Accelerating Roundabout Implementation in the United States – Volume VI of VII

Investigation of Crosswalk Design and Driver Behaviors

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Federal Highway Administration

Safe Roads for a Safer Future

Investment in roadway safety saves lives

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

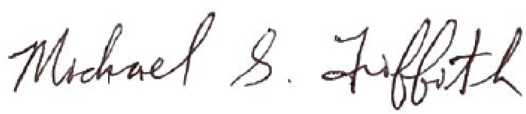
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

FOREWORD

Since the Federal Highway Administration (FHWA) published the first *Roundabouts Informational Guide* in 2000, the estimated number of roundabouts in the United States has grown from fewer than one hundred to several thousand. Roundabouts remain a high priority for FHWA due to their proven ability to reduce severe crashes by an average of 80 percent. They are featured as one of the Office of Safety *Proven Safety Countermeasures* and were included in the *Every Day Counts 2* campaign for Intersection & Interchange Geometrics.

As roundabouts became more common across a wide range of traffic conditions, specific questions emerged on how to further tailor certain aspects of their design to better meet the needs of a growing number and diversity of stakeholders. The substantial work performed for this project – *Accelerating Roundabout Implementation in the United States* – sought to address several of the most pressing issues of National significance, including enhancing safety, improving operational efficiency, considering environmental effects, accommodating freight movement and providing pedestrian accessibility. This work represents yet another notable step forward in advancing roundabouts in the United States.

The electronic versions of each of the seven report volumes that document this project are available on the Office of Safety website at http://safety.fhwa.dot.gov/.



Michael S. Griffith
Director
Office of Safety Technologies

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16. Abstract

This volume is sixth in a series of seven. The other volumes in the series are: Volume I - Evaluation of Rectangular Rapid-Flashing Beacons (RRFB) at Multilane Roundabouts, Volume II – Assessment of Roundabout Capacity Models for the Highway Capacity Manual, Volume III – Assessment of the Environmental Characteristics of Roundabouts, Volume IV – A Review of Fatal and Severe Injury Crashes at Roundabouts, Volume V – Evaluation of Geometric Parameters that Affect Truck Maneuvering and Stability, and Volume VII – Human Factor Assessment of Traffic Control Device Effectiveness. These reports document a Federal Highway Administration (FHWA) project to investigate and evaluate several important aspects of roundabout design and operation for the purpose of providing practitioners with better information, leading to more widespread and routine implementation of higher quality roundabouts.

This research explored location and configuration of pedestrian crosswalks at roundabouts. Two experiments were conducted for this project. The first examined driver yielding behavior at roundabouts by having researcher-pedestrians attempt to cross at several crosswalks and several intersections. The second examined drivers' eye-glance behavior by having participants drive through several roundabouts while wearing an eye-tracking device. Drivers were found to yield more often at the crosswalks at roundabout entries than at crosswalks at roundabouts exits and were also more likely to yield to pedestrians waiting at the splitter island than those waiting at the curb. A model of yielding behavior found crosswalk distance from circulatory roadway affected yielding percentage, but the effect was too small to be practically significant. Drivers spent a considerable amount of time glancing toward pedestrians and pedestrian-related signs and markings, reducing the amount of time they glanced at navigation aids.

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CHAPTER 1. INTRODUCTION

Pedestrian safety and access are important considerations for the design and operation of all intersections, including roundabouts. A multitude of factors and their interactions influence a pedestrian's ability to safely traverse a crosswalk. Roundabout designers and stakeholders seek to maximize safety and convenience, yet questions remain regarding the best location and orientation of pedestrian facilities for doing that. The objective of this task was to develop design guidance for the placement and configuration of pedestrian crosswalks at modern roundabouts, with the goal of improving drivers' propensity to yield to pedestrians.

This research effort included two studies: (1) a naturalistic study of staged crossings, exploring the yielding behavior of drivers based on operational and geometric conditions at roundabouts, and (2) an eye-tracking study recording participant eye movements when driving through roundabouts. The team focused the study on roundabouts in a limited geographic area to control for driver and pedestrian culture and behavioral biases, which does vary across the United States. The observational driver yielding study offered a macroscopic examination of yielding behavior across a broad set of crosswalk design parameters. The eye-tracking study involved participants who were asked to drive through several roundabouts while wearing an eye tracker that recorded where they looked and for how long.

Previous research has demonstrated a wide range of yielding percentages at one- and two-lane roundabouts at sites across the United States.(1,2) Past research further suggests a strong correlation between driver yielding behavior and vehicular speeds, which may partly describe the generally lower yielding rates at crosswalks at roundabout exits, where drivers are typically accelerating, than at roundabout entries, where drivers are typically decelerating.(2) The visibility of the crosswalk and pedestrians waiting to cross were also expected to play a key role in driver yielding. A study of pedestrian crosswalk treatments and roundabout configurations performed using a driving simulator found a 30 percent increase in driver yielding when a crosswalk at a roundabout exit was moved from 6.1 m (20 ft) downstream to 18 m (60 ft) downstream from the circulating lane.(3) Salamati et al.(3) found this strong effect of crosswalk location, and they further validated the finding through eye-tracker studies showing that many drivers did not see the pedestrians at the crosswalk that was 6.1 m (20 ft) from the circulating lane.

Driver sight distance and reaction time also likely impact yielding behavior, particularly where sight distances are at or near the minimum recommended values for safe stopping. Drivers' sight distance to pedestrians waiting at the crosswalks may also explain why yield rates are greater at roundabout entries, where crosswalks are often more visible, than those at roundabout exits. Differences in vehicular speed and acceleration, as described above, may also contribute to yielding behavior.

From this discussion, key research questions related to crosswalk design and configuration emerged:

- Should crosswalks be located closer to the roundabout, where vehicle speeds are lower?

- Should crosswalks be located farther away from the roundabout, at a point where drivers have a better line of sight to the crosswalk and increased reaction time?
- Should the crosswalk be oriented perpendicular to the approach center line, versus perpendicular to the travel lane center line?
- Is there an optimum distance for a crosswalk from the circulatory roadway?
- Is this optimum distance different at the entry approach versus the exit?

This research attempts to answer these questions using a series of naturalistic yielding, speed, and eye-tracking studies performed at a number of single-lane and two-lane roundabouts in two cities: Carmel, IN, and Hilliard, OH.

CHAPTER 2. BACKGROUND

There are limited studies of pedestrian crossing design elements and their associated yielding rates at roundabouts, but several studies provided useful information, including research into characteristics such as traffic volumes, pedestrian volumes, numbers of approaching and circulating lanes, distance to the first sight of the roundabout, and the length of vehicle storage between the crosswalk and the circulating lane (as summarized in [4]). The distance from the crosswalk to the yield line at roundabout entries should typically be at least one vehicle length to separate conflict points and yielding areas.(5) At roundabout exits, crosswalks farther from the circle are expected to make pedestrians more visible, but the added distance results in some adverse travel for pedestrians and potentially higher vehicle speeds.

Table 1 shows yielding rates at two single-lane and nine multilane roundabouts for 10 cities from two national studies, by Rodegerdts et al. (2006) and Salamati et al. (2013). All sites had a minimum of 15 observations.

Table 1. Vehicle yielding behavior at roundabouts.

Intersection	City, State	Entry Crosswalk Yielding Percent (No. of Observations)*	Exit Crosswalk Yielding Percent (No. of Observations)*	Overall Yielding Percent
High School Rd/Madison Ave(1)**	Bainbridge Island, WA	93 (105)	92 (61)	93
Route 7A/Equinox (Grand Union)(1)**	Manchester, VT	74 (82)	73 (56)	74
SR 60/Coronado Drive (SR 699)/Mandalay Ave/Poinsettia Ave (Gateway Roundabout)(1)	Clearwater, FL	68 (84)	82 (55)	73
MD 45/MD 146/Joppa Rd/Allegheny Ave (W Leg)(1)	Towson, MD	87 (15)	28 (21)	53
MD 45/MD 146/Joppa Rd/Allegheny Ave (NW Leg)(1)	Towson, MD	60 (30)	22 (9)	51
MD 45/MD 146/Joppa Rd/Allegheny Ave (N Leg)(1)	Towson, MD	30 (25)	48 (25)	39
MD 45/MD 146/Joppa Rd/Allegheny Ave (S Leg)(1)	Towson, MD	50 (98)	27 (121)	38
MD 450 (West St)/Taylor Ave/Spa Rd (Gateway Circle)(2)	Annapolis, MD	40 (25)	29 (25)	35
Demonbreun St/16th Ave/Division St/Music Square E(2)	Nashville, TN	39 (25)	0 (25)	20
Town Center Dr/Village Center Cir/Library Hills Dr(1)	Las Vegas, NV	50 (2)	14 (14)	19
Hillsborough St/Pullen Rd(2)	Raleigh, NC	17 (25)	16 (25)	17
Old Meridian St/Guilford Ave(2)	Carmel, IN	16 (25)	0 (25)	8
Salem Rd/Old Salem Rd/S Main St(2)	Winston-Salem, NC	0 (25)	0 (25)	0

* Yielding percentage includes passive yields (events where the motorist yielded to the pedestrian but was already stopped for another reason, such as a queue) and active yields (events where the motorist chose to yield to the pedestrian).
** Single-lane roundabout (all other locations are multilane).

There is no comprehensive national data source for pedestrian activity, but the presence of pedestrians is thought to influence driver yielding behavior. Increased pedestrian activity might increase driver awareness of pedestrians and therefore increase yielding rates. As a surrogate for pedestrian volumes, the percentage of trips made by walking, from the National Household Travel Survey(9), was used to estimate the level of pedestrian activity for each state. A comparison of pedestrian activity and yielding rates in table 1 shows a strong positive correlation between the two variables. The yielding rates and percentage of walking trips that were compared for this analysis were collected over different time periods and were produced to evaluate the general relationship that may be present between driver yielding behavior and the prevalence of pedestrians. In general, figure 1 shows that as the percentage of walking trips increases in a state, drivers' yielding rate also increases. The area of each circle in the figure is proportional to the number of observations made in that location; for instance, 394 observations were made in Maryland, 139 in Florida, and 16 in Nevada. The estimated regression equation in figure 1 suggests that the percentage of walking trips alone explains almost 60 percent of the variability in yielding behavior across these studies. The results in figure 1 further illustrate that yielding data collected across different geographic regions are expected to vary greatly, making it difficult to isolate and test for effects of crosswalk geometry and configuration. As such, these results motivated the present research study design of focusing on only two cities and conducting yielding studies at a large number of roundabouts with different crosswalk geometries in those two locations. In other words, this study controlled for potential regional differences in yielding rate, thereby maximizing the potential to isolate crosswalk attributes as explanatory variables for yielding.

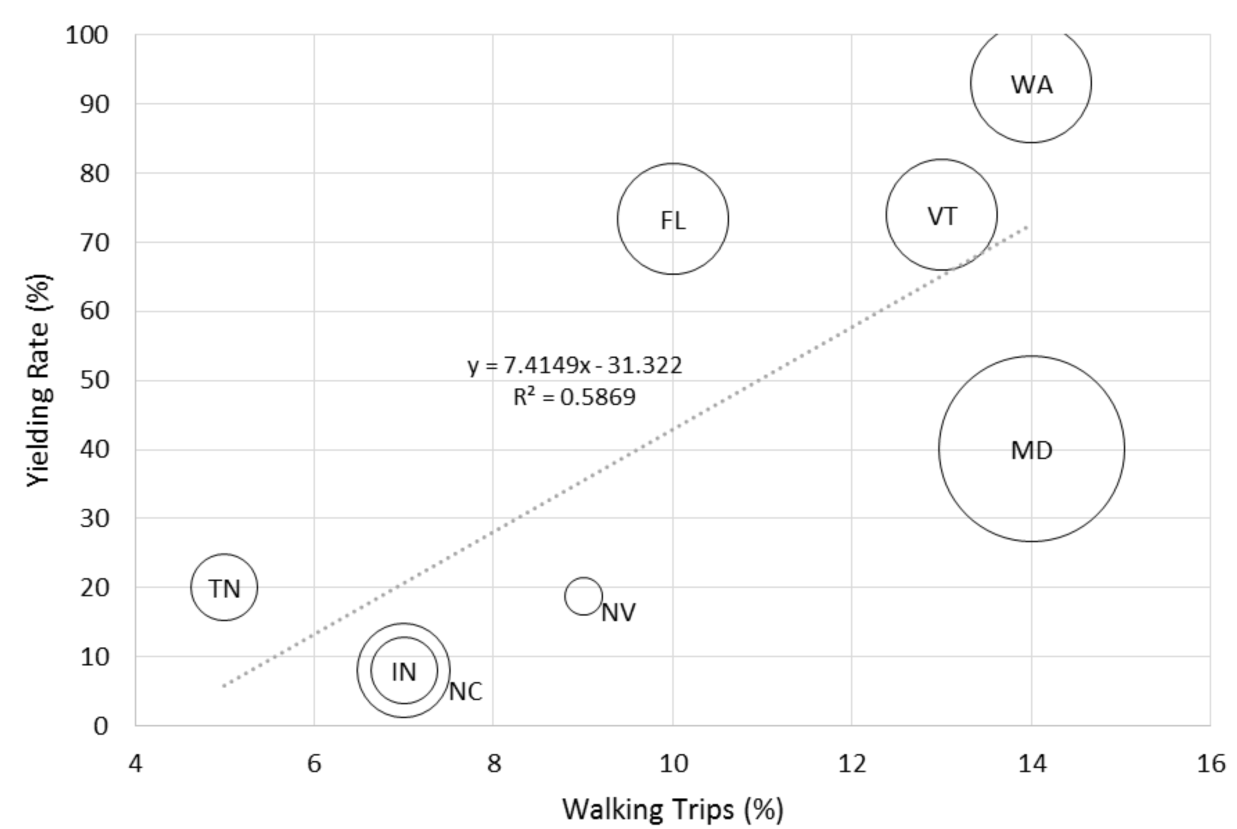

Figure 1. Graph. Yielding rate and percentage of walking trips by state.

This project used a research methodology consisting of a naturalistic yielding study with staged pedestrian behavior at roundabouts with different crosswalk configurations. This effort is intended to form the basis of developing multivariable linear regression models to predict the probability of driver yielding to pedestrians. Unlike previous studies, this research focused primarily on geometric factors at roundabouts as predictors for driver yielding. As a result, the project team focused data collection on two targeted locations for comparisons of features in each city separately (Carmel, IN, and Hilliard, OH) to avoid the bias from varying driver and pedestrian cultures often found in studies performed at more disparate locations. The primary study was performed in Carmel, IN, and the locations in Hilliard, OH, provided supplemental information. By focusing on locations in one city per analysis (i.e., Carmel sites compared with Carmel sites and Hilliard sites compared with Hilliard sites), the effect of local driver and pedestrian cultures was minimized.

This research seeks to contribute to an improved understanding of driver yielding behavior at roundabouts and, in turn, greater pedestrian accessibility and safety. Results from this effort are intended to inform roundabout guideline development with respect to the location and configuration of crosswalks at modern roundabouts in the United States.

CHAPTER 3. METHODOLOGY – YIELDING STUDY

The objective of this research was to provide guidance for locating crosswalks at roundabouts. This was achieved by developing exploratory statistical regression models for predicting driver yielding behavior at one- and two-lane roundabouts and for identifying the contributing factors to yielding. A naturalistic yielding study with staged pedestrian behavior was performed to generate and collect driver-yielding data. Because the study was naturalistic, it was necessarily constrained to existing crosswalk designs, but it also resulted in practical observations of motorists' reactions to pedestrian crossing attempts.

Carmel, IN, was chosen as the research location based on a site-selection process detailed in the following section. The Hilliard, OH, location was added later in the project because it was also included in the Task 9 eye-tracker study. As such, Hilliard, OH, was not included in the initial site selection but was added at a later date to confirm the findings from Carmel, IN, and for consistency with Task 9.

SITE SELECTION

The goal of the site selection process was to choose a location with a wide distribution of roundabout characteristics, the most important of which was the distance between crosswalks at roundabout entries and exits and the circulatory roadway, as shown in figure 3. This distance was measured from the edge of the crosswalk closest to the circulatory roadway. The team initially focused on crosswalk distances at two-lane roundabouts because two-lane roundabouts are rarer than single-lane roundabouts, and it was postulated that any region with a large number of two-lane roundabouts would also have a large number of single-lane roundabouts.

The team assembled a database of approximately 500 two-lane U.S. roundabout entries and exits and decided that the site selected for the experiment should have at least four approaches in the middle 50th percentile for crosswalk distance (i.e., 0.25 to 0.75 cumulative distribution) and at least two approaches outside these limits. Figure 2 shows the distribution of crosswalk distances for entry and exit crosswalks for 555 two-lane roundabout entries and 487 two-lane roundabout exits. The middle 50th percentile for crosswalk distance fell between 9.1 and 15 m (30 and 50 ft). Thus, the crosswalk distances were divided into three groups, listed in table 2: *proximal*, or less than 9.1 m (30 ft); *medial*, or greater than or equal to 9.1 m but less than 15 m (50 ft); and *distal*, or greater than or equal to 15 m (50 ft).

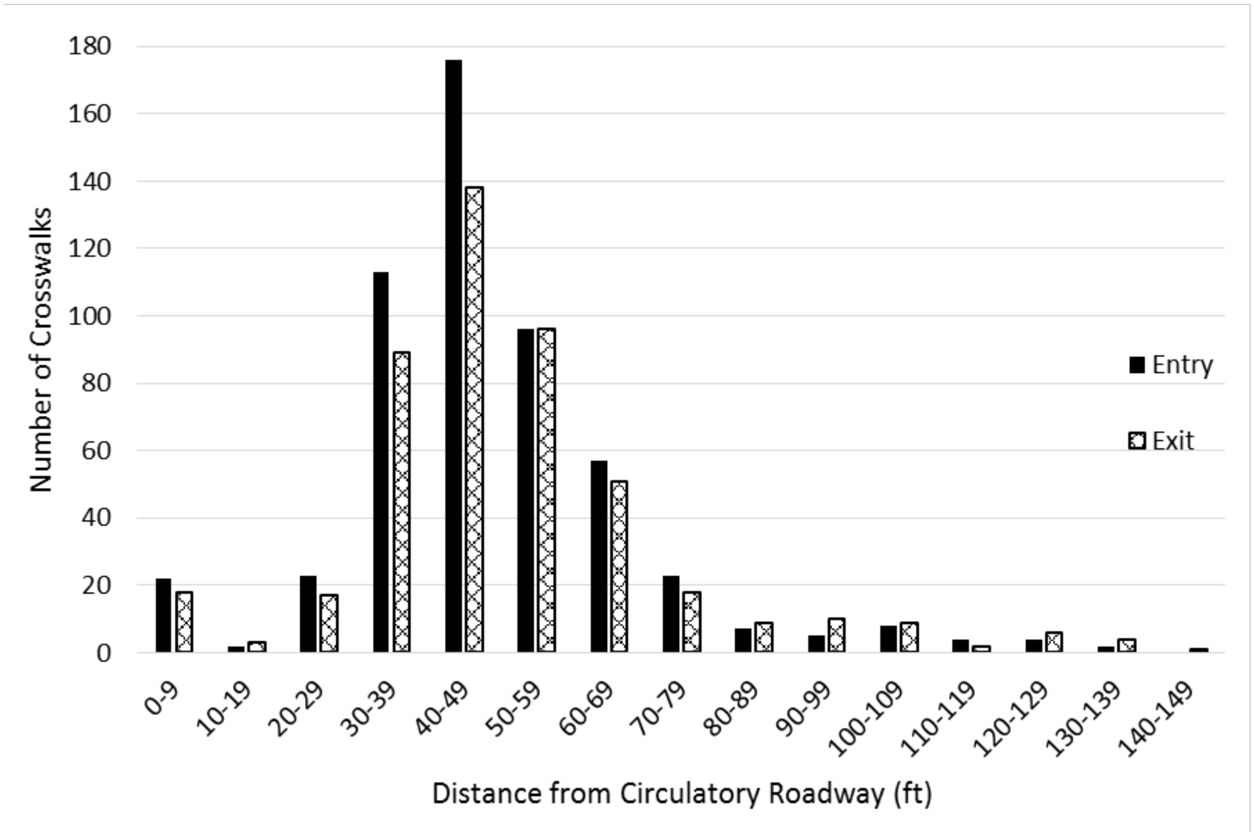

Figure 2. Bar Chart. Distribution of crosswalk distances for two-lane roundabouts in the United States (1 ft = 0.3048 m).

Table 2. Crosswalk distance categories.

Crosswalk Distance Category	Percentile	Crosswalk Distance
Proximal	Bottom 25th	<9.1 m (30 ft)
Medial	Middle 50th	≥9.1 m (30 ft) and <15 m (50 ft)
Distal	Top 75th	≥15 m (50 ft)

Site selection proceeded with the goal of finding an area with roundabouts with entry and exit crosswalk distances distributed among the proximal, medial, and distal categories. The team identified eight cities with at least one entry and exit crosswalk distance in each category. Those cities and their number of entry and exit crosswalk distances are listed by crosswalk-distance category in table 3.

Table 3. Number of entry and exit crosswalk distances by category for two-lane roundabouts in selected U.S. cities.

City	Entry, Proximal	Entry, Medial	Entry, Distal	Exit, Proximal	Exit, Medial	Exit, Distal
Avon, CO	12	4	1	10	5	1
Carmel, IN	2	20	8	5	11	7
Golden, CO	3	3	1	3	2	2
Las Vegas, NV	1	3	1	1	3	1
Lenexa, KS	4	26	4	10	23	3
Loveland, CO	2	5	2	1	2	2
Madison, WI	2	7	1	1	5	1
Phoenix, AZ	2	2	4	2	1	5

The team wanted to collect data at only one or two locations to control for regional variations in driver yielding behavior and isolate the effect of crosswalk geometry, as well as other variables, on yielding behavior. From the table, Carmel, IN, and Lenexa, KS, emerged as the two most promising data-collection sites because they had at least two entries or exits in each of the six categories and at least four entries and exits in the middle category. Because both locations have a large number of roundabouts, it was expected that local drivers and pedestrians would be familiar with traversing roundabouts.

Carmel, IN, and Lenexa, KS, met the criteria for two-lane roundabouts, but single-lane roundabouts were also part of this study, so a further review of single-lane roundabouts in those cities was performed. Table 4 lists the number of entries and exits for single-lane and two-lane roundabouts by crosswalk-distance category. Lenexa, KS, did not have any entry or exit crosswalks in the *distal* category for single-lane roundabouts, so Carmel, IN, was chosen for data collection. No previous yielding data were available in Lenexa, KS. A small dataset from Carmel, IN, indicated low yielding rates, which were expected to be acceptable for the study because geometric elements were likely to influence yielding more than the culture of driver and pedestrian interactions.

Table 4. Number of crosswalks in selected U.S. cities by distance from the front edge of the crosswalk to the circulatory roadway.

City, State	Number of Lanes Approaching Crosswalk	Crosswalk Position	No. in Proximal Category	No. in Medial Category	No. in Distal Category
Carmel, IN	1	Entry	29	79	9
Carmel, IN	1	Exit	46	63	16
Carmel, IN	2	Entry	2	28	8
Carmel, IN	2	Exit	5	16	9
Lenexa, KS	1	Entry	21	27	0
Lenexa, KS	1	Exit	37	10	1
Lenexa, KS	2	Entry	4	26	4
Lenexa, KS	2	Exit	10	23	3

SITE DESCRIPTION

Data were initially collected in Carmel, IN. Data for Hilliard, OH, were collected later. The roundabouts in Carmel, IN, where data were collected are listed in table 5. Seven of the Carmel, IN, roundabouts were in suburban areas, and three were in urban areas.

Table 5. Listing of roundabout locations in Carmel, IN.

Intersection	Number of Legs	Area Type
103rd St./Pennsylvania St.	4	Suburban
106th St./Pennsylvania St.	4	Suburban
116th St./Illinois St.	4	Suburban
116th St./Clay Center Rd.	3	Suburban
116th St./Spring Mill Rd.	4	Suburban
Old Meridian St./131st (Main) St.	4	Urban
Old Meridian St./Grand Blvd.	3	Urban
Old Meridian St./Pennsylvania St.	4	Urban
Spring Mill Rd./131st (Main) St.	4	Suburban
Spring Mill Rd./136th St.	4	Suburban

In Carmel, IN, data collection was conducted at all entry and exit crosswalks at each of the 10 roundabouts for a total of 76 crosswalks (with each approach including two crosswalks: one entry and one exit) studied, as shown in table 6, which lists the inscribed diameter of the roundabout, the number of travel lanes intersecting each crosswalk, and the crosswalks' distances to the circulatory roadway.

For the single-lane crosswalks, the study included 22 crosswalks on entry and 24 crosswalks on exit. For the two-lane crossings, the study included 16 crosswalks on entry and 14 crosswalks on exit. None of the crosswalks featured a zig-zag alignment, where the exit portion of the crosswalk is located farther from the circulating lane than entry portion of the crosswalk. None had crosswalk configurations located mid-block between roundabouts. The majority have high-visibility parallel crosswalk pavement markings (closely spaced solid white lines parallel to the direction of traffic), with only one roundabout featuring standard transverse-lines crosswalk markings (two parallel solid white lines oriented perpendicular to traffic). That roundabout had all two-lane crossings, with two crosswalks at entry and two crosswalks at exit. All sites had pedestrian facilities, that is, accessible paths (including sidewalks) that connected to the crosswalks. Table 6 presents the detailed geometric data for the 38 studied roundabout legs, resulting in 76 total crosswalks (entry and exit) included in the study.

Table 6. Characteristics of selected roundabout sites in Carmel, IN.

No.	Intersection	Inscribed Diameter [m (ft)]	Leg (N, S, E, W, etc.)	Number of Lanes at Entry	Number of Lanes at Exit	Entry Crosswalk Offset [m (ft)]	Exit Crosswalk Offset [m (ft)]
1	116th St./Clay Center Rd.	39.6 (130)	N	1	1	5.2 (17)	5.2 (17)
2	116th St./Clay Center Rd.	39.6 (130)	E	1	1	13.4 (44)	11.6 (38)
3	116th St./Clay Center Rd.	39.6 (130)	W	1	1	11 (36)	11.3 (37)
4	116th St./Illinois St.	54.9 (180)	N	2	2	10.1 (33)	10.1 (33)
5	116th St./Illinois St.	54.9 (180)	E	2	2	9.8 (32)	9.8 (32)
6	116th St./Illinois St.	54.9 (180)	S	2	2	10.1 (33)	10.1 (33)
7	116th St./Illinois St.	54.9 (180)	W	2	2	9.8 (32)	9.8 (32)
8	116th St./Spring Mill Rd.	39.6 (130)	N	1	1	7.3 (24)	7.6 (25)
9	116th St./Spring Mill Rd.	39.6 (130)	E	1	1	12.5 (41)	13.4 (44)
10	116th St./Spring Mill Rd.	39.6 (130)	S	1	1	8.2 (27)	7.9 (26)
11	116th St./Spring Mill Rd.	39.6 (130)	W	1	1	7.6 (25)	7.6 (25)
12	Old Meridian St./131st (Main) St.	62.5 (205)	N	2	2	9.4 (31)	6.7 (22)
13	Old Meridian St./131st (Main) St.	62.5 (205)	E	1	1	9.8 (32)	8.5 (28)
14	Old Meridian St./131st (Main) St.	62.5 (205)	S	2	2	8.8 (29)	6.4 (21)
15	Old Meridian St./131st (Main) St.	62.5 (205)	W	1	1	8.2 (27)	7.3 (24)
16	Old Meridian St./Grand Blvd.*	54.9 (180)	N	2	2	9.1 (30)	9.4 (31)
17	Old Meridian St./Grand Blvd.	54.9 (180)	E	1	1	14.6 (48)	16.8 (55)
18	Old Meridian St./Grand Blvd.*	54.9 (180)	S	2	2	9.4 (31)	8.8 (29)
19	Old Meridian St./Pennsylvania St.	62.2 (204)	N	1	1	7 (23)	5.8 (19)
20	Old Meridian St./Pennsylvania St.*	62.2 (204)	NE	2	2	6.4 (21)	4 (13)
21	Old Meridian St./Pennsylvania St.*	62.2 (204)	S	2	2	27.4 (90)	26.8 (88)
22	Old Meridian St./Pennsylvania St.	62.2 (204)	SW	2	1	8.5 (28)	9.1 (30)
23	Spring Mill Rd./W. 131st St.	49.7 (163)	N	1	1	10.4 (34)	9.8 (32)
24	Spring Mill Rd./W. 131st St.	49.7 (163)	E	1	1	4.3 (14)	5.2 (17)

No.	Intersection	Inscribed Diameter [m (ft)]	Leg (N, S, E, W, etc.)	Number of Lanes at Entry	Number of Lanes at Exit	Entry Crosswalk Offset [m (ft)]	Exit Crosswalk Offset [m (ft)]
25	Spring Mill Rd./W. 131st St.	49.7 (163)	S	1	1	8.2 (27)	7.9 (26)
26	Spring Mill Rd./W. 131st St.	49.7 (163)	W	1	1	9.1 (30)	9.8 (32)
27	Spring Mill Rd./W. 136th St.	47.2 (155)	N	1	1	10.7 (35)	8.5 (28)
28	Spring Mill Rd./W. 136th St.	47.2 (155)	E	1	1	7.9 (26)	7.6 (25)
29	Spring Mill Rd./W. 136th St.	47.2 (155)	S	1	1	8.8 (29)	9.1 (30)
30	Spring Mill Rd./W. 136th St.	47.2 (155)	W	1	1	7.6 (25)	7.9 (26)
31	W 103rd St./Pennsylvania St.	45.7 (150)	N	2	2	15.5 (51)	15.2 (50)
32	W 103rd St./Pennsylvania St.	45.7 (150)	E	1	1	7.9 (26)	7.9 (26)
33	W 103rd St./Pennsylvania St.	45.7 (150)	S	2	2	15.2 (50)	14.9 (49)
34	W 103rd St./Pennsylvania St.	45.7 (150)	W	1	1	15.5 (51)	15.2 (50)
35	W 106th St./Pennsylvania St.	44.8 (147)	N	2	2	16.2 (53)	15.2 (50)
36	W 106th St./Pennsylvania St.	44.8 (147)	E	1	1	8.5 (28)	7.6 (25)
37	W 106th St./Pennsylvania St.	44.8 (147)	S	2	2	21 (69)	19.5 (64)
38	W 106th St./Pennsylvania St.	44.8 (147)	W	2	1	15.2 (50)	14.6 (48)

* Included in eye tracking study

Figure 4 through figure 9 show the distribution of entry and exit crosswalks for three geometric features shown in figure 3: crosswalk distance from circulatory roadway, entry path radius and exit path radius, and crosswalk angle. Data are listed for crosswalks with one- and two-lane approaching roadways in Carmel, IN.

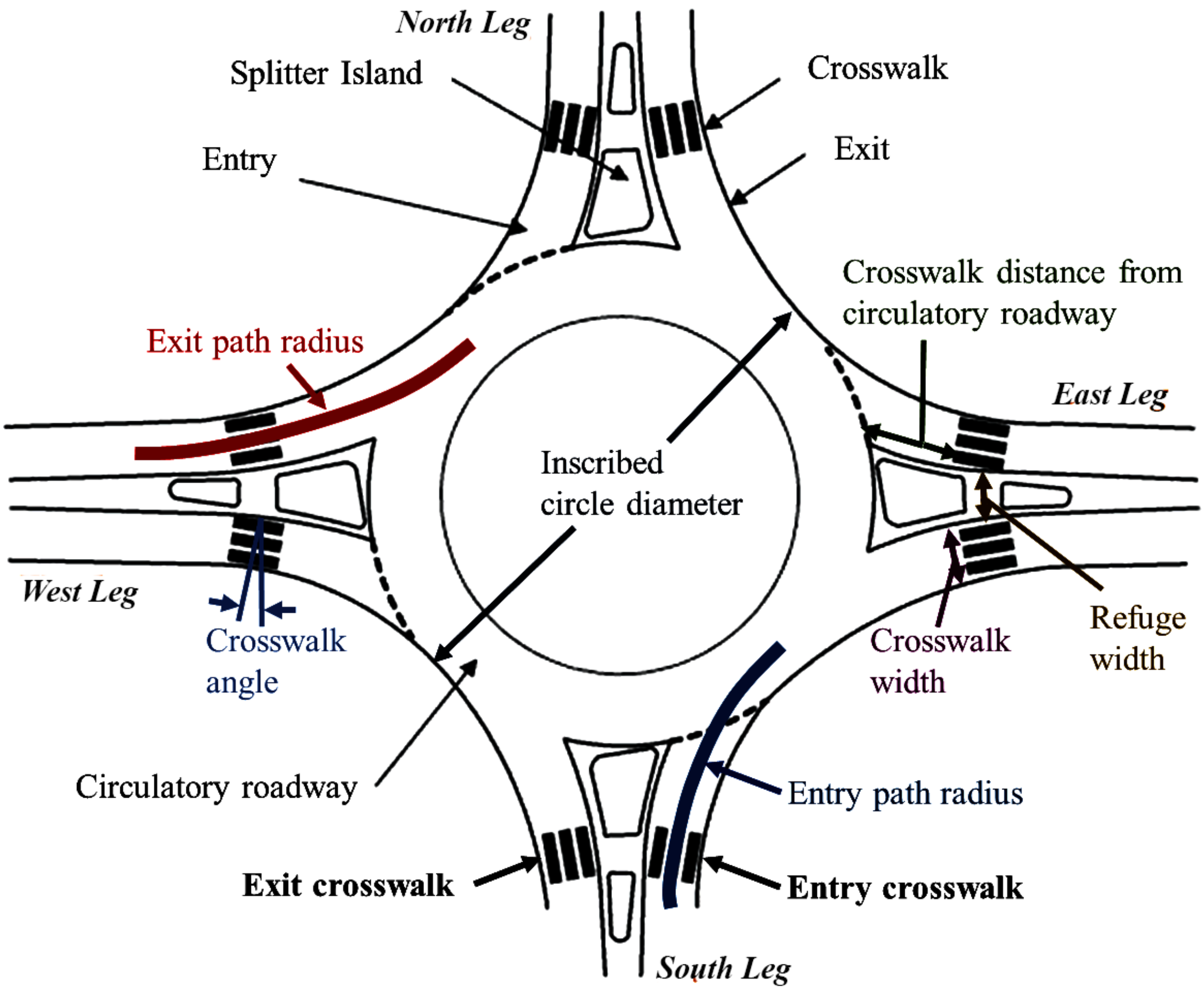

Figure 3. Diagram. Geometric variables for Carmel, IN, roundabout descriptions.

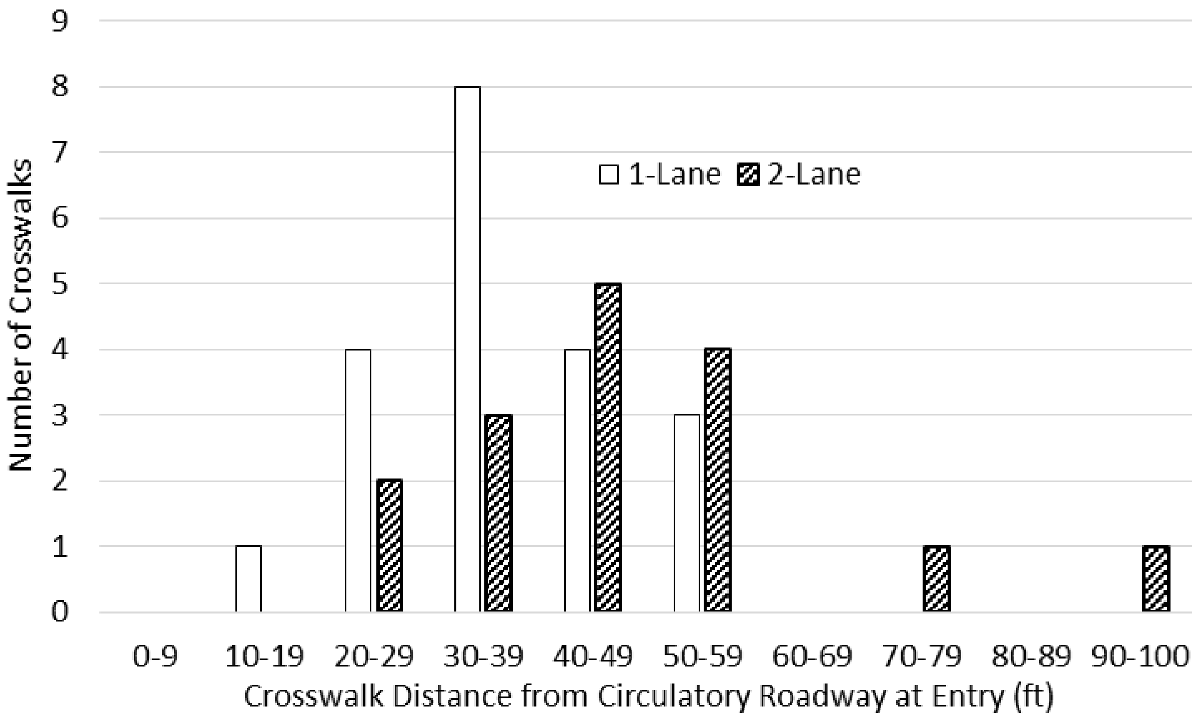

Figure 4. Bar Chart. Entry crosswalk distance from circulatory roadway for Carmel, IN, sites (1 ft = 0.3048 m).

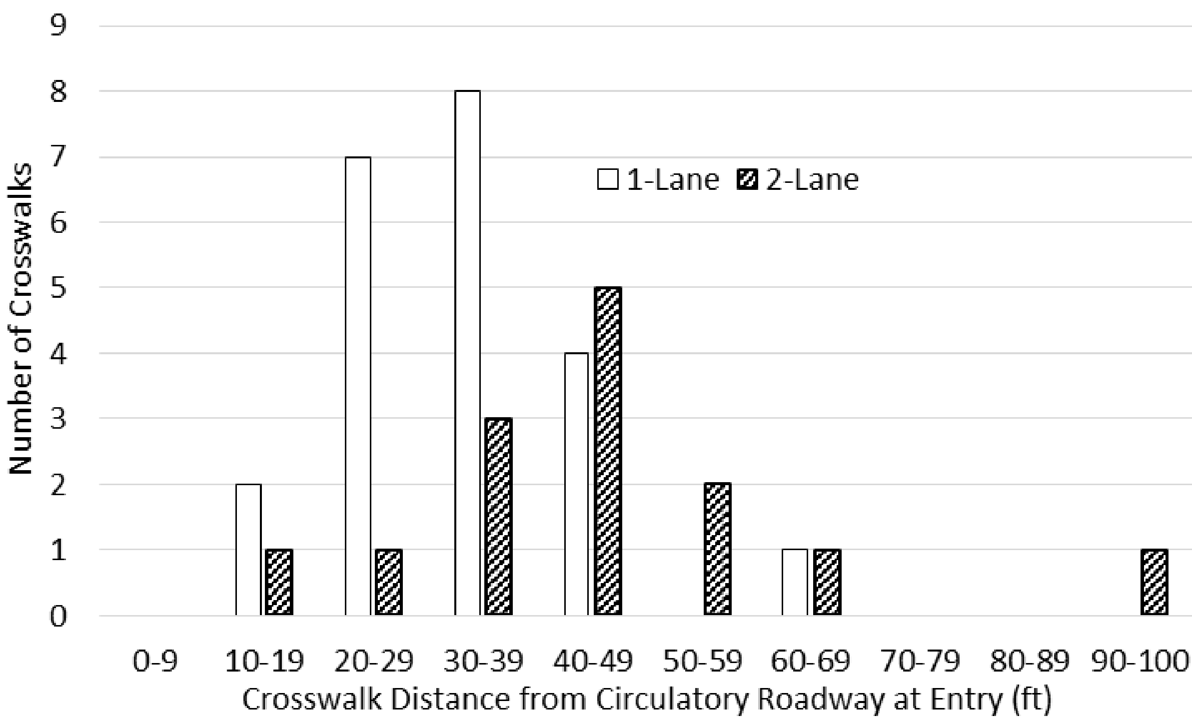

Figure 5. Bar Chart. Exit crosswalk distance from circulatory roadway for Carmel, IN, sites (1 ft = 0.3048 m).

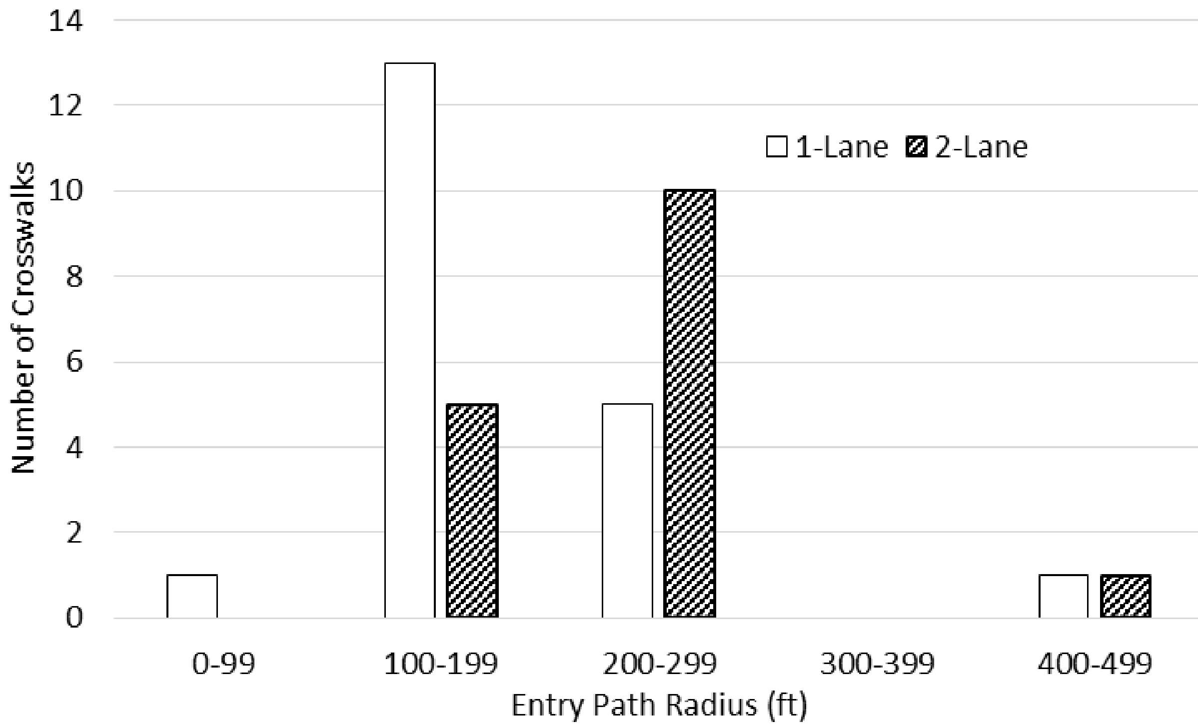

Figure 6. Bar Chart. Entry path radius for Carmel, IN, sites (1 ft = 0.3048 m).

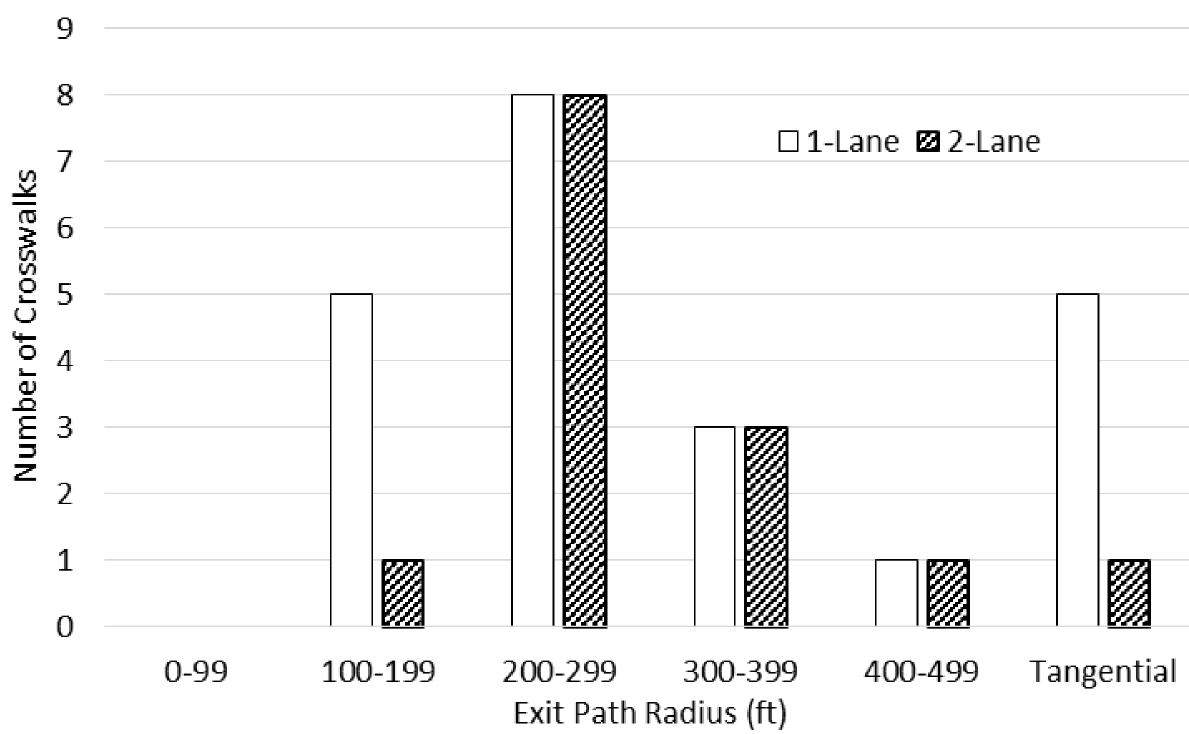

Figure 7. Bar Chart. Exit path radius for Carmel, IN, sites (1 ft = 0.3048 m).

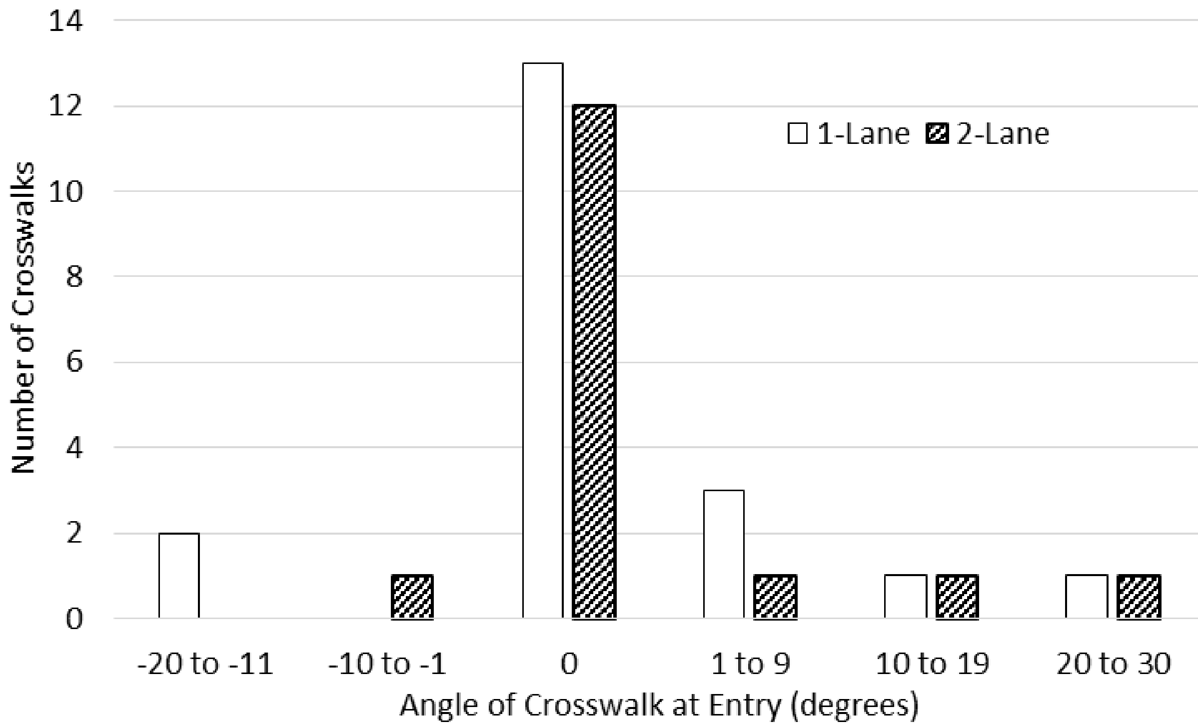

Figure 8. Bar Chart. Entry crosswalk angle for Carmel, IN, sites (1 ft = 0.3048 m).

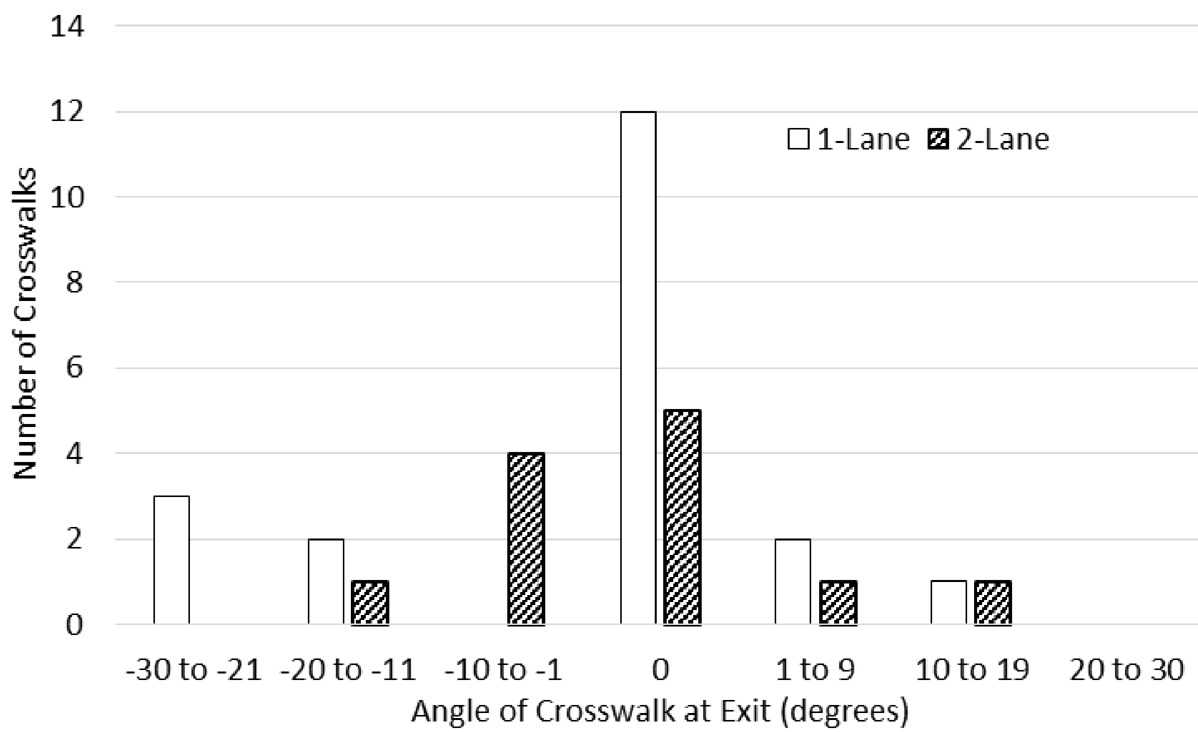

Figure 9. Bar Chart. Exit crosswalk angle for Carmel, IN, sites (1 ft = 0.3048 m).

Protocol for Staged Pedestrian Crossings

To better identify how roundabout geometry affected drivers' yielding behavior to pedestrians, pedestrian positions were controlled to the extent possible for all trials by having a research team member act as a pedestrian. As stated in NCHRP Report 562,[(6)] the rationale for staging pedestrian crossings instead of observing pedestrians is as follows:

> "Staged pedestrians were used in the belief that consistent presentation of a pedestrian intent to cross was critical for comparing motorist compliance results from different locations or areas of the country; in other words, pedestrian positioning, stance, and aggressiveness affect a motorist's decision to stop or yield at a pedestrian crossing. For example, motorists are less likely to stop or yield when pedestrians stand several feet behind the curb line (e.g., the pedestrian may appear as though they are waiting instead of intending to cross)."

In the experiment, the pedestrian waited at the edge of the curb, as shown in figure 10, facing the crosswalk and with the head turned towards oncoming traffic to indicate the intention to cross. In both Indiana and Ohio, vehicles are legally obligated to yield the right of way when the pedestrian is within a crosswalk. The pedestrian accepted a yield or gap by completing the crossing from the curb to the splitter island or vice versa. To prevent unusual driver reactions, the pedestrians wore no unusually bright or distracting attire.

Figure 10. Photo. Pedestrian waiting at edge of curb.

Each trial with the pedestrian was classified into one of four scenarios described in table 7. The scenarios depended on both the vehicle's distance from the crosswalk when the pedestrian was presented, which affected yielding decision, and the yielding decision itself. The vehicle's position relative to the crosswalk (too close to be expected to yield, in particular) was based on average speeds and corresponding available stopping sight distance. The pedestrian crossed when the vehicle yielded or when the gap was so large that the vehicle did not need to yield for the pedestrian to safely cross.

Table 7. Pedestrian crossing and vehicle behavior scenarios.

Case	Vehicle Position with Respect to Crosswalk	Vehicle Behavior	Pedestrian Behavior
1	Too close to be expected to yield	Did not yield	Did not cross
2	Close enough to yield	Did not yield	Did not cross
3	Close enough to yield	Yielded	Crossed
4	So far that pedestrian could safely cross without driver yielding	Did not have to yield	Crossed in gap

When vehicles yielded or the gap was large enough for the pedestrian to cross, no other vehicles were classified, so only one yield or gap per lane of traffic per trial was collected in those cases. When vehicles did not yield or were too close to be expected to yield, data for multiple vehicles were collected.

Fifty crossings were conducted at each crosswalk in each direction, and crossings were not conducted when other pedestrians were present. The pedestrian's sole responsibility was to act as a pedestrian; therefore, a second research team member was present to record data and assist in the experiment. The data collection forms for single-lane and two-lane roundabouts are included in Appendix A. This protocol is generally consistent with similar, previous efforts.[6,7]

At a two-lane roundabout, the pedestrian considered each lane separately and initiated the crossing if the driver in the closer lane yielded. Vehicles in both lanes were classified for driver behavior. To avoid confusing drivers and collecting inaccurate data, the pedestrian, after crossing, acted naturally and continued walking beyond the end of the crosswalk before turning around to begin the next trial.

VARIABLES OF INTEREST

Because the analysis focused on the probability of drivers yielding, the team derived the dependent variable, yielding rate, from observed active yields at each site. An active yield occurred when the motorist slowed or stopped for a crossing pedestrian or waiting pedestrian, and the pedestrian was the only reason the motorist yielded. Instead of passive yields (events where the motorist yielded to the pedestrian but was already stopped for another reason), the team focused on active yields because passive yields are typically a function of traffic volume and not related to geometric factors. Data collection was performed at less congested times to limit the number of passive yields. For example, if a vehicle slowed due to a queue, it was not considered an active yield. Yield probability was calculated by dividing the number of active yields (case two in table 7) by the sum of active yields and no yields (cases two and three in table 7).

$$Yield\ Probability = \frac{\#\ of\ Active\ Yields}{Sum\ of\ Active\ Yields\ and\ No\ Yields}$$

Figure 11. Equation. Yield probability.

Several explanatory variables of interest were examined as predictors for yielding rate. These variables focus on macroscopic conditions and were used to represent the overall roundabout and not a microscopic, vehicle-by-vehicle environment. Many of these variables were assessed using data sources available off site and were confirmed during the field visit, when researchers viewed and photographed the crosswalk environment. The variables are listed in table 8 and table 9 below and are categorized as operational variables and geometric variables. The average speed at the crosswalk for free-flowing vehicles was evaluated with a sampling of at least 30 free-flowing passenger vehicles at each approach.

Table 8. Yielding study operational variables.

Variable	Units
Average speed at crosswalk for free-flowing vehicles	Km/h (mi/h)
Circulating volume	Vehicles per hour (veh/h)

Table 9. Yielding study geometric variables.

Variable	Values (for categorical) or Units (for continuous)
Number of lanes at crosswalk	One, Two
Pedestrian crossing starting point	Curb, Island
Inscribed circle diameter	m (ft)
Entry path radius (figure 3, figure 12)	m (ft)
Exit path radius (figure 3, figure 12)	m (ft)
Crosswalk distance (from near edge of crosswalk to circulatory roadway)	m (ft)
Crosswalk angle (figure 3)	degrees
Pedestrian refuge width in splitter island (figure 3)	m (ft)
Crosswalk width (figure 3)	m (ft)
Presence of slip lanes	Yes, No

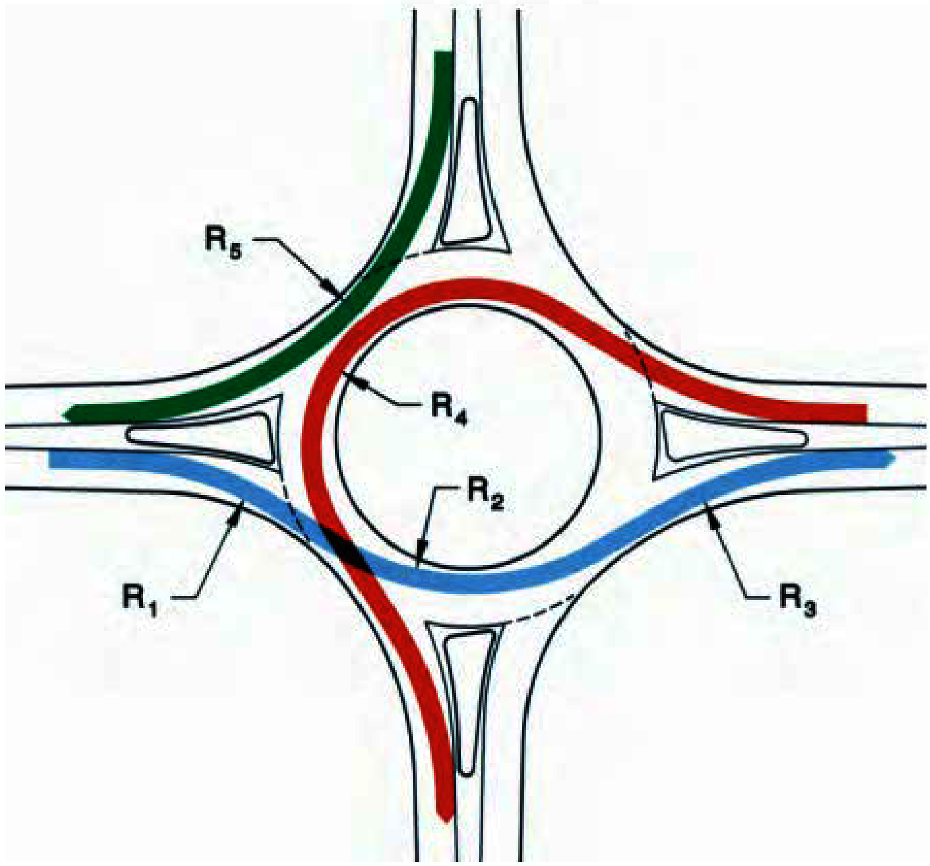

Figure 12. Diagram. Vehicle path radii (exhibit 6-46 from [5]).

The resulting data were analyzed using various statistical methods and modeling. The team applied multivariable linear regression models that can predict driver yielding probability, or yielding rate, as a function of the explanatory variables, including the geometric attributes of the crosswalk. The key element of this study's experimental design—controlling for pedestrian behavior and driver culture—was expected to deliver more conclusive results than studies performed at disparate geographic locations.

The data collection and analysis focused on macroscopic characteristics affecting yielding behavior, such as the geometric and operational variables listed above, so the results can be more easily integrated into engineering practice.

CHAPTER 4. METHODOLOGY – EYE-TRACKING STUDY

The eye-tracking experiment was a pseudo-naturalistic study in which participants drove on a specific route through several roundabouts while wearing an eye tracker. The study is described as pseudo-naturalistic because the environment and interactions with other vehicles and pedestrians were as they would have occurred naturally, but the route that the participant drove was determined by the experimenter. The route was designed to include particular intersections and maneuvers, but all other interactions with vehicles, pedestrians, and the environment along the route were naturalistic.

INDEPENDENT VARIABLES

Data for several independent variables were collected by the eye-tracking equipment and are listed and described in table 10. In a true naturalistic study, many different independent variables can be selected based on the question the researcher intends to answer and are limited only by what data was collected. For this experiment, the research team wanted to determine what drivers glanced at, where they glanced, and from which part of the roundabout they made these glances. Therefore, the following variables were defined and pulled from the eye-tracker data.

Table 10. Eye-tracking study independent variables.

Variable	Description (values)
Gaze Direction	The object at which the drivers' eyes were directed
Object Location	The location of the object at which a drivers' eyes were directed
Vehicle Location	Location of vehicle (approach, entrance, circle, exit)

DEPENDENT VARIABLES

Data for several dependent variables were collected by the eye-tracking equipment and are listed and described in table 11.

Table 11. Eye-tracking study dependent variables.

Variable	Description (values)
Glance Count	How many times participants looked at an object. A glance was defined as any instance in which the gaze point remained on a particular object for at least two video frames (~69 ms).
Fixation Time	The length of time between saccades. Saccades are rapid eye movements that quickly change the point of fixation. These can be voluntary, but they also occur reflexively any time the eyes are open, even while fixating on a target.(8)
Dwell Time	The duration in milliseconds that a glance remained directed at a particular object. Dwell time is the sum of all saccades and fixation times that occurred while the gaze remained directed at a particular object.

PARTICIPANTS

Participants were recruited using flyers posted in each of the locations where testing occurred, as well as through word of mouth. A total of 21 participants completed the eye-tracking study. Participants ranged in age from 18 to 72 years old, with a median age of 39. Twelve males and nine females participated. Participants had to successfully complete a screening questionnaire over the phone to be eligible for participation. Participants had to be at least 18 years old, hold a valid driver's license, and not have any medical conditions or be taking any medications that might make it unsafe for them to drive. Participants were compensated $50.

EQUIPMENT

The study used a ViewPoint eye tracker, a head-mounted system that uses infrared lights and cameras mounted on a plastic frame to track the movement of the wearer's eyes (figure 13). The eye tracker also includes a forward-facing color camera to record the scene in front of the wearer. After calibration, the eye tracker provides a video recording of the scene with the wearer's gaze point overlaid on the image, as well as the XY coordinates of the gaze point, and fixation times, among other variables. A screenshot is shown in figure 14.

The frames are connected to a laptop with a cable that runs behind the wearer's right ear. This cable is clipped to the wearer's shirt to prevent pulling on the frames and allows unrestricted movement of the wearer's head. The system calculates eye movement with an accuracy between 0.25° and 1° of visual arc and a spatial resolution of approximately 0.15° of visual arc.

Figure 13. Photo. ViewPoint eye tracker goggles.

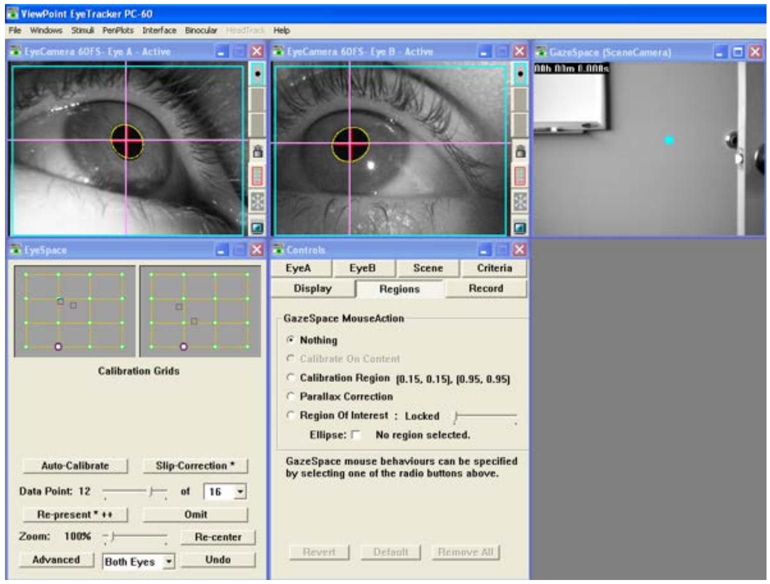

Figure 14. Screenshot. ViewPoint eye tracker software.

LOCATIONS

The study was conducted in two locations: Carmel, IN, and Hilliard, OH. These locations were selected for their high density of roundabouts. A total of nine different roundabouts were included in the study, four in Carmel, IN, and five in Hilliard, OH. Eight were two-lane roundabouts, and one was a single-lane roundabout with a single two-lane approach. Routes were designed so participants performed 21 different movements through these roundabouts: 5 left turns, 3 right turns, 3 U-turns, and 10 through movements (Appendices B and C).

EXPERIMENTAL PROCEDURE

Participants were instructed to meet the research team in a parking lot located near the test route at their scheduled time. Upon arrival, participants were greeted by an experimenter who administered the informed-consent form, which participants were asked to read and sign.

After completing the paperwork, participants were escorted to the vehicle, familiarized with the vehicle controls (e.g., seat, mirror, and steering adjustments), and fitted with the eye-tracker, which was then calibrated. An experimenter explained the instructions for the study: that the experimenter would provide directions for the travel route, to refrain from casual conversation, and to drive safely. The participant was then instructed to begin the drive and was directed along the test route. The participant was offered no guidance for lane selection and was only told which way to turn at upcoming roundabouts.

Depending on traffic conditions, driving the test route took participants approximately 40 min to 1 h. Upon returning to the starting point, participants filled out a post-drive questionnaire asking about their experience and comfort level with driving through roundabouts, and they were compensated and dismissed.

DATA REDUCTION

Objects of Interest

Data reductionists viewed the eye-tracker video for each participant, created a spreadsheet of all the glances a participant made to any object of interest, and tracked numerous contextual variables. The objects of interest included vehicles, pedestrians, signs, and pavement markings in or related to the roundabouts. The signs and markings included in this analysis are listed in table 12. While both test locations had the same categories of signs and markings, they were often not identical versions. For example, the circular intersection signs used in Carmel, IN, were an older version of the W2-6 sign (a circle with lines representing the legs of the intersection), while those in Hilliard, OH, were the updated version (three arrows forming a counter-clockwise circle).

Table 12. Objects of interest.

Category	Object of Interest
Traffic	Vehicles in or near the roundabout
Pedestrians	Pedestrians in or near the roundabout
Markings	Circulatory roadway lane striping
Markings	Circulatory roadway lane use marking
Markings	Yield line
Signs	Circular intersection sign
Signs	Destination sign
Signs	Directional arrow
Signs	Lane control sign
Signs	One-way sign
Signs	Yield ahead sign
Signs	Yield sign
Pedestrian-Related Signs and Markings	Crosswalk
Pedestrian-Related Signs and Markings	Pedestrian crossing/yield to pedestrian signs

Glances

A glance was defined as the duration of time that a participant's gaze rested on an object of interest. A glance did not include any transitional movements from one glance to the next, unless the gaze simply moved from one part of an object to another (such as scanning one side of a crosswalk to the other). A glance would begin as soon as the gaze point stopped on an object and end just before the gaze point moved away from the object. A glance also had to last for at least two video frames (~69 ms) to be included. Any glance that lasted less than two video frames was indistinguishable from transitional or random eye movements due to the limitations of the eye tracker.

Data reductionists began analyzing glances for a particular roundabout when the participant was approximately 73.2 m (250 ft) upstream from the first roundabout-related sign or marking. A circular intersection sign indicating the presence of a downstream roundabout (MUTCD W2-6) was usually the first object in the approach. Data reductionists stopped analyzing glances for a roundabout once the participant vehicle reached the exit crosswalk. Figure 15 shows an example of these points.

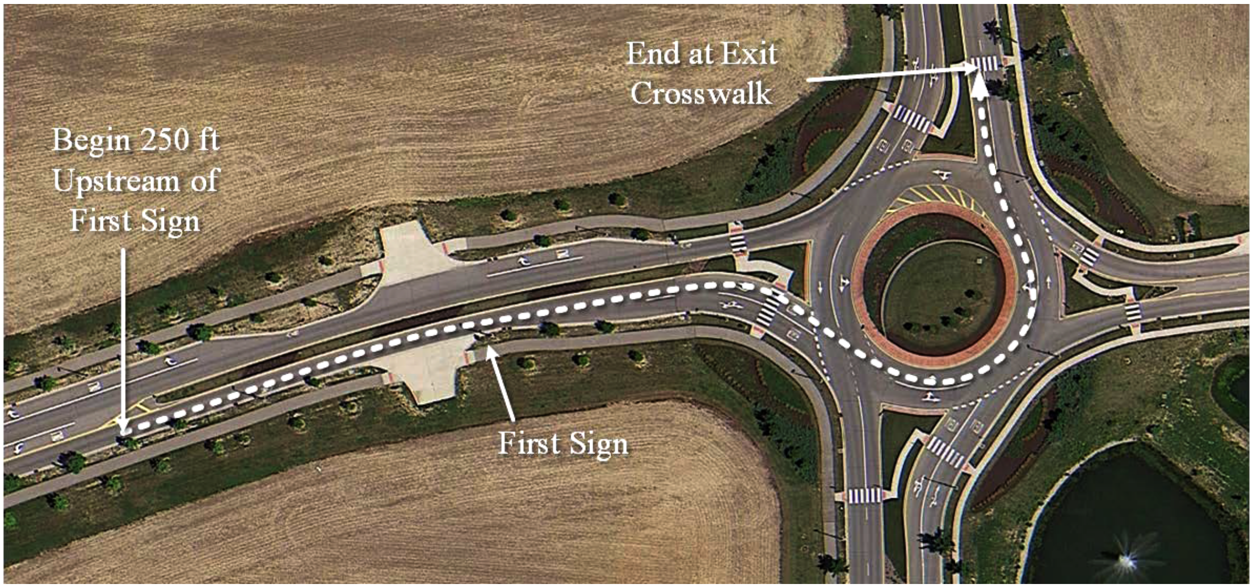

Figure 15. Diagram. Example segment for eye-glance data collection and analysis.

When data reductionists found glances to the objects of interest, they entered the times at which the glance began and ended into a spreadsheet. They also entered contextual information that existed at the beginning of the glance, such as which lane the participant was in and the participant's location within the roundabout.

Locations

In order to track the location of the participants as they drove through the roundabout, as well as the location of objects that the drivers glanced toward, roundabouts were conceptually divided into 13 segments as shown in the example in figure 16. These segments were always based on the participant's perspective, not on cardinal directions. Additional location information was collected for glances at pedestrians, such as the sidewalk, crosswalk, or splitter island.

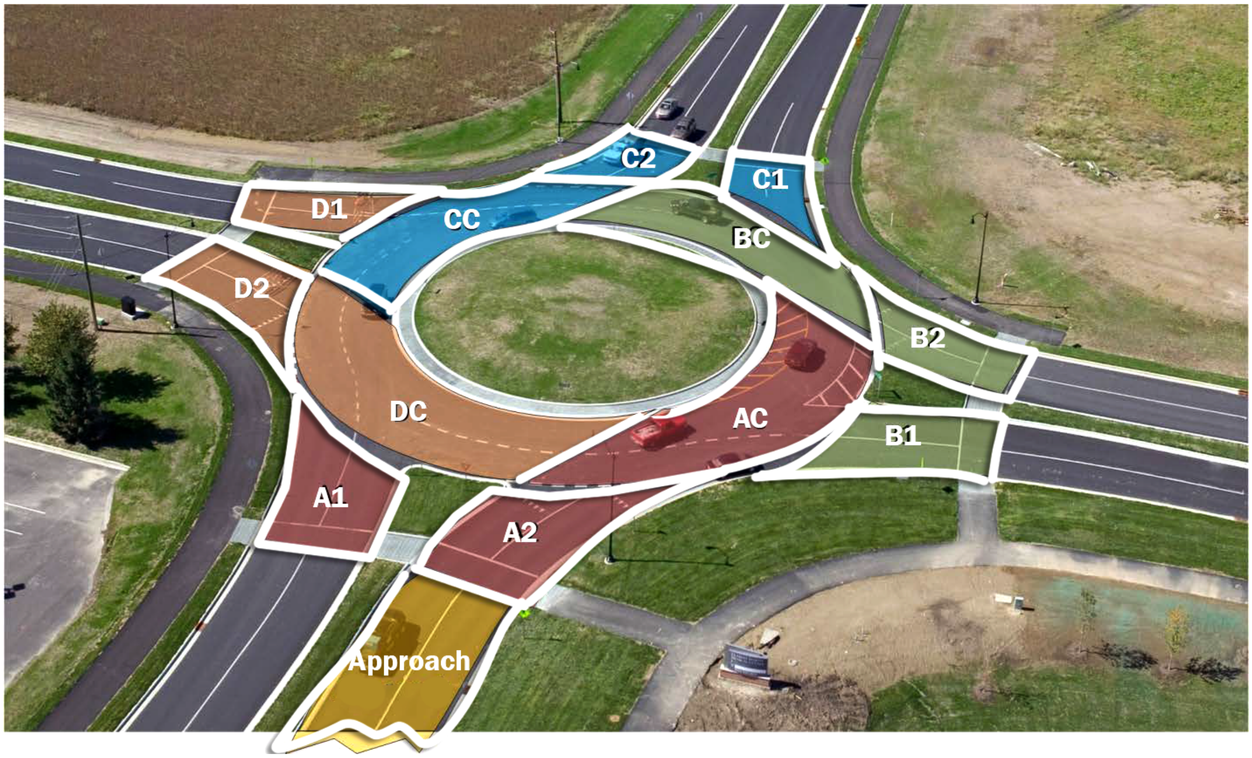

Figure 16. Diagram. Segmentation of the roundabouts for tracking vehicle and object locations.

CHAPTER 5. RESULTS – YIELDING STUDY

Data were collected for 50 staged crossing attempts from both pedestrian starting points (curb or island), 38 legs (north, south, east, or west), and 2 crosswalk positions (entry and exit), resulting in 7,600 data points.

To develop yielding models, yielding rates were generated from the 50 staged crossing attempts for each unique crossing type and location as defined by intersection, crosswalk position, leg, and pedestrian starting point. The yielding rate for each crossing type and location was found by dividing the total number of active yields by the sum of active yields and no yields. The yielding rate for each unique crossing type and location was then weighted based on the total number of valid trials (trials with an interaction between the pedestrian and a vehicle) across the 50 trials undertaken at the location. The weighting accounted for higher confidence in yielding rates at approaches with more valid trials. The weighted yielding rate, YIELDR, was the dependent variable. The weights were calculated using the standard deviation of the yielding rate, and crossing types and locations with more valid trials had lower standard deviations. For example, the average standard deviation was 25 percent lower for 20 valid trials than for 5 valid trials. A total of 50 staged crossings were made from both pedestrian starting points, and the subsequent number of valid trials was based primarily on traffic volumes, which influenced the number of crossings that had an interaction with a vehicle.

Values for crosswalk distance to circulatory roadway (OFF) were measured as shown in figure 3. The radius of each approach (RAD) was based on the fastest path approach from NCHRP Report 672[(5)]; R1 was used for entry approaches, and R3 was used for exit approaches (figure 12). Additional explanatory variables are shown in table 13 and are used to develop a model to describe the YIELDR response variable.

Table 13. Variables of interest in yielding study.

Variable Type	Variable	Description	Value
Independent	EXIT	Exit or entry approach of roundabout	Exit=1, Entry=0
Independent	LANE	Number of lanes at crosswalk	1 or 2 lanes
Independent	ISLAND	Pedestrian crossing starting point	Island=1, Curb=0
Independent	DIA	Inscribed diameter of roundabout in feet	Continuous variable
Independent	RAD	Fastest path radius of roundabout in feet, nearest 10 ft	Continuous variable
Independent	OFF	Crosswalk distance to circulatory roadway in feet	Continuous variable
Independent	OFF30	Crosswalk distance to circulatory roadway in feet <9.1 m (30 ft)	Yes=1, No=0
Independent	OFF50	Crosswalk distance to circulatory roadway in feet ≥15 m (50 ft)	Yes=1, No=0
Independent	ANG	Corrected crosswalk angle in degrees, rounded to nearest 10°	Continuous variable
Independent	REFW	Pedestrian refuge width, nearest 0.15 m (0.5 ft)	Continuous variable
Independent	CROSSW	Crosswalk width, nearest 0.15 m (0.5 ft)	Continuous variable
Independent	VOL	Traffic volume, number of circulating vehicles per hour	Continuous variable
Independent	SLP	Slip lane presence	Yes=1, No=0
Dependent	YIELDR	Weighted yielding rate	Continuous variable

The pedestrian crossing starting point (ISLAND) was determined by examining data collected by trial approach location and pedestrian crossing direction. The crosswalk angle (ANG) was determined based on the angle of deviation from a perpendicular crossing at each individual entry and exit crosswalk. The angle was measured between the perpendicular crossing and a line that starts at the edge of the roadway in the center of the crosswalk and goes through the centerline of the roadway in the center of the crosswalk. A positive angle faces pedestrians on the crosswalk towards oncoming traffic, and vice versa for a negative angle, as illustrated in figure 17.

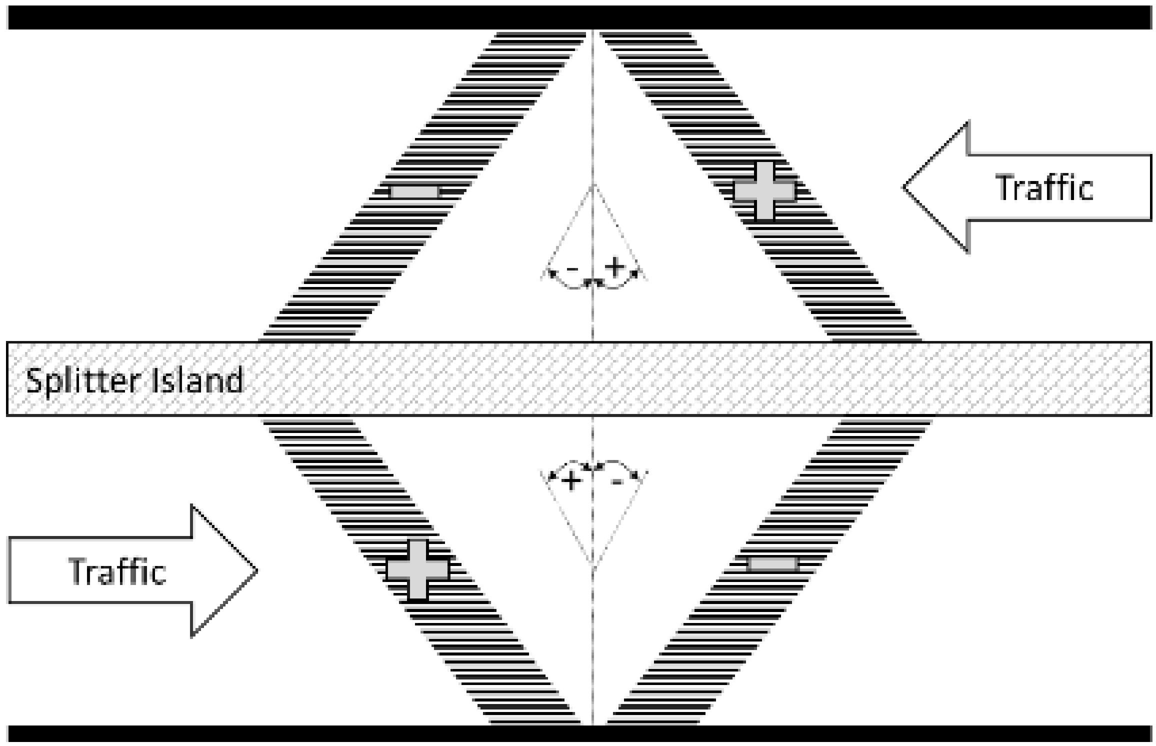

Figure 17. Diagram. Illustration of crosswalk angle measurement and sign conventions.

Pedestrian refuge width (REFW) was found by measuring the width of the splitter island to the nearest 0.15 m (0.5 ft). Crosswalk width (CROSSW) was determined by measuring the width of the crosswalk from asphalt edge to asphalt edge to the nearest 0.15 m (0.5 ft). Traffic volume (VOL) information as number of circulating vehicles per hour was found by examining video footage taken at each site during the trial periods. Traffic volume values are representative for the time periods in which yielding data were collected. Slip lane presence (SLP) indicates whether a slip lane was present at the crosswalk location.

DESCRIPTIVE STATISTICS

Across all approaches, statistically significant differences were found in driver yielding behavior based on crosswalk at roundabout entry or exit ($p<0.01$) and number of lanes ($p<0.01$ for entry, $p<0.05$ for exit). Overall, average weighted yielding rates were higher at entry crosswalks than at exit crosswalks and higher at single-lane than two-lane configurations. Further differences were found in driver yielding behavior based on crossing starting point, with average weighted yielding rates higher for pedestrians waiting on the island than those waiting on the curb. The difference in driver yielding behavior based on crossing starting point at entry crosswalks was statistically significant at $p<0.01$.

Statistically significantly higher speeds were found at the exit crosswalks, with an average free flow speed of 40 km/h (25 mi/h) compared to 32 km/h (20 mi/h) at entry crosswalks ($p<0.01$). These results are summarized in table 14 and table 15. Results in table 15 are similar to a previous effort in Carmel, IN, which resulted in an overall yielding rate of 8 percent (table 1).

Table 14. Yielding rates and speeds in Carmel, IN

Yield Rate or Speed	All	Entry	Exit	Entry, One-Lane	Entry, Two-Lane	Exit, One-Lane	Exit, Two-Lane
Average Weighted Yield Rate (percent)	10	17	4	21	10	5	3
Average Free Flow Speed at Crosswalk [km/h (mi/h)]	37 (23)	32 (20)	40 (25)	32 (20)	34 (21)	40 (25)	40 (25)
Max Free Flow Speed at Crosswalk [km/h (mi/h)]	45 (28)	40 (25)	45 (28)	35 (22)	40 (25)	43 (27)	45 (28)

Table 15. Average weighted yield rate in Carmel, IN, by crosswalk and pedestrian position.

Crosswalk Position	No. Lanes	Pedestrian Waiting Position	Average Weighted Yield Rate (percent)
Entry	1	Curb	13
Entry	1	Island	7
Entry	2	Curb	7
Entry	2	Island	14
Exit	1	Curb	4
Exit	1	Island	5
Exit	2	Curb	2
Exit	2	Island	4

Additional Data Collection

Additional yielding data were collected at entry and exit crosswalks at four roundabouts in Hilliard, OH, and weighted yielding rates were derived in the same manner as for the Carmel, IN, dataset. While the Hilliard, OH, dataset was not large enough to generate reliable regression models, it was examined for general trends in yielding behavior to corroborate findings from the Carmel, IN, sites. To avoid the potential bias from differences in driver and pedestrian cultures between the cities, the sites were not combined.

In Hilliard, OH, data were collected at 32 crosswalks of the 4 roundabouts: 6 entry crosswalks with single lanes, 10 entry crosswalks with 2 lanes, 8 exit crosswalks with single lanes, and 8 exit crosswalks with 2 lanes. As in Carmel, IN, 50 staged crossing attempts were performed at each crosswalk from both the curb and island, resulting in a dataset with 3,200 data points. Data from four locations in Hilliard, OH, were dropped from the analysis because no valid trials were found: Emerald Parkway at Glendon Court, east leg, exit roundabout, curb starting point; Emerald Parkway at Glendon Court west leg, entry crosswalk, island starting point; Emerald Parkway at Glendon Court west leg, exit crosswalk, curb starting point; and Leap Road at Anson Drive, west leg, entry crosswalk, curb starting point. Detailed site information is included in table 16.

Table 16. Characteristics of selected roundabout sites in Hilliard, OH.

No.	Intersection	Inscribed Diameter [m (ft)]	Approach (N, S, E, W)	Number of Lanes at Entry	Number of Lanes at Exit	Crosswalk Offset at Entry Leg [m (ft)]	Crosswalk Offset at Exit Leg [m (ft)]
1	Britton Rd./Hayden Run Rd.	55.8 (183)	N	2	2	10.7 (35)	11.3 (37)
2	Britton Rd./Hayden Run Rd.	55.8 (183)	W	1	1	8.2 (27)	9.4 (31)
3	Britton Rd./Hayden Run Rd.	55.8 (183)	S	2	2	9.1 (30)	7.6 (25)
4	Britton Rd./Hayden Run Rd.	55.8 (183)	E	1	1	8.2 (27)	7.9 (26)
5	Emerald Pkwy/Glendon Ct.	46 (151)	N	2	2	8.2 (27)	7.6 (25)
6	Emerald Pkwy/Glendon Ct.	46 (151)	W	1	1	7.3 (24)	6.4 (21)
7	Emerald Pkwy/Glendon Ct.	46 (151)	S	2	2	9.1 (30)	9.8 (32)
8	Emerald Pkwy/Glendon Ct.	46 (151)	E	2	1	8.2 (27)	7.9 (26)
9	Leap Rd./Anson Dr.	51.2 (168)	N	1	1	8.2 (27)	20.7 (68)
10	Leap Rd./Anson Dr.	51.2 (168)	W	1	1	6.4 (21)	6.7 (22)
11	Leap Rd./Anson Dr.*	51.2 (168)	S	2	1	8.2 (27)	19.8 (65)
12	Leap Rd./Anson Dr.*	51.2 (168)	E	1	1	8.2 (27)	21.9 (72)
13	Main St./Cemetery Rd.*	48.5 (159)	N	2	2	8.2 (27)	12.2 (40)
14	Main St./Cemetery Rd.*	48.5 (159)	W	2	2	7.9 (26)	7.9 (26)
15	Main St./Cemetery Rd.*	48.5 (159)	S	2	2	9.1 (30)	8.5 (28)
16	Main St./Cemetery Rd.*	48.5 (159)	E	2	2	8.5 (28)	21 (69)

*Included in eye tracking study

Across all crosswalk trials, statistically significant differences were found in driver yielding behavior based on crosswalk at roundabout entry versus exit (p<0.01) and number of lanes (p<0.10 for entry, p<0.05 for exit). Overall, average weighted yielding rates were higher at entry crosswalks than exit crosswalks. Unlike the Carmel, IN, sites, however, average weighted yielding rates were higher at two-lane than single-lane crosswalks, suggesting that yielding rates are impacted by more than just the number of lanes. Differences in yielding across the two studied areas may be related to a host of factors, including state and local laws, pedestrian expectation, and driver culture. These factors were not a focus in this study, but they are believed to play a large role in differences in yielding across cities and regions in the United States, as noted, for example, in figure 1. Further differences were found in driver yielding behavior based on pedestrian crossing starting point, with average weighted yielding rates higher for pedestrians waiting on the island than those waiting on the curb, but those differences were not statistically significant, possibly due to the small sample size. These findings are presented in table 17 and table 18.

Table 17. Yielding rates in Hilliard, OH.

Yield Rate or Speed	All	Entry	Exit	Entry, One-Lane	Entry, Two-Lane	Exit, One-Lane	Exit, Two-Lane
Average Weighted Yield Rate (percentage)	19	28	11	22	31	7	14

Table 18. Average weighted yield rate in Hilliard, OH, by crosswalk and pedestrian position.

Crosswalk Position	No. Lanes	Pedestrian Waiting Position	Average Weighted Yield Rate for Hilliard, OH, (percent)
Entry	1	Curb	19
Entry	1	Island	24
Entry	2	Curb	29
Entry	2	Island	34
Exit	1	Curb	6
Exit	1	Island	7
Exit	2	Curb	12
Exit	2	Island	16

MODEL DEVELOPMENT

The research team sought to develop a model to determine whether significant relationships existed between geometric factors and yielding rates at the trial roundabout crosswalks and to predict driver yielding probability as a function of geometric factors. The team was particularly interested in the relationship between a crosswalk's distance from the circulatory roadway and the yielding rate to determine if that relationship was different for entry and exit crosswalks and to determine the safest entry and exit crosswalk locations.

The model development applied multivariable linear regression models to the geometric factors detailed in table 13 to determine which factors significantly contributed to driver yielding behavior. Circulating volume as number of vehicles per hour was also included as an explanatory variable for the first step of the analysis. The weighted yielding rate is a continuous variable constrained to between 0 and 100 percent, making it suitable for use in multivariable linear regression modeling. Regression diagnostics were applied to the dependent and explanatory variables to verify the data met the assumptions of linear regression. The form of the multivariable linear regression model for yielding rate is given in figure 18.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_{3\,(\ldots)}$$

Figure 18. Equation. Linear regression model for yielding rate.

Where:

Y is the value of the dependent variable, what is being predicted or explained;

a is the constant or intercept;

b_1 is the slope for X_1, the first independent variable that is explaining the variance in Y;

b_2 is the slope for X_2, the second independent variable that is explaining the variance in Y;

b_3 is the slope for X_3, the third independent variable that is explaining the variance in Y; and

b_4 and onwards are the slopes for additional independent variables that explain the variance in Y.

Based on this equation, if the values of all variables except one independent variable (X_i) are kept constant, a one-unit increase in X_i will increase the value of the response variable Y by the slope of X_i. The R^2 statistic is generally used in regression models to describe the extent to which the model explains the variability of the data. For multivariable linear regression models, the variability of the model can be evaluated by the adjusted R^2 statistic, an adjustment of the R^2 based on the number of observations and predictors in the model. A higher adjusted R^2 indicates a better fit and a higher proportion of data explained by the model.

Data sources for entry crosswalks at one- and two-lane roundabouts are listed in table 19. Descriptive statistics for all variables at entry roundabouts are shown in table 20 for one-lane roundabouts and table 21 for two-lane roundabouts. Data sources for exit crosswalks at one- and two-lane roundabouts are listed in table 22. Descriptive statistics for all variables at exit roundabouts are shown in table 23 for one-lane roundabouts and table 24 for two-lane roundabouts.

Table 19. Data sources and trials for entry crosswalks at one- and two-lane roundabouts.

Item	Entry, One-Lane Total	Entry, Two-Lane Total
No. Intersections	9	6
No. Approaches	22	16
No. Unique Crossing Locations	44	32
Total No. Valid Trials	768	708

Table 20. Descriptive statistics for entry crosswalks at one-lane roundabouts.

Type	Variable/Item	Avg	St Dev	Max	Min
Count of Trials	Valid Trials per Unique Crossing Location	17	n/a	35	3
Response Variable	YIELDR (percent)	21.4	14.7	53.0	0
Binary Factor	ISLAND	0.5	0.5	1	0
Binary Factor	SLP	0.32	0.47	1	0
Continuous Factor	DIA [m (ft)]	47.5 (156)	7.3 (24)	62.5 (205)	39.6 (130)
Continuous Factor	RAD [m (ft)]	35.1 (115)	8.5 (28)	64.0 (210)	24.4 (80)
Continuous Factor	OFF [m (ft)]	9.1 (30)	4.6 (15)	13.4 (44)	4.3 (14)
Continuous Factor	ANG (degrees)	0	7.2	20	-20
Continuous Factor	CROSSW [m (ft)]	2.7 (8.8)	0.3 (1.0)	3.0 (10)	2.1 (7.0)
Continuous Factor	REFW [m (ft)]	4.6 (15)	2.1 (6.9)	10.1 (33)	1.2 (4.0)
Continuous Factor	VOL (veh/h)	344	164	757	70
Continuous Factor	Speed [km/h (mi/h)]	32 (20)	2.1 (1.3)	35 (22)	30 (18)

Table 21. Descriptive statistics for entry crosswalks at two-lane roundabouts.

Type	Variable/Item	Avg	Std Dev	Max	Min
Count of Trials	Valid Trials per Unique Crossing Location	22	n/a	39	5
Response Variable	YIELDR (percent)	10.3	6.4	26	0
Binary Factor	ISLAND	0.5	0.5	1	0
Binary Factor	SLP	0.31	0.47	1	0
Continuous Factor	DIA [m (ft)]	54.3 (178)	6.9 (22.7)	62.5 (205)	44.8 (147)
Continuous Factor	RAD [m (ft)]	39.9 (131)	9.4 (30.8)	57.9 (190)	27.4 (90)
Continuous Factor	OFF [m (ft)]	12 (41)	4.9 (16)	9.8 (32)	6.4 (21)
Continuous Factor	ANG (degrees)	0	7.2	23	-23
Continuous Factor	CROSSW [m (ft)]	3.0 (9.9)	0.3 (0.97)	3.4 (11)	2.3 (7.5)
Continuous Factor	REFW [m (ft)]	4.4 (14.3)	0.9 (2.9)	5.6 (18.5)	2.3 (7.5)
Continuous Factor	VOL (veh/h)	466	243	919	134
Continuous Factor	Speed [km/h (mi/h)]	6.4 (21)	0.5 (1.5)	7.6 (25)	5.8 (19)

Table 22. Data sources and trials for exit crosswalks at one- and two-lane roundabouts.

Item	Exit, One-Lane Total	Exit, Two-Lane Total
No. Intersections	9	6
No. Approaches	24	14
No. Unique Crossing Locations	48	28
Total No. Valid Trials	718	584

Table 23. Descriptive statistics for exit crosswalks at one-lane roundabouts.

Type	Variable/Item	Avg	St Dev	Max	Min
Count of Trials	Valid Trials per Unique Crossing Location	15	n/a	34	3
Response Variable	YIELDR (percent)	4.4	3.9	17	0
Binary Factor	ISLAND	0.5	0.51	1	0
Binary Factor	SLP	0.33	0.48	1	0
Continuous Factor	DIA [m (ft)]	47.9 (157)	7.7 (25.4)	62.5 (205)	39.6 (130)
Continuous Factor	RAD [m (ft)]	51.2 (168)	19.4 (63.8)	107 (350)	30.5 (100)
Continuous Factor	OFF [m (ft)]	9.3 (30.5)	4.4 (14.4)	16.8 (55)	5.2 (17)
Continuous Factor	ANG (degrees)	0	10.1	30	-30
Continuous Factor	CROSSW [m (ft)]	2.7 (8.9)	0.3 (1.0)	3.0 (10)	2.1 (7.0)
Continuous Factor	REFW [m (ft)]	4.6 (15)	2.0 (6.7)	10 (33)	1.2 (4.0)
Continuous Factor	VOL (veh/h)	324	165	699	48
Continuous Factor	Speed [km/h (mi/h)]	7.6 (25)	0.5 (1.7)	8.2 (27)	6.4 (21)

Table 24. Descriptive statistics for exit crosswalks at two-lane roundabouts.

Type	Variable/Item	Avg	Std Dev	Max	Min
Count of Trials	Valid Trials per Unique Crossing Location	21	n/a	36	5
Response Variable	YIELDR (percent)	2.6	2.3	8.0	0
Binary Factor	ISLAND	0.5	0.51	1	0
Binary Factor	SLP	0.29	0.46	1	0
Continuous Factor	DIA [m (ft)]	54.3 (178)	6.6 (21.6)	62.5 (205)	44.8 (147)
Continuous Factor	RAD [m (ft)]	45.7 (150)	10.9 (35.9)	79.2 (260)	33.5 (110)
Continuous Factor	OFF [m (ft)]	12 (39)	4.3 (14)	26.8 (88)	4.0 (13)
Continuous Factor	ANG (degrees)	0	4.0	11	-11
Continuous Factor	CROSSW [m (ft)]	3.0 (10)	0.3 (1.0)	3.4 (11)	2.3 (7.5)
Continuous Factor	REFW [m (ft)]	4.3 (14)	0.9 (2.8)	5.8 (19)	2.3 (7.5)
Continuous Factor	VOL (veh/h)	474	184	904	205
Continuous Factor	Speed [km/h (mi/h)]	7.7 (25.4)	0.3 (1.1)	8.5 (28)	7.3 (24)

Where:

EXIT = exit or entry crosswalk.
LANE = number of lanes at crosswalk.
CPT = pedestrian crossing starting point.
DIA = inscribed diameter of roundabout in feet.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk offset in feet.
ANG = corrected crosswalk angle in degrees, rounded to nearest 10°.
REFW = pedestrian refuge width.
CROSSW = crosswalk width.
VOL = traffic volume, number of circulating vehicles per hour.
SLP = slip lane presence.
YIELDR = weighted yielding rate.

All data from the roundabouts were analyzed using multivariable linear regression modeling in Stata® to develop yielding rate models. We first used all variables, EXIT, LANE, ISLAND, DIA, RAD, OFF, ANG, REFW, CROSSW, VOL, and SLP, regardless of *p*-value, from all roundabout locations in the Stata® multivariable linear regression model.

The descriptive statistics, supported by findings from the Pearson correlation tables, indicated a strong, significant correlation between the variables EXIT and LANE and the weighted yielding rate, YIELDR. Therefore, it was decided to subdivide the data by approach and number of lanes to examine any changes in the significance of the explanatory variables. A summarized version of the Pearson correlation tables showing the correlation between the weighted yielding rate and the explanatory variables is provided in table 25.

Table 25. Pearson correlation values between YIELDR and explanatory variables.

Variable	Entry, One-Lane	Entry, Two-Lane	Exit, One-Lane	Exit, Two-Lane	All
EXIT	-	-	-	-	-0.5630*
LANE	-	-	-	-	-0.2482*
ISLAND	0.5528*	0.5819*	0.2282	0.4365*	0.3090*
DIA	-0.2557**	0.3489**	-0.2969*	-0.2259	-0.2050*
RAD	0.2860**	-0.1328	0.1107	-0.1788	-0.1970*
OFF	-0.1183	-0.2737	0.2307	0.3380**	-0.1074
OFF30	-0.0256	-0.2471	0.0212	0.3455**	-0.1353**
OFF50	-0.1111	0.4692*	-0.3223*	-0.2504	0.0675
ANG	-0.0325	-0.3068**	0.0855	0.1957	-0.0286
REFW	0.4151*	0.1140	0.2201	0.0433	0.2401*
CROSSW	-0.196	0.1304	-0.0663	-0.2227	-0.1987*
VOL	0.4034*	-0.0428	0.1054	-0.3553**	0.0482
SLP	-0.1863	0.4349*	-0.3150*	-0.0665	-0.0505

$^{*}p<0.05$, $^{**}p<0.10$

The exploratory statistical analysis consisted of two parts. The first part of the analysis included all explanatory variables for all locations, subdivided by entry/exit crosswalk and number of lanes. For the second part, the data were examined for strong correlations and significant relationships between the independent variables for all locations, entry/exit crosswalk, and number of lanes. Any two independent variables found to be significantly related were not included in the same model. Through manual selection, final models were generated as informed by previous analysis steps. These models took into account practical significance and the feasibility of implementing variables in simulation, and they were not exclusively motivated by statistical fit.

Two variables for crosswalk distance from circulatory roadway were included in the analysis for locations (subdivided by entry/exit crosswalk and number of lanes): crosswalk distance in feet (OFF) and crosswalk distance divided into three categories. The categories were *short*, or less than 9.1 m (30 ft), *medium*, or greater than or equal to 9.1 m but less than 15 m (50 ft), and *long*, or greater than or equal to 15 m (50 ft). The distances for the categories were selected so that the reference category contained the middle 50 percentile of crosswalk distances for two-lane roundabouts across the U.S.

To produce models generalizable to any time of day, circulating volume (VOL) was not included in part two of the analysis, since traffic volume depends on time of day. A detailed write-up of the entire exploratory statistical analysis is included in Appendices G and H. The following sections present a summary of the statistical analysis results.

MODEL RESULTS

The full model for all locations indicated that crosswalk at entry or exit (EXIT), number of lanes (LANE), and pedestrian crossing starting point (ISLAND) were significant explanatory factors ($p<0.05$) for driver yielding behavior across the 10 Carmel, IN, roundabout sites (table 26). These factors remained significant at the same level for all locations in the reduced (forward selection) model (table 27). The full model for all locations is provided in table 26, and the reduced model for all locations is provided in table 27. The adjusted R^2 values are the same (0.48) for both the full and reduced models for all locations and are listed, along with p values, for both models in table 28.

Table 26. Results of full multivariable linear regression on all locations.

Variable	Regression Coefficient	Standard Error	*p*	95 Percent Confidence Interval Lower Bound	95 Percent Confidence Interval Upper Bound
EXIT	-13.637	1.487	0.000*	-16.575	-10.699
LANE	-6.182	1.473	0.000*	-9.093	-3.272
ISLAND	7.092	1.356	0.000*	4.413	9.771
OFF	-0.036	0.050	0.469	-0.135	0.062
RAD	0.008	0.015	0.587	-0.022	0.039
Constant	22.235	3.118	0.000	16.072	28.399

Table 27. Results of reduced forward selection multivariable linear regression on all locations.

Variable	Regression Coefficient	Standard Error	*p*	95 Percent Confidence Interval Lower Bound	95 Percent Confidence Interval Upper Bound
EXIT	-13.279	1.352	0.000*	-15.950	-10.607
LANE	-6.547	1.383	0.000*	-9.279	-3.814
ISLAND	7.092	1.350	0.000*	4.424	9.760
OFF	-	-	-	-	-
RAD	-	-	-	-	-
Constant	22.494	2.287	0.000	17.975	27.013

Table 28. Model results *p*, R-squared, and adjusted R-squared values for full and reduced models.

Item	Full Model	Reduced Model
Prob > F	0.000	0.000
R2	0.492	0.489
Adj. R2	0.475	0.479

Significant Results

Crosswalk at Entry/Exit

The reduced model controlled for collinearity and estimated that the yielding rate was 13.3 percent lower for a crossing at the exit versus the entry (p=0.000).

Number of Lanes

The reduced model controlled for collinearity and estimated that the yielding rate was 6.6 percent lower for two-lane crossings compared to one-lane crossings (p=0.000).

Pedestrian Crossing Start Point

The reduced model controlled for collinearity and estimated that the yielding rate was 7.1 percent higher for a crossing from the island versus the curb (p=0.000).

ANOVA Testing

An ANOVA test was performed on the reduced model for all locations to determine what proportion of the variation in observed yield rates was accounted for by entry/exit crosswalk, number of lanes, and pedestrian crossing starting point. Due to the presence of heteroscedasticity in the residual plot, a log transformation was executed on the response variable, YIELDR, to make it meet the assumptions of the ANOVA test. The Mean Squares and F-value results estimate which factors account for more or less variation in yield rates, and the adjusted R^2 value estimates how much variability in the data is accounted for by the model, as visualized in figure 19. It appears that three factors, entry/exit (EXIT), pedestrian crossing starting point (ISLAND), and number of lanes at crosswalk (LANE), account for nearly half of the variability in yield rates, with rest of the variability not explained by the model. In other words, effects of other variables, such as the crosswalk distance from the circulatory roadway, were not significant at the given sample size. This result is consist with previous efforts in driver yielding and pedestrian crossing decisions,[10] which found that the statistical fit for pedestrian crossing models were much stronger than driver yielding models. The lower strength of driver yielding models might be explained by the risk posed by improper decisions—a poor crossing decision by a pedestrian has serious personal safety implications, while a driver may not have a comparable urgency to yield even under ideal conditions. A more robust dataset (more sites and more staged trials) should improve predictive abilities, but situational factors (including traffic conditions, weather, and individual driver characteristics, such as their general propensity to yield to pedestrians) will likely continue to have a considerable influence.

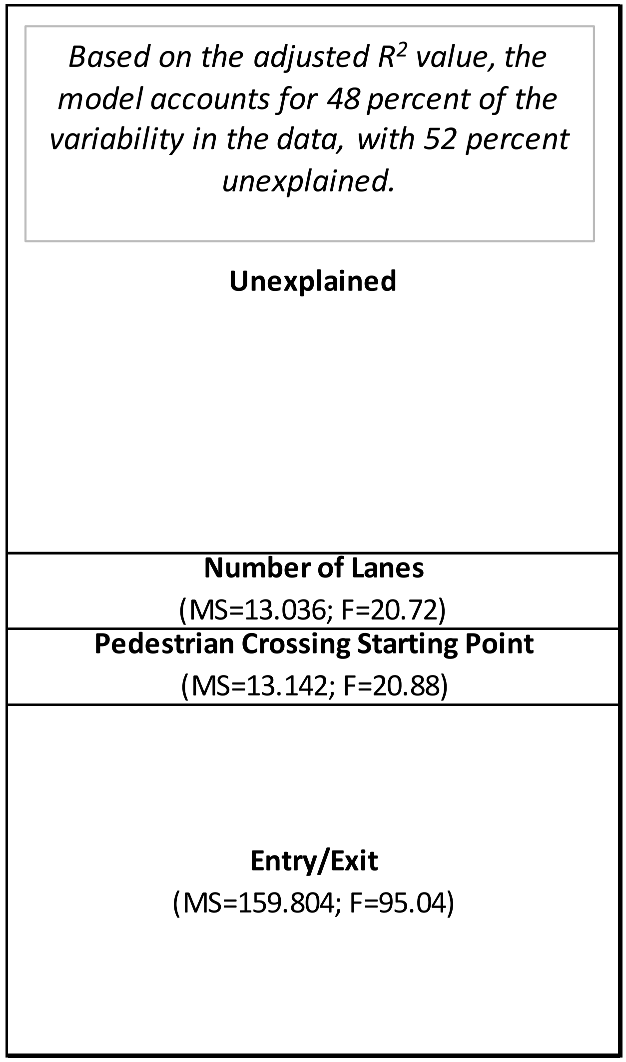

Figure 19. Diagram. Simplified visual display of analysis of variance results for reduced model for all locations.

General Fit

In terms of model fit, the "Entry, 1-Lane" and "Entry, 2-Lane" models account for approximately one-third of the variation in their data. The "Exit, 2-Lane" model accounts for approximately one-quarter of the variation in its data, while the "Exit, 1-Lane" model accounts for less than one-tenth of the variation in its data. The adjusted R^2 values for the models suggest that some variation in driver yielding behavior is caused by factors other than those included in the analysis.

Pedestrian Crossing Starting Point

Controlling for crosswalk at entry/exit and number of lanes, pedestrian crossing starting point was found to be the significant ($p<0.05$) explanatory factor accounting for the greatest change in yielding rates in the "Entry, 1-Lane," "Entry, 2-Lane," and "Exit, 2-Lane" models. In these models, the yielding rate was estimated to be 16.0 percent higher for crossings from the island compared to crossings from the curb for crosswalks on one-lane roundabout entries, 7.3 percent higher for crosswalks on two-lane roundabout entries, and 2.0 percent higher for crosswalks on two-lane roundabout exits. For crosswalks on one-lane roundabout exits, the p-value for the pedestrian crossing starting point variable was just above the $p<0.10$ threshold and thus not significant given the sample size. The effect of pedestrian crossing starting point in the models indicates higher yielding rates when pedestrians were crossing from the island than from the curb.

Crosswalk Distance from Circulatory Roadway

Controlling for the effects of collinearity, none of the manually selected models by crosswalk at entry/exit and number of lanes provided meaningful conclusions about the relationship between driver yielding and crosswalk distance from the circulatory roadway. While variables reflecting crosswalk distance were significant at the selected confidence levels in all models (except for "Entry, 1-Lane"; see Appendix E), the differences in yielding rates were small. For crosswalks at one- and two-lane roundabout exits, there was an increase in yielding of 0.8 percent and 0.4 percent, respectively, for each 3.0 m (10 ft) of added distance from the circulatory roadway. Clearly, these effects are not practically meaningful, as even a 15-m (50-ft) crosswalk distance would only result in 4 percent and 2 percent increases in yield rates for one- and two-lane roundabout exits, respectively. It is noteworthy, though, that the base yield rate (intercept of the models) was less than about one percent for both numbers of lanes, suggesting that even the modest increase in yield rates caused by added crosswalk distance from the circulatory roadway is a noteworthy increase over the overall mean yielding rate. Future researchers may want to focus on sites with a higher base yield rate to explore if the effect of crosswalk distance on yield rate holds true at those sites. For crosswalks at two-lane roundabout entries, crosswalk distance from the circulatory roadway had a negative coefficient; yielding decreased 0.9 percent for each 3.0 m (10 ft) of increased crosswalk distance. Again, additional research sites with higher yield rates are recommended to explore these effects. For more detailed results, please see Appendix E.

CHAPTER 6. RESULTS – EYE-TRACKING STUDY

Due to the pseudo-naturalistic nature of the data, descriptive statistics were used to analyze the results. Objects of interest were grouped into five main categories: traffic, pedestrians, markings, signs, and pedestrian-related markings and signs. Crosswalks and pedestrian crossing signs were put into this last category because their purpose is not to assist in navigating the roundabouts, but to alert drivers to possible pedestrian encounters.

EYE-GLANCE BEHAVIOR VS. OBJECT CATEGORY

Percent of Glances and Dwell Time

Figure 20 shows the total number of glances and the total dwell time of glances for each category of objects, and figure 21 shows the percentage of total dwell time by category. Out of the 1,759 glances that were reduced, glances at traffic were most common and accounted for over half of all the time participants spent glancing at objects of interest in the roundabouts. Pedestrian-related signs and markings accounted for twenty-eight percent of all glances and nearly a quarter of all dwell time. Glances toward crosswalks accounted for most of these. Glances toward other markings and signs made up less than a third of all glances and less than a quarter of all dwell time. Very few pedestrians were encountered during data collection, resulting in only 19 total glances at pedestrians. Pedestrian glances occurred in eight different instances among six different participants.

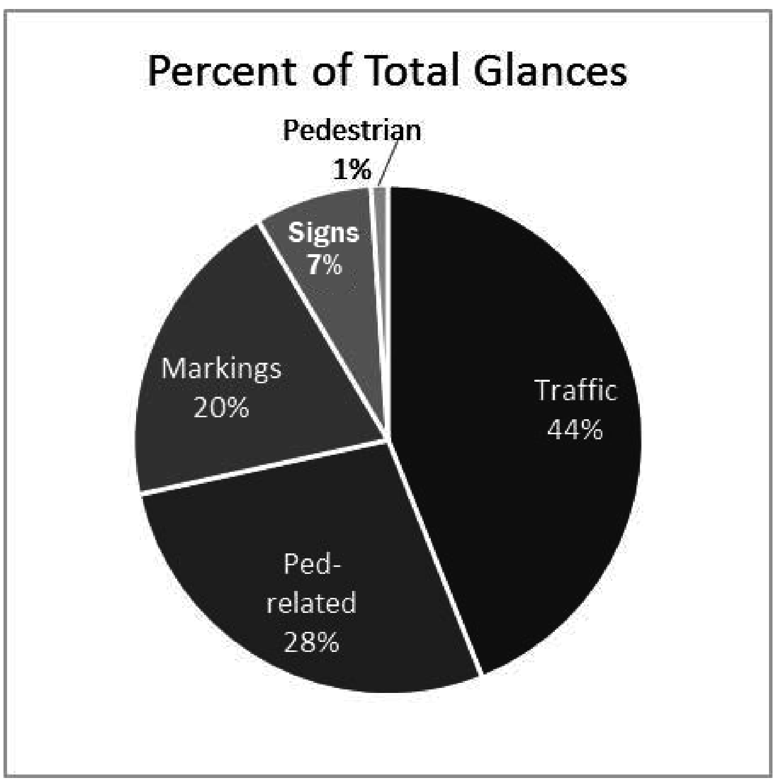

Figure 20. Pie chart. Percentage of the total number of glances by category.

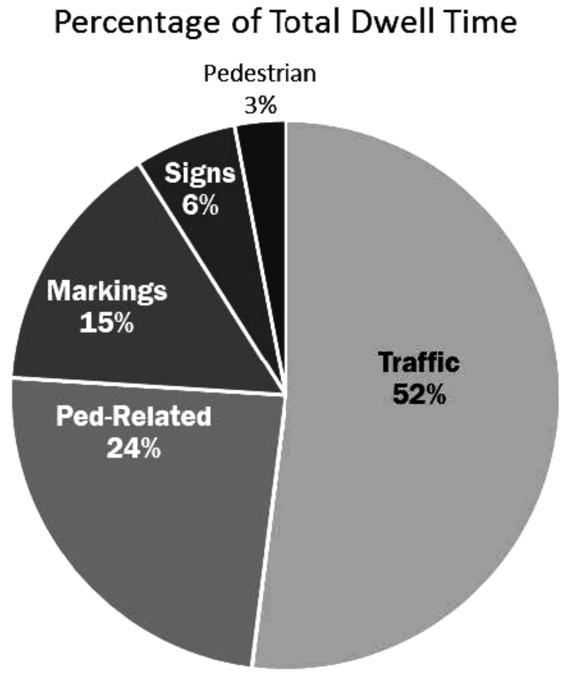

Figure 21. Pie chart. Percentage of the total dwell time by category.

Dwell and Fixation Times

Figure 22 shows the mean dwell time, and figure 23 the mean fixation time, for each category. As described previously, dwell time refers to the length of time that a participant's gaze was focused on an object, and fixation time refers to the length of time between saccades. A single dwell time can contain numerous fixations. The mean dwell time for glances at pedestrians was far longer than that of any other category. Glances toward pedestrians lasted more than 1 s on average—twice as long as glances toward other vehicles and roughly three times as long as glances toward markings or signs. Additionally, pedestrian glances had a longer mean fixation time (89 ms) than any other category. Mean fixation times for the remaining categories were very similar; all fell within 7 ms of each other.

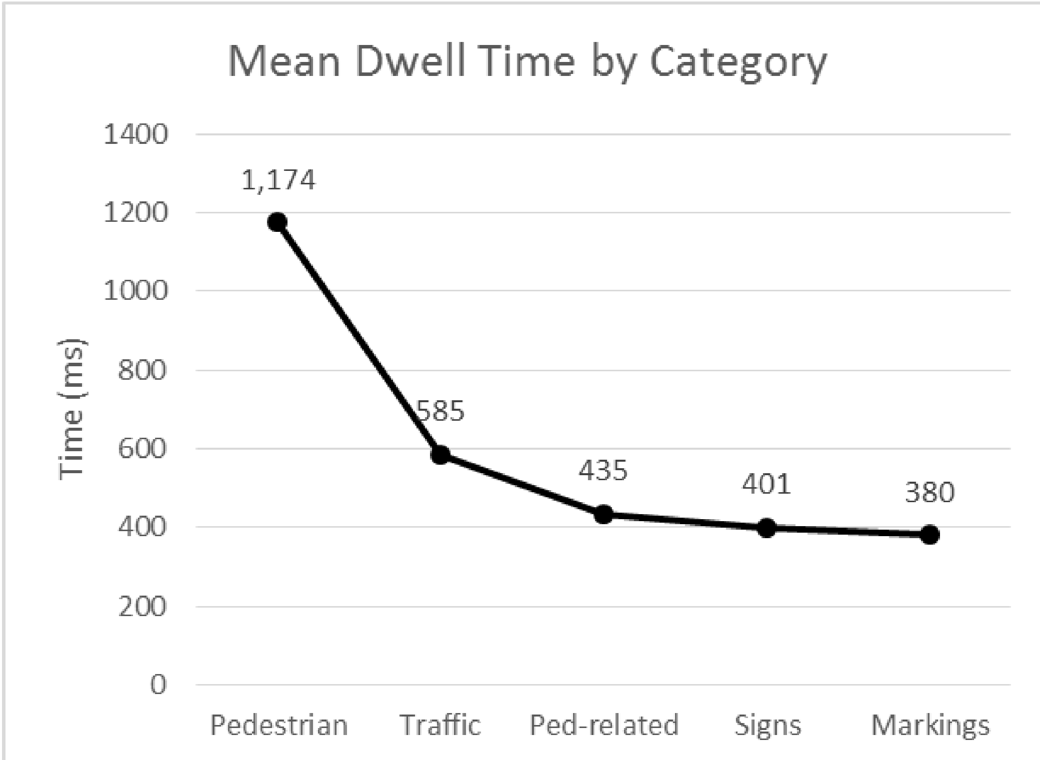

Figure 22. Graph. Mean dwell time by category.

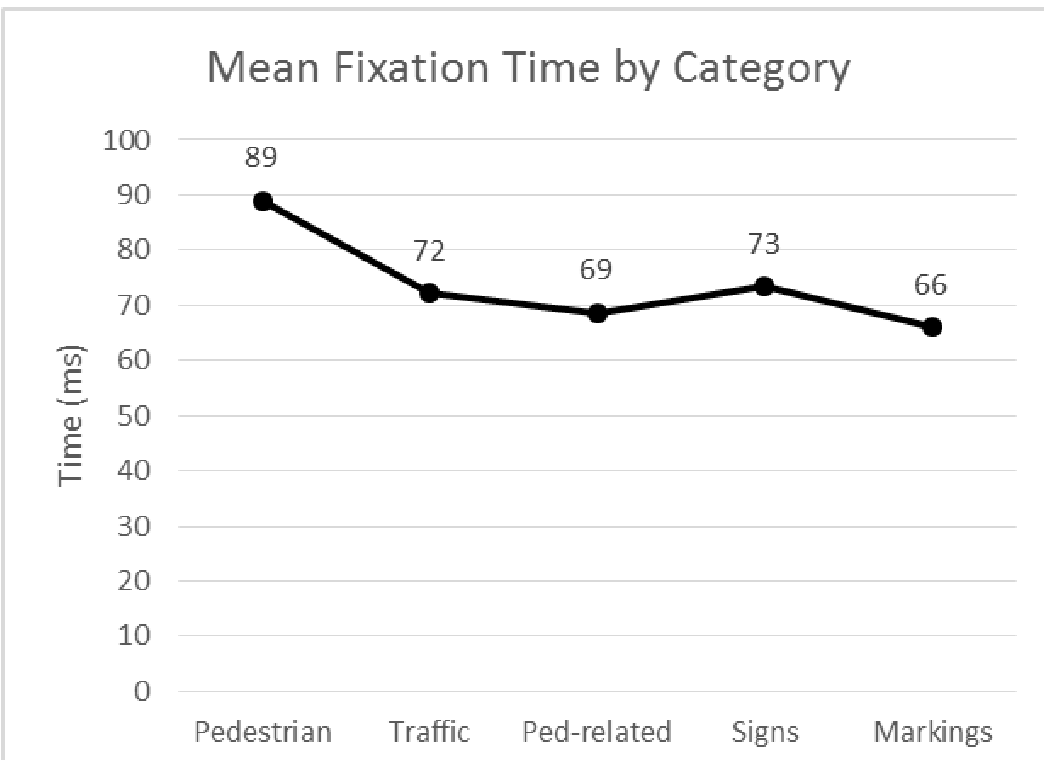

Figure 23. Graph. Mean fixation time by category.

Pedestrian-Related Categories Only

For the remaining analyses, the categories of traffic, markings, and signs were removed so that glances toward pedestrians and pedestrian-related signs and markings could be analyzed. This left a total of 504 glances. Figure 24 shows the total number of glances, mean dwell time, and mean fixation time for each of the pedestrian-related objects. Glances toward crosswalks accounted for 71 percent of pedestrian-related glances, followed by glances toward pedestrian crossing signs (25 percent) and glances toward pedestrians (4 percent).

On average, glances toward pedestrians lasted about 2.5 times longer than glances toward crosswalks and over 3 times longer than glances at pedestrian crossing signs. Additionally, the average fixation time for glances towards pedestrians (89 ms) was longer than that for crosswalks (70 ms) and pedestrian crossing signs (63 ms).

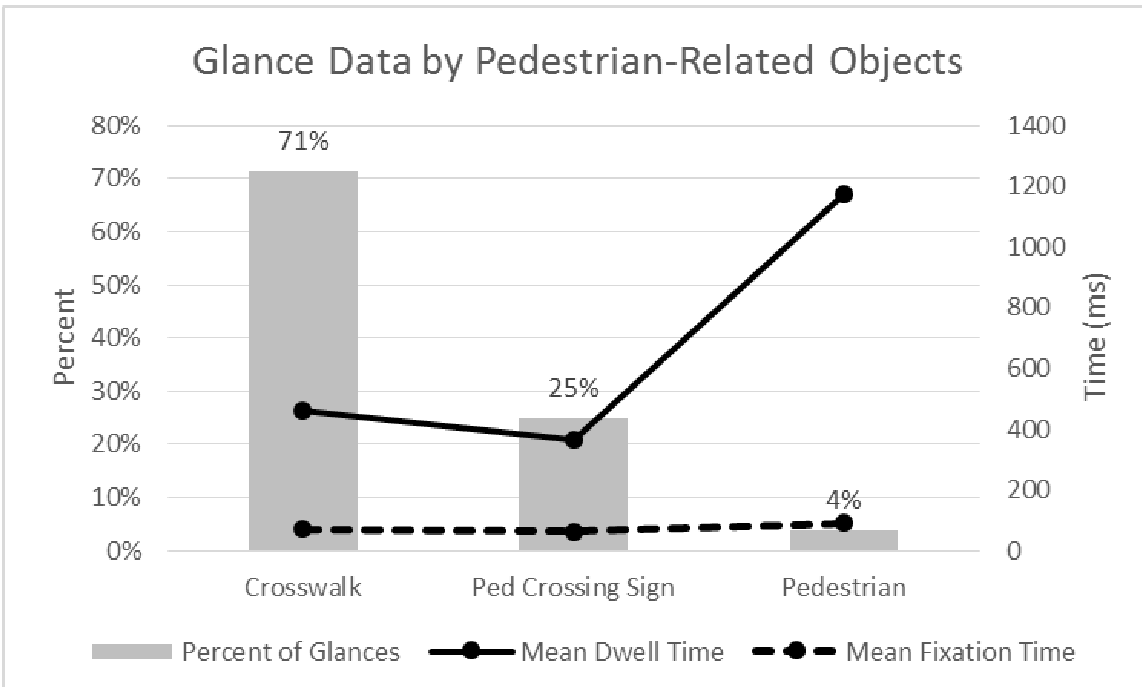

Figure 24. Chart. Glance data by pedestrian-related objects.

EYE-GLANCE BEHAVIOR VS. VEHICLE LOCATION IN ROUNDABOUT

Figure 25 shows the number of glances, mean dwell times, and fixation times for all glances towards crosswalks, separated by the location of the driver's vehicle. Nearly 50 percent of glances toward crosswalks occurred while the driver was approaching a roundabout. Only three total glances (less than one percent) to crosswalks were made when drivers were in the entrance of a roundabout. Thirty-six percent of crosswalk glances occurred while the driver was within the circulatory roadway, and the majority of those were toward the crosswalk at their intended exit leg (116 of 131 glances). Glances toward crosswalks made while the vehicle was in the exit (13 percent), combined with those from within the circle, form nearly the same percentage as glances made while the driver was approaching the roundabout. This suggests that drivers make a roughly equal number of glances toward crosswalks when entering and when exiting the roundabouts.

Glances made toward crosswalks while in the circle had a mean dwell time of 523 ms and tended to last longer than those made from other parts of the roundabout. Glances in the approach were slightly shorter with a mean of 438 ms, followed by glances in the entrance at 402 ms, and glances in the exit at 369 ms. Mean fixation times were slightly longer during the approach (75 ms) than at any other location (64 ms +/-2.7 ms).

Although participants were found to make a roughly equal number of glances toward crosswalks at the entry and exit of the roundabout, the yielding study identified a generally lower rate of yielding at roundabout exits than entries, which is consistent with prior research. This difference in driver yield rates has often been explained by differences in speed (generally higher at exits than entries) and acceleration/deceleration patterns (drivers tend to be slowing down at entries but speeding up at exits). A possible alternative explanation for this phenomenon may be a driver's mental framing of the entry and exit of the roundabout. Perhaps a driver is more likely to yield to a pedestrian at the entry crosswalk because they are already mentally primed to yield to traffic in the circle. Conversely, a driver who has already entered the circle and has the right of way may not be as mentally prepared to yield to a pedestrian at the exit.

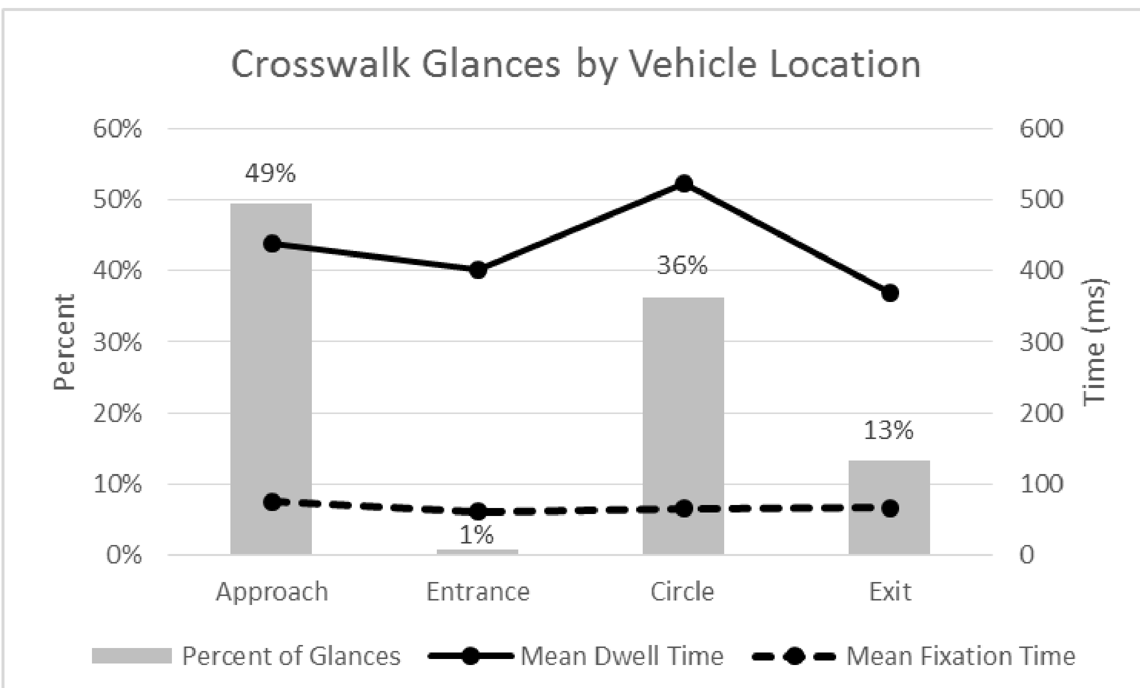

Figure 25. Chart. Crosswalk glances by vehicle location.

Eye-Glances at Pedestrians vs. Vehicle Location in Roundabout

Data for glances toward pedestrians based on the driver's location are shown in figure 26. Due to the relatively low number of pedestrian glances, it is difficult to say with much certainty what the effects of vehicle location are. However, it appears that pedestrian glances tend to last much longer when they are made from within the circle. These glances had a mean dwell time of

1,633 ms, 732 ms longer than glances made from the approach (901 ms) and 900 ms longer than glances made from the exit of the roundabout. Pedestrian glances made from within the circle also had the highest mean fixation time, 104 ms, followed by glances in the exit (88 ms), and glances in the approach (62 ms). However, there were only 8 encounters with pedestrians, resulting in 19 total glances, so these patterns may not represent typical driver behavior.

These findings may suggest some benefit of assuring that the exit crosswalk is clearly visible from the circulatory roadway—at least when the exit crosswalk is close to the circulatory roadway. It could be that glances and fixation time may increase at exits for roundabouts with crosswalks located farther from the circulatory roadway. However, an analysis of the few pedestrian data points available in the sample data did not show any conclusive results.

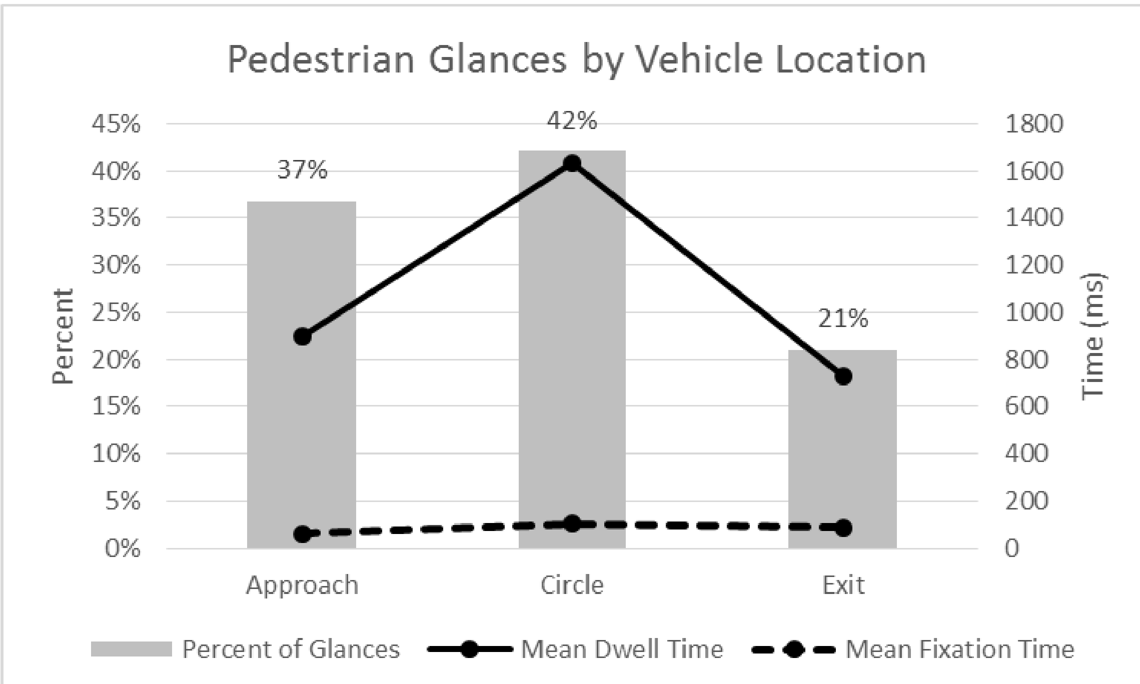

Figure 26. Chart. Pedestrian glances by vehicle location.

EYE-GLANCE BEHAVIOR VS. PEDESTRIAN LOCATION

Figure 27 shows the data for glances toward pedestrians based on pedestrian location. Pedestrian glances occurred in eight different instances for six different participants. Of the 19 pedestrian glances, 12 occurred when the pedestrian was in a crosswalk, 4 occurred when the pedestrian was in the splitter island, and 3 when the pedestrian was on the right-hand sidewalk. Again, these were very few samples and may not be representative of a larger sample of glances. However, it appears that glances toward pedestrians on the sidewalk tend to have the longest mean dwell time, followed by those in the crosswalk and those in the splitter island.

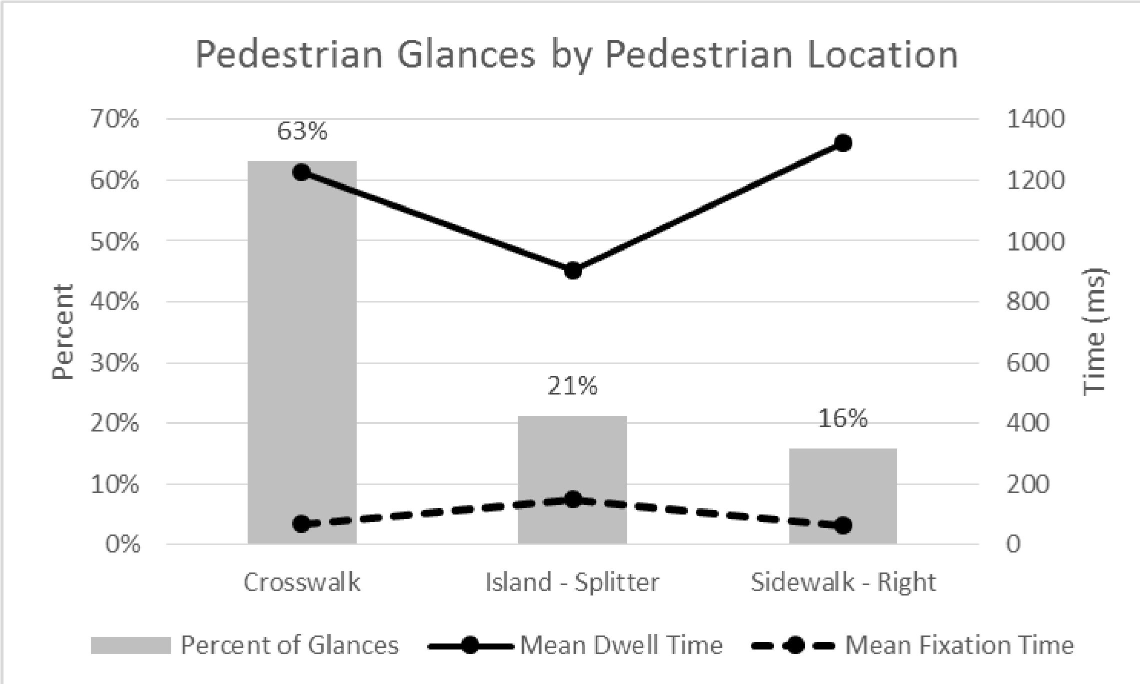

Figure 27. Chart. Pedestrian glances by pedestrian location.

EYE-GLANCE BEHAVIOR VS. PEDESTRIAN/NON-PEDESTRIAN RELATED OBJECT

As participants navigated the roundabouts, the number and duration of glances they made toward pedestrian-related signs and markings were roughly equal to those of glances they made toward other signs and markings. Glances toward crosswalks made up the bulk of glances towards pedestrian-related objects, and accounted for 20 percent of all glances tracked. Additionally, glances toward crosswalks were evenly spread among crosswalks at the entrance (49 percent of crosswalk glances) and exits (45 percent). This information suggests that motorists are attentive and actively scanning for potential pedestrian crossings at all points through the roundabout, with the exception of when they are about to enter the circle and must focus on oncoming traffic.

EYE-GLANCE BEHAVIOR WITH AND WITHOUT PEDESTRIANS

Percent of Glances by Object Category

Figure 28 shows the percentage of glances by category for instances when no pedestrian was present and when there was a pedestrian present. When a pedestrian was present, the percentage of glances toward all signs and markings was lower; however, the percentage of glances toward traffic was slightly higher.

Glances towards pedestrians had mean dwell times two to three times longer than glances towards static objects of interest. In fact, glances at pedestrians had dwell times more than twice as long (1,174 ms) as dwell times on other traffic objects (585 ms) as was shown above infigure 22. It could be that glances at other objects will be fewer and shorter in duration when a pedestrian is present at the roundabout.

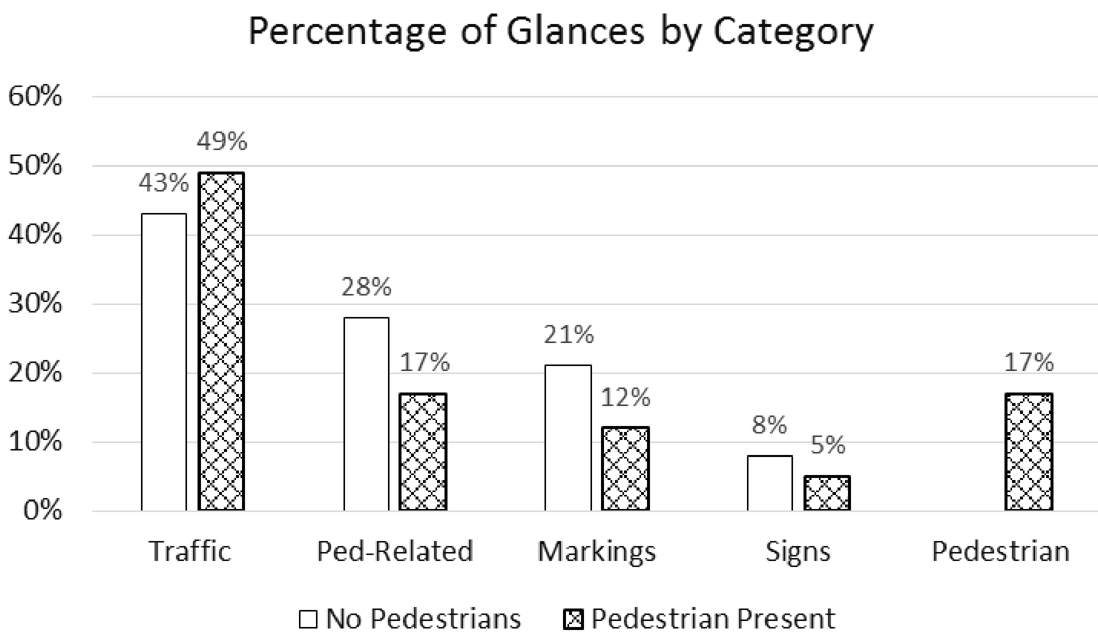

Figure 28. Chart. Percentage of glances by category and pedestrian presence.

Dwell Times

Figure 29 shows the percentage of total dwell time by category for instances where pedestrians were and were not present. When a pedestrian was present, the percentage of dwell time for all other objects was lower. Though glances at traffic made up a slightly higher percentage of glances when pedestrians were present, the total dwell time for those glances was shorter. When pedestrians were present, signs were the object of five percent of glances, representing two percent of dwell time.

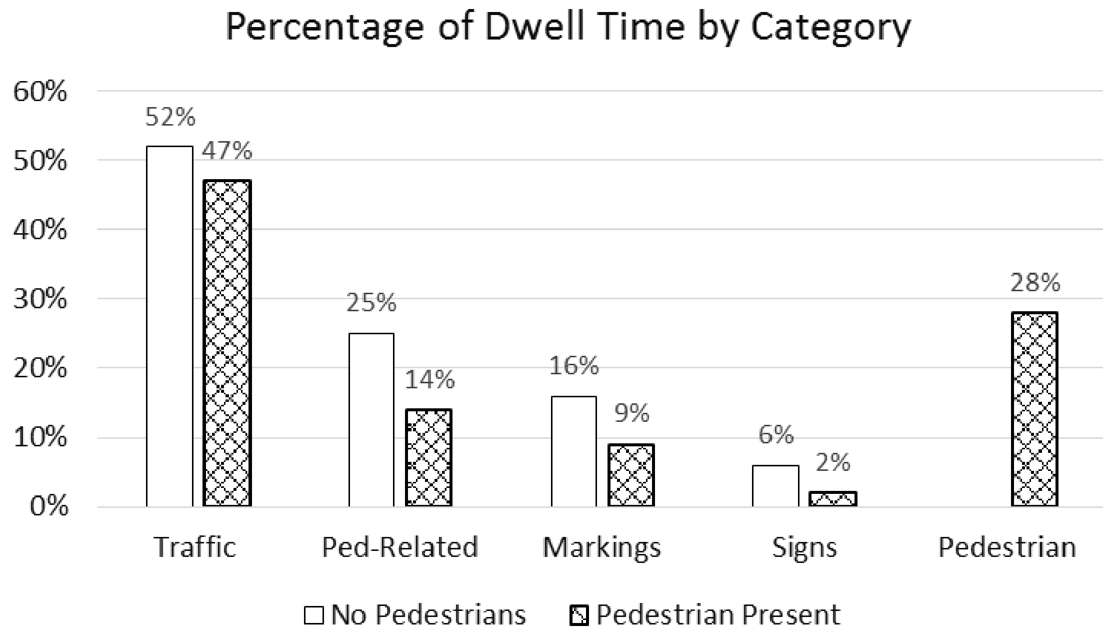

Figure 29. Chart. Percentage of dwell time by category and pedestrian presence.

Of the 17 percent of glances towards pedestrians (figure 28), it could be argued that 11 percent was accounted for by the fact that, when pedestrians were present, drivers made 11 percent fewer glances towards pedestrian-related signs and markings, leaving only a 6 percent net change in the number of glances towards signs and markings. However, because mean dwell time for pedestrian glances is 2.7 times longer than for glances at pedestrian-related signs and markings (1,174 ms and 435 ms, respectively), an equal number of glances between the two resulted in different dwell times. When a pedestrian was present, the total dwell time of glances toward pedestrian-related signs and markings was 11 percent lower, but pedestrian glances accounted for 28 percent of total dwell time. So even if the number of glances towards signs and markings was 6 percent lower when a pedestrian was present, the dwell time of those glances was 11 percent lower.

This information shows that drivers spend a significant amount of time glancing at pedestrians and pedestrian-related markings and signs at roundabouts (28 percent of total glances and 27 percent of total dwell time among glances toward traffic, pedestrians, markings, and signs). This suggests that moving crosswalks farther away from the intersections could allow a driver to spend more time attending to traffic and navigation aids as they drive through a roundabout, rather than scanning for or glancing at pedestrians.

CHAPTER 7. CONCLUSIONS

The yielding and eye-tracking experiments performed in this study confirmed several key findings about driver behavior with respect to pedestrians at roundabouts. First and foremost, yielding at crosswalks at roundabout entries was higher than that at roundabout exits. The eye-tracker results showed that drivers glance at exit crosswalks about the same amount as entry crosswalks. This suggests pedestrians are as likely to be seen at the exit as they are at the entry, and yet drivers are evidently less likely to yield at exit. Previous research suggests this finding is likely because drivers decelerate at the approach and accelerate at the exit.[1,2] It is also possible that yielding behavior is related to a driver's frame of mind when approaching or exiting a crosswalk. Some drivers approaching a roundabout may be prepared to consistently yield the right-of-way to any and all perceived conflicts. The fact that they are already prepared to yield to traffic may make them more likely to yield to a pedestrian. Conversely, other drivers may behave as if the right-of-way continues upon exiting the roundabout. This state of mind may make them less likely to yield to pedestrians at the exit, even though they are just as likely to see them. However, assessment of a driver's state of mind was beyond the scope of this project, and is offered only as a possible explanation that may warrant further investigation.

A second key finding is that yield rates are higher at single-lane crosswalks than at two-lane crosswalks. This is also intuitive because traffic volumes and vehicles speeds are likely to be higher at two-lane sites, and higher speeds in particular have been linked to lower yield rates.[2] The eye tracker study results further suggest that two-lane roundabouts feature more objects of interest (table 12) that may divert drivers' attention from a waiting pedestrian.

A third important finding is that vehicles are more likely to yield to pedestrians who are crossing from the splitter island than from the curb. This finding might be indicative of the conspicuity of the pedestrian and the clarity of the pedestrian's intent to cross. While the eye tracker data showed that pedestrian glances have a mean dwell time much longer than that of signs and markings, it was found that glances toward pedestrians located in the splitter island actually had a shorter mean dwell time than glances at pedestrians on the sidewalk. It may be that the intent to cross is much more ambiguous for pedestrians on the sidewalk, causing drivers to spend more time glancing at them. However, the pedestrian interactions in the eye tracker study were not controlled and were few in number. Further research into this aspect might help isolate the impact of these factors for explaining the differences in yielding rates. Controlling for crosswalk at entry/exit and number of lanes, crossing from the island appears to be the most significant explanatory factor accounting for the most change in driver yielding behavior for crosswalks at one- and two-lane roundabout entries and for crosswalks at two-lane roundabout exits. The yielding rate was estimated to be 16.0 percent higher for crossings from the island than from the curb for crosswalks at one-lane roundabout entries, 7.3 percent higher for crosswalks at two-lane roundabout entries, and 2.0 percent higher for crosswalks at two-lane roundabout exits. For crosswalks at one-lane exits, the *p*-value for pedestrian crossing starting point was just above the $p<0.10$ threshold and not significant at the study's sample size. Potential explanations for this effect include (a) that pedestrians are more conspicuous by being in a more direct line of sight on the island than on the curb, (b) that the pedestrian's crossing intent is unambiguous when standing on the island, and (c) that the pedestrian's perceived exposure to risk is higher on the island. The findings are consistent across all tested conditions and are, in general, intuitive.

This result also suggests that studies on driver yielding at roundabouts using only the curb pedestrian starting point might result in a lower, and therefore more conservative, estimate of yielding rate than studies with both curb and island starting points. However, the majority of pedestrian crossings start from the curb, so focusing on crossings starting at the curb would be appropriate for measuring yielding and the potential need for improved crossing treatments.

The eye-tracking study found that drivers glance considerably longer at pedestrians, two to three times longer than at other static objects and more than twice as long than at other traffic. Among signs and markings, drivers spent the most time glancing at pedestrian-related signs and markings, with 20 percent of glances at crosswalks and 7 percent at pedestrian-crossing or yield-to-pedestrian signs. Drivers made a similar number of glances toward entry and exit crosswalks. These findings suggest that drivers have the desire to look for and capability to identify pedestrians, but, according to the yielding study, they do not generally yield to pedestrians. Therefore, other non-geometric techniques, such as marketing campaigns, education, and enforcement, might be needed to increase yielding.

The eye-tracker research supports that drivers' visual task load upon entering the roundabout is heavily focused on the circulating traffic, supporting the current design practice of separating the decision points of drivers for (1) identifying and reacting to pedestrians at the crosswalk, and (2) screening for gaps in circulating traffic. However, additional separation between the circulating lane and the crosswalk at the entry (in excess of 9.1 m (30 ft)) appears to reduce the propensity of drivers to yield. While statistically significant, this effect was small in terms of its actual magnitude and thus has low practical significance. Potential reasons for this effect may be an increase in vehicle speed (less deceleration has taken place) when drivers are farther from the roundabout.

For the exit crosswalks, the study showed a statistically significantly higher yielding rate when the crosswalk is farther away from the circulatory roadway. However, similar to the findings for entry crosswalks, the practical effect was small in absolute terms. For the crosswalks at one-lane and two-lane roundabout exits, the coefficient for crosswalk distance from circulatory roadway suggested an increase in yielding of 0.8 percent and 0.4 percent for each 3.0 m (10 ft) of added distance from the circulatory roadway. It is possible that this effect would have been greater for roundabouts with a higher base yielding rate, but that was impossible to verify using data from the sites used in this study, which had very low yielding rates at exits.

CHAPTER 8. RECOMMENDATIONS FOR FUTURE GEOMETRIC RESEARCH

This study did not find any meaningful change in driver yielding behavior based on the geometric design elements (location and alignment) of the crosswalk. Future research could target these elements more explicitly by controlling for other, more significant factors found in this effort: crosswalk at entry/exit, number of lanes, and pedestrian crossing starting point.

With some exceptions, higher yielding rates were found when the crosswalk was situated closer to the circulatory roadway at entries and farther from the circulatory roadway at exits. However, in some cases these effects were not significant for the given sample size, and in other cases the effect was very small, rendering it impractical. Nonetheless, the general pattern that entry crosswalks closer to the circulatory roadway had higher yield rates tended to hold up in the various models and tests, as did the general pattern that exit crosswalks farther from the circulatory roadway tended to have higher yielding rates.

For crosswalks at roundabout exits, there is some evidence that a crosswalk distance of over 9.1 m (30 ft) from the circulatory roadway results in a somewhat increased likelihood of yielding. More research specifically exploring exit crosswalk configurations, while controlling for roundabout geometry, number of lanes, and curb versus island crossings, is needed to truly isolate these effects. A driver simulator study may be well suited for this type of analysis, similar to the work described in Salamati et al.[3] Additionally, though possibly difficult to establish, research into drivers' mental state as they approach and exit roundabouts might shed light on why the yielding rates were different for entry and exit crosswalks.

REFERENCES

1. Rodegerdts, L., et al. (2006). *Appendixes to NCHRP Report 572: Roundabouts in the United States*. Web-Only Document 94. Transportation Research Board. Washington, DC.
2. Salamati, K., B.J. Schroeder, D.R. Geruschat, and N.M. Rouphail. (January 2013). *Event-Based Modeling of Driver Yielding Behavior to Pedestrians at Two-Lane Roundabout Approaches*. Transportation Research Board. 92nd Annual Meeting. Paper 13-0419.
3. Salamati, K., B.J. Schroeder, N.M. Rouphail, C.M. Cunningham, Y. Zhang, and D.B. Kaber. (January 2012). *Simulator Study of Driver Responses to Pedestrian Treatments at Multilane Roundabouts*. Transportation Research Board. 91st Annual Meeting. Paper 132-0365.
4. Rodegerdts, L., et al. (2007). *Roundabouts in the United States*. NCHRP Report 572. Transportation Research Board. Washington, DC.
5. Rodegerdts, L., et al. (2010). *Roundabouts: An Informational Guide*. Second Edition. NCHRP Report 672. Transportation Research Board. Washington, DC.
6. Fitzpatrick, K., et al. (2006). *Improving Pedestrian Safety at Unsignalized Crossings*. NCHRP 562. Transportation Research Board. Washington, DC.
7. Schroeder, B., et al. (2011). *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*. NCHRP Report 674. Transportation Research Board. Washington, DC.
8. Purves, D., G.J. Augustine, D. Fitzpatrick, L.C. Katz, A. LaMantia, J.O. McNamara, and S.M. Williams. (2001). *Neuroscience, 2nd Ed.* Sinauer Associates. Sunderland, MA.
9. U.S. Department of Transportation, Federal Highway Administration, *2009 National Household Travel Survey*. URL: http://nhts.ornl.gov
10. Schroeder, B. (2008). *A Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalks.* Dissertation. North Carolina State University.

APPENDIX A. EYE-TRACKER STUDY MANEUVERS (HILLIARD, OH)

The maneuvers performed by the participant drivers at each of the roundabouts in Hilliard, OH, are shown in figure 30, figure 31, figure 32, figure 33, figure 34, and figure 35.

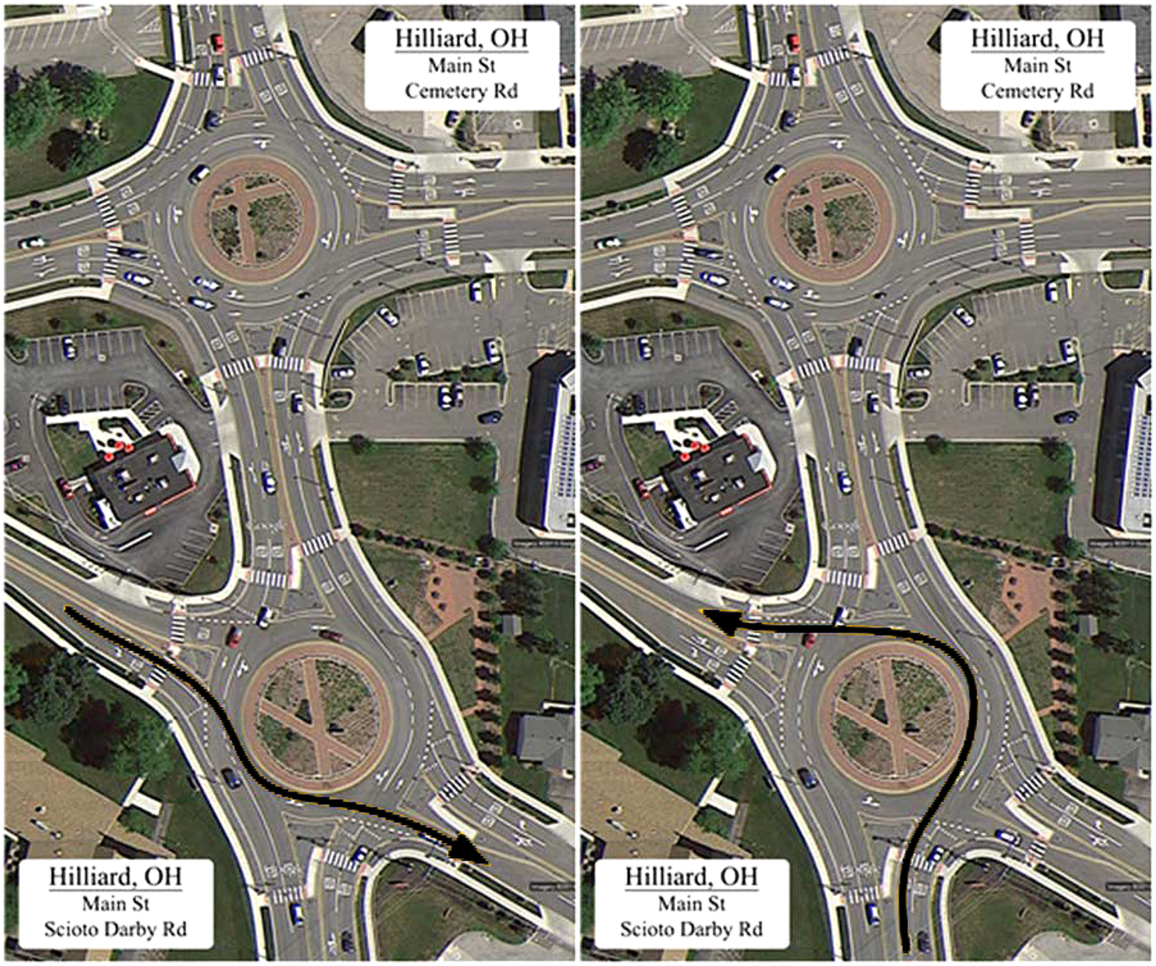

Figure 30. Diagrams. Hilliard, OH, roundabout: Main St. and Scioto Darby St.

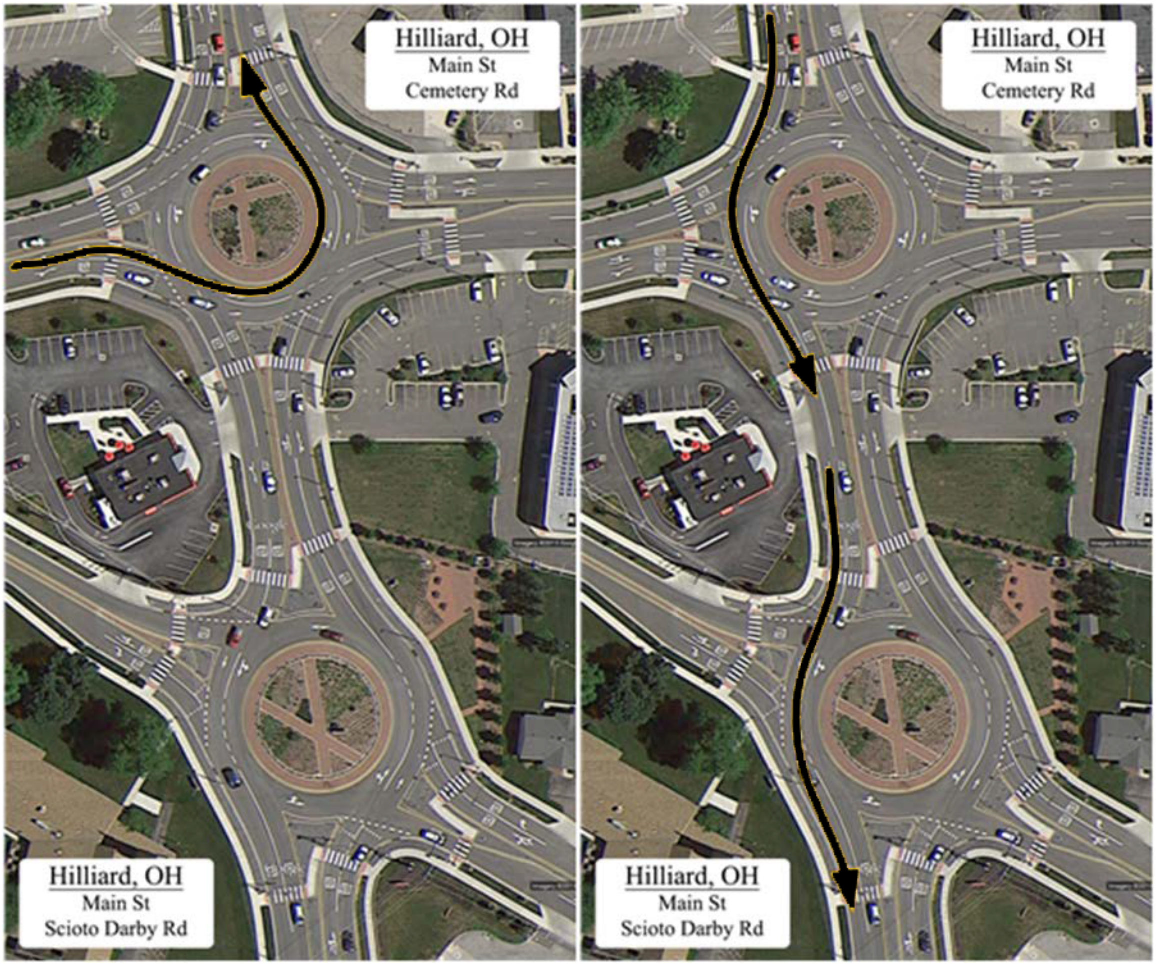

Figure 31. Diagrams. Hilliard, OH, roundabout: Main St. and Cemetery Rd.

Figure 32. Diagrams. Hilliard, OH, roundabout: Main St., Cemetery Rd., and Scioto Darby Rd.

Figure 33. Diagrams. Hilliard, OH, roundabout: Leap Rd. and Anson Dr.

Figure 34. Diagrams. Hilliard, OH, roundabout: Britton Pkwy. and Anson Dr.

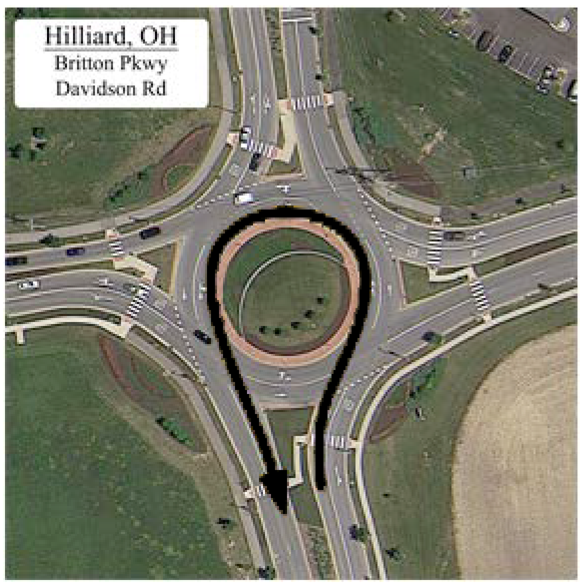

Figure 35. Diagram. Hilliard, OH, roundabout: Britton Pkwy. and Davidson Rd.

APPENDIX B. EYE-TRACKER STUDY MANEUVERS (CARMEL, IN)

The maneuvers performed by the participant drivers at each of the roundabouts in Carmel, IN, are shown in figure 36, figure 37, figure 38, and figure 39.

Figure 36. Diagrams. Carmel, IN, roundabout: Old Meridian St. and Grand Blvd.

Figure 37. Diagrams. Carmel, IN, roundabout: Old Meridian St. and N. Pennsylvania St.

Figure 38. Carmel, IN, roundabout: Clay Terrace Blvd., North Roundabout.

Figure 39. Carmel, IN, roundabout: Clay Terrace Blvd., South Roundabout

APPENDIX C. DETAILED ANALYSIS RESULTS

The explanatory variable Pearson correlations are listed in table 29, table 30, table 31, table 32, and table 33.

Table 29. Explanatory variable Pearson correlation table for all locations.

All Locations	EXIT	LANE	ISLAND	DIA	RAD	OFF	ANG	REFW	CROSSW	SLP
EXIT	1.0000									
LANE	-0.0538	1.0000								
ISLAND	0.0000	0.0000	1.0000							
DIA	0.0000	0.4054*	0.0000	1.0000						
RAD	0.4060*	-0.0318	0.0000	-0.2422*	1.0000					
OFF	-0.0474	0.3339*	0.0000	-0.0556	0.0217	1.0000				
ANG	0.0000	0.0000	0.0187	0.0000	0.0000	0.0000	1.0000			
REFW	0.0000	-0.0605	0.0000	-0.2565*	0.4982*	-0.0091	0.0000	1.0000		
CROSSW	0.0000	0.4731*	0.0000	0.3089*	-0.1464**	-0.0312	0.0000	-0.3336*	1.0000	
SLP	0.0000	-0.0274	0.0000	0.3894*	-0.2433*	-0.1213	0.0000	-0.3326*	0.4030*	1.0000

*$p<0.05$, **$p<0.10$

Table 30. Explanatory variable Pearson correlation table for entry, single-lane locations.

Entry, 1-Lane	ISLAND	DIA	RAD	OFF	OFF30	OFF50	ANG	REFW	CROSSW	SLP
ISLAND	1.0000									
DIA	0.0000	1.0000								
RAD	0.0000	-0.1788	1.0000							
OFF	0.0000	-0.0497	0.1224	1.0000						
OFF30	0.0000	-0.1063	-0.0112	-0.7939*	1.0000					
OFF50	0.0000	-0.0507	-0.1978	0.4991*	-0.2623**	1.0000				
ANG	-0.1862	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000			
REFW	0.0000	0.6972*	0.6972*	0.1735	0.0807	-0.0948	0.0000	1.0000		
CROSSW	0.0000	-0.2947**	-0.2947**	-0.2201	-0.2189	0.2631**	0.0000	-0.3927*	1.0000	
SLP	0.0000	0.1818	-0.3760*	-0.1503	-0.2075	-0.1491	0.0000	-0.4610*	0.8024*	1.0000

*$p<0.05$, **$p<0.10$

Table 31. Explanatory variable Pearson correlation table for entry, two-lane locations.

Entry, 2-Lane	ISLAND	DIA	RAD	OFF	OFF30	OFF50	ANG	REFW	CROSSW	SLP
ISLAND	1.0000									
DIA	0.0000	1.0000								
RAD	0.0000	-0.6017*	1.0000							
OFF	0.0000	-0.3737*	0.0772	1.0000						
OFF30	0.0000	0.5739*	-0.2741	-0.4233*	1.0000					
OFF50	0.0000	-0.7011*	0.3674*	0.8427*	-0.3721*	1.0000				
ANG	0.3415**	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000			
REFW	0.0000	0.0090	0.0090	-0.2426	-0.0421	-0.2260	0.0000	1.0000		
CROSSW	0.0000	-0.1832	-0.1832	-0.2631	-0.0527	-0.5606*	0.0000	-0.2822	1.0000	
SLP	0.0000	-0.4589*	-0.4589*	-0.0630	0.7125*	-0.2437	0.0000	-0.0118	-0.0266	1.0000

*$p<0.05$, **$p<0.10$

Table 32. Explanatory variable Pearson correlation table for exit, single-lane locations.

Exit, 1-Lane	ISLAND	DIA	RAD	OFF	OFF30	OFF50	ANG	REFW	CROSSW	SLP
ISLAND	1.0000									
DIA	0.0000	1.0000								
RAD	0.0000	-0.3593*	1.0000							
OFF	0.0000	-0.1149	0.1610	1.0000						
OFF30	0.0000	0.0690	-0.3895*	-0.7777*	1.0000					
OFF50	0.0000	0.0931	-0.1095	0.6725*	-0.3568*	1.0000				
ANG	0.3214*	0.0000	0.0000	0.0000	0.000	0.0000	1.0000			
REFW	0.0000	-0.2863*	0.6900*	0.0729	-0.4519*	-0.1549	0.0000	1.0000		
CROSSW	0.0000	0.0185	-0.2247	-0.1954	0.2501**	-0.4210*	0.0000	-0.3926*	1.0000	
SLP	0.0000	0.2818**	-0.2007	-0.2095	0.2390	-0.2132	0.0000	-0.3833*	0.7367*	1.0000

*$p<0.05$, **$p<0.10$

Table 33. Explanatory variable Pearson correlation table for exit, single-lane locations.

Exit, 2-Lane	ISLAND	DIA	RAD	OFF	OFF30	OFF50	ANG	REFW	CROSSW	SLP
ISLAND	1.0000									
DIA	0.0000	1.0000								
RAD	0.0000	-0.0057	1.0000							
OFF	0.0000	-0.3807**	-0.2088	1.0000						
OFF30	0.0000	0.6100*	0.2691	-0.5970*	1.0000					
OFF50	0.0000	-0.4761*	-0.4036*	0.8015*	-0.4000*	1.0000				
ANG	0.0360	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000			
REFW	0.0000	-0.1554	0.2173	-0.1221	-0.0877	-0.3216**	0.0000	1.0000		
CROSSW	0.0000	0.4467*	0.0201	-0.2756	0.0224	-0.3696**	0.0000	-0.2718	1.0000	
SLP	0.0000	0.7886*	-0.3139	-0.1029	0.6500*	-0.0500	0.0000	-0.2339	0.0224	1.0000

*$p<0.05$, **$p<0.10$

APPENDIX D. EXPLORATORY STATISTICAL ANALYSIS: PART 1

The results of the Stata® multivariable linear regression model development for all locations are included in table 34, table 35, table 36, table 37, table 38, table 39, table 40, and table 41. All approach and lane number combinations were modeled together. The parameter significance level is indicated by superscripted asterisks. This table shows that factors entry and exit (EXIT), number of lanes (LANE), pedestrian crossing starting point (ISLAND), fastest path radius (RAD), and pedestrian refuge width (REFW) are significant in the model with p-value<0.05 and that inscribed diameter (DIA) is significant to the model with p-value<0.10. The adjusted R^2 value is 0.53.

Table 34. Results of multivariable linear regression for all locations.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
EXIT	-11.639	1.462	0.000*	-14.530	-8.748
LANE	-4.775	1.941	0.015*	-8.612	-0.939
ISLAND	7.107	1.278	0.000*	4.579	9.634
DIA	-0.053	0.032	0.097**	-0.116	0.010
RAD	-0.039	0.018	0.028*	-0.074	-0.004
OFF	-0.053	0.050	0.287	-0.152	0.045
ANG	-0.051	0.083	0.542	-0.214	0.113
VOL	0.005	0.004	0.163	-0.002	0.013
REFW	0.519	0.156	0.001*	0.211	0.826
CROSSW	-0.454	0.788	0.566	-2.013	1.105
SLP	0.917	1.756	0.602	-2.554	4.388
Constant	29.545	9.301	0.002	11.157	47.934

*p<0.05, **p<0.10

Where:

EXIT = exit or entry crosswalk.
LANE = number of lanes at crosswalk.
CPT = pedestrian crossing starting point.
DIA = inscribed diameter of roundabout in feet.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk distance from circulatory roadway.
ANG = corrected crosswalk angle in degrees, rounded to nearest 10°.
REFW = pedestrian refuge width.
CROSSW = crosswalk width.
VOL = traffic volume- number of circulating vehicles per hour.
SLP = slip lane presence.
YIELDR = weighted yielding rate.

Table 35. Probability, R-squared, and adjusted R-squared values for one- and two-lane entry crosswalks.

Item	Value
Prob > F	0.000
R2	0.567
Adj. R2	0.533

Table 36 presents separate models based on crosswalk at entry/exit and number of lanes. The factor pedestrian crossing starting point (ISLAND) is significant with *p*-value<0.05 in all the models except "Exit, 1-Lane," where presence of a slip lane (SLP) is the only significant factor with *p*-value<0.10. Pedestrian crossing starting point (ISLAND) is the only significant factor in the "Exit, 2-Lane" model.

Crosswalk distance from circulatory roadway (OFF) was significant in both crosswalk at "Entry" models with *p*-value<0.05. Additional significant factors in the "Entry, 1-Lane" model were circulating volume (VOL) (*p*<0.05) and pedestrian refuge width (REFW) (*p*<0.10), while additional significant factors in the "Entry, 2-Lane" model with *p*-value<0.05 were inscribed diameter (DIA), crosswalk width (CROSSW), and the presence of a slip lane (SLP). Pedestrian refuge width (REFW) was also significant in the "Entry, 2-Lane" model with *p*-value<0.10. The "Entry" models have relatively high adjusted R^2 values (0.59 for single-lane and 0.61 for two-lane), while the "Exit" models have relatively low adjusted R^2 values (0.12 for single-lane and 0.15 for two-lane).

Table 36. Results of multivariable linear regression by approach and number of lanes for one-lane entry crosswalks.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	16.440	2.896	0.000*	10.555	22.324
DIA	-0.007	0.072	0.928	-0.154	0.141
RAD	-0.154	0.086	0.082**	-0.329	-0.021
OFF	-0.711	0.192	0.001*	-1.100	-0.321
ANG	0.149	0.204	0.470	-0.266	0.565
VOL	0.056	0.016	0.001*	0.024	0.087
REFW	0.568	0.332	0.096**	-0.107	1.244
CROSSW	0.199	2.745	0.943	-5.379	5.777
SLP	-5.638	6.395	0.384	-18.634	7.359
Constant	25.995	29.707	0.388	-34.376	86.367

*p<0.05, **p<0.10

Table 37. Results of multivariable linear regression by approach and number of lanes for two-lane entry crosswalks.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	6.795	1.490	0.000*	3.686	9.904
DIA	-0.267	0.110	0.024*	-0.495	-0.039
RAD	-0.014	0.031	0.666	-0.078	0.050
OFF	-0.126	0.053	0.026*	-0.236	-0.017
ANG	-0.106	0.105	0.323	-0.324	0.112
VOL	-0.0004	0.004	0.926	-0.008	0.008
REFW	0.559	0.299	0.075**	-0.061	1.179
CROSSW	3.125	1.145	0.012*	0.750	5.500
SLP	15.957	4.148	0.001*	7.354	24.559
Constant	17.542	17.144	0.317	-18.013	53.096

$^*p<0.05$, $^{**}p<0.10$

Where:

EXIT = exit or entry crosswalk.
LANE = number of lanes at crosswalk.
CPT = pedestrian crossing starting point.
DIA = inscribed diameter of roundabout in feet.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk offset in feet.
ANG = corrected crosswalk angle in degrees, rounded to nearest 10°.
REFW = pedestrian refuge width.
CROSSW = crosswalk width.
VOL = traffic volume, number of circulating vehicles per hour.
SLP = slip lane presence.
YIELDR = weighted yielding rate.

Table 38. Probability, R-squared, and adjusted R-squared values for one- and two-lane entry crosswalks.

Item	YIELDR-Entry, 1-Lane	YIELDR-Entry, 2-Lane
Prob > F	0.000	0.000
R2	0.673	0.725
Adj. R2	0.587	0.613

Table 39. Results of multivariable linear regression by approach and number of lanes for one-lane exit crosswalks.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	1.670	1.116	0.143	-0.588	3.929
DIA	-0.022	0.025	0.396	-0.072	0.029
RAD	-0.011	0.013	0.388	-0.036	0.014
OFF	0.077	0.056	0.179	-0.037	0.191
ANG	0.006	0.056	0.916	-0.107	0.119
VOL	0.002	0.004	0.594	-0.006	0.011
REFW	0.114	0.128	0.378	-0.146	0.374
CROSSW	1.376	0.853	0.115	-0.351	3.104
SLP	-3.730	1.944	0.063**	-7.666	0.206
Constant	-6.928	10.291	0.505	-27.762	13.906

**$p < 0.10$

Table 40. Results of multivariable linear regression by approach and number of lanes for two-lane exit crosswalks.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	1.971	0.803	0.024*	0.285	3.658
DIA	-0.003	0.057	0.962	-0.123	0.118
RAD	-0.008	0.014	0.579	-0.038	0.022
OFF	0.026	0.025	0.322	-0.028	0.079
ANG	0.100	0.101	0.336	-0.113	0.313
VOL	-0.003	0.003	0.280	-0.009	0.003
REFW	0.005	0.175	0.978	-0.363	0.373
CROSSW	-0.093	0.669	0.891	-1.497	1.312
SLP	0.032	2.487	0.990	-5.192	5.257
Constant	4.658	7.086	0.519	10.228	19.545

*$p < 0.05$

Where:

EXIT = exit or entry crosswalk.
LANE = number of lanes at crosswalk.
CPT = pedestrian crossing starting point.
DIA = inscribed diameter of roundabout in feet.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk offset in feet.
ANG = corrected crosswalk angle in degrees, rounded to nearest 10°.
REFW = pedestrian refuge width.

CROSSW = crosswalk width.
VOL = traffic volume, number of circulating vehicles per hour.
SLP = slip lane presence.
YIELDR = weighted yielding rate.

Table 41. Probability, R-squared, and adjusted R-squared values for one- and two-lane exit crosswalks.

Item	YIELDR-Exit, 1-Lane	YIELDR-Exit, 2-Lane
Prob > F	0.123	0.217
R2	0.287	0.431
Adj. R2	0.119	0.146

APPENDIX E. EXPLORATORY STATISTICAL ANALYSIS: PART 2

For all locations and for crosswalk at entry/exit and lane number configuration, the data were examined for strong correlations and significant linear relationships between the independent variables. Strong collinearity effects were additionally corroborated by performing VIF (variance inflation factor) tests in Stata®. Any two explanatory variables found to be significantly linearly related were not included in the same model. Two variables for crosswalk distance to circulatory roadway were employed for each approach and lane number configuration: crosswalk distance to circulatory roadway in ft (OFF) and crosswalk distance to circulatory roadway broken out into three categories: *short*, or less than 9.1 m (30 ft); *medium*, or greater than or equal to 9.1 m but less than 15 m (50 ft); and *long*, or greater than or equal to 15 m (50 ft), dummy coded as OFF30 and OFF50. Circulating volume (VOL) was not included in this analysis.

Final models were generated using manual selection informed by the previous analysis steps. While the team also used some automated selection tools (i.e., forward selection based on an inclusion threshold of variables at $p<0.10$), manual selection was preferred because it (a) allows for symmetry of models across different conditions (e.g., entry and exit) and (b) allows a focus on variables that are readily available to an analyst and have established practical application in roundabout design.

The final proposed models take into account practical significance and the feasibility of implementing variables in practice, as opposed to being motivated exclusively by statistical fit. Manually selected models for "All," "Entry, 1-Lane," "Entry, 2-Lane," "Exit, 1-Lane," and "Exit, 2-Lane" locations include ISLAND, OFF, and RAD as explanatory variables. Additional manually selected models were generated for "Entry, 1-Lane," "Entry, 2-Lane," "Exit, 1-Lane," and "Exit, 2-Lane" locations that include the categorical distance from circulatory roadway (OFF30 and OFF50) as explanatory variables.

A reduced model for "All" locations with weighted yielding rate as the dependent variable is also provided based on a forward selection algorithm with threshold $p<0.10$ in Stata®.

The p-values associated with the F-values for the final and reduced models are significant at <0.05, suggesting that the explanatory variables reliably predict the yielding rate in all the final and reduced models.

For "All" locations, significant linear relationships and strong significant correlations were found between:

- Number of lanes at crosswalk (LANE) and Inscribed diameter (DIA).
- Number of lanes at crosswalk (LANE) and Crosswalk offset (OFF).
- Number of lanes at crosswalk (LANE) and Crosswalk width (CROSSW).
- Crosswalk width (CROSSW) and Pedestrian refuge width (REFW).
- Inscribed diameter (DIA) and Pedestrian refuge width (REFW).

- Crosswalk width (CROSSW) and Presence of slip lane (SLP).
- Pedestrian refuge width (REFW) and Presence of slip lane (SLP).
- Pedestrian refuge width (REFW) and Fastest path radius (RAD).
- Fastest path radius (RAD) and Presence of slip lane (SLP).
- Inscribed diameter (DIA) and Presence of slip lane (SLP).
- Fastest path radius (RAD) and Inscribed diameter (DIA).

The full model for all locations indicates that crosswalk at entry/exit (EXIT), number of lanes (LANE), and pedestrian crossing starting point (ISLAND) are significant explanatory factors ($p<0.05$) for driver yielding behavior across the 10 roundabout sites (table 26). These factors remain significant at the same level in the reduced model for all locations (table 27). The reduced model controls for collinearity and estimates that the yielding rate decreases by 13.3 percent for a crossing at the exit, decreases by 6.6 percent for each additional lane, and increases by 7.1 percent for a crossing from the island. The adjusted R^2 values are the same (0.48) for both the full and reduced models for all locations. The full model for all locations is provided in table 26, and the reduced model for all locations is provided in table 27. Both tables can be found in the body of the report.

An ANOVA test was performed on the reduced model for all locations to determine what proportion of the variation in the set of observations was accounted for by the factors entry/exit, number of lanes, and pedestrian crossing starting point. Due to the presence of heteroscedasticity in the residual plot, a log transformation was executed on the response variable, YIELDR, in order to meet the assumptions of the ANOVA test. The Mean Squares and F-value results provides an estimate of which factors account for more or less variation in the model's observations, and the adjusted R^2 value provides an estimate of how much variability in the data is accounted for by the model, as visualized in figure 19, which can be found in the body of the report. It appears that the three factors, crosswalk at entry/exit (EXIT), pedestrian crossing starting point (ISLAND), and number of lanes at crosswalk (LANE) account for nearly half of the variability in the data, with rest of the variability not explained by the model.

Final manually selected models for each approach and lane number configuration are provided in table 42, table 43, table 44, table 45, table 46, and table 47 for crosswalk distance as a continuous explanatory variable. Table 48, table 49, table 50, table 51, table 52, and table 53 provide the final manually selected models for crosswalk distance as a categorical explanatory variable, and a discussion of each combination follows the tables.

Table 42. Results of multivariable linear regression by approach and number of lanes for one-lane entry crosswalks with continuous crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	16.045	3.521	0.000*	8.929	23.162
OFF	-0.251	0.197	0.210	-0.649	0.147
RAD	0.158	0.063	0.017*	0.030	0.285
Constant	2.790	9.198	0.763	-15.800	21.380

*$p<0.05$

Table 43. Results of multivariable linear regression by approach and number of lanes for two-lane entry crosswalks with continuous crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	1.815	0.000*	3.594	11.031	1.815
OFF	0.052	0.092**	-0.197	0.016	0.052
RAD	0.030	0.410	-0.087	0.036	0.030
Constant	4.514	0.005	4.479	22.972	4.514

*p<0.05, **p<0.10

Where:

ISLAND = pedestrian crossing starting point.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk distance from circulatory roadway.
YIELDR = weighted yielding rate.

Table 44. Probability, R-squared, and adjusted R-squared values for one- and two-lane entry crosswalks with continuous crosswalk distance as an explanatory variable.

Item	YIELDR-Entry, 1-Lane	YIELDR-Entry, 2-Lane
Prob > F	0.0001	0.002
R2	0.411	0.419
Adj. R2	0.367	0.357

Table 45. Results of multivariable linear regression by approach and number of lanes for one-lane exit crosswalks with continuous crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	1.708	1.100	0.128	-0.509	3.926
OFF	0.084	0.057	0.145	-0.030	0.199
RAD	0.004	0.009	0.648	-0.014	0.022
Constant	0.0372	2.218	0.868	-4.099	4.842

Table 46. Results of multivariable linear regression by approach and number of lanes for two-lane exit crosswalks with continuous crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	2.00	0.752	0.014*	0.448	3.552
OFF	0.039	0.020	0.066**	-0.003	0.081
RAD	-0.007	0.011	0.506	-0.030	0.015
Constant	1.219	2.035	0.555	-2.981	5.418

*$p<0.05$, **$p<0.10$

Where:

ISLAND = pedestrian crossing starting point.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk distance from circulatory roadway.
YIELDR = weighted yielding rate.

Table 47. Probability, R-squared, and adjusted R-squared values for one- and two-lane exit crosswalks with categorical crosswalk distance as an explanatory variable.

Item	YIELDR-Exit, 1-Lane	YIELDR-Exit, 2-Lane
Prob > F	0.178	0.019
R2	0.105	0.333
Adj. R2	0.044	0.250

Table 48. Results of multivariable linear regression by approach and number of lanes for one-lane entry crosswalks with categorical crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	16.045	3.628	0.000*	8.708	23.383
OFF30	0.498	3.967	0.901	-7.526	8.522
OFF50	-3.582	9.358	0.704	-22.510	15.346
RAD	0.144	0.068	0.041*	0.006	0.283
Constant	-3.427	9.320	0.715	-22.279	15.425

*p<0.05

Table 49. Results of multivariable linear regression by approach and number of lanes for two-lane entry crosswalks with categorical crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	7.313	1.575	0.000*	4.086	10.539
OFF30	7.071	2.174	0.003*	2.618	11.525
OFF50	-1.095	1.753	0.537	-4.686	2.495
Constant	5.772	1.428	0.000	2.848	8.697

*p<0.05

Where:

ISLAND = pedestrian crossing starting point.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk distance from circulatory roadway.
YIELDR = weighted yielding rate.

Table 50. Probability, R-squared, and adjusted R-squared values for one- and two-lane entry crosswalks with categorical crosswalk distance as an explanatory variable.

Item	YIELDR-Entry, 1-Lane	YIELDR-Entry, 2-Lane
Prob > F	0.0005	0.000
R2	0.391	0.563
Adj. R2	0.328	0.516

Table 51. Results of multivariable linear regression by approach and number of lanes for one-lane exit crosswalks with categorical crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	1.708	1.074	0.119	-0.458	3.915
OFF30	-3.058	1.315	0.025*	-5.710	-0.340
OFF50	-1.745	2.173	0.426	-6.127	3.064
RAD	-0.004	0.010	0.698	-0.023	0.001
Constant	6.188	2.294	0.010	1.562	10.814

*p<0.05

Table 52. Results of multivariable linear regression by approach and number of lanes for two-lane exit crosswalks with categorical crosswalk distance as an explanatory variable.

Variable	Regression Coefficient	Std Error	*p*	95 Percent Confidence Interval, Lower	95 Percent Confidence Interval, Upper
ISLAND	2.000	0.753	0.014*	0.446	3.554
OFF30	-0.667	0.909	0.471	-2.544	1.210
OFF50	1.458	0.909	0.122	-0.002	2.836
Constant	1.417	0.688	0.050	-0.002	2.836

*p<0.05

Where:

ISLAND = pedestrian crossing starting point.
RAD = fastest path radius of roundabout in feet, nearest 10 ft.
OFF = crosswalk distance from circulatory roadway.
YIELDR = weighted yielding rate.

Table 53. Probability, R-squared, and adjusted R-squared values for one- and two-lane exit crosswalks with categorical crosswalk distance as an explanatory variable.

Item	YIELDR-Exit, 1-Lane	YIELDR-Exit, 2-Lane
Prob > F	0.092	0.020
R2	0.166	0.331
Adj. R2	0.089	0.247

Entry 1-Lane Results

For "Entry, 1-Lane" locations, significant linear relationships and strong significant correlations were found between:

- Crosswalk width (CROSSW) and Pedestrian refuge width (REFW).
- Inscribed diameter (DIA) and Pedestrian refuge width (REFW).
- Crosswalk width (CROSSW) and Presence of slip lane (SLP).
- Pedestrian refuge width (REFW) and Presence of slip lane (SLP).
- Pedestrian refuge width (REFW) and Fastest path radius (RAD).
- Fastest path radius (RAD) and Presence of slip lane (SLP).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Crosswalk width (CROSSW).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Pedestrian refuge width (REFWID).

Controlling for the effects of collinearity, both manually selected models for "Entry, 1-Lane" indicated that pedestrian crossing starting point (ISLAND) and fastest path radius (RAD) were significant explanatory factors (p<0.05) for driver yielding behavior at single-lane locations with crosswalk at entry sites. Crosswalk distance to circulatory roadway was not a significant explanatory factor in either model for the single-lane entry at the selected confidence levels. Both models estimated that the yielding rate for crossings from the island was 16.0 percent higher than for crossings from the curb. The yielding rate was also estimated to increase by 0.1 percent for every 3.0 m (10 ft) increase in the fastest path radius for both models. The adjusted R^2 values are similar for both the model with a continuous offset variable (0.37) and for the model with a categorical offset variable (0.33) for one-lane entry sites. The "Entry, 1-Lane" results provide no meaningful conclusion about the relationship between driver yielding and crosswalk offset.

Entry 2-Lane Results

For "Entry, 2-Lane" locations, significant linear relationships and strong significant correlations were found between:

- Crosswalk width (CROSSW) and Inscribed diameter (DIA).
- Fastest path radius (RAD) and Inscribed diameter (DIA).
- Fastest path radius (RAD) and Presence of slip lane (SLP).
- Inscribed diameter (DIA) and Presence of slip lane (SLP).
- Crosswalk offset (OFF) and Inscribed diameter (DIA).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Presence of slip lane (SLP).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Inscribed diameter (DIA).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Crosswalk width (CROSSW).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Inscribed diameter (DIA).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Fastest path radius (RAD).

Controlling for the effects of collinearity, both manually selected models for "Entry, 2-Lane" indicate that pedestrian crossing starting point (ISLAND) and crosswalk distance from circulatory roadway (OFF and OFF30) are significant explanatory factors ($p<0.05$) for driver yielding behavior at two-lane entry sites. Both models estimated that the yielding rate for crossings from the island is 7.3 percent higher than for crossings from the curb. The yielding rate was estimated to decrease by 0.1 percent for each 0.3 m (1 ft) increase in crosswalk offset in the model using the continuous offset distance variable. In the alternate model, the yielding rate was estimated to be 7.6 percent higher for crosswalk distances less than 9.1 m (30 ft) compared to crosswalk distances between 9.1 m (30 ft) and 15 m (50 ft). The adjusted R^2 value is lower for the model with a continuous crosswalk distance from circulatory variable (0.36) than for the model with a categorical crosswalk distance variable (0.56) for two-lane, entry sites. The "Entry, 2-Lane" results provide no meaningful conclusion about the relationship between driver yielding and crosswalk offset.

Exit 1-Lane Results

For "Exit, 1-Lane" locations, significant linear relationships and strong significant correlations were found between:

- Fastest path radius (RAD) and Inscribed diameter (DIA).
- Inscribed diameter (DIA) and Presence of slip lane (SLP).

- Crosswalk width (CROSSW) and Pedestrian refuge width (REFW).
- Inscribed diameter (DIA) and Pedestrian refuge width (REFW).
- Crosswalk width (CROSSW) and Presence of slip lane (SLP).
- Pedestrian refuge width (REFW) and Presence of slip lane (SLP).
- Crosswalk distance to circulatory roadway ≥15 m (50 ft) (OFF50) and Crosswalk width (CROSSW).

Controlling for the effects of collinearity, both manually selected models for "Exit, 1-Lane" indicated that pedestrian crossing starting point (ISLAND) and fastest path radius (RAD) were not significant explanatory factors for driver yielding behavior at one-lane exit sites. The continuous crosswalk distance variable (OFF) was also not found to be a significant explanatory factor for driver yielding behavior at one-lane exit sites. However, when evaluating offset as a categorical variable, crosswalk distance <9.1 m (30 ft) (OFF30) was a significant explanatory factor ($p<0.05$). The model estimated the yielding rate to be 3.1 percent lower for crosswalk distances that are less than 9.1 m (30 ft) compared to crosswalk distances between 9.1 m (30 ft) and 15 m (50 ft). The adjusted R^2 values are similar for both the model with a continuous offset variable (0.04) and for the model with a categorical offset variable (0.09) for one-lane exit sites. The adjusted R^2 values suggest that 90 percent to 95 percent of the variation in the data is unaccounted for by the models. The "Exit, 1-Lane" results provide no meaningful conclusion about the relationship between driver yielding and crosswalk offset.

Exit 2-Lane Results

For "Exit, 2-Lane" locations, significant linear relationships and strong significant correlations were found between:

- Crosswalk width (CROSSW) and Inscribed diameter (DIA).
- Inscribed diameter (DIA) and Presence of slip lane (SLP).
- Crosswalk distance from circulatory roadway (OFF) and Inscribed diameter (DIA).
- Crosswalk distance from circulatory roadway rounded (OFF) and Crosswalk width (CROSSW).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Fastest path radius (RAD).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Crosswalk width (CROSSW).
- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Pedestrian refuge width (REFW).

- Crosswalk distance from circulatory roadway ≥15 m (50 ft) (OFF50) and Inscribed diameter (DIA).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Presence of slip lane (SLP).
- Crosswalk distance from circulatory roadway <9.1 m (30 ft) (OFF30) and Inscribed diameter (DIA).

Controlling for the effects of collinearity, both manually selected models for "Exit, 2-Lane" indicated that pedestrian crossing starting point (ISLAND) was a significant explanatory factor ($p<0.05$) for driver yielding behavior at two-lane exit sites. Crosswalk distance (OFF) was also significant at $p<0.10$. Both models estimated that the yielding rate for crossings from the island was 2.0 percent higher than for crossings from the curb. The yielding rate was estimated to increase by 0.04 percent for each 1-ft increase in crosswalk distance. The adjusted R^2 value is 0.25 for both models for two-lane exit sites. The adjusted R^2 values suggest that 75 percent of the variation in the data is unaccounted for by the models. The "Exit, 2-Lane" results provide no meaningful conclusion about the relationship between driver yielding and crosswalk distance.

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