Driveways	2016	80	45	18	14	45	45	12	90	No	2816	None	8
59.	**Newark, OH Licking Co. United States**	S 3rd St./S Park Pl. (40.05716, -82.40227)	All-Way Yield None	3 Approaches 0 Driveways	2016	80	50	15	14	45	45	12	90	No	2792	None	8
60.	**Newark, OH Licking Co. United States**	S 2nd St./S Park Pl. (40.05760, -82.40059)	All-Way Yield None	3 Approaches 0 Driveways	2016	80	50	15	14	45	45	12	90	No	5554	None	8
61.	**Newark, OH Licking Co. United States**	N 2nd St./N Park Pl. (40.05874, -82.40112)	All-Way Yield None	3 Approaches 0 Driveways	2016	80	50	15	14	45	45	12	90	No	5578	None	10
62.	**Portland, OR Multnomah**	SW 47th Dr./SW 43rd	All-Way Yield None	3 Approaches 0 Driveways	2007	44	22, not raised	12	13	None	None	None	85	No		15	10

Co. United States	Ave. (45.49245, -122.72111)															
63. **Lancaster, PA Lancaster Co. United States**	N Plum St & E New St & Park Ave (40.05000, -76.29883)	Unknown Unknown	4 Approaches 0 Driveways	2019												10
64. **Lincoln, RI Providence Co. United States**	School St./Main St./Briarwood Rd. (41.95141, -71.45445)	All-Way Yield Unknown	4 Approaches 0 Driveways	2017	70	30, not fully traversable	20	12	40, not raised	10, not raised	15, not raised	70, skewed	Yes	9100	20*	10
65. **Chattanooga, TN Hamilton Co. United States**	4th Ave./E 37th St (35.00101, -85.28883)	All-Way Yield None	4 Approaches 0 Driveways	2013	60	25, flexible post used	17	12	20, flexible post used	20, flexible post used	6, flexible post used	90	No	5574*	15	None
66. **Bryan, TX Brazos Co. United States**	Esther Blvd./Bennett St. (30.65622, -96.35323)	All-Way Yield None	3 Approaches 0 Driveways	2018								90				10
67. **Canyon Rim, UT Salt Lake Co. United States**	S 23rd E St./E Vimont Ave. (40.71203, -111.82460)	All-Way Yield None	4 Approaches 0 Driveways	2017	70	25	17	13	15, not raised	10, not raised	6, not raised	70, skewed	Yes	3910*		10
68. **Canyon Rim, UT Salt Lake Co. United States**	Heritage Way/Claybourne Ave. (40.71132, -111.82322)	All-Way Yield Unknown	3 Approaches 0 Driveways	2017	55	15	20	10	20, not raised	15, not raised	6, not raised	120, skewed	No			10
69. **Lynchburg, VA Lynchburg City United States**	University Blvd./Williams Stadium Rd. (37.35301, -79.17631)	All-Way Yield None	3 Approaches 0 Driveways	2015	65	35	15	15	45	35	10	120, skewed	No			10
70. **Annandale, VA Fairfax Co. United States**	Ravensworth Rd/Jayhawk St/Fountain Head Dr (38.82630, -77.19993)	All-Way Yield Unknown	4 Approaches 0 Driveways	2018								90, Modular, Rapid-Install Roundabout		14850	15	10
71. **Warrenton, VA Fauquier Co. United States**	E Shirley Ave./Falmouth St. (38.69843, -77.78795)	All-Way Yield Unknown	3 Approaches 0 Driveways	2018								60, skewed, mini-roundabout with bypass lane		13700	15	10
72. **Charlottesvill**	109 Burnet St	All-Way Yield	3 Approaches	2017	60, not	20	40	10	25, not	10, not	6, not	90	No		15*	10

e, VA **Charlottesville** **United States**	(38.02424, -78.48827)	Unknown	0 Driveways		fully traversable				raised	raised	raised					
73. Vienna, VA **Fairfax Co.** **United States**	Park St. SE/Locust St. SE (38.90205, -77.26091)	All-Way Yield None	3 Approaches 0 Driveways	2018	60	30	15	12	115	115	8	90	Yes	16800*	10	10
74. Manchester, VT **Bennington Co. United States**	Main St./Bonnet St. (43.17692, -73.05688)	All-Way Yield Unknown	3 Approaches 0 Driveways	2013	65	32	17	15	150	45	6	75, skewed	No	11850	15*	10
75. Issaquah, WA **King Co.** **United States**	Maple St. NW/(parking lots) (47.54340, -122.05121)	All-Way Yield None	4 Approaches 0 Driveways	2017	70	40	15	14	100	10, not raised	8	90	No	8732*	15	10
76. Wenatchee, WA **Chelan Co.** **United States**	S Miller St/Red Apple Rd (47.40797, -120.32456)	All-Way Yield Unknown	4 Approaches 0 Driveways	2018								90			15	10
77. Federal Way, WA **King Co.** **United States**	S 308th St./14th Ave. S (47.32601, -122.31601)	All-Way Yield Rectangular Rapid Flashing Beacon (RRFB)	4 Approaches 0 Driveways	2014	60	34	13	10	95, not raised	80, not raised	10, not raised	90	No	6040	15	10
78. Bellingham, WA **Whatcom Co.** **United States**	Everson Goshen Rd./E Smith Rd. (48.83263, -122.37755)	All-Way Yield None	4 Approaches 0 Driveways	2015	75	40	17	12	50	50	6	90	No	6810	10	10
79. Lynden, WA **Whatcom Co.** **United States**	SR 546/Northwood Rd. (48.96424, -122.40709)	All-Way Yield None	4 Approaches 0 Driveways	2016	85	50	17	12	60	20	12	90	No	8914	10	10
80. Mount Vernon, WA **Skagit Co.** **United States**	Anderson Rd./Cedardale Rd. (48.39915, -122.32710)	All-Way Yield None	4 Approaches 0 Driveways	2013	80	35	17	13	120, not raised	30, not raised	15, not raised	90	Yes	9807	10	10
81. Kennewick, WA **Benton Co.** **United States**	W Metaline Ave./N Nevada St./W Montana St. (46.22031, -119.23826)	All-Way Yield None	3 Approaches 0 Driveways	2013	60	30	15	12	20, not raised	20, not raised	6, not raised	65, skewed	Yes		10-15	10
82. Mill Creek, WA **Snohomish**	SE 116th St./56th Ave SE (47.89201, -	All-Way Yield None	4 Approaches 0 Driveways	2012	65	30	17	14	140	15	8	65, skewed	Yes	3746	10-15	10

Co. United States	122.15856)															
83. Lake Stevens, WA Snohomish Co. United States	N Davies Rd./Frontier Village Access Rd. (48.00447, -122.10403)	All-Way Yield None	4 Approaches 0 Driveways	2012	60	25	17	12	150, not raised	45, not raised	10, not raised	90	Yes	8001*	15	10
84. Lake Stevens, WA Snohomish Co. United States	Vernon Rd./N Davies Rd. (48.00495, -122.10586)	All-Way Yield None	3 Approaches 0 Driveways	2012	60	25	17	14	110, not raised	25, not raised	8, not raised	90	Yes	10970	15	10
85. Marysville, WA Snohomish Co. United States	25th Ave. NE/174th St. NE (48.15374, -122.19930)	All-Way Yield None	3 Approaches 0 Driveways	2017	100	70	15	14	75	60	20	80, skewed 10, flared, compact roundabout	Yes		15	10
86. White Center, WA King United States	9th Ave. SW/SW 100th St. (47.51379, -122.34640)	All-Way Yield None	4 Approaches 0 Driveways	2006	60	25	17	12	75	15	10	90	Yes		15	10
87. White Center, WA King United States	10th Ave. SW/SW 100th St. (47.51379, -122.34770)	All-Way Yield None	4 Approaches 0 Driveways	2006	60	25	17	12	50	15	10	90	No		15	10
88. Redmond, WA King United States	Eastridge Dr. NE/244th Pl. NE (47.68499, -122.01300)	All-Way Yield None	3 Approaches 1 Driveways	2014	70	35	17	12	40	40	8	90	No		15	10
89. Federal Way, WA King Co. United States	Military Rd. S/S 298 St. (47.33514, -122.29673)	All-Way Yield None	4 Approaches 0 Driveways	2019								65, skewed		12980	10-15	10
90. Ferndale, WA Whatcom Co. United States	Slater Rd./I-5 NB Ramps (48.81737, -122.54604)	All-Way Yield None	3 Approaches 0 Driveways	2014	90	54	18	12	40	15	15	80, skewed	No	14335	10	10
91. Ferndale, WA Whatcom	Slater Rd./I-5 SB Ramps (48.81707, -	All-Way Yield None	3 Approaches 0 Driveways	2014	90	55	18	12	50	20	20	85, skewed	No	18220	10	10

Co. United States	122.55050)															
92. Ferndale, WA Whatcom Co. United States	Slater Rd./Pacific Hwy. (48.81718, -122.54435)	All-Way Yield None	4 Approaches 0 Driveways	2014	75	40	17	12	25	25	10	85, skewed	No	9705	10	10
93. Ferndale, WA Whatcom Co. United States	Portal Way/I-5 NB Ramps (48.85836, -122.58613)	All-Way Yield None	3 Approaches 0 Driveways	2019								70, skewed	No	11660	10	10
94. Shelton, WA Mason Co. United States	N 1st St./W Alder St. (47.21590, -123.09963)	All-Way Yield None	4 Approaches 0 Driveways	2019								90		11032	10-15	10
95. Renton, WA King Co. United States	SE 176th St./SE 171st Way (47.44500, -122.14831)	All-Way Yield None	3 Approaches 0 Driveways	2019								90		12611	10-15	10
96. Eastgate, WA King Co. United States	SE 40th St./138th Ave. SE (47.57459, -122.15670)	All-Way Yield None	4 Approaches 0 Driveways	2019	60	35						90	No		10-15	10
97. Burlington, WA Skagit Co. United States	E George Hopper Rd./S Walnut St. (48.45200, -122.33174)	All-Way Yield None	4 Approaches 0 Driveways	2015	85	45	20	15	15	15	10	70, skewed	No	7032*	15	10
98. Burlington, WA Skagit Co. United States	Marketplace Dr./S Walnut St. (48.44859, -122.33169)	Other None	4 Approaches 0 Driveways	2015	65	30	17	12	15	15	10	90	No		15	10

P.S: The difference between 90 degrees and the smallest acute angle between the intersection legs is referred to as the intersection skew angle.

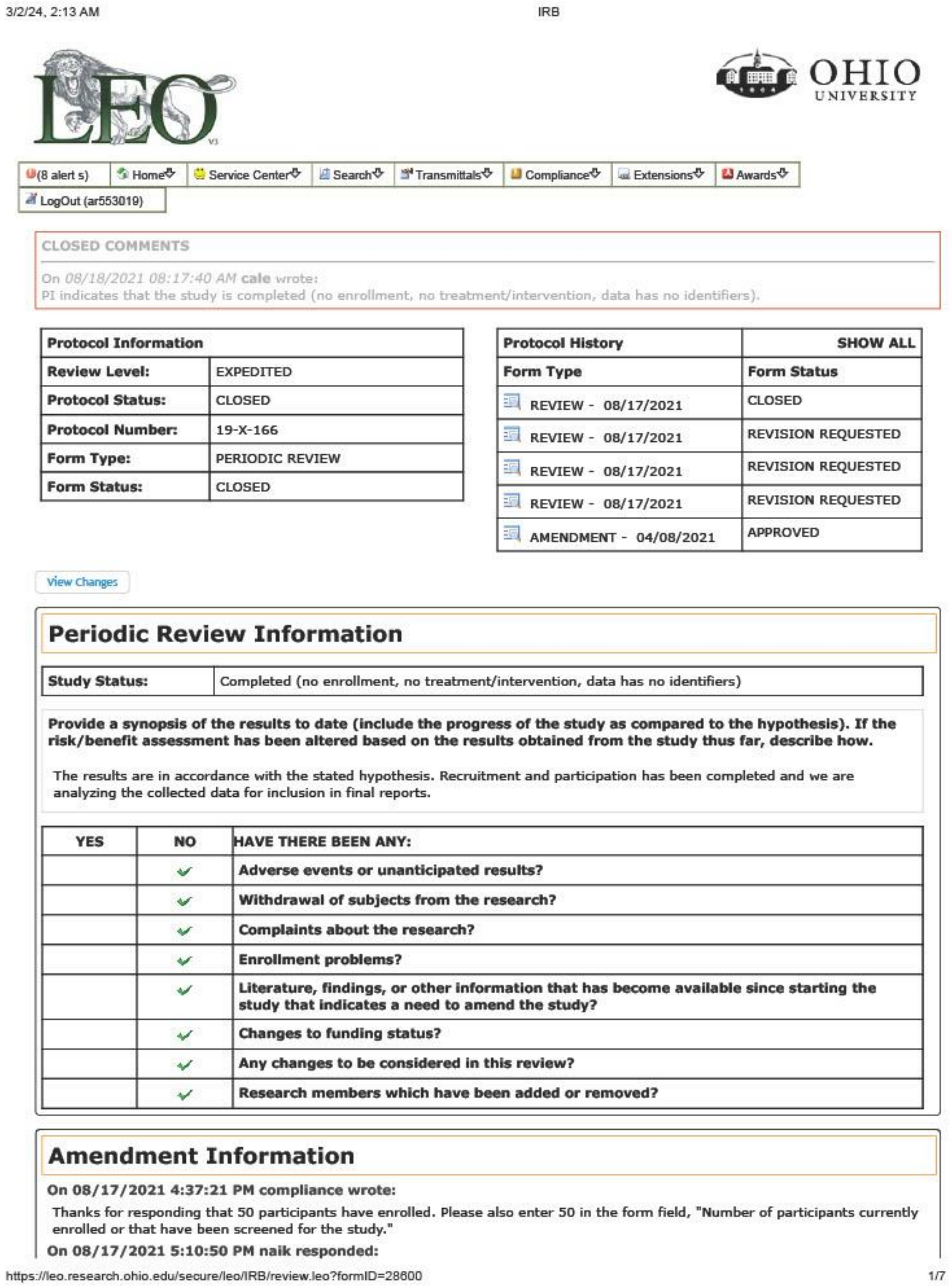
APPENDIX B: Current In-Service Mini-Roundabouts Characteristics

Sl	Mini-Roundabout Location	State	Features
1	Creyts Rd @ East Rd.	Michigan	ICD 69 ft, Central Island 13 ft
	City: Dimondale		AADT forecast (2020): 9550 vpd
			Trucks 4%
			Cost $47000
2	Parker Blvd @ Decatur Rd	New York	ICD 75 ft, Central Island 45 ft
	City: Tonawanda		Circulatory Roadway Width 15 ft
			Design Speed 15-20 mph
			Throat widths: Approach 10 ft, Departure 10-12 ft
			Crosswalk Setback 20 ft
			Splitter Islands Height 4"
3	Parker Blvd @ Harrison Ave	New York	ICD 60 ft, Central Island 30 ft
			Circulatory Roadway Width 15 ft
			Design Speed 15 mph
			Throat widths vary 10-12 ft
			Crosswalk Setback 20 ft
			Splitter Islands Refuge Width 6 ft minimum
			Flush Splitter Islands
4	133rd Street and 132nd Street/Hemlock	Kansas	ICD 100 ft
			Crosswalk Setback 20 ft
			Cost $180000
			AADT: 13520 vpd
			PM Peak Hourly volume = 1,352 veh/h
			PM LOS (Existing Conditions): F, PM LOS (mini-roundabouts): A
			PM LOS (Existing plus Apartments Conditions): F, PM LOS (Mini-roundabouts plus Apartments Conditions): B
5	132nd Street and Foster Street	Kansas	ICD 70 ft
			Crosswalk Setback 20 ft
			Cost $80000
			AADT: 13570 vpd
			PM Peak Hourly volume = 1,357 veh/h
			LOS (Existing Conditions): F, LOS (mini-roundabouts): C
			PM LOS (Existing plus Apartments Conditions): F, PM LOS (Mini-roundabouts plus Apartments Conditions): E
6	Tollgate & MacPhail Road	Maryland	ICD 67 ft, Central Island 37 ft
			Circulatory Roadway Width 15 ft
			Throat widths: Approach 13 ft, Departure 15 ft
			PM Peak Hourly volume = 1150 veh/h
			AADT: 11741 vpd
			Number of reported reduced from 8 to 2
			Cost $100000
7	County Road 79 and Vierling Drive	Minnesota	ICD 75 ft, Central Island 45 ft
			Circulatory Roadway Width 30 ft
			Cost $338,000
			AADT: 12000 vpd
			PM Peak Hourly volume = 1,235 veh/h
8	Textile / Hitchingham / Stony Creek	Michigan	ICD 90 ft
	(2 mini-roundabouts)		Project Cost: $840,000
			ADT: Textile - 6600 vpd, Hitchingham – 6,800 vpd
			Stony Creek - 4,200 vpd
			Truck %: 4%

9	Lake Stevens	Washington	Cost $20,000
	(2 mini-roundabouts)		Quick Construction
10	Takoma Park	Maryland	Cost $25,000
	(2 mini-roundabouts)		
11	Lake Stevens	Washington	Cost $20,000
	(2 mini-roundabouts)		
12	Snohomish Co.	Washington	Cost $367,000
13	Bel Air	Maryland	Cost $172,000 + $20,000 LED lights
14	Elmira	New York	Cost $97500
	(2 mini-roundabouts)		
15	Jefferson	Georgia	Cost $63,353
16	White Center	Washington	Main Feature: 100% crash reduction
			Number of crashes reduced from 9 to 0
17	Redmond	Washington	Main Feature: Commercial Access
18	Bellingham	Washington	Main Feature: Detour Routing
19	Howard County	Maryland	Main Feature: Permeable Pavers
20	Annandale	Virginia	Modular Mini-roundabout
			PM Peak Hourly volume = 1400 veh/h
			AADT: 13000 vpd
			Use of recycled materials
21	Courthouse Square, Newark	Ohio	ICD 80 ft, Central Island 50 ft
	(4 mini-roundabouts)		$560000 savings
			65% Crash Reduction
			100% Injury Crash Reduction
22	Baker Road	Michigan	ICD: 100 feet (Shield), 105 ft x 95 ft (Dan Hoey)
	(2 mini-roundabouts)		ADT: Baker - 14000 vpd, Shield – 3200 vpd
			Dan Hoey - 5800 vpd
			Truck Traffic: 3%
			Cost $1.3 million
23	SR 11 @ SR 124, Jackson	Georgia	ICD = 90 ft
			ADT: SR 11 - 11700 vpd, SR 124 – 5590 vpd
			$62,994 Maintenance Funds
24	SR 5 @ SR 16/US 27 Alt	Georgia	ICD = 90 ft
			ADT: SR 16 - 12100 vpd, SR 5 – 2360 vpd
			$152,430 Quick Response Project
25	SR 81 @ Jackson Lake Rd	Georgia	ICD = 85 ft
	(Temporary Mini RAB)		ADT: SR 81 - 5310 vpd, Jackson Lake Rd – 1160 vpd, Snapping Shoals Rd - 2060 Rd
			$255,879 Quick Response/Maintenance Funds
26	SR 138 @ N Moseley Dr	Georgia	ICD = 70 ft
			ADT: SR 138 - 12900 vpd
			$189,400 Quick Response Project

27	SR 87 @ Bass Rd	Georgia	ICD = 95 ft
			ADT: SR 87 - 8810 vpd, Bass Rd – 3810 vpd
			$242,750 Quick Response/Maintenance Funds
28	SR 36 @ Keys Ferry Rd	Georgia	ICD = 68 ft
			SPIDER Modular - recycled plastic boards – FHWA sponsored experimental
			$44,437 Maintenance Funds + ~$100k
			ADT: SR 36 - 6040 vpd, Keys Ferry Rd – 2140 vpd
29	SR 14 @ Hal Jones Rd	Georgia	ICD = 87 ft
			ADT: SR 14 - 8640 vpd, Hal Jones Rd – 5150 vpd
			$199,447 Quick Response Project
30	SR 14 @ Green Top Rd	Georgia	ICD = 74 ft
			ADT: SR 14 - 8640 vpd, Greentop Rd – 3380 vpd
			$398818 Quick Response Project
31	SR 212 @ SR 36	Georgia	ICD = 104 ft
			$57490 Quick Response Project
32	SR 5 @ Old Hwy 27		ICD = 90 ft
			~$10,000 Maintenance Funds
33	Flat Shoals Rd @ McPherson, Atlanta	Georgia	ICD = 48 ft
			Cost ~$100,000
			Part of enhancement project
34	SR 16 @ SR 54	Georgia	ICD = 78 ft
			$77100 Maintenance Funds
			Cost doesn ftt include asphalt + striping; done through resurfacing project
35	SR 902 / Craig Road	Washington	ICD = 95 ft, central island 60 ft,
	(Compact Roundabout)		circulating lanes 17.5 ft
			AADT: SR 902 – 8,200 west, 7,600 east, Craig north – 1,900, south – 1,800
			Truck % – 5%
			Project Cost - $300,000
36	Bozeman modular roundabout	Montana	central island 24 ft
			< $25000 for the circle
			1 day installation
			Made from recycled plastic material
37	Bliley/Blakemore intersection	Virginia	Cost ~$50,000

APPENDIX C: IRB Approval Form



3/2/24, 2:13 AM IRB

CLOSED COMMENTS

On 08/18/2021 08:17:40 AM **cale** wrote:
PI indicates that the study is completed (no enrollment, no treatment/intervention, data has no identifiers).

Protocol Information	
Review Level:	EXPEDITED
Protocol Status:	CLOSED
Protocol Number:	19-X-166
Form Type:	PERIODIC REVIEW
Form Status:	CLOSED

Protocol History	**SHOW ALL**
Form Type	**Form Status**
REVIEW - 08/17/2021	CLOSED
REVIEW - 08/17/2021	REVISION REQUESTED
REVIEW - 08/17/2021	REVISION REQUESTED
REVIEW - 08/17/2021	REVISION REQUESTED
AMENDMENT - 04/08/2021	APPROVED

Periodic Review Information

Study Status:	Completed (no enrollment, no treatment/intervention, data has no identifiers)

Provide a synopsis of the results to date (include the progress of the study as compared to the hypothesis). If the risk/benefit assessment has been altered based on the results obtained from the study thus far, describe how.

The results are in accordance with the stated hypothesis. Recruitment and participation has been completed and we are analyzing the collected data for inclusion in final reports.

YES	NO	HAVE THERE BEEN ANY:
	✓	**Adverse events or unanticipated results?**
	✓	**Withdrawal of subjects from the research?**
	✓	**Complaints about the research?**
	✓	**Enrollment problems?**
	✓	**Literature, findings, or other information that has become available since starting the study that indicates a need to amend the study?**
	✓	**Changes to funding status?**
	✓	**Any changes to be considered in this review?**
	✓	**Research members which have been added or removed?**

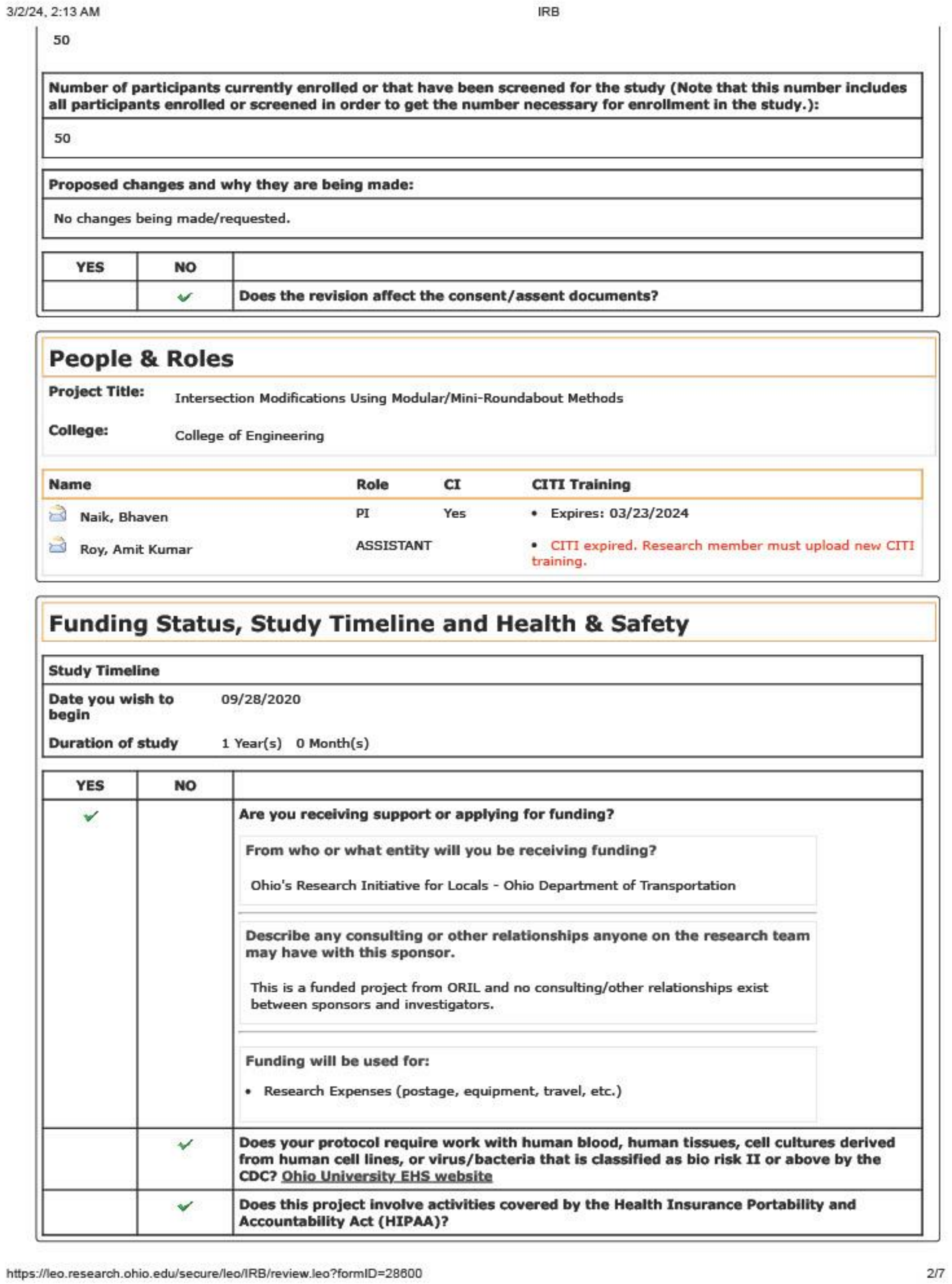
Amendment Information

On 08/17/2021 4:37:21 PM compliance wrote:

Thanks for responding that 50 participants have enrolled. Please also enter 50 in the form field, "Number of participants currently enrolled or that have been screened for the study."

On 08/17/2021 5:10:50 PM naik responded:

https://leo.research.ohio.edu/secure/leo/IRB/review.leo?formID=28600 1/7



50

Number of participants currently enrolled or that have been screened for the study (Note that this number includes all participants enrolled or screened in order to get the number necessary for enrollment in the study.):
50

Proposed changes and why they are being made:
No changes being made/requested.

YES	NO	
	✓	**Does the revision affect the consent/assent documents?**

People & Roles

Project Title: Intersection Modifications Using Modular/Mini-Roundabout Methods

College: College of Engineering

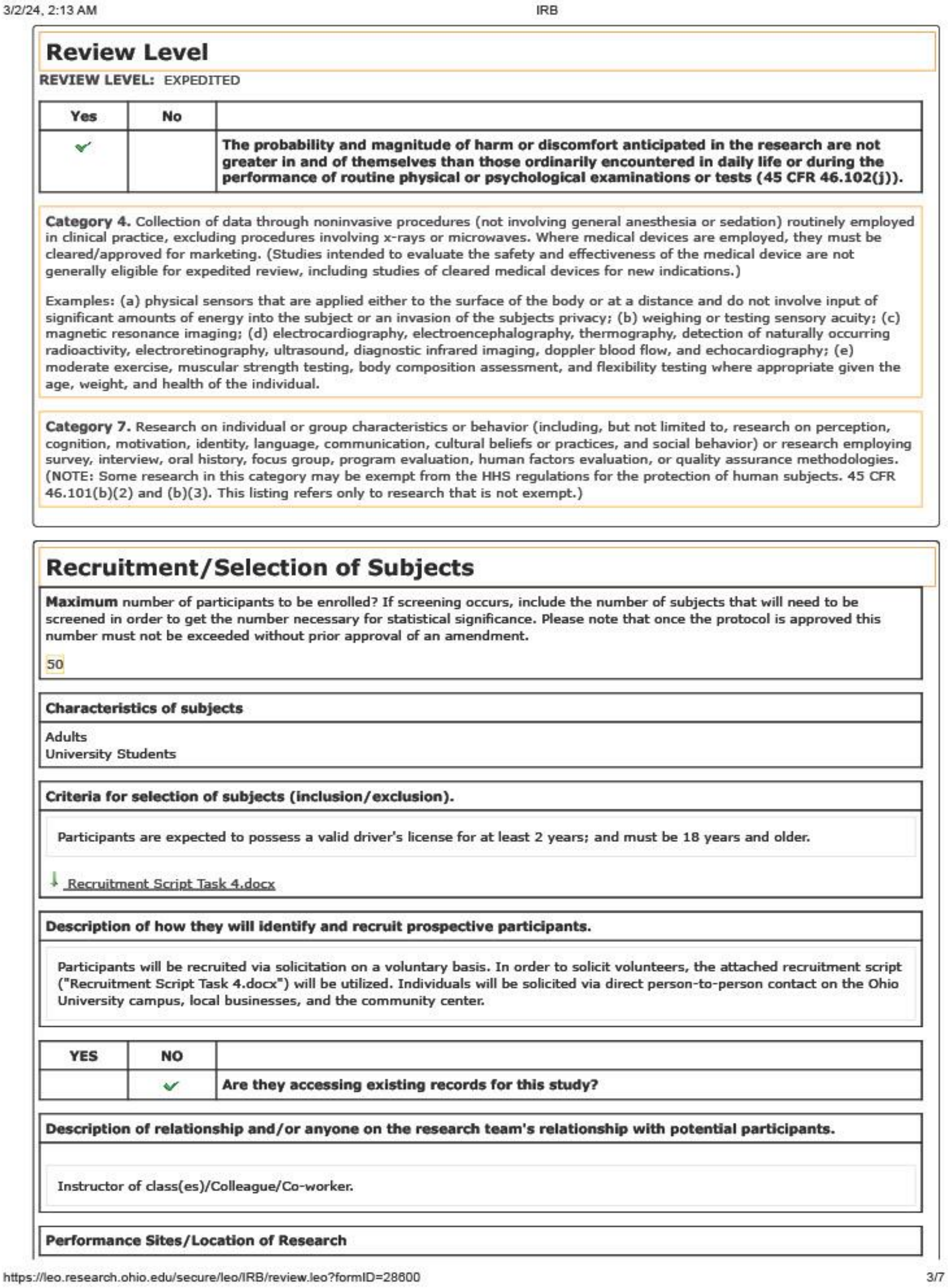
Name	Role	CI	CITI Training
Naik, Bhaven	PI	Yes	• Expires: 03/23/2024
Roy, Amit Kumar	ASSISTANT		• CITI expired. Research member must upload new CITI training.

Funding Status, Study Timeline and Health & Safety

Study Timeline

Date you wish to begin	09/28/2020
Duration of study	1 Year(s) 0 Month(s)

YES	NO	
✓		**Are you receiving support or applying for funding?** **From who or what entity will you be receiving funding?** Ohio's Research Initiative for Locals - Ohio Department of Transportation **Describe any consulting or other relationships anyone on the research team may have with this sponsor.** This is a funded project from ORIL and no consulting/other relationships exist between sponsors and investigators. **Funding will be used for:** • Research Expenses (postage, equipment, travel, etc.)
	✓	**Does your protocol require work with human blood, human tissues, cell cultures derived from human cell lines, or virus/bacteria that is classified as bio risk II or above by the CDC? Ohio University EHS website**
	✓	**Does this project involve activities covered by the Health Insurance Portability and Accountability Act (HIPAA)?**



Review Level

REVIEW LEVEL: EXPEDITED

Yes	No	
✓		**The probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests (45 CFR 46.102(j)).**

Category 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subjects privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

Category 7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)

Recruitment/Selection of Subjects

Maximum number of participants to be enrolled? If screening occurs, include the number of subjects that will need to be screened in order to get the number necessary for statistical significance. Please note that once the protocol is approved this number must not be exceeded without prior approval of an amendment.

50

Characteristics of subjects

Adults
University Students

Criteria for selection of subjects (inclusion/exclusion).

Participants are expected to possess a valid driver's license for at least 2 years; and must be 18 years and older.

Recruitment Script Task 4.docx

Description of how they will identify and recruit prospective participants.

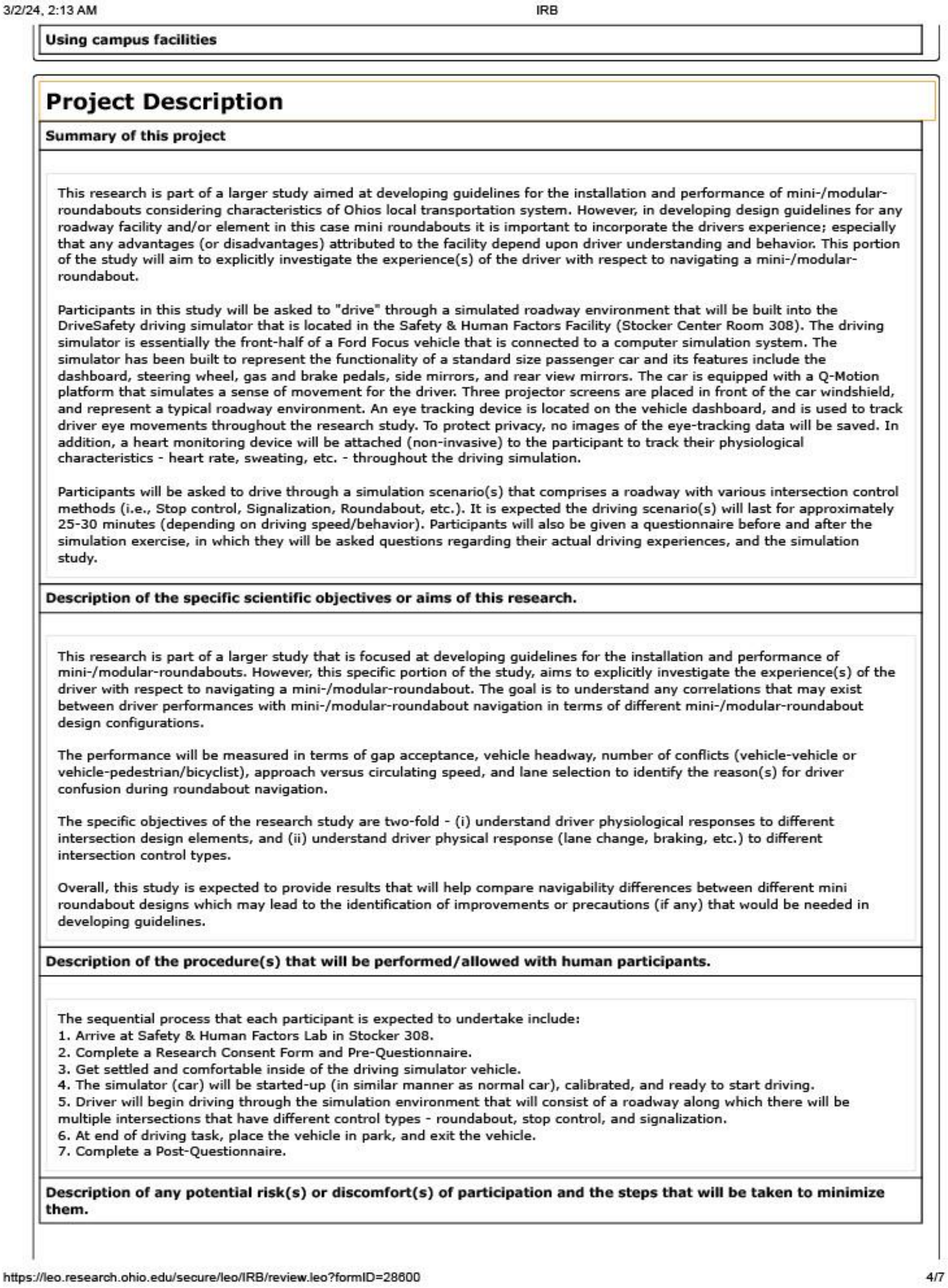
Participants will be recruited via solicitation on a voluntary basis. In order to solicit volunteers, the attached recruitment script ("Recruitment Script Task 4.docx") will be utilized. Individuals will be solicited via direct person-to-person contact on the Ohio University campus, local businesses, and the community center.

YES	NO	
	✓	**Are they accessing existing records for this study?**

Description of relationship and/or anyone on the research team's relationship with potential participants.

Instructor of class(es)/Colleague/Co-worker.

Performance Sites/Location of Research



Using campus facilities

Project Description

Summary of this project

This research is part of a larger study aimed at developing guidelines for the installation and performance of mini-/modular-roundabouts considering characteristics of Ohios local transportation system. However, in developing design guidelines for any roadway facility and/or element in this case mini roundabouts it is important to incorporate the drivers experience; especially that any advantages (or disadvantages) attributed to the facility depend upon driver understanding and behavior. This portion of the study will aim to explicitly investigate the experience(s) of the driver with respect to navigating a mini-/modular-roundabout.

Participants in this study will be asked to "drive" through a simulated roadway environment that will be built into the DriveSafety driving simulator that is located in the Safety & Human Factors Facility (Stocker Center Room 308). The driving simulator is essentially the front-half of a Ford Focus vehicle that is connected to a computer simulation system. The simulator has been built to represent the functionality of a standard size passenger car and its features include the dashboard, steering wheel, gas and brake pedals, side mirrors, and rear view mirrors. The car is equipped with a Q-Motion platform that simulates a sense of movement for the driver. Three projector screens are placed in front of the car windshield, and represent a typical roadway environment. An eye tracking device is located on the vehicle dashboard, and is used to track driver eye movements throughout the research study. To protect privacy, no images of the eye-tracking data will be saved. In addition, a heart monitoring device will be attached (non-invasive) to the participant to track their physiological characteristics - heart rate, sweating, etc. - throughout the driving simulation.

Participants will be asked to drive through a simulation scenario(s) that comprises a roadway with various intersection control methods (i.e., Stop control, Signalization, Roundabout, etc.). It is expected the driving scenario(s) will last for approximately 25-30 minutes (depending on driving speed/behavior). Participants will also be given a questionnaire before and after the simulation exercise, in which they will be asked questions regarding their actual driving experiences, and the simulation study.

Description of the specific scientific objectives or aims of this research.

This research is part of a larger study that is focused at developing guidelines for the installation and performance of mini-/modular-roundabouts. However, this specific portion of the study, aims to explicitly investigate the experience(s) of the driver with respect to navigating a mini-/modular-roundabout. The goal is to understand any correlations that may exist between driver performances with mini-/modular-roundabout navigation in terms of different mini-/modular-roundabout design configurations.

The performance will be measured in terms of gap acceptance, vehicle headway, number of conflicts (vehicle-vehicle or vehicle-pedestrian/bicyclist), approach versus circulating speed, and lane selection to identify the reason(s) for driver confusion during roundabout navigation.

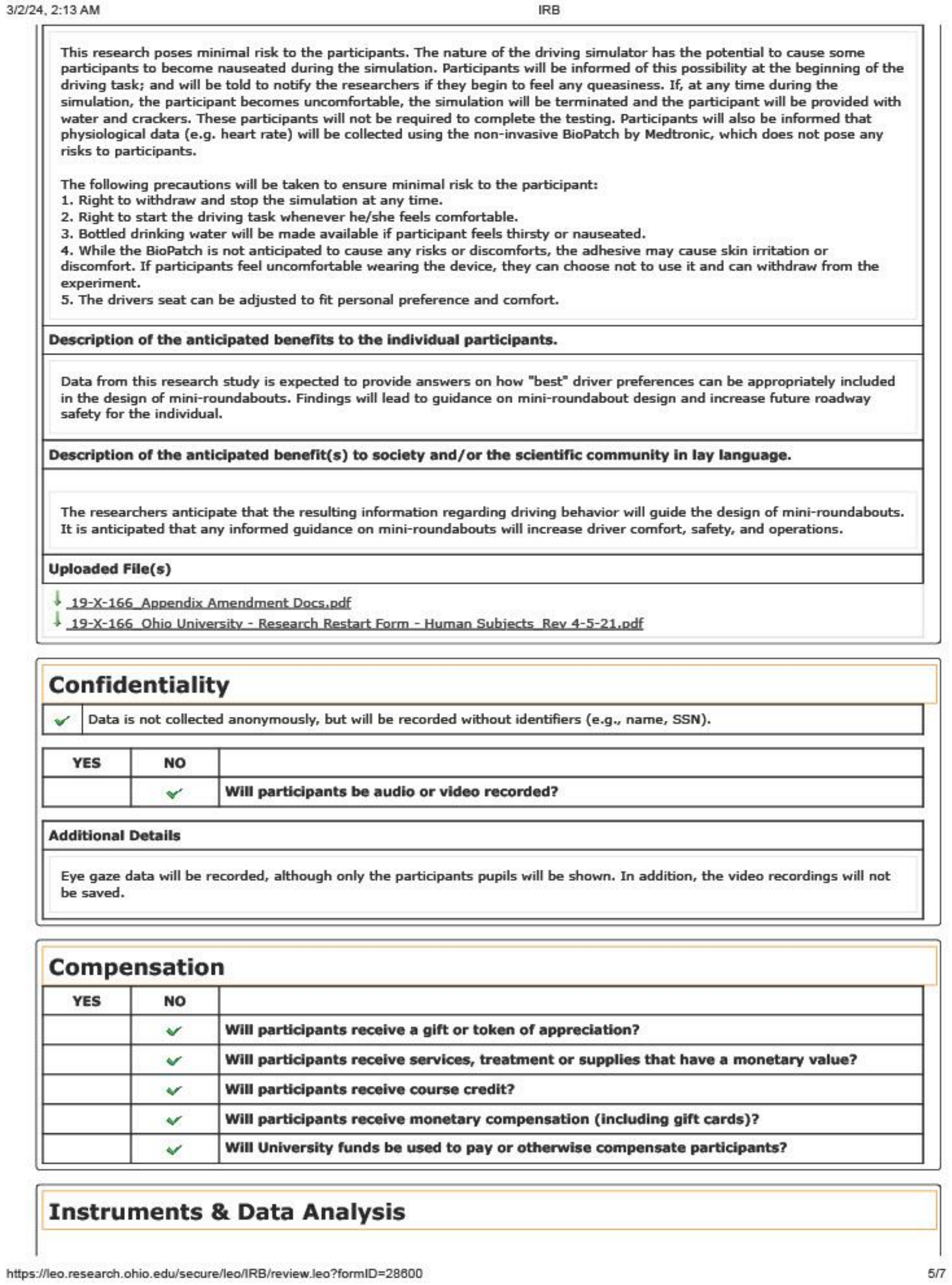
The specific objectives of the research study are two-fold - (i) understand driver physiological responses to different intersection design elements, and (ii) understand driver physical response (lane change, braking, etc.) to different intersection control types.

Overall, this study is expected to provide results that will help compare navigability differences between different mini roundabout designs which may lead to the identification of improvements or precautions (if any) that would be needed in developing guidelines.

Description of the procedure(s) that will be performed/allowed with human participants.

The sequential process that each participant is expected to undertake include:
1. Arrive at Safety & Human Factors Lab in Stocker 308.
2. Complete a Research Consent Form and Pre-Questionnaire.
3. Get settled and comfortable inside of the driving simulator vehicle.
4. The simulator (car) will be started-up (in similar manner as normal car), calibrated, and ready to start driving.
5. Driver will begin driving through the simulation environment that will consist of a roadway along which there will be multiple intersections that have different control types - roundabout, stop control, and signalization.
6. At end of driving task, place the vehicle in park, and exit the vehicle.
7. Complete a Post-Questionnaire.

Description of any potential risk(s) or discomfort(s) of participation and the steps that will be taken to minimize them.



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This research poses minimal risk to the participants. The nature of the driving simulator has the potential to cause some participants to become nauseated during the simulation. Participants will be informed of this possibility at the beginning of the driving task; and will be told to notify the researchers if they begin to feel any queasiness. If, at any time during the simulation, the participant becomes uncomfortable, the simulation will be terminated and the participant will be provided with water and crackers. These participants will not be required to complete the testing. Participants will also be informed that physiological data (e.g. heart rate) will be collected using the non-invasive BioPatch by Medtronic, which does not pose any risks to participants.

The following precautions will be taken to ensure minimal risk to the participant:
1. Right to withdraw and stop the simulation at any time.
2. Right to start the driving task whenever he/she feels comfortable.
3. Bottled drinking water will be made available if participant feels thirsty or nauseated.
4. While the BioPatch is not anticipated to cause any risks or discomforts, the adhesive may cause skin irritation or discomfort. If participants feel uncomfortable wearing the device, they can choose not to use it and can withdraw from the experiment.
5. The drivers seat can be adjusted to fit personal preference and comfort.

Description of the anticipated benefits to the individual participants.

Data from this research study is expected to provide answers on how "best" driver preferences can be appropriately included in the design of mini-roundabouts. Findings will lead to guidance on mini-roundabout design and increase future roadway safety for the individual.

Description of the anticipated benefit(s) to society and/or the scientific community in lay language.

The researchers anticipate that the resulting information regarding driving behavior will guide the design of mini-roundabouts. It is anticipated that any informed guidance on mini-roundabouts will increase driver comfort, safety, and operations.

Uploaded File(s)

- 19-X-166_Appendix Amendment Docs.pdf
- 19-X-166_Ohio University - Research Restart Form - Human Subjects_Rev 4-5-21.pdf

Confidentiality

✓ Data is not collected anonymously, but will be recorded without identifiers (e.g., name, SSN).

YES	NO	
	✓	**Will participants be audio or video recorded?**

Additional Details

Eye gaze data will be recorded, although only the participants pupils will be shown. In addition, the video recordings will not be saved.

Compensation

YES	NO	
	✓	**Will participants receive a gift or token of appreciation?**
	✓	**Will participants receive services, treatment or supplies that have a monetary value?**
	✓	**Will participants receive course credit?**
	✓	**Will participants receive monetary compensation (including gift cards)?**
	✓	**Will University funds be used to pay or otherwise compensate participants?**

Instruments & Data Analysis

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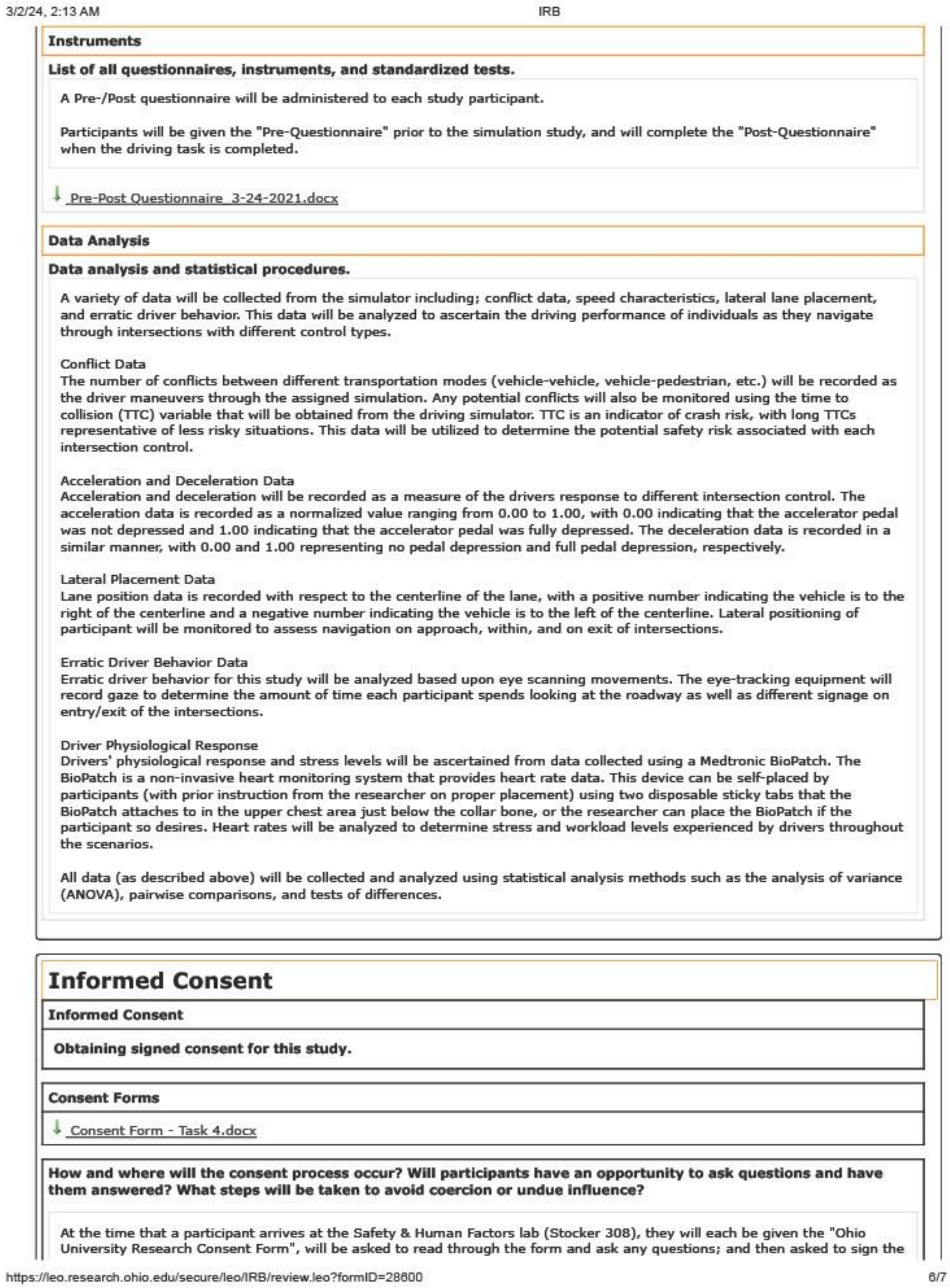


Instruments

List of all questionnaires, instruments, and standardized tests.

A Pre-/Post questionnaire will be administered to each study participant.

Participants will be given the "Pre-Questionnaire" prior to the simulation study, and will complete the "Post-Questionnaire" when the driving task is completed.

↓ Pre-Post Questionnaire 3-24-2021.docx

Data Analysis

Data analysis and statistical procedures.

A variety of data will be collected from the simulator including; conflict data, speed characteristics, lateral lane placement, and erratic driver behavior. This data will be analyzed to ascertain the driving performance of individuals as they navigate through intersections with different control types.

Conflict Data
The number of conflicts between different transportation modes (vehicle-vehicle, vehicle-pedestrian, etc.) will be recorded as the driver maneuvers through the assigned simulation. Any potential conflicts will also be monitored using the time to collision (TTC) variable that will be obtained from the driving simulator. TTC is an indicator of crash risk, with long TTCs representative of less risky situations. This data will be utilized to determine the potential safety risk associated with each intersection control.

Acceleration and Deceleration Data
Acceleration and deceleration will be recorded as a measure of the drivers response to different intersection control. The acceleration data is recorded as a normalized value ranging from 0.00 to 1.00, with 0.00 indicating that the accelerator pedal was not depressed and 1.00 indicating that the accelerator pedal was fully depressed. The deceleration data is recorded in a similar manner, with 0.00 and 1.00 representing no pedal depression and full pedal depression, respectively.

Lateral Placement Data
Lane position data is recorded with respect to the centerline of the lane, with a positive number indicating the vehicle is to the right of the centerline and a negative number indicating the vehicle is to the left of the centerline. Lateral positioning of participant will be monitored to assess navigation on approach, within, and on exit of intersections.

Erratic Driver Behavior Data
Erratic driver behavior for this study will be analyzed based upon eye scanning movements. The eye-tracking equipment will record gaze to determine the amount of time each participant spends looking at the roadway as well as different signage on entry/exit of the intersections.

Driver Physiological Response
Drivers' physiological response and stress levels will be ascertained from data collected using a Medtronic BioPatch. The BioPatch is a non-invasive heart monitoring system that provides heart rate data. This device can be self-placed by participants (with prior instruction from the researcher on proper placement) using two disposable sticky tabs that the BioPatch attaches to in the upper chest area just below the collar bone, or the researcher can place the BioPatch if the participant so desires. Heart rates will be analyzed to determine stress and workload levels experienced by drivers throughout the scenarios.

All data (as described above) will be collected and analyzed using statistical analysis methods such as the analysis of variance (ANOVA), pairwise comparisons, and tests of differences.

Informed Consent

Informed Consent

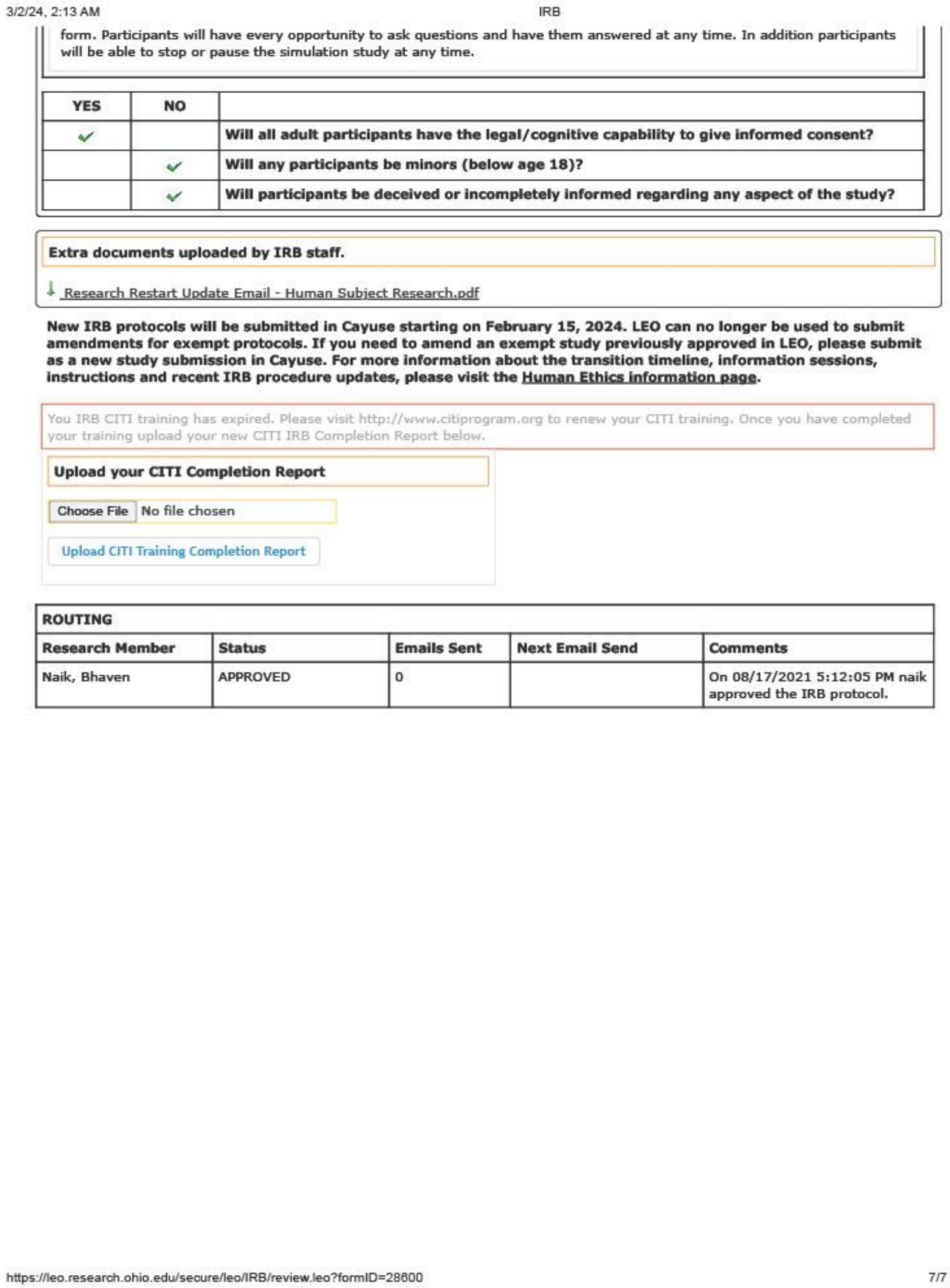
Obtaining signed consent for this study.

Consent Forms

↓ Consent Form - Task 4.docx

How and where will the consent process occur? Will participants have an opportunity to ask questions and have them answered? What steps will be taken to avoid coercion or undue influence?

At the time that a participant arrives at the Safety & Human Factors lab (Stocker 308), they will each be given the "Ohio University Research Consent Form", will be asked to read through the form and ask any questions; and then asked to sign the



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form. Participants will have every opportunity to ask questions and have them answered at any time. In addition participants will be able to stop or pause the simulation study at any time.

YES	NO	
✓		**Will all adult participants have the legal/cognitive capability to give informed consent?**
	✓	**Will any participants be minors (below age 18)?**
	✓	**Will participants be deceived or incompletely informed regarding any aspect of the study?**

Extra documents uploaded by IRB staff.

Research Restart Update Email - Human Subject Research.pdf

New IRB protocols will be submitted in Cayuse starting on February 15, 2024. LEO can no longer be used to submit amendments for exempt protocols. If you need to amend an exempt study previously approved in LEO, please submit as a new study submission in Cayuse. For more information about the transition timeline, information sessions, instructions and recent IRB procedure updates, please visit the Human Ethics information page.

You IRB CITI training has expired. Please visit http://www.citiprogram.org to renew your CITI training. Once you have completed your training upload your new CITI IRB Completion Report below.

Upload your CITI Completion Report

ROUTING				
Research Member	**Status**	**Emails Sent**	**Next Email Send**	**Comments**
Naik, Bhaven	APPROVED	0		On 08/17/2021 5:12:05 PM naik approved the IRB protocol.

https://leo.research.ohio.edu/secure/leo/IRB/review.leo?formID=28600 7/7

APPENDIX D: Ohio University Adult Consent Form with Signature

Title of Research: Intersection Modifications Using Modular/Mini-Roundabout Methods.

Researchers: Bhaven Naik, PhD, PE, PTOE, RSP. – PI.

Amit Kumar Roy, B.S. – Graduate Research Assistant.

IRB number: 19-X-166

You are being asked by an Ohio University researcher to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks of the research project. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

Summary of Study

The aim of this research study is to investigate driver performance as he/she navigates through a variety of roadway scenarios. A driving simulator, which features half of a Ford Focus connected to a computer simulation system, will be used. This driving simulator has been built to mimic the functionality of a standard size passenger car. The simulation software will display a typical roadway environment, in which you will be asked to drive. As you drive through the simulation, your performance/response to certain roadway events will be recorded.

Explanation of Study

This research study will investigate how drivers respond to various roadway scenarios. You will be asked to drive our DriveSafety Simulator. An eye-tracker is located on the vehicle dashboard, and will be used to track your eye movement throughout the study. You will be driving through three driving scenarios that lasts a total of approximately 40-45 minutes and will be given full control of the vehicle. A researcher will be present during the simulation, and will be giving you driving instructions. You will also complete a questionnaire. Your total time commitment for this study is approximately 60 minutes (or less depending on driving speed and behavior).

Risks and Discomforts

The risks to which you will be exposed by participating in this research study are minimal. Risks and discomforts include:

1. Simulator sickness due to driving in a simulator; generally one percent of participants experience nausea and a headache at the onset of driving or after driving for an hour or more. You have the right to withdraw and stop the simulation at any time. In addition, water bottles are available if you feel thirsty or have nausea.
2. Discomfort while sitting in the simulator for an extended period of time. The drivers seat can be adjusted to fit your personal preference and comfort.

Benefits

Data from this research study are meant to provide design guidelines for geometric design and are likely to lead to improved – safe, efficient, and economical - transportation facilities. Through this study, researchers anticipate that the resulting information regarding driving behavior can be implemented in assisting better responses to roundabout usage/navigation. You may not benefit, personally, from your participation.

Confidentiality and Records

The simulation data and responses collected during this research study will be identified by a time stamp including date and time of run. To protect your personal privacy, no images of the eye-tracking data will be saved. **This consent form is the only document that will contain your name, and no identifying data will be linked to the study data.**

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

- Federal agencies, such as the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
- Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU.

Compensation

No compensation will be provided.

Future Use Statement

Data/samples collected as part of this research will not be used for future research studies.

Contact Information

If you have any questions regarding this research study, please contact Dr. Bhaven Naik, PE, PTOE, RSP. at (402)-805-5679, naik@ohio.edu, or Amit Kumar Roy at (740)590-8857, ar553019@ohio.edu

If you have any questions regarding your rights as a research participant, please contact Dr. Chris Hayhow, Director of Research Compliance, Ohio University, (740)593-0664 or hayhow@ohio.edu.

By signing below, you are agreeing that you:

- have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered;
- have been informed of potential risks and they have been explained to your satisfaction;
- understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study;
- are 18 years of age or older;
- are participating in this research on a completely voluntary basis; and
- may leave the study at any time; if you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature____Date________________

Printed Name____

Version Date: ***04/13/2021***

APPENDIX E: Simulation Questionnaire

Pre-Test Questionnaire

Participant # _____ Date:____ /____ / 2021

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1. What is your age?
   - ☐ 18-25.
   - ☐ 26-40.
   - ☐ 41-55.
   - ☐ 56-65.
   - ☐ 65+.
2. What is your gender/gender preference?
   - ☐ Male.
   - ☐ Female.
   - ☐ Other.
   - ☐ Prefer not to answer.
3. How much would you say you drive on average?
   - ☐ 0-1 days per week.
   - ☐ 2-4 days per week.
   - ☐ 5-7 days per week.
4. How familiar are you with the concept of a **roundabout**?
   - ☐ Not familiar.
   - ☐ Somewhat familiar.
   - ☐ Very familiar.
5. How familiar are you with the concept of a **mini-roundabout**?
   - ☐ Not familiar.
   - ☐ Somewhat familiar.
   - ☐ Very familiar.
6. Have you ever driven through a **mini-roundabout** before?
   - ☐ Yes.
   - ☐ No.

7. When you think of roundabouts, have you ever received any information on how to navigate through the following: (Select all that apply)

   - ☐ Roundabouts (single-lane and/or double-lane), specifically.
   - ☐ Mini-roundabouts, specifically.
   - ☐ Turbo-roundabouts, specifically.
   - ☐ None.

   Please take a moment to explain the source (brochure/demonstration/website/video/etc.)

8. What type of information source would be most helpful to you to understand how to navigate through a Roundabout (Select all that apply)?

   - ☐ No information is needed.
   - ☐ Brochure.
   - ☐ Demonstration.
   - ☐ Website.
   - ☐ Video/Film.
   - ☐ Presentation.
   - ☐ Driver's Manual.
   - ☐ Other (please specify below).

9. Which type of roundabout sign is more beneficial for you to drive through a mini-roundabout?

☐ 

☐ CAUTION: ROUNDABOUT AHEAD

☐ Both messages are equally beneficial

☐ Neither of them is beneficial

Post-Test Questionnaire

Participant # _____

Date:____ /____ / 2021

---

1. With respect to the roundabouts in the simulation, did you notice/feel any differences between them?
    a. YES.
    b. NO.

If YES, did you observe differences such as navigation, size, other. (check all that apply)

- ☐ Difference in navigation.
- ☐ Difference in size.
- ☐ Other (please specify below).

2. Please <u>rank **your comfort level** while you were navigating/maneuvering</u> through the following situations in the simulator:

Simulator Driving Task .	**Comfort Level**				
At the start of the simulation.	1 (low)	2	3	4	5 (high)
As you drove through the **STOP controlled intersection**.	1 (low)	2	3	4	5(high)
As you drove through the **Roundabout**.	1 (low)	2	3	4	5(high)
As you drove through the smaller (**mini-roundabouts)**.	1 (low)	2	3	4	5(high)

3. Recall the intersections you just experienced in the simulation and indicate your order of preference based on comfort of navigating them.

Stop Controlled = _____

Mini-roundabouts = _____

Roundabout = _____

3. In general, will you be more comfortable driving through roundabouts with pedestrian crosswalks?

YES NO

4. In general, will you be more comfortable driving through roundabouts with bicycles?

YES NO

5. If yes, which one would be more comfortable?

- ☐ Bikes operating with the regular traffic
- ☐ Bikes in the pedestrian crossing

6. Provide any additional feedback on your experience driving through the different roundabouts.

Comments:

____

____

____

____

____

____

THANK YOU FOR PARTICIPATING IN OUR RESEARCH STUDY!

APPENDIX F: Raw Data

Raw Simulation Data Example

Name	Frame	Velocity	SpeedLimit	Brake	SubjectX	SubjectY	HeadwayTime
P46	10205	17.161	11.111	0.003	3918.158	6698.034	10.446
P46	10211	17.164	11.111	0	3919.875	6698.037	10.344
P46	10217	17.166	11.111	0.003	3921.591	6698.041	10.243
P46	10223	17.167	11.111	0	3923.308	6698.043	10.142
P46	10229	17.169	11.111	0	3925.025	6698.046	10.042
P46	10235	17.17	11.111	0.007	3926.742	6698.049	9.941
P46	10241	17.171	11.111	0.003	3928.459	6698.052	9.841
P46	10247	17.172	11.111	0.003	3930.176	6698.055	9.74
P46	10253	17.173	11.111	0.003	3931.893	6698.058	9.639
P46	10259	17.174	11.111	0	3933.61	6698.061	9.539
P46	10265	17.175	11.111	0.003	3935.328	6698.063	9.438
P46	10271	17.177	11.111	0.003	3937.045	6698.067	9.337
P46	10277	17.18	11.111	0	3938.763	6698.07	9.235
P46	10283	17.184	11.111	0.007	3940.481	6698.074	9.133
P46	10289	17.187	11.111	0.003	3942.2	6698.077	9.032

Raw data Summary Table (Entry Speed at 500 feet)

Roundabout Diameter (ft)	**45**	**60**	**75**	**90**	**Single-Lane**
P1	31.9	34.9	29.7	26.1	29.1
P2	33.4	28.8	27.8	25.8	26.7
P3	30.5	29.3	31.3	30.4	31.0
P4	34.7	29.6	27.4	37.2	46.1
P5	29.1	32.3	31.2	31.2	31.7
P6	32.4	30.2	27.7	32.1	28.9
P7	27.0	31.0	25.4	27.3	23.6
P8	28.0	30.3	28.5	25.5	27.6
P9	28.2	28.6	29.2	27.4	26.1
P10	31.5	30.4	26.6	31.5	23.6
P11	36.6	28.1	30.6	44.3	28.4
P12	39.4	38.0	36.0	31.5	32.1
P13	29.6	31.0	30.6	28.1	30.6
P14	29.5	27.9	27.2	31.1	31.0
P15	46.1	36.2	30.4	41.6	34.6
P16	26.9	33.3	29.0	29.0	27.2
P17	31.7	34.2	32.1	29.9	25.9
P18	28.3	44.3	32.1	29.9	19.3

APPENDIX G: Gap Data and Critical Gap Graphs

Gap Data (Mini-Roundabout ICD 45')

Gap length (s)	Accepted Gaps	Rejected Gaps	Cumulative Percentage of Accepted Gaps	Cumulative Percentage of Rejected Gaps
0	1	49	2%	98%
1	1	49	2%	98%
2	1	49	2%	98%
3	2	48	4%	96%
4	7	43	14%	86%
5	29	21	58%	42%
6	38	12	76%	24%
7	46	4	92%	8%
8	47	3	94%	6%
9	49	1	98%	2%

Gap Data (Mini-Roundabout ICD 60')

Gap length (s)	Accepted Gaps	Rejected Gaps	Cumulative Percentage of Accepted Gaps	Cumulative Percentage of Rejected Gaps
0	9	41	18%	82%
1	9	41	18%	82%
2	9	41	18%	82%
3	11	39	22%	78%
4	23	27	46%	54%
5	32	18	64%	36%
6	43	7	86%	14%
7	47	3	94%	6%
8	47	3	94%	6%
9	49	1	98%	2%

Gap Data (Mini-Roundabout ICD 75')

Gap length (s)	Accepted Gaps	Rejected Gaps	Cumulative Percentage of Accepted Gaps	Cumulative Percentage of Rejected Gaps
0	6	44	12%	88%
1	6	44	12%	88%
2	6	44	12%	88%
3	6	44	12%	88%
4	19	31	38%	62%
5	31	19	62%	38%
6	40	10	80%	20%
7	43	7	86%	14%
8	50	0	100%	0%
9	50	0	100%	0%

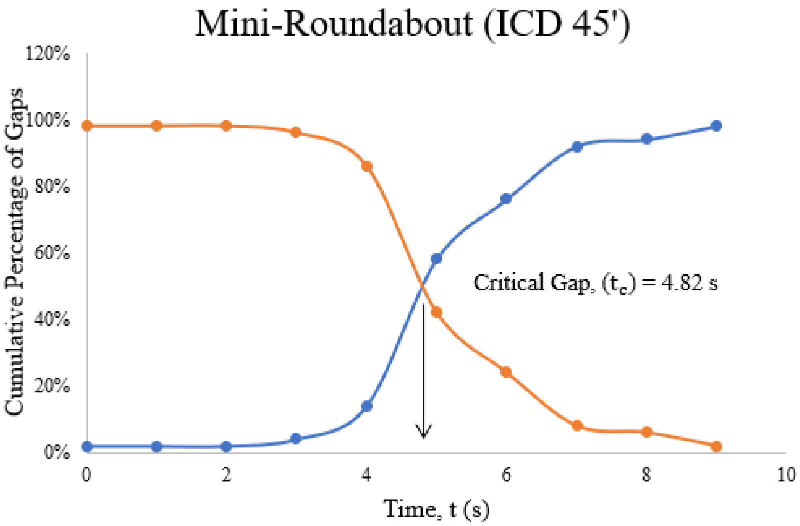
Gap Data (Mini-Roundabout ICD 90')

Gap length (s)	Accepted Gaps	Rejected Gaps	Cumulative Percentage of Accepted Gaps	Cumulative Percentage of Rejected Gaps
0	4	46	8%	92%
1	4	46	8%	92%
2	4	46	8%	92%
3	5	45	10%	90%
4	16	34	32%	68%
5	33	17	66%	34%
6	43	7	86%	14%
7	47	3	94%	6%
8	47	3	94%	6%
9	50	0	100%	0%

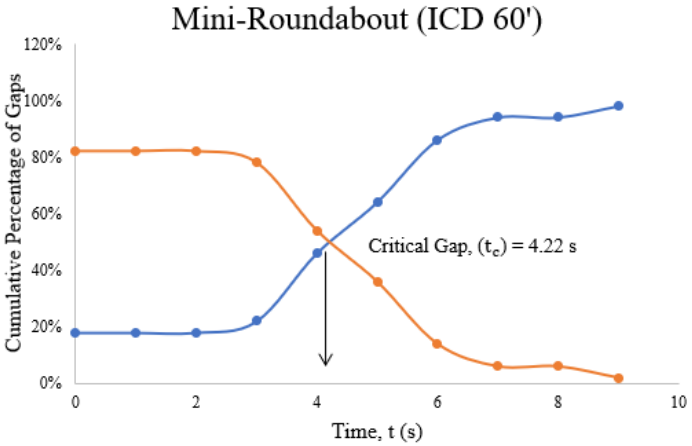
Gap Data (Single-Lane Roundabout ICD 120')

Gap length (s)	Accepted Gaps	Rejected Gaps	Cumulative Percentage of Accepted Gaps	Cumulative Percentage of Rejected Gaps
0	18	32	36%	64%
1	18	32	36%	64%
2	19	31	38%	62%
3	19	31	38%	62%
4	24	26	48%	52%
5	33	17	66%	34%
6	44	6	88%	12%
7	50	0	100%	0%
8	50	0	100%	0%
9	50	0	100%	0%

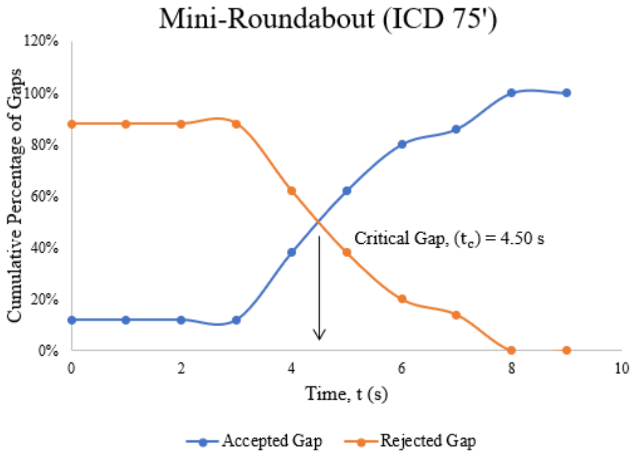
Combined Critical Gap Estimation for Mini-roundabout (ICD 45')



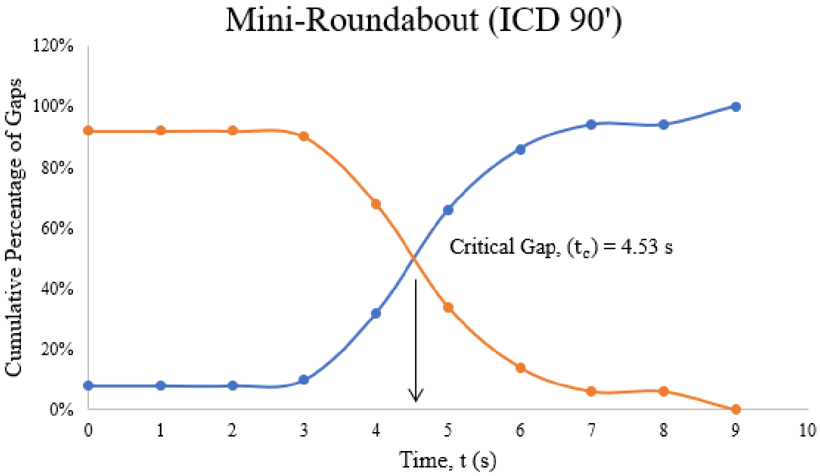
Combined Critical Gap Estimation for Mini-roundabout (ICD 60')



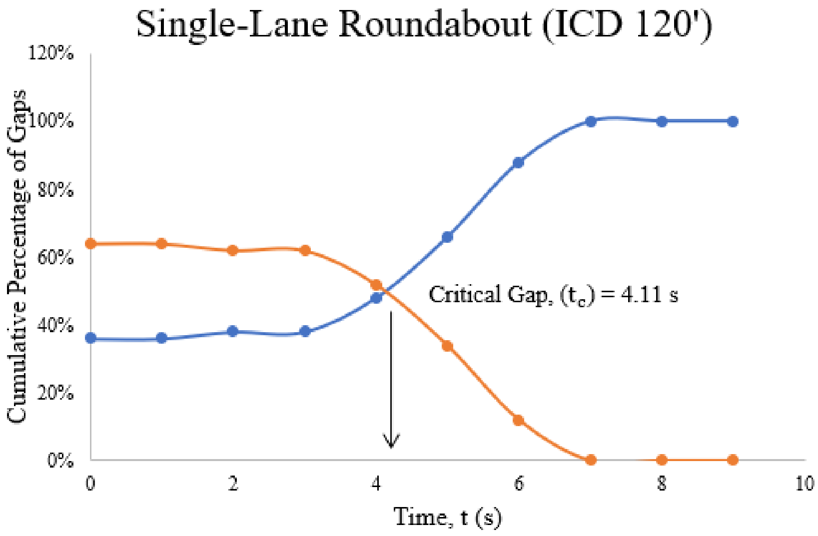
Combined Critical Gap Estimation for Mini-roundabout (ICD 75')



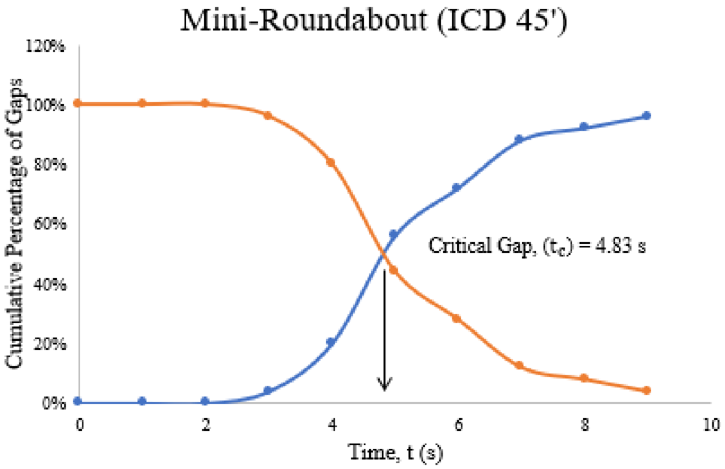
Combined Critical Gap Estimation for Mini-roundabout (ICD 90')



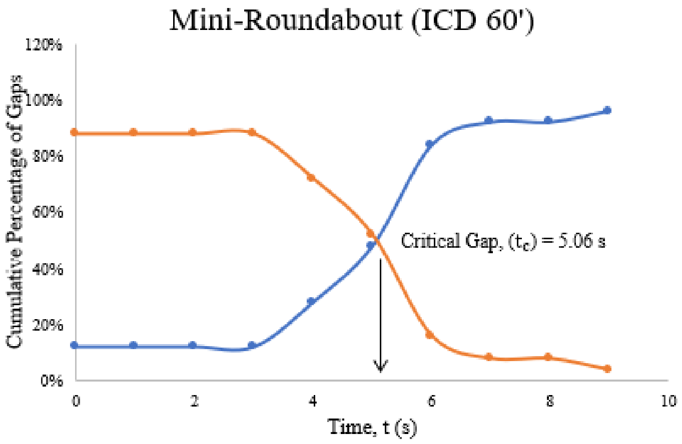
Combined Critical Gap Estimation for Single-Lane Roundabout (ICD 120')



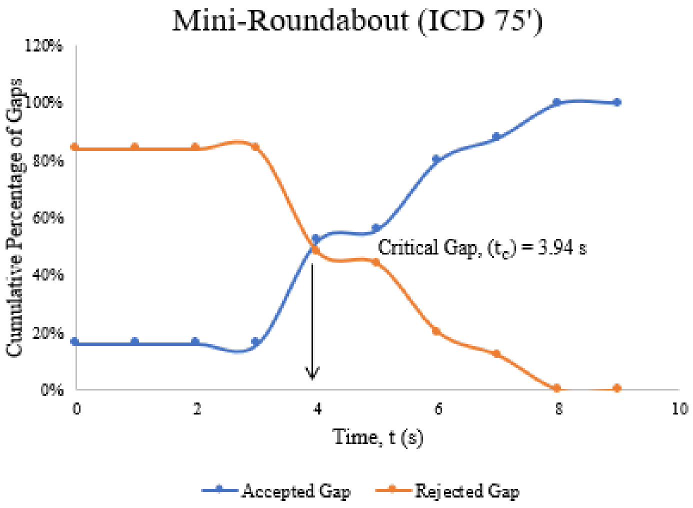
Daytime Critical Gap Estimation for Mini-roundabout (ICD 45')



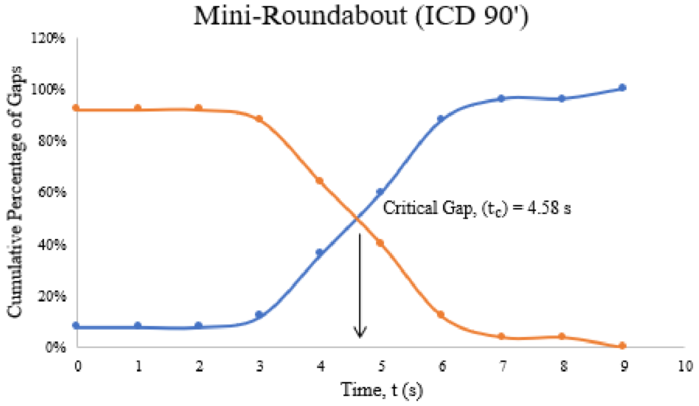
Daytime Critical Gap Estimation for Mini-roundabout (ICD 60')



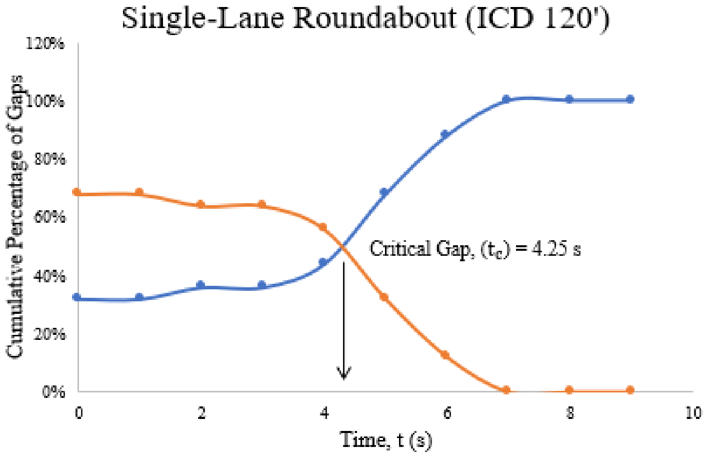
Daytime Critical Gap Estimation for Mini-roundabout (ICD 75')



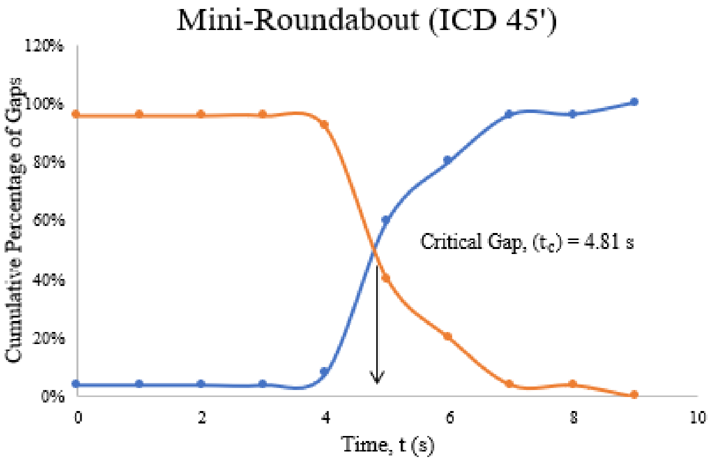
Daytime Critical Gap Estimation for Mini-roundabout (ICD 90')



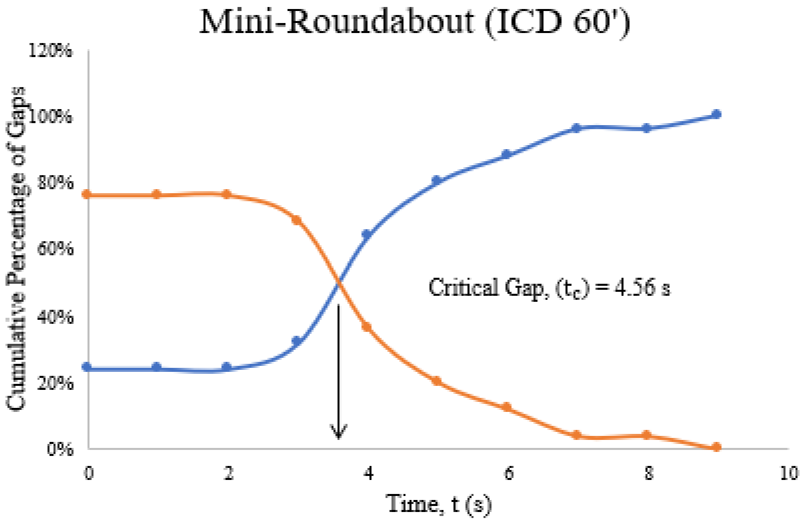
Daytime Critical Gap Estimation for Single-Lane Roundabout (ICD 120')



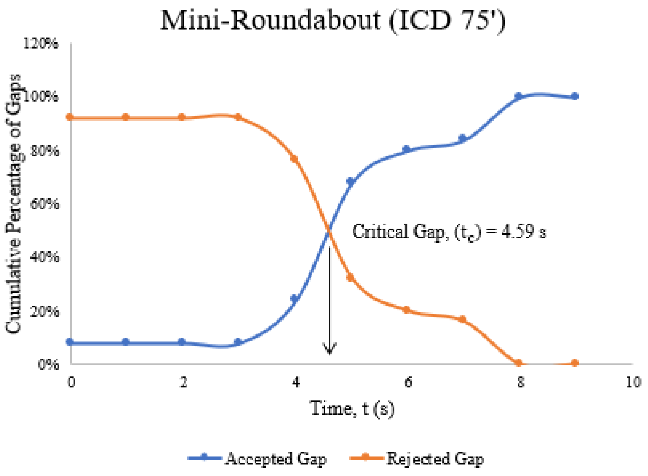
Nighttime Critical Gap Estimation for Mini-roundabout (ICD 45')



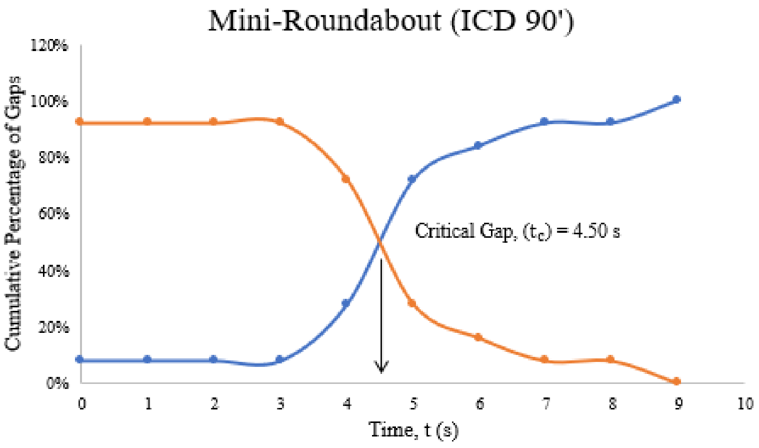
Nighttime Critical Gap Estimation for Mini-roundabout (ICD 60')



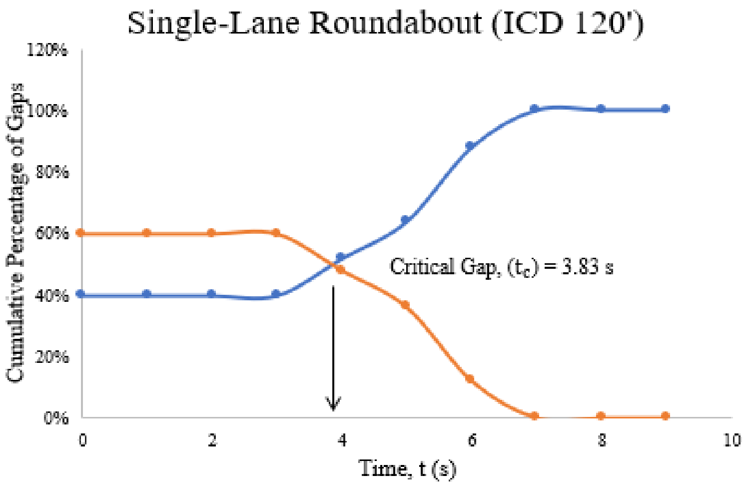
Nighttime Critical Gap Estimation for Mini-roundabout (ICD 75')



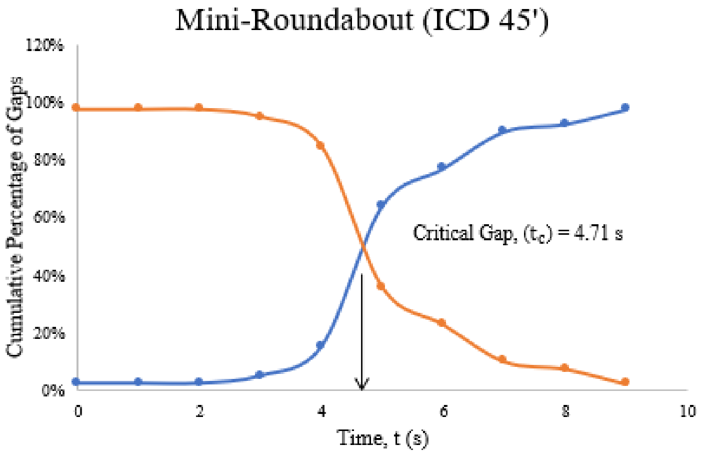
Nighttime Critical Gap Estimation for Mini-roundabout (ICD 90')



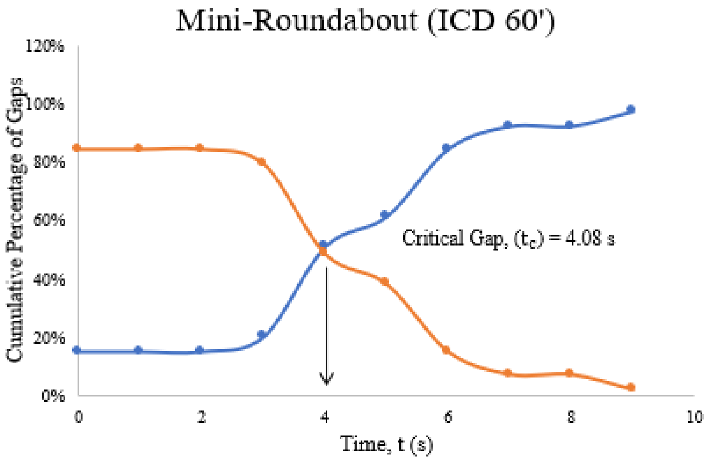
Nighttime Critical Gap Estimation for Single-Lane Roundabout (ICD 120')



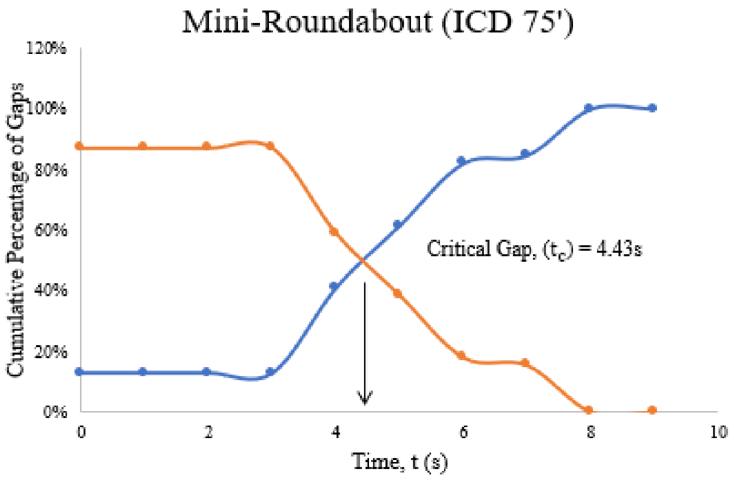
Critical Gap (Male) Estimation for Mini-roundabout (ICD 45')



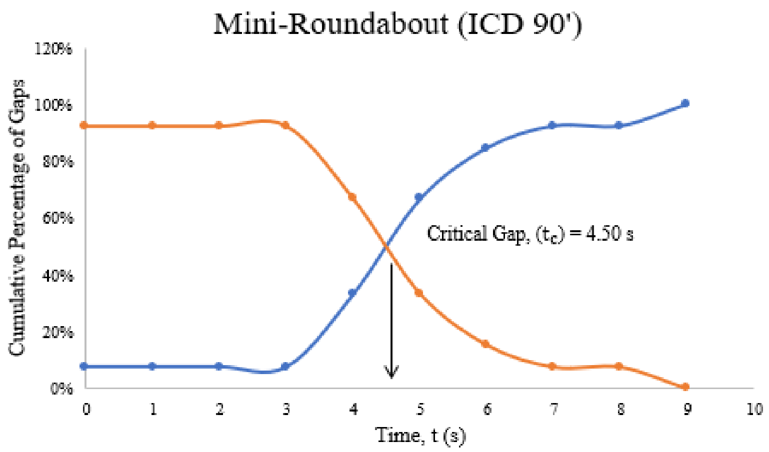
Critical Gap (Male) Estimation for Mini-roundabout (ICD 60')



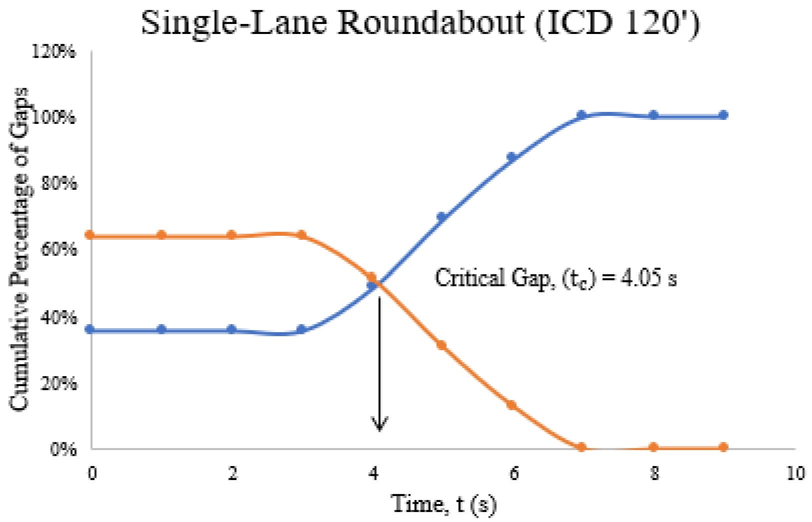
Critical Gap (Male) Estimation for Mini-roundabout (ICD 75')



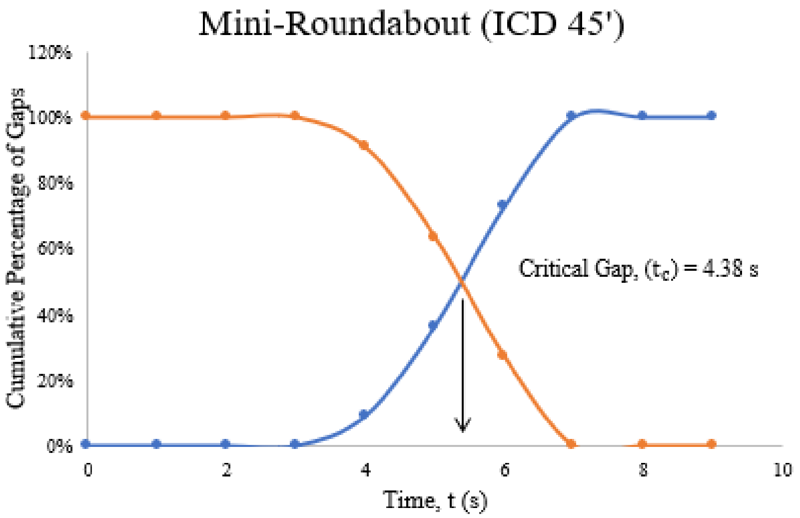
Critical Gap (Male) Estimation for Mini-roundabout (ICD 90')



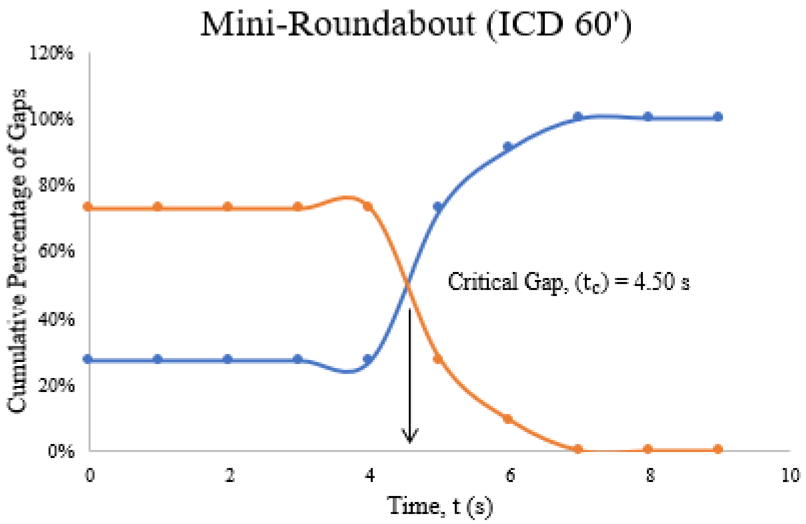
Critical Gap (Male) Estimation for Single-Lane Roundabout (ICD 120')



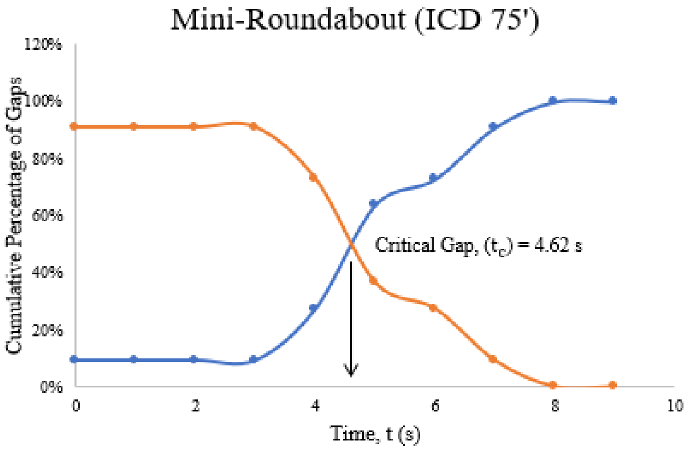
Critical Gap (Female) Estimation for Mini-roundabout (ICD 45')



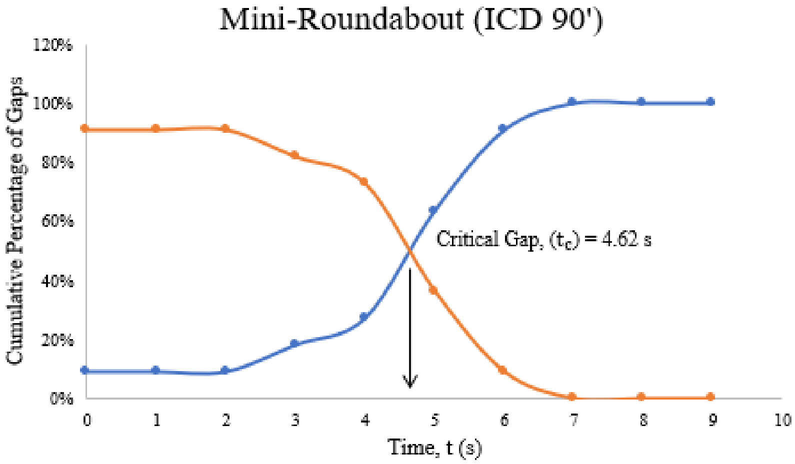
Critical Gap (Female) Estimation for Mini-roundabout (ICD 60')



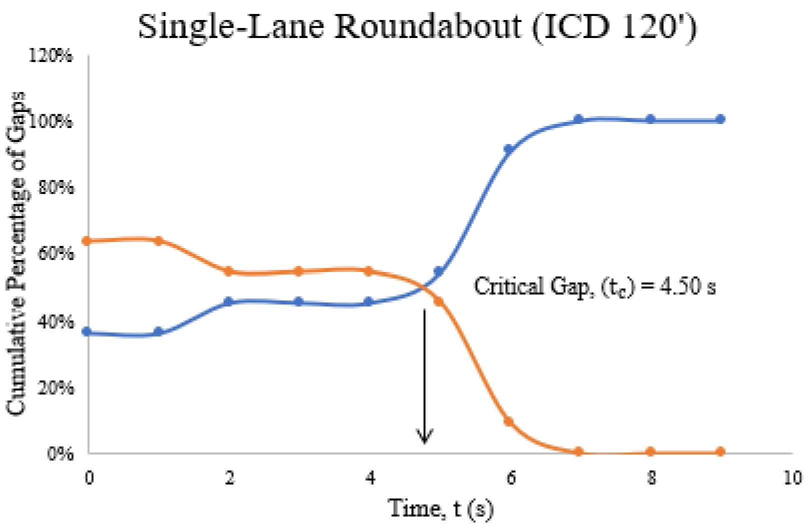
Critical Gap (Female) Estimation for Mini-roundabout (ICD 75')



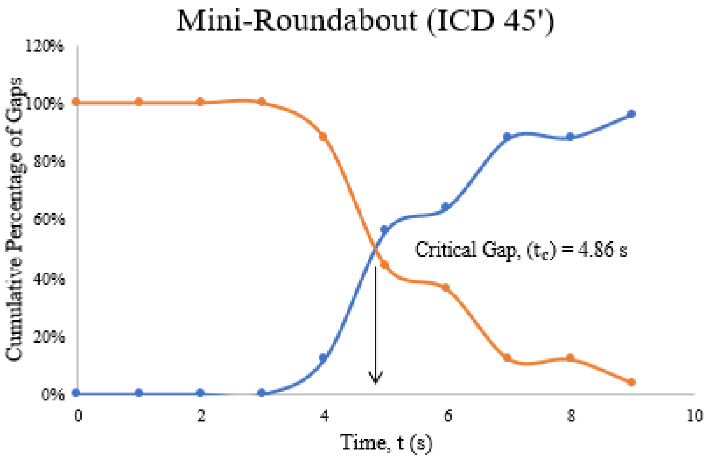
Critical Gap (Female) Estimation for Mini-roundabout (ICD 90')



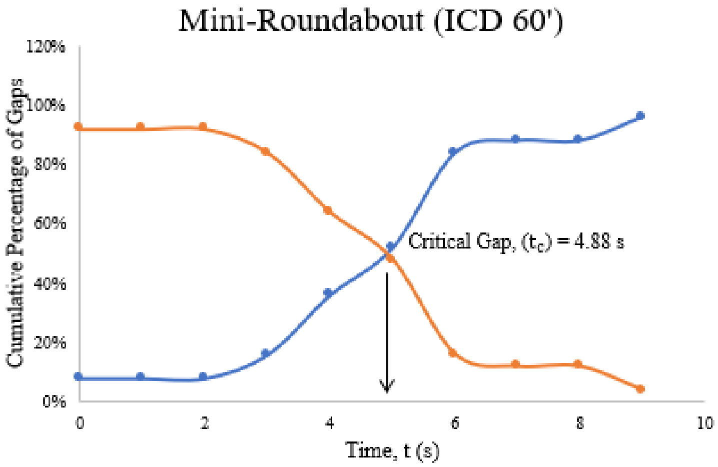
Critical Gap (Female) Estimation for Single-Lane Roundabout (ICD 120')



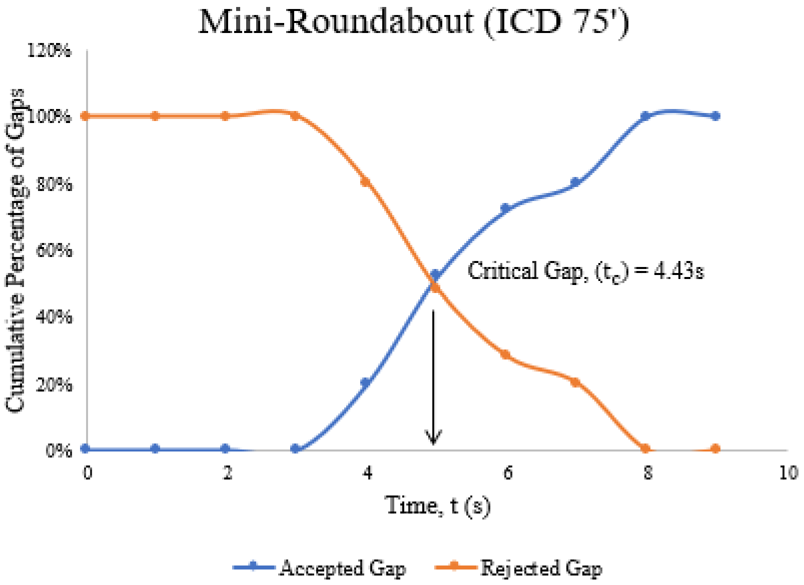
Critical Gap (Age Group 18-25) Estimation for Mini-roundabout (ICD 45')



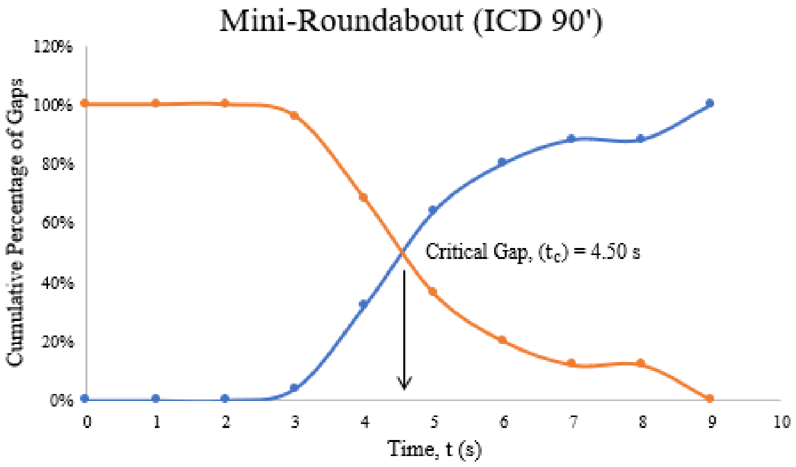
Critical Gap (Age Group 18-25) Estimation for Mini-roundabout (ICD 60')



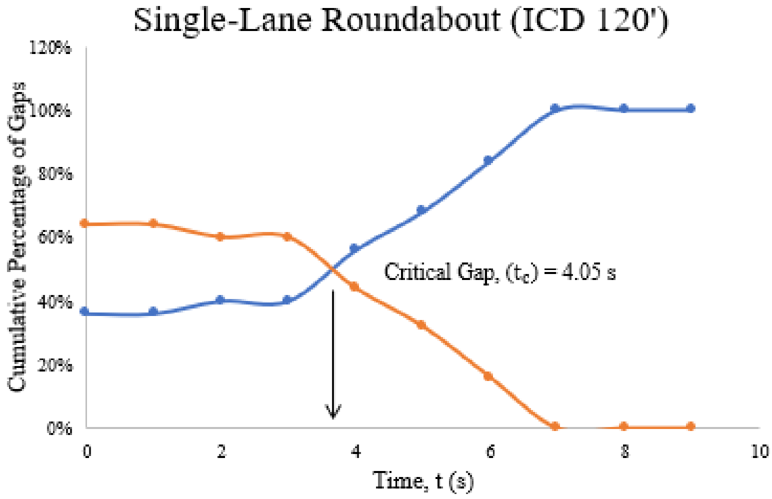
Critical Gap (Age Group 18-25) Estimation for Mini-roundabout (ICD 75')



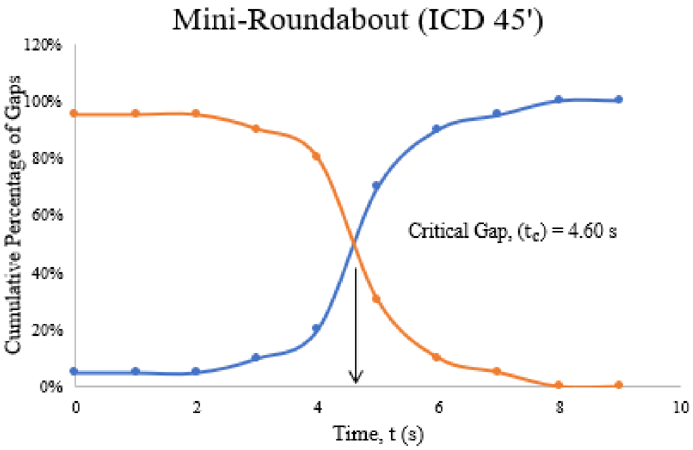
Critical Gap (Age Group 18-25) Estimation for Mini-roundabout (ICD 90')



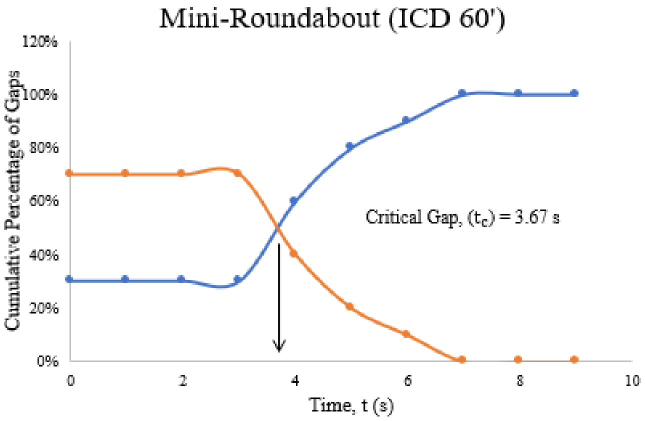
Critical Gap (Age Group 18-25) Estimation for Single-Lane Roundabout (ICD 120')



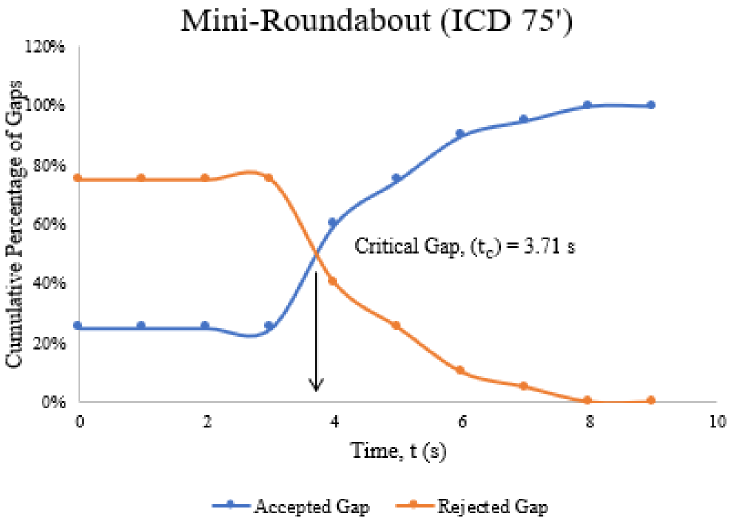
Critical Gap (Age Group 26-40) Estimation for Mini-roundabout (ICD 45'



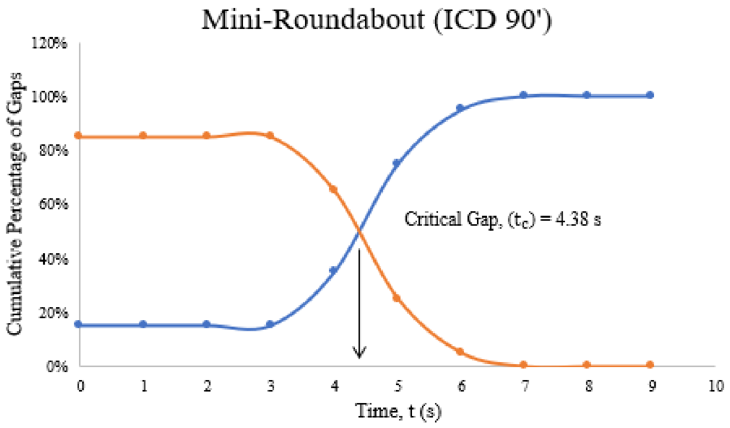
Critical Gap (Age Group 26-40) Estimation for Mini-roundabout (ICD 60')



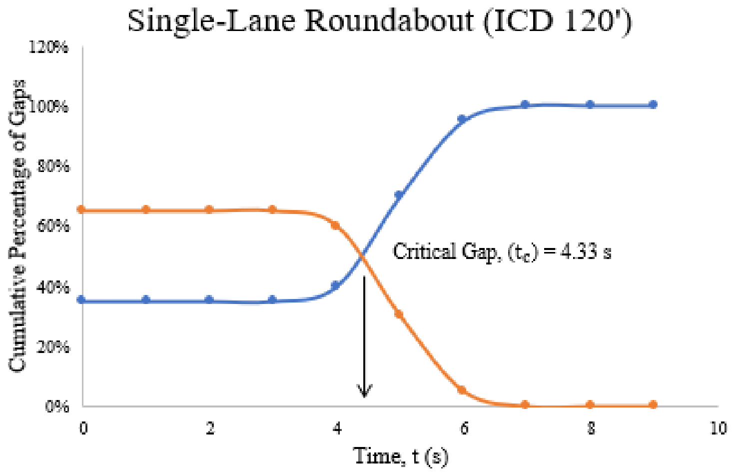
Critical Gap (Age Group 26-40) Estimation for Mini-roundabout (ICD 75')



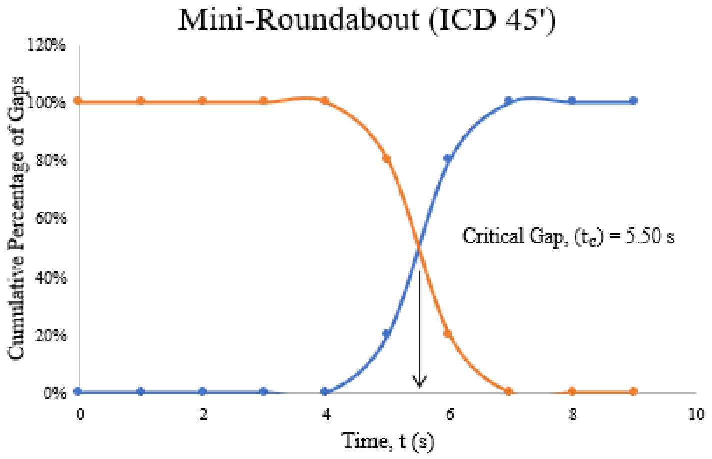
Critical Gap (Age Group 26-40) Estimation for Mini-roundabout (ICD 90')



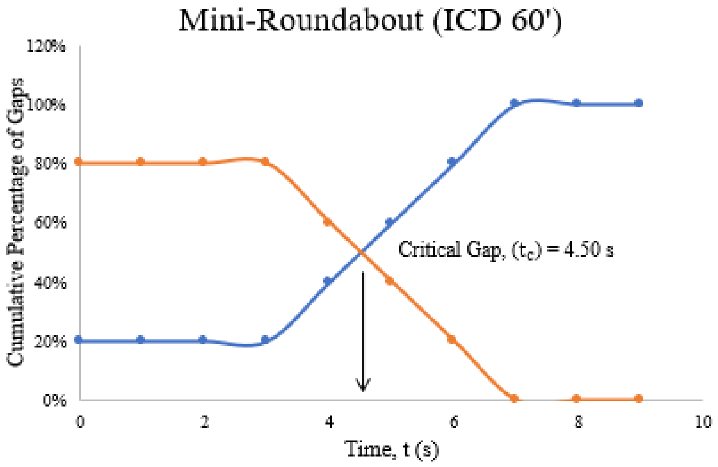
Critical Gap (Age Group 26-40) Estimation for Single-Lane Roundabout (ICD 120')



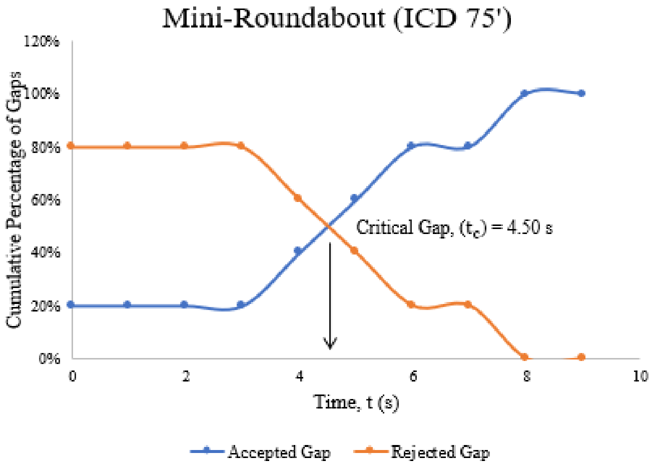
Critical Gap (Age Group 41-65) Estimation for Mini-roundabout (ICD 45')



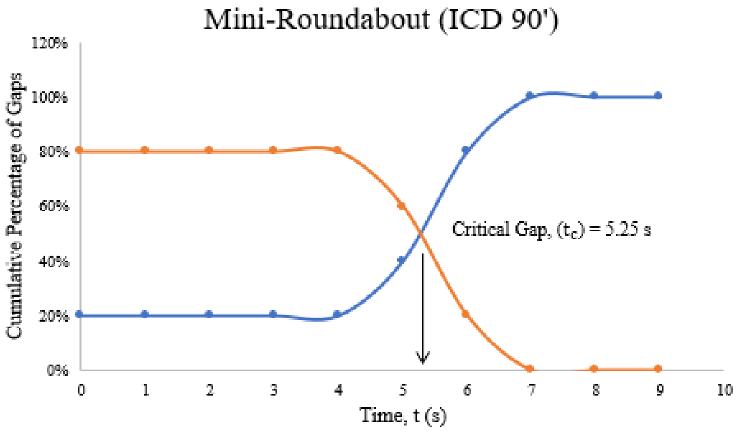
Critical Gap (Age Group 41-65) Estimation for Mini-roundabout (ICD 60')



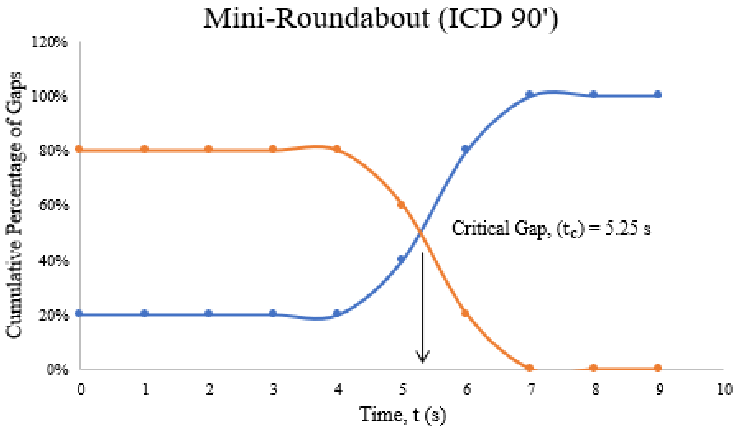
Critical Gap (Age Group 41-65) Estimation for Mini-roundabout (ICD 75')



Critical Gap (Age Group 41-65) Estimation for Mini-roundabout (ICD 90')



Critical Gap (Age Group 41-65) Estimation for Mini-roundabout (ICD 90')



APPENDIX H: Logistic Regression SPSS Outputs

Logistic Regression

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	47	100.0
	Missing Cases	0	0.0
	Total	47	100.0
Unselected Cases		0	0.0
Total		47	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No	0
Yes	1

Categorical Variables Codings

			Parameter coding	
		Frequency	(1)	(2)
AgeGroup	18-25	23	0.000	0.000
	26-40	18	1.000	0.000
	41-65	6	0.000	1.000
Condition	Day	24	0.000	
	Night	23	1.000	
Gender	Male	38	0.000	
	Female	9	1.000	

Block 0: Beginning Block

Iteration History[a,b,c]

			Coefficients
Iteration		-2 Log likelihood	Constant
Step 0	1	55.476	-0.894
	2	55.433	-0.960
	3	55.433	-0.961

a. Constant is included in the model.

b. Initial -2 Log Likelihood: 55.433

c. Estimation terminated at iteration number 3 because parameter estimates changed by less than .001.

Classification Table[a,b]

			Predicted		
			Speeding		Percentage Correct
Observed			No	Yes	
Step 0	Speeding	No	34	0	100.0
		Yes	13	0	0.0
	Overall Percentage				72.3

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-0.961	0.326	8.692	1	0.003	0.382

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Gender(1)	0.164	1	0.685
		AgeGroup	0.125	2	0.939
		AgeGroup(1)	0.000	1	0.989
		AgeGroup(2)	0.111	1	0.739
		Condition(1)	5.633	1	0.018
	Overall Statistics		6.330	4	0.176

Block 1: Method = Enter

Iteration History[a,b,c,d]

Iteration		-2 Log likelihood	Coefficients				
			Constant	Gender(1)	AgeGroup(1)	AgeGroup(2)	Condition(1)
Step 1	1	49.454	-1.375	-0.581	-0.254	0.561	1.263
	2	48.671	-1.749	-0.990	-0.302	0.954	1.672
	3	48.643	-1.827	-1.136	-0.300	1.091	1.753
	4	48.643	-1.830	-1.146	-0.300	1.099	1.756
	5	48.643	-1.830	-1.146	-0.300	1.099	1.756

a. Method: Enter

b. Constant is included in the model.

c. Initial -2 Log Likelihood: 55.433

d. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	6.789	4	0.147
	Block	6.789	4	0.147
	Model	6.789	4	0.147

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	48.643[a]	0.135	0.194

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.927	6	0.926

Contingency Table for Hosmer and Lemeshow Test

		Speeding = No		Speeding = Yes		
		Observed	Expected	Observed	Expected	Total
Step 1	1	3	2.854	0	0.146	3
	2	6	6.256	1	0.744	7
	3	2	1.735	0	0.265	2
	4	9	9.480	2	1.520	11
	5	2	1.495	0	0.505	2
	6	6	5.923	4	4.077	10
	7	1	1.590	2	1.410	3
	8	5	4.666	4	4.334	9

Classification Table[a]

Observed			Predicted		
			Speeding		Percentage Correct
			No	Yes	
Step 1	Speeding	No	34	0	100.0
		Yes	13	0	0.0
	Overall Percentage				72.3

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Gender(1)	-1.146	1.493	0.590	1	0.442	0.318
	AgeGroup			0.802	2	0.670	
	AgeGroup(1)	-0.300	0.775	0.149	1	0.699	0.741
	AgeGroup(2)	1.099	1.567	0.492	1	0.483	3.002
	Condition(1)	1.756	0.773	5.164	1	0.023	5.791
	Constant	-1.830	0.700	6.842	1	0.009	0.160

a. Variable(s) entered on step 1: Gender, AgeGroup, Condition.

```
Step number: 1

Observed Groups and Predicted Probabilities

16 +                                                                                                    +
I                                                                                                    I
I                                                                                                    I
F        I             Y                                                                                      I
R     12 +             Y                                                                                      +
E        I             N                                                                                      I
Q        I             N                          Y                                                           I
U        I             N                          Y       Y                                                   I
E      8 +             N                          Y       Y                                                   +
N        I          Y  N                          Y       Y                                                   I
C        I          N  N                          N       Y                                                   I
Y        I          N  N                          N       N                                                   I
4 +          N  N                          N       N                                                   +
I    N     N  N                          N     Y N                                                   I
I    N     N  N                          N     Y N                                                   I
I    N     N  N   N              N       N     N N                                                   I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
Prob:   0       .1        .2        .3        .4        .5        .6        .7        .8        .9         1
Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYY

Predicted Probability is of Membership for Yes
The Cut Value is .50
Symbols: N - No
Y - Yes
Each Symbol Represents 1 Case.
```