Investigation of Pedestrian/Bicyclist Risk in Minnesota Roundabout Crossings

John Hourdos, Principal Investigator
Minnesota Traffic Observatory
Department of Civil Engineering
University of Minnesota

September 2012

Your Destination...Our Priority

Technical Report Documentation Page

1. Report No. MN/RC 2012-28	2.	3. Recipients Accession No.	
4. Title and Subtitle Investigation of Pedestrian/Bicyclist Risk in Minnesota Roundabout Crossings		5. Report Date September 2012	
		6.	
7. Author(s) John Hourdos, Veronica Richfield, and Melissa Shauer		8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Minnesota Minnesota Traffic Observatory Department of Civil Engineering 500 Pillsbury Drive, SE Minneapolis, MN 55455		10. Project/Task/Work Unit No. CTS Project #2010099	
		11. Contract (C) or Grant (G) No. (C) 89261 (WO) 194	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services 395 John Ireland Boulevard, MS 330 St. Paul, MN 55155		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://www.lrrb.org/pdf/201228.pdf			

16. Abstract (Limit: 250 words)

Many cities in the United States are installing roundabouts instead of traditional intersections, due to evidence that roundabouts dramatically reduce fatal and severe injury crashes compared to traditional signalized intersections. However, the impact on pedestrian safety is not clear. This project was developed to investigate pedestrian accessibility in Minnesota urban roundabouts, addressing complaints from pedestrians regarding difficulties in crossing and safety. The methodology followed in this ongoing research is typical of other observational studies. A sufficiently large number of observations on the interactions between pedestrians or bicycles (peds/bikes) and vehicles at two modern urban roundabouts in the Twin Cities of Minneapolis and St. Paul in Minnesota were collected and reduced. These observations have supported a two phased analysis. Phase 1 involved the extraction of general information describing the crossing event, such as who yielded, the location of the crossing, or the number of subjects involved. Phase 2 looked deeper into these factors by considering the conditions inside the roundabout before the vehicle proceeds to the crossing and meets with the ped/bike. The results presented, although containing no surprises, do highlight and categorize the existence of friction between pedestrians and drivers at roundabout crossings. Also the identification of factors affecting driver yield behavior and pedestrian wait time do offer good background for modeling such interactions.

17. Document Analysis/Descriptors Roundabouts, Pedestrians, Crosswalks		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 78	22. Price

Investigation of Pedestrian/Bicyclist Risk in Minnesota Roundabout Crossings

Final Report

Prepared by:

John Hourdos
Veronica Richfield
Melissa Shauer

Minnesota Traffic Observatory
Department of Civil Engineering
University of Minnesota

September 2012

Acknowledgements

Table of Contents

Appendix A: Site Selection Survey

List of Tables

List of Figures

Executive Summary

Roundabouts are new to the USA which generates various issues for drivers and pedestrians. Specifically, there are very strong feelings and concerns regarding the accessibility and safety of modern urban roundabouts for pedestrians. There is a need to assess the nature and magnitude of the problems pedestrians experience crossing existing roundabouts and, if necessary, provide better guidelines for design or treatments of new and existing roundabouts. The research project described in this report focused on the experience of pedestrians and bicyclists utilizing crossings on roundabouts in the Twin Cities by investigating the conditions that could affect the yielding behavior of drivers. Pedestrians and bicyclists were observed while using the roundabout crossings at two study sites. Driver and pedestrian behavior as well as parameters involving the operations of the roundabouts and their vehicular traffic were collected. The observations were collected with the help of specialized video surveillance equipment developed by the Minnesota Traffic Observatory (MTO) of the University of Minnesota. The study design followed an observational statistical and causal relations analysis methodology.

The results, although containing no surprises, do highlight the existence of friction between pedestrians and drivers at roundabout crossings. The law in Minnesota states that all vehicles must yield for pedestrians in the crossing. From the results we can see that the location where crossing starts and the direction the vehicle is driving are important determinants of drivers' yielding behavior. Specifically, a pedestrian or bicyclist (ped/bike) crossing event that starts in the island has a higher probability for a driver yielding, while when a vehicle is exiting the roundabout there is a lower probability it will yield. The size of the pedestrian group, although not a strong predictor, indicated a tendency for drivers to yield to larger groups. More cases of larger groups are needed to verify this possible effect. In the subcategory analysis utilizing equally-sized cases of pedestrians and bicyclists there was no distinctive effect on the yielding behavior of the drivers.

This research also explored the relationships of several measurements related to the driver experience inside the roundabout with yielding behavior and pedestrian waiting time. Although there was no strong correlation between any of the parameters and the probability of a driver yielding we did notice some interesting trends. For example, vehicles exiting the roundabout that have entered at the immediate upstream entrance turn to have increased probability of yielding, in comparison to vehicles coming from other directions. One can hypothesize that such vehicles have bigger chances noticing the pedestrians even while they are still close to the yield line. The yielding probability decreases if there is a vehicle trying to merge into the roundabout at the entrance next to the exit that the subject vehicle encounters the pedestrian. In this case a reasonable hypothesis is that drivers could get distracted when a moving vehicle enters their trajectory path and do not notice the pedestrians. Finally, the more vehicles inside the roundabout, the lower the probability they would yield to pedestrians.

The delays experienced by pedestrians and bicyclists at the two study roundabouts describe a situation that is much better than the average experience of a pedestrian at a signalized intersection. For the daily traffic (AADT) present at the Richfield roundabout, the typical signalized intersection would have a cycle length of no less than 60 seconds. The typical pedestrian delay at signalized intersection is approximately ½ of the signal cycle. In this case the

average delay would have been 30 seconds as compared to the very conservative 9.04 seconds pedestrians currently experience at the roundabout.

It was the intention of this study to attempt to evaluate the pedestrian experience in roundabout crossings in terms of safety as well as to focus on issues involving pedestrians with disabilities. Indeed, one of the reasons this study went to great lengths to collect long periods of video records and observe tens of thousands of pedestrians and bicyclists using the crossings was so the chances of capturing near-accident events and events involving visually impaired people were maximized. Unfortunately, there were no observations of the latter interacting with traffic, and, although fortunate, among the thousands of crossing events, there were only three cases that can marginally be considered close-calls. The study would have been richer if pedestrian accidents were observed but the presented results do not lose any of their value.

The fact that this study was not able to capture any safety compromising situations or observe the interaction of people with disabilities with traffic neither offers evidence that roundabout crossings are perfectly safe or that visually impaired people have no issues. Indeed, as it pertains to the visually impaired, there are real problems with the safety and comfort of visually impaired individuals at roundabout crossings. Working only with the fact that on the Richfield roundabout driver yielding rate was at best 45%, it is clear that visually impaired individuals cannot assume that drivers see them, are willing to stop, or moving slowly which are common assumptions made on regular signalized intersections with turn-on-red right and permitted left turns. These uncertainties coupled with the other problems reported in the literature form a negative picture regarding the experience of visually impaired individuals on urban roundabout pedestrian crossings. Regardless this experience is not uncommon but similar to their experience in any uncontrolled intersection with similar volumes.

Chapter 1.   Introduction

Roundabouts are new to the USA and this fact generates various issues to drivers and pedestrians. Specifically, to the latter, there are very strong feelings and concerns regarding the accessibility and safety of modern urban roundabouts for pedestrians. In difference, based on the proven benefits to vehicle traffic in terms of safety and efficiency, many cities in the US are installing roundabouts instead of traditional intersections. The evidence shows, when not signalized, roundabouts facilitate higher vehicle flows and generally provide traffic in all directions with virtually no flow interruption in a self-coordinated manner. Additional evidence suggests that roundabouts dramatically reduce the incidence of fatal and severe injury crashes as compared to traditional signalized intersections. Following this general trend, MnDOT and other local governments have constructed several roundabouts in the Twin Cities metro as well as other cities around the state. Although there is no evidence that the roundabouts have not achieved their traffic operations objective, they have generated a significant amount of complaints from pedestrians suggesting difficulties in crossing and reduced safety. Some may suggest that an obvious solution to the pedestrian problems is the installation of traffic signals regulating the crossings. Signalization of roundabouts is discouraged in the United States. The Federal Highway Administration's roundabout informational guide states "roundabouts should never be planned for metering or signalization." However, the guide does concede that "unexpected demand" may require signalization after a roundabout is constructed. Regardless, such a solution may negate the benefits from constructing a roundabout instead of a traditional signalized intersection and it is not certain that it will solve the issue. Roundabouts have not matured yet as a roadway design in which case the long term crash records would offer evidence regarding pedestrian safety and even then the experience of pedestrian use of roundabouts would not be clarified. There is a need to assess the nature and magnitude of the problems pedestrians experience crossing existing roundabouts and, if necessary, provide better guidelines for design or treatments of new and existing roundabouts respectively.

Problem Addressed

The research project described in this report focused on the experience of pedestrians and bicyclists utilizing crossings (Figure 1-1) on roundabouts in the Twin Cities urban area focusing on the investigation of the conditions that could affect the yielding behavior of drivers. Pedestrians and bicyclists were observed while using the roundabout crossings at two study sites while other parameters involving the operations of the roundabouts and their vehicular traffic were also collected.

Figure 1-1 Example Pedestrians Crossing on the Richfield Roundabout

Project Scope and Objectives

The scope of this research project is limited to the collection observations involving pedestrians and bicyclists using crossings on urban modern roundabouts around the Twin Cities metro area. The observations were collected with the help of specialized video surveillance equipment developed by the Minnesota Traffic Observatory (MTO) of the University of Minnesota. The study design followed an observational statistical and causal relations analysis methodology, which leaves open the possibility that other influences on driver and pedestrian behavior may exist confounding the findings presented in this report. To minimize the latter, a robust methodology for reducing the video and extracting as much detail from the events as possible was developed and followed.

Thus the primary objective of the project described in this report was to collect and evaluate the potential influences to driver – pedestrian interactions at roundabout crossings. The findings are discussed and where possible attention is drawn at issues identified. The overall goal is to inform professionals and the public of the pros and cons of roundabout crossings in hope of resolution through refinement of the design standards and better education of the latter.

Report Organization

There are five chapters in this project report. Chapter 1 describes the problem addressed, the scope, and the objectives of the overall research project. Chapter 2 includes a summary of literature relevant to this project. Chapter 3 describes the site selection methodology applied in this project and its results. It also includes a summary of the data collection process used during this project. Chapter 4 describes the data reduction and analysis methodology followed in the study while Chapter 5 presents the study results. Finally, Chapter 6 gives conclusions and recommendations.

Chapter 2.   Literature Review

There is an extensive literature regarding roundabouts (*Rodegerdts et al. 2006)* including publications discussing the issues of pedestrians and blind pedestrians (Inman et al. 2007, Inman et al. 2006, Russell, 2008) on roundabout crossings. Despite this attention, we believe that no adequate progress has been made in answering the important questions. Paraphrased from presentations of the recently concluded NCHRP 3-78A project (TRB, 2008), the important questions regarding blind pedestrians, which we think important to everyone, are the following:

- At what point does pedestrian delay make a site "inaccessible"?
- When does 'risk' (interventions, pull backs, acceptance of 'risky gaps') make a facility inaccessible, or does it?
- When does 'risk' become unacceptable from a safety standpoint? Can you have accessibility and some level of risk? How much?
- Is there a level of drivers' failing to yield to pedestrians that constitutes inaccessibility?
- Using micro-simulation, can results from treatments at a limited number of test sites be reliably 'generalized' to the broader range of site conditions?

Currently there are no warrants for what is "accessible" and, as pointed out in NCHRP 3-78A, "We can't develop a 'warrant' until we understand the factors that have a measurable effect on the various performance conditions upon which the concept is based". The current efforts described in the recent literature, although comprehensive, do not advance this understanding. In general, the available results come from three types of research efforts: observational, modeling (Schroeder et al. 2008, Rouphail et al. 2005), and safety audits (Turner et al. 2007). Safety audits in the US are hampered from the limited number and age of roundabouts. Pedestrian and bicycle (ped/bike) crash frequencies are in general low and specifically on roundabouts too low to be reliably diagnostic. Modeling efforts are either based on assumptions or are founded on results from observational studies. Observational studies are the only credible efforts that would allow an understanding of the factors affecting roundabout pedestrian accessibility. In this area there are three seminal efforts, two human factor studies involving test subjects (blind and sighted) and the major NCHRP 3-65 (Rodegerdts et al. 2006) study of roundabouts in the US.

Ashmead et al. (2005) studied pedestrian behavior at roundabouts. The study involved six blind and six sighted pedestrians negotiating crossings at a two-lane urban roundabout in Tennessee. Each pedestrian performed six round-trip crossings of one leg of the roundabout (i.e. from one side to the splitter island, island to the far side, and back again) during a high volume period (approximately 2300 vehicles per hour), and six crossings during a low volume period (approximately 1000 vph). The blind pedestrians were monitored by certified Orientation and Mobility (OM) Specialists who acted as spotters and provided guidance not related to gap selection. The study found that blind participants took more than three times as long to select a gap for crossing and selected gaps nearly twice as long as the sighted participants. Additionally, only one of the crossings caused a self-initiated intervention (the individual began crossing, stopped, and returned to the curb) among the sighted pedestrians. However, among the blind participants, 15 crossings were self-aborted and 10 required experimenter-intervention by the OM spotter. Five of the six blind participants had such an intervention and, in post-experiment interviews, reported that they were unaware of the potential danger. The study noted that the

sighted participants often selected gaps which were unsafe unless an approaching vehicle decelerated. The sighted pedestrians tended to establish visual/non-verbal communication with the approaching driver in order to interpret whether they could safely cross, the driver would slow and give way, etc. As a result, the study notes, any increase in yield rates for drivers has little impact for blind pedestrians unless accompanied by a method by which to indicate that a yield has occurred.

Inman et al. (2006) conducted a double study with subjects observed in a controlled 2-lane location and on a normal 2-lane roundabout, both focusing on the effectiveness of sound strip treatment. The sound strips consisted of PVC pipe segments adhered to the pavement using asphalt tape. The strips were placed on the roadway so that a passing vehicle would encounter two prior to the yield-line for the crosswalk and one at the crosswalk so that a blind pedestrian could distinguish relative position from the pattern of sounds. Seven pedestrians with extremely limited or no vision participated in the study. At the controlled location, two crossings were tested: one with no treatment (control) and one with sound strips added (treated). Each participant stood at the crosswalk as vehicles passed by according to 18 randomly ordered, pre-determined scripts. Participants gave hand signals to indicate when they detected vehicles approaching or departing. On the controlled experiment, sound strip treatment increased the number of correct detections (from a mean of 36 percent without to 57 percent with treatment across the participants) but did not significantly change the number of false detections (from a mean of 10 percent without to 13 percent with treatment across the participants). False detections could result in the pedestrian crossing when moving vehicles are approaching the crosswalk. In the operational roundabout experiment, sound strips were placed along with a "Yield to Pedestrians", State Law sign located in the roundabout exit between the two travel lanes. The sign resulted in an increase in drivers' yielding from 11 percent (115 of 996 vehicles) in the control condition to 16 percent (158 of 948 vehicles) in the experimental condition. Five of the original seven participants, along with a mobility specialist as with the Ashmead study, performed 151 total trials (65 at a control crossing, 86 at the treated crossing). Participants spoke into a wireless microphone to indicate when they detected vehicles stopped in both lanes. Across all trials, participants correctly identified both lanes occupied 19% in the control condition and 12% in the treatment condition while the number of time-outs (both lanes not blocked within a sufficiently short time or one lane delayed significantly without the other lane being blocked) increased from 25% to 37%. The number of false alarms decreased from 14% in the control to 5% with the treatment. It was observed that vehicles in the treated location tended to stop well before the sound strips and did not cause the desired sound cue. Overall, it was concluded that the treatments explored in these studies do not appear promising for double-lane roundabouts, but should be explored further to see if they might work at single-lane crossings.

As part of NCHRP 3-65, Harkey and Carter conducted one of the most comprehensive studies to date of pedestrian safety at roundabouts in the U.S. They carefully tabulated 769 pedestrian crossing events at seven roundabouts in six states. Most of the crossings did not involve vehicle-pedestrian interactions. Across all crossings, only four were considered conflicts (either the pedestrian or vehicle involved in the interaction must rapidly change course or speed to avoid a collision). When pedestrians began their trip on the entry-side of the crossing, 60% of the crossing were normal, 33% hesitated before crossing the first leg (the entry lanes) while only 7% ran, and 29% ran during the second leg (the exit lanes) and only 10% hesitated. The reverse occurred when the crossings began on the exit-side: approximately 50% of crossings were

normal, 39% hesitated on the exit first leg while only 3% ran, and 10% ran on the second leg while 23% hesitated. This suggests that pedestrians tend to hesitate initially while selecting a gap and adjust speed (by running) on the second leg in order to avoid interactions with vehicles. However, the limited number of pedestrian movements in the behavior videos was not sufficient to support significant statistical analyses or draw definitive conclusions.

It is interesting to note that in all the aforementioned studies, the continuous observation period at any given location was relatively short (a maximum of 611 minutes with an average around 200 minutes). Although extrapolations where made, we do not believe that such a limited observation on each site can describe the relationships between factors affecting accessibility, i.e. approach volume vs. pedestrian volume, lighting conditions, yielding rate vs. pedestrian volume, etc.

The overall result of the methods and weight given in the research of pedestrian safety in roundabouts has generated a number of conflicting guidelines. For example, although all of the aforementioned references agree that roundabouts provide a safer environment for pedestrians, since accident reductions have been reported in before-after studies, the FHWA guide suggest that roundabouts are "generally inappropriate" in locations where pedestrians are frequent. The usability of roundabout crossings by blind and low-vision pedestrians has been questioned by the US Access Board, orientation and mobility professionals, and advocates for blind and low-vision pedestrians in the U.S. Currently, the issue of accessibility may be the most controversial issue surrounding roundabouts. It is an issue that must be resolved. It needs to be satisfactorily resolved in such a way that a balanced solution accommodates all roundabout users and is not detrimental to new roundabout growth (Russell, 2008).

Chapter 3.   Study Site Selection and Video Data Collection Process

Desirable Study Site Characteristics

The first step in the study site selection process was the definition of desirable study site characteristics. These characteristics were identified because they assist with meeting the project objective (i.e., the evaluation of pedestrian experience in crossing a roundabout). It was concluded that the following study site characteristics were beneficial to this research project:

- The sites must be modern urban roundabouts
- The sites must have adequate pedestrian/bicycle traffic
- The sites selected must be adequately different from each other, in terms of location, geometry and pedestrian/bicycle population
- The sites must be in urban, densely populated areas

A preliminary investigation of existing roundabouts in the greater are around the Twin Cities region was conducted. Site visits were completed in spring and early summer 2010 for most of the candidate study sites identified. At each site, information that defined their existing physical conditions was collected. The result of this investigation assisted in designing a survey of roundabouts that were possible candidates for this study. The survey was distributed to members of the project Technical Advisory Panel (TAP) and others to solicit comments and information regarding the aforementioned characteristics. The survey is included in Appendix A and it included the following sites:

1. Minnehaha Ave & Minnehaha Pkwy, Minneapolis, MN
2. 66th & 17th in Richfield, MN
3. 66th & Portland in Richfield, MN
4. 70th St. Edina, MN (Three small roundabouts)
5. Wentworth and TH-52, South St. Paul, MN (two roundabouts)
6. Jamaica Ave, Cottage Grove, MN (two roundabouts)
7. Denmark Ave, Eagan, MN
8. Difley and Rahn, Eagan, MN
9. New Prague, MN (two roundabouts)
10. Setzler Pkwy N & Neddersen Pkwy N, Brooklyn Park, MN
11. TH-284 and CR-32, Waconia, MN
12. CSAH 18 and Fenning Ave, Monticello, MN

The survey had limited response from people outside the project TAP. Regardless, the comments and feedback received allowed the research team to select two of these sites to collect observations: 66th St. and Portland Ave, in Richfield (2-lane roundabout with 2-lane entrances and exits), and Minnehaha Parkway and Minnehaha Ave in Minneapolis (1-lane roundabout with 1-lane entrances and exits).

Roundabout at 66th Street and Portland Avenue in Richfield

The roundabout at 66th St and Portland Ave in Richfield is the second roundabout that was constructed in the city of Richfield and started operating in late fall of 2008. The roundabout was constructed in order to improve safety at the aforementioned intersection since in the past there was a long history of severe crashes. Reports from this location indicate that the facility is a relatively new concept to area residents and the proper use of the roundabout has created some confusion and complaints from the pedestrians using the facility.

Figure 3–1 and Figure 3-2 present the intersection before and after the roundabout construction. In addition, basic geometric features of the Richfield roundabout are presented in Figure 3-2. More specifically, using aerial photos, the diameter of the center island was measured to be approximately equal to 70 feet, the size of the pedestrian crossings is 63 feet long, the distance between the outer lane of the roundabout and the pedestrian crossing is 44. As is the case with all roundabouts, the distance a pedestrian would need to walk in order to cross through the junction is greater than the same distance in the case of a signalized intersection. Specifically, Figures 3-1 and 3-2 indicate a possible path starting and ending at the same points on 66th Street (path between A and B). The difference between points A and B distances "before" and "after the implementation of the roundabout increased by approximately 70 feet.

The video analysis process, also delivered accurate estimates of the number of pedestrians that use the roundabout on Richfield. The pedestrian traffic for the days that were analyzed was on average approximately equal to 155 per day while there were 46 bicyclists per day using the crossings.

The Richfield site is a high volume roundabout, with two lanes inside and two lanes on each exit and entrance. The site is well illuminated at night and has traffic control signs and markings in accordance to the 2009 MUTCD. There are bus stops at two approaches of the roundabout, which contributes to the site's complexity and pedestrian traffic. The AADTs normally are approximately 16,000 and 11,500 vehicles/day, at 66th St. and Portland Ave respectively. During the course of this study, Portland Ave was closed north of the roundabout at the interchange with I-35W. This reduced the ADT to approximately half the normal. Overall, the site is well organized and lends itself to being representative of modern urban two-lane roundabouts.

Figure 3-1 66th St and Portland Ave Intersection before the Roundabout Construction

Figure 3-2 66th St and Portland Ave Intersection after the Roundabout Construction

Roundabout at Minnehaha Parkway and Minnehaha Avenue in Minneapolis

The Minnehaha Parkway roundabout, shown in Figure 3-3, is a much older, single lane roundabout. Basic geometric features of the Minneapolis roundabout are also presented in Figure 3-3. More specifically, using aerial photos as in the case of the Richfield roundabout, the diameter of the center island was measured to be equal to 85 feet, the size of the pedestrian crossings 29 feet, the distance between the outer lane of the roundabout and the pedestrian crossing 58 feet and finally the distance that a pedestrian would need to walk starting at the east pedestrian crossing on Minnehaha Pkwy and reaching the west pedestrian crossing on Minnehaha Pkwy, 358 feet (distance AB in Figure 3-3).

The Minneapolis roundabout does not have the traffic control features that Richfield does and by being next a park and a regional trail it has more subdued illumination during the night. Pedestrians on the Minneapolis roundabout are a more recreational crowd, including a very high volume of bicyclists and pedestrians. Minnehaha Park gets more than 850,000 visitors annually (MPB) while the Minnehaha regional trail attracts over 1,500,000 visits per year (METC). Both the park and the regional trail have a major contribution in the pedestrian traffic of the roundabout. From the analysis of the recorded video data, pedestrian counts were also collected. The pedestrian traffic for the days that were analyzed was on average approximately equal to 424 per day while there were 875 bicyclists per day using the crossings.

The roads carry lower volumes than the Richfield roundabout; Minnehaha Pkwy and Minnehaha Avenue have similar AADTs, approximately 8,000 vehicles/day each. Overall, this site was selected because it provides an excellent contrast overall to the Richfield roundabout.

Overall Data Collection Process

The initial data collection process applied for this research project was relatively simple and straightforward. At the beginning of this study, there were no specific attributes of pedestrian crossing events identified, instead, it was understood that the observation of such events would help define them. Therefore, the research aimed in capturing in video the entire scene of the roundabout during pedestrian crossing events. The following sections describe the on-site video data collection while the next chapter describes the methodology followed in reducing the video records in quantifiable variables.

Figure 3-3 Roundabout at Minnehaha Pkwy and Minnehaha Ave

Equipment Description and Deployment

In order to collect the necessary video recordings, custom-made surveillance hardware was developed and utilized (Figure 3-4). The base of the surveillance equipment was an extendable mast trailer frequently utilized in highway workzones to carry and provide surveillance or illumination. The mast can reach a height of 38 feet. The power source of the deployed equipment consisted of rechargeable batteries that were built in the trailer's structure. Even though the power consumption of the recording equipment was not high, the batteries were recharged at certain points so that the process was not interrupted. The recharge process was made with the help of a portable generator.

Figure 3-4 Surveillance Trailer

The surveillance equipment consisted of eight CCTV cameras (Figure 3-5) and two Digital Video Recorders (DVR) mounted on the extendable mast trailer. Four of these cameras have a wide angle lens, and when viewed simultaneously, provide a seamless 360 degree image of the roundabout lanes. Following some adjustments during the installation process, these cameras provide a clear view of the roundabout lanes without any blind spots. The other four cameras were trained toward each of the four pedestrian crossings.

Figure 3-5 CCTV Cameras

Richfield Roundabout

With the help of the Richfield city engineer and the Hennepin county Right-Of-Way (ROW) engineer, both members of the project TAP, an understanding concerning the trailer deployment at the center of the central island of the roundabout was reached. The main concern

was the fact that drivers could be distracted after the trailer was deployed in the middle of the roundabout. The research team at the Minnesota Traffic Observatory (MTO) made an effort to ensure that the surveillance trailer would get the least amount of attention. For this reason, the trailer was completely covered with a dark green tarp. In addition, the extendable mast and the transparent cover on the top that the cameras were nested in, gives them resemblance to the lighting poles in the area (Figure 3-6).

Figure 3-6 The Surveillance Trailer Deployed at Richfield Roundabout

After deploying the trailer, the eight CCTV cameras on the top of the mast needed to be adjusted so that the recordings were as clear as possible. Several trials for different zoom and focus settings were conducted in order to identify the optimal set up. The resulting video views for the deployment in Richfield are presented in Figures 3-7 and 3-8.

Figure 3-7 360 Degree Roundabout Image for Richfield Roundabout
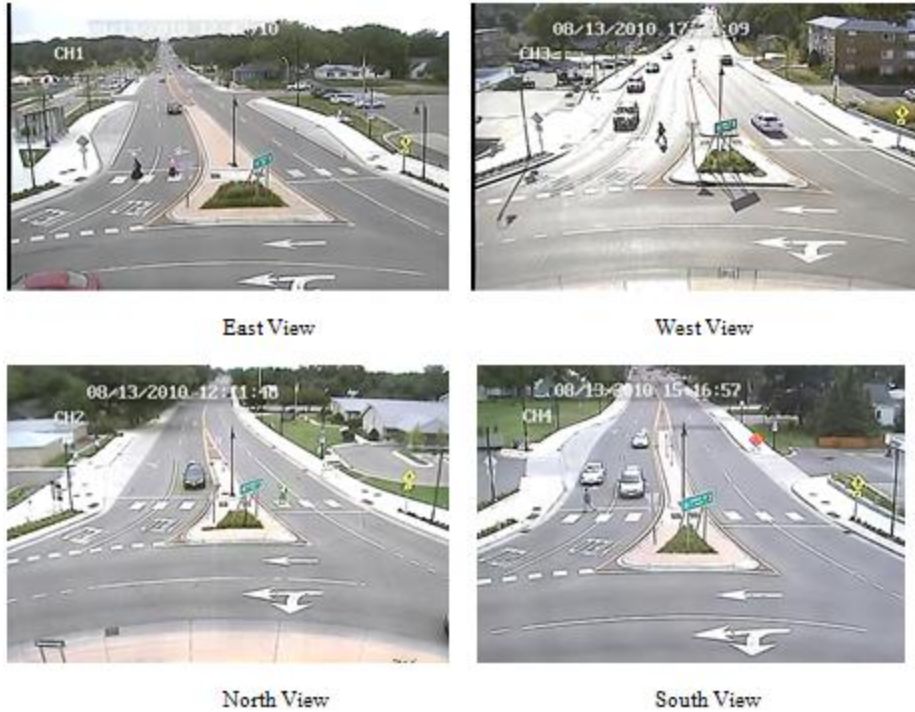
Figure 3-8 Pedestrian Crossing Footage at Richfield Roundabout

The trailer was deployed at the Richfield site from August 7, 2010 until September 4, 2010, totaling 29 days. Recordings were made between 7 AM and 9 PM daily. Although not all days resulted in successful recordings due to minor equipment malfunctions, more usable data was generated than this project was able to utilize given its budget.

Minneapolis Roundabout

With the help of City of Minneapolis engineers, it was "discovered" that the actual owner of the ROW of the roundabout island was the Minneapolis Park Board. Though more difficult than with the Richfield site, an understanding concerning the trailer deployment was reached, and the necessary permits were acquired. The deployment followed the same practice as in the Richfield site. Views of the video collected at the Minneapolis site are shown in Figures 3-9 and 3-10. The trailer was deployed on September 18, 2010 and remained in this location until October 11, 2010. Recording was scheduled between 5 AM to 8 PM daily. Due to concerns of the Park Board, we limited the deployment to only 24 days. Regardless, the video collected was more than enough for the purposes of this project.
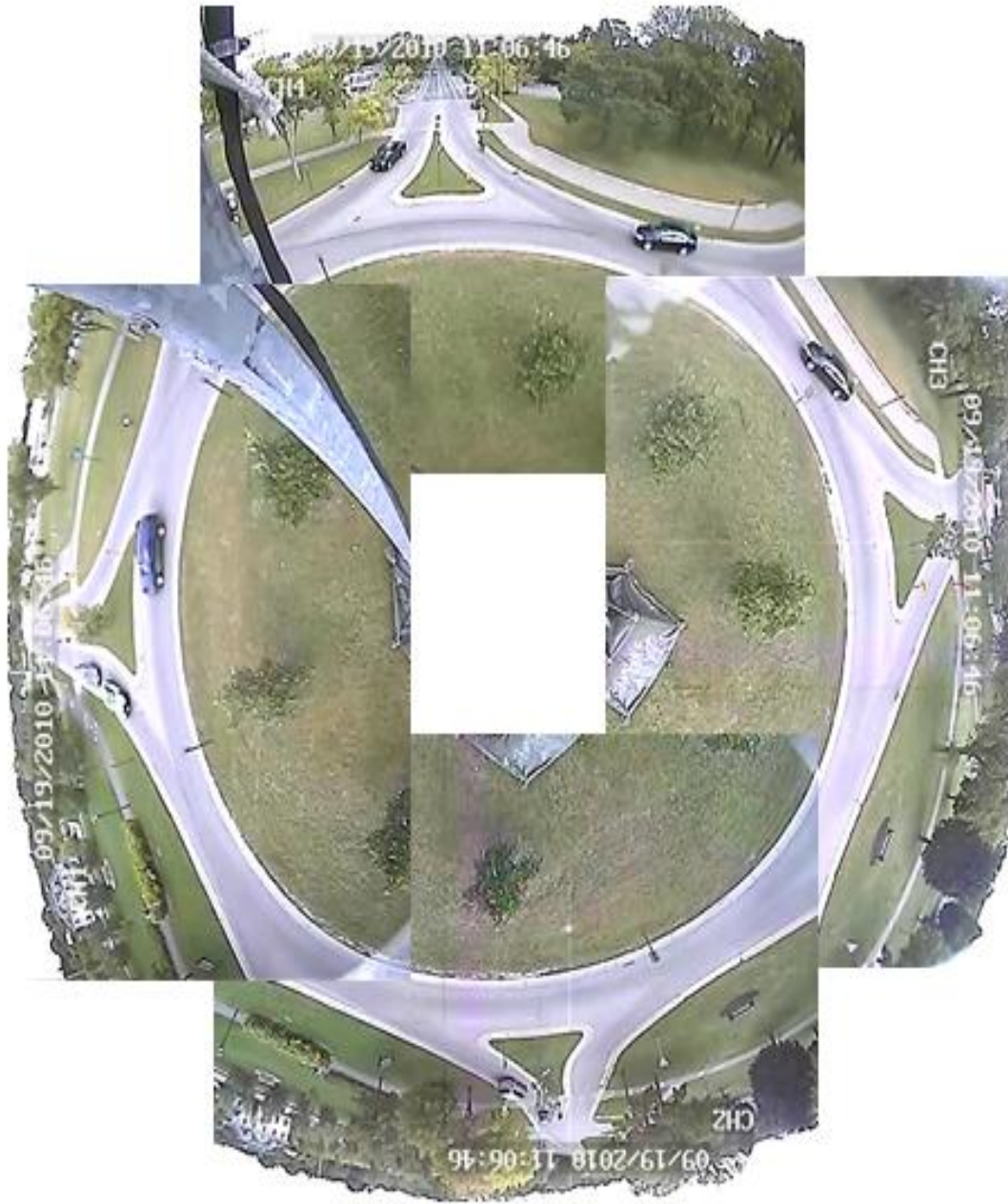
Figure 3-9 360 Degree Roundabout Image for Minneapolis Roundabout

Figure 3-10 Pedestrian Crossing Footage at Minneapolis Roundabout

The trailer was deployed at the Richfield roundabout on August 7, 2010 and remained at this location until September 4, 2010, totaling 29 days. Recording was scheduled between 7 AM to 9 PM daily. Although not all days resulted in successful recordings due to minor equipment malfunctions, we collected more than enough data. Phase 1 reduced 16 days of data. During these days we collected information on an average of 76 pedestrian crossing events involving interaction with traffic and 15 bicycle crossings per day. In total from the Richfield site we have 1,203 pedestrian crossing and 232 bicycle crossing events. Phase 2 extracted the additional information from 441 of the events identified in Phase 1.

The same video collection set up was followed for the data collection at the Minneapolis roundabout. The trailer was deployed September 18, 2010 and remained in this location until October 11, 2010. Recording was scheduled between 5 AM to 8 PM daily. The pedestrian and bicycle traffic at the Minneapolis roundabout was considerably higher as compared to the one in Richfield. Specifically, Phase 1 reduced 16 days of data. During these days we collected information on an average of 257 pedestrian crossing involving interaction with traffic and 394 bicycle crossings per day. In total, we have 4,730 pedestrian crossing and 7,302 bicycle crossing events. Phase 2 extracted the additional information from 586 of the events identified in Phase 1.

16

Chapter 4.   Data Reduction and Analysis

The objective of this study was to understand how different factors affect pedestrian and bicyclist crossings on modern urban roundabouts. Specifically, it focused on understanding the factors that affect driver yielding behavior to pedestrians and bicyclist at such crossings. This is an observational study. Therefore, all knowledge is acquired by observing actual crossing events and reducing the observed information to a set of quantitative and qualitative characteristics. Since at the beginning of the project, it was unclear which are the important characteristics, as described in the previous chapter, a comprehensive observation collection system was deployed maximizing the potential of capturing most if not all of the important information.

Original data reduction plan involved three phases. The first phase involved collecting basic information on all of the ped/bike crossing events during the study period. Phase 2 involved drilling down into collection of information involving the driving environment inside the roundabout. Finally, Phase 3 planned to scrutinize accidents and near-accidents involving ped/bike and vehicles. Phase 3 was eventually dropped because there were no close-call events in any of the study dates. Instead effort was redirected to expanding the event set of Phase 2. The following sections describe the video processing and data reduction process developed and followed in this project.

Video Processing

Before any video is used for collecting information, a lengthy period of transforming it from the proprietary DVR medium it was captured to more convenient AVI clips viewable on PC computers was necessary. This process allowed us to create backup copies of all data and avoid loss when some of the project HDs malfunctioned. Specifically, the video recorders utilized in this study save the video in a proprietary format based on the H.264 Mpeg4 video compression protocol. Software provided by the manufacturer allows the conversion to the industry standard Mpeg4 protocol. Because of playback constraints of the Mpeg4 codec and to facilitate video reduction productivity, a final conversion step was performed transforming the video to Xvid format which is most efficient for desktop computer playback.

Although Phase 1 of the video data reduction process did not require any further automation, Phase 2 because it involved analysis of events covered by more than one cameras required development of video playback and synchronization software. Specifically, as it will be explained in greater detail later in this chapter, Phase 2 involved the collection of information on the vehicle while driving inside the roundabout and before reaching the crossing and the ped/bike. This information is spread over up to four cameras depending on where the vehicle entered the roundabout. The following figure illustrates the Phase 2 video reduction workstation. The videos are rotated to match their orientation in the roundabout while a fifth window displays the video of the crossing. Special productivity enhancement features were developed to facilitate better video playback. These features include:

- Video synchronization: This enhancement allows the control of all five video players to play the video in synch with each other.

- Video control: This enhancement allows the user to use keyboard shortcuts in order to control the video playback on all players. The shortcuts allow:
  - play all five videos from their current position
  - stop all five videos at their current position
  - advance or reverse all five videos by 1 frame or by keyframe
  - advance or reverse all five videos by 50 frames
  - skip to the end or beginning of all five videos
  - synchronize the videos to a certain time
  - change the frame rate at which all five videos play

Figure 4-1 Video Reduction Workstation View

Phase 1 involved 16 days' worth of data, given 15 hours of observation per day and four videos per hour, the effort covered 960 hours of video in each roundabout for a total of 1,920 hours of video footage. Phase 2 dealt with randomly selected events isolated during Phase 1. Although the overall video time is much less, the effort was greater since the subject vehicle had to be identified in each view and followed over the five video streams described above. This involved playing the same sequence several times in order to extract all the desired information.

Video Data Reduction

In the early fall of 2010, the MTO staff started reducing the raw video data to information that can be used for analysis of the ped/bike interactions. As already mentioned, the data reduction was performed in two phases. Phase 1 aimed on identifying all ped/bike crossing events and for the ones involving interaction with traffic extracted basic information. Phase 2 drilled down on randomly selected events identified in Phase 1 and extracted information involving the condition inside the roundabout at the time of the ped/bike crossing. The following sections describe in detail the methodology followed and the information collected.

Phase 1

In Phase 1, 16 days of collected video was analyzed to identify all instances of pedestrian and bicycle activity in both roundabouts. The events identified were classified in one of the categories listed in the following table. Each event takes place at one of the eight crossings available at each roundabout (two per approach). Although all events are recorded, extra details are recorded regarding pedestrian and bicycle interactions with traffic.

Within ped/bike interactions with traffic, events are categorized based on whether the ped/bike yielded when they reached the curb, or if the driver yielded. For every crossing, the number of ped/bikes in the group is noted. In cases of ped/bike yield, it was recorded whether the driver who should have yielded was alone, followed by another vehicle, or was closely following a vehicle that did not have time to yield itself. Also, for pedestrian yields, the number of vehicles who should have yielded was recorded. In cases of driver yield on the Richfield roundabout, the lane the yielding vehicle was traveling in as it approached the pedestrian crossing was recorded.

Table 4-1 Reduced Event Categories

Ped_traffic	Pedestrian passes over cross walk with traffic present
B_traffic	Bicycle passes over cross walk with traffic
Ped_cross	Pedestrian crosses without interference
Bic_cross	Bicycle passes over cross walk without traffic
Bic_road	Bicycle on the road (car direction)
In_bus_bay	Pedestrian in bus bay
Upstream	Pedestrian crosses away from traffic circle

- Crossing-with-traffic event info:
    - Day, time, crossing.
    - Yielding subject, ped/bike or driver
    - # of vehicles not yielding
    - # of pedestrians in group
    - Far or near lane for vehicle in respect to the pedestrian.
    - Vehicle direction, entering or exiting the circle
    - Start of crossing, sidewalk or mid-island
    - Whether a non-yielding driver was alone, followed, or following

For example, based on the frame seen in Figure 4-2, the record would read the following with 1 indicating true, 0 indicating false, -1 is N/A, and A/F/F is 1 to 3:

- Filename (day & approach)= 100807-ch01-152216-162216_xvid
- Frame (time)= 5210
- Bicycle? = 0
- Driver Yield? = 1
- No. of veh not yielding = -1
- No. of Pedestrians = 1

- Near Lane? = 0
- Entering Roundabout? = 1
- Island? = 1
- A/F/F = -1
- Portland Roundabout? = 1

Figure 4-2 Example of an Event Frame

This first phase data allows for straightforward statistical analysis investigating the hypothesis that pedestrians or bicyclists are yielding more often than vehicles as well as explores some of the elements of the crossings immediate environment in regards to their influence on driver yielding behavior. For example, we explore the role of the size of the pedestrian group, the number of vehicles surrounding the crossing, and the time of day have in the yielding behavior. This phase also prioritized events for analysis during the second phase.

Phase 2

The data collected for this phase was appended to a selected set of data from Phase 1. Given the fact that Phase 2 focused in the investigation of the influence of the driving environment inside the roundabout on the driver's yielding behavior, the analysis focused on ped/bike crossing events where the vehicle was exiting the roundabout. As discussed later in the results section, this also made sense since exiting vehicles displayed considerably lower yielding rate than entering ones. A balanced approach was followed in randomly selecting cases from the two study sites of Minnehaha Parkway in Minneapolis and 66th Street and Portland Avenue in Richfield, Minnesota.   The days chosen for analysis were separated into three time periods: morning peak, midday off peak, and afternoon peak, from 07:00-08:59, 09:00-13:59, and 14:00-18:00, respectively. From each of these periods for each day of data, ten instances distributed evenly among the collected data were selected to append with further data from Phase 2. In cases where there is not enough data, analysis was performed until instances were exhausted.

As described earlier, configuring videos for data collection consisted of an arrangement of four video player windows so that the screens exhibit an aerial-like view of the roundabout,

along with an additional video that exhibits the appropriate crosswalk. This arrangement process involves accessing and loading into each video playing window the five video files that correspond to the appropriate date and time of analysis and using the rotation filters embedded in the software to achieve the configuration demonstrated in Figure 4-3. Each of the videos is then synced to the nearest seventh of a second to one another. Once this preparation is achieved, data collection may commence.

Figure 4-3 Phase 2 Video Reduction Arrangement

Appended data collection pertaining to an instance from Phase 1 concerns the vehicle that interacted with the pedestrian at the crosswalk. The observer follows the vehicle as it traverses through the roundabout to record information describing vehicle and driving behavior, and prevailing roundabout conditions.

The information recorded by the observer is all in numerical form, with values being counts, arbitrary classifications, and surrogate values. The parameters recorded include:
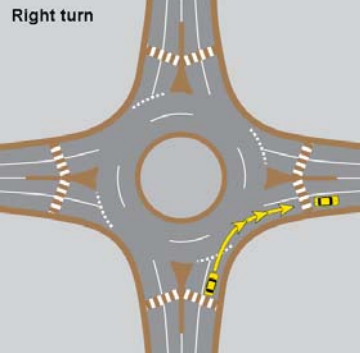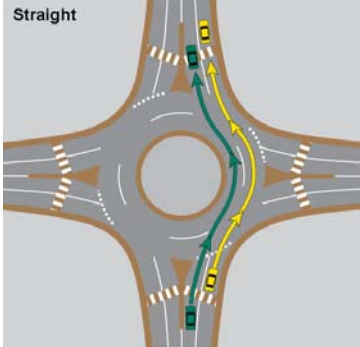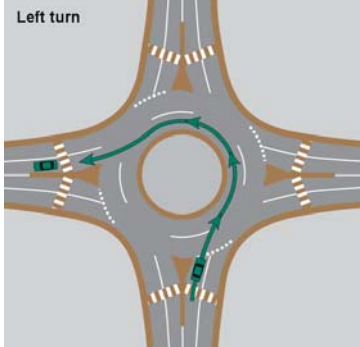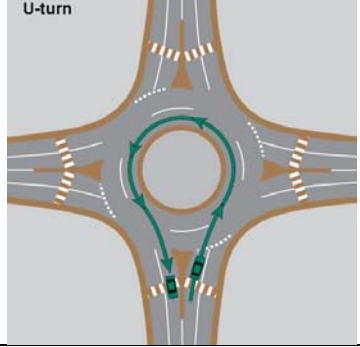
- Degrees entrance to exit: The degrees of the angle between the entrance of the vehicle in the roundabout and the exit it encountered the pedestrian. This is an indication of the distance the vehicle covered inside the roundabout (table 2).
- Vehicles in 90 degrees: The number of vehicles in the roundabout 90 degrees clockwise with respect to the used entrance. This variable is a measure of the drivers load during the merge with the roundabout traffic. Example presented in Figure 4-5.
- Speed: An estimate of the vehicles speed approximately 90 degrees before its exit (Figure 4-6).
- Vehicles Entering/yielding: A classification denoting whether there are vehicles entering the roundabout 90 degrees before the vehicle of interest exits. It differentiates between a vehicle present and not moving and vehicle present and moving. This variable describes if there were vehicle yielding to the subject vehicle one entrance before its exit. Example seen in Figure 4-7.

- Vehicles in 360: A count of the number of vehicles in the roundabout when the car is 90 degrees from exiting. This is a general estimate of the traffic density inside the roundabout circle at the time of the event.
- Bicycles in 360: The number of bicyclists in the roundabout driving lanes.
- Lane Change and Violations: A classification denoting whether the vehicle performed any lane changes and a classification denoting whether the vehicle committed any other vehicular violations.
- A classification denoting general vehicle type.
- Pedestrian delay: The amount of time the pedestrian spends standing at the curb before crossing.

All digitized information is recorded in a database, as shown in Figure 4-4. The already described the information recorded from Phase 1 can be seen in the first columns followed by the Phase 2 information. All information pertaining to an instance is recorded along a single row, with each column representing one of the aforementioned parameters. The following describes the coding methodology, pertaining to the appended data only.

Vehicle Path

Table 4-2 Classification of the Length of the Vehicle Path from Entrance to Exit

Recorded Value	Description	Image
1	90 degrees/ right turn	Right turn
2	180 degrees/ straight through	Straight
3	270 degrees/ left turn	Left turn
4	360 degrees/ u-turn	U-turn
Images from wsdot.wa.gov/		

	File	Frame	Bicycle?	Driver Yield?	Number of Cars	Number of Pedestrians	Near Lane?	Entering Roundabout?	Island?	A/F/F	Portland Roundabout?	Turn Value	Lane (Inner/Outer)	Vehs In 90	Speed	Entering	Vehs in 360	Bicycles in 360	Lane Change	Violations	Veh Type	Ped. Wait
159	100826-ch01-070444-080444_xvid	3137	0	0	1	1		0	0	1	1	3	1	1	29	0	3	0	0	0	1	34
160	100826-ch01-090444-100444_xvid	8511	0	0	9	1		0	0	1	1	2	2	0	38	2	1	0	0	0	1	226
161	100826-ch01-100444-110444_xvid	22069	0	0	2	1		0	1	1	1	2	1	1	27	1	2	0	0	0	3	36
162	100826-ch01-110444-120444_xvid	6365	0	0	2	1		0	0	3	1	2	1	0	45	0	4	0	0	0	6	61
163		10543	0	0	1	3		0	0	1	1	1	2	0	0	-1	3	0	0	0	4	64
164		22055	0	0	2	1		0	0	3	1	2	2	0	31	2	4	0	0	0	1	0
165	100826-ch01-130444-140444_xvid	9161	0	0	2	1	1	0	0	2	1	2	2	1	51	0	3	0	0	0	3	135
166	100826-ch01-140444-150444_xvid	22941	0	1	0	3	0	0	1	0	1	2	2	0	28	0	3	0	0	0	2	18
167	100826-ch01-150444-160444_xvid	5971	1	1	0	1	1	0	0	0	1	2	1	0	32	0	3	0	0	0	3	0
168		10899	0	0	3	1		0	1	3	1	2	1	0	30	0	1	0	0	0	1	89
169		15891	0	0	1	1		0	1	1	1	2	2	0	25	0	3	0	0	0	1	50
170	100826-ch01-160444-170444_xvid	132	0	0	12	1		0	0	3	1	2	2	1	48	1	4	0	0	0	3	169
171		289	0	1	0	2	0	0	0	0	1	2	1	0	31	1	4	0	0	0	3	22
172		2674	0	1	0	1	1	0	0	0	1	2	2	0	34	1	7	0	0	0	3	21
173		3021	1	0	0	2	1	0	1	0	1	2	1	1	40	0	1	0	0	0	3	38
174		6432	0	1	0	1	1	0	0	0	1	2	2	2	36	0	5	0	0	0	1	0
175	100826-ch01-170444-180444_xvid	8757	0	0	1	1		0	0	1	1	1	2	0	0	-1	7	0	0	0	1	51
176	100826-ch02-100444-110444_xvid	15780	0	1	0	1	1	0	1	0	1	1	1	1	26	2	5	0	0	0	4	0
177	100826-ch02-130444-140444_xvid	23810	0	0	1	1		0	0	1	1	1	1	1	26	2	2	0	0	0	3	12
178	100826-ch02-140444-150444_xvid	1644	1	0	1	1		0	1	1	1	2	0	27	2	5	0	0	0	1	25
179	100826-ch02-150444-160444_xvid	8338	0	0	2	1		0	0	1	1	1	2	0	30	0	3	0	0	0	3	53
180	100826-ch02-160444-170444_xvid	18439	0	1	0	1	1	0	1	0	1	2	0	35	2	6	0	0	0	1	12
181	100826-ch02-170444-180444_xvid	17588	0	0	9	1		0	0	3	1	1	2	0	34	0	6	0	0	0	3	211
182	100826-ch03-070444-080444_xvid	11700	0	0	14	1		0	1	1	4	1	1	23	0	2	0	0	0	1	295
183		12350	0	0	4	1		0	1	3	1	4	2	2	36	0	5	0	0	0	3	21

Figure 4-4 Snapshot of the Reduced Data Records for Both Phases

Vehicles in 90

 The recorded value is an integer count. Figure 4-5 demonstrates the area in which the observer counts vehicles, noting that video overlap exists. The rational regarding this measurement is to see if the pressure during merging into the roundabout affects the yielding behavior of the drivers.
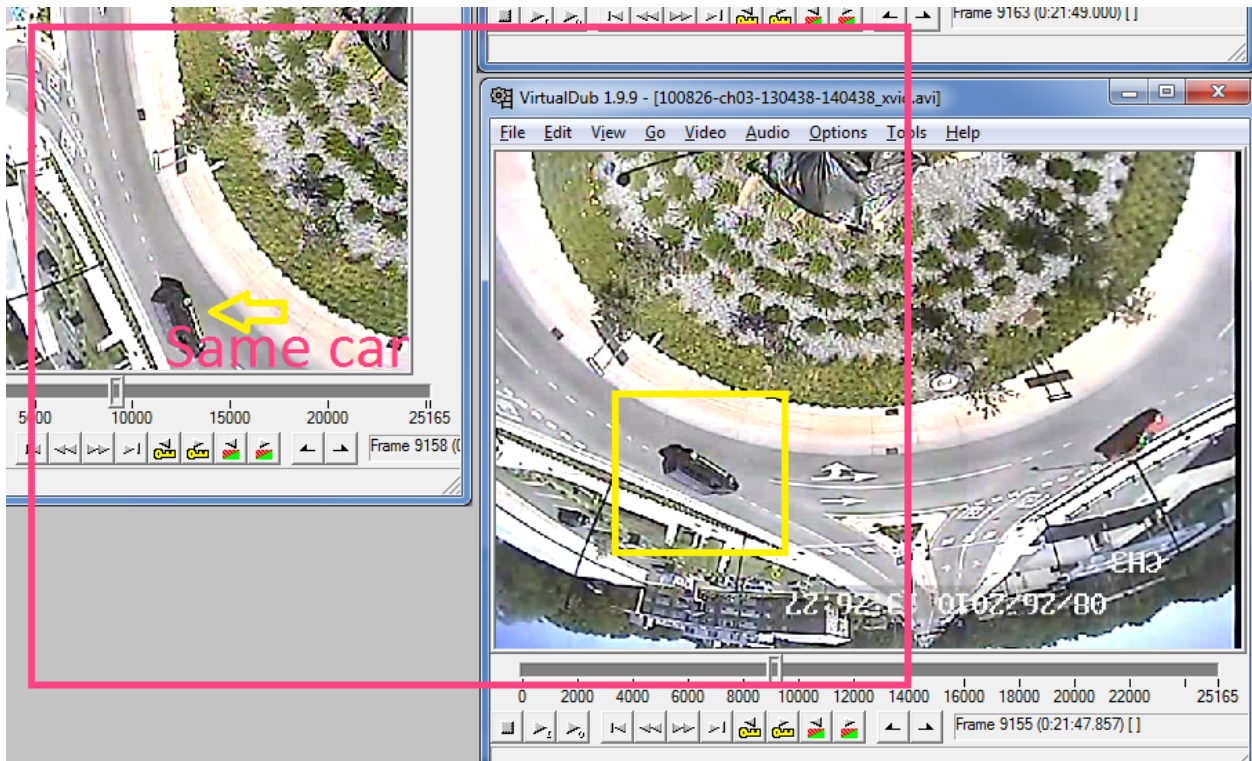
Figure 4-5 Example of Vehicle Count 90 Degrees to the Left of the Subject Vehicle Entrance

Speed before Exit

        The recorded value is the number of frames it takes for the vehicle to traverse a specified distance on the screen at 75% video resolution. In the instance given below in Figure 4-6, for the specified distance the vehicle traveled, it took 21 frames, or 3 seconds, allowing for speed to be calculated based on the distance in the analysis. For the purposes of this study, the actual speed of the vehicle is not relevant since only the relative speed between different events is needed in order to explore correlation with yielding behavior. The measurement is taken on the circle quadrant before the vehicle exit.
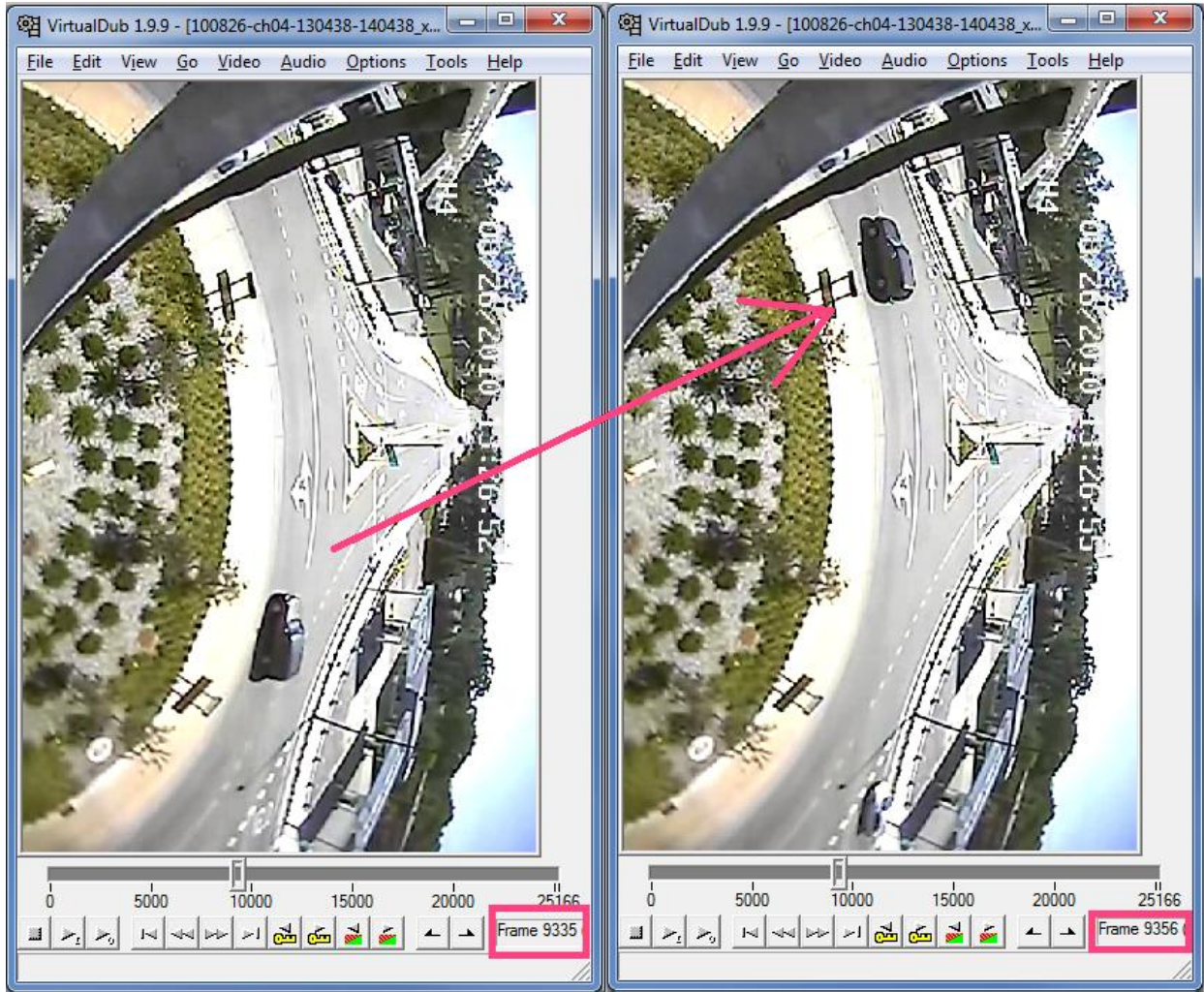
Figure 4-6 Example of Estimating Vehicle Speed inside the Roundabout

<u>Vehicles Yielding to Subject Vehicle</u>

The recorded value is a classification that denotes the status of vehicles waiting to enter the roundabout in the instance in which the vehicle of interest is approaching the entrance 90 degrees before its exit.

Recorded Number	Description	Image
-1	90 degree/ right turn	Not applicable
0	No vehicles present	
1	Vehicles present and not moving	
2	Vehicles present and moving	

Figure 4-7 Method for Classifying Vehicles Yielding to Subject Vehicle before Exit.

The rational for this extracted information is to see if the driver workload paying attention to vehicles in the nearest entrance is affecting the yielding behavior. One hypothesis is that the driver, in the case where an entering vehicle is still moving, is unsure if it will yield or

not and devotes his/hers attention to it and misses the pedestrian which is in an almost perpendicular line-of-sight.

Vehicles in 360

The recorded value is an integer count. Figure 4-8 below, demonstrates an instance in which, including the vehicle of interest, there are 4 vehicles present in the roundabout. The instance at which this value is recorded is the same as it is for the Entering category. Note that there are three vehicles whose images are repeated due to video overlap. This is a surrogate for the prevailing traffic density in the roundabout during the event.

Figure 4-8 Estimation of Vehicle Density inside the Roundabout through Vehicle Count

Bicycles in 360

The recorded value is an integer count. Figure 4-9 below, demonstrates an instance in which there is one bicyclist present in the roundabout. The instance at which this value is recorded is the same as it is for the Entering category. This information was recorded to examine if there is any undue hardship on the driver due to the presence of the bicycle inside the driving lanes and if this affects yielding behavior.
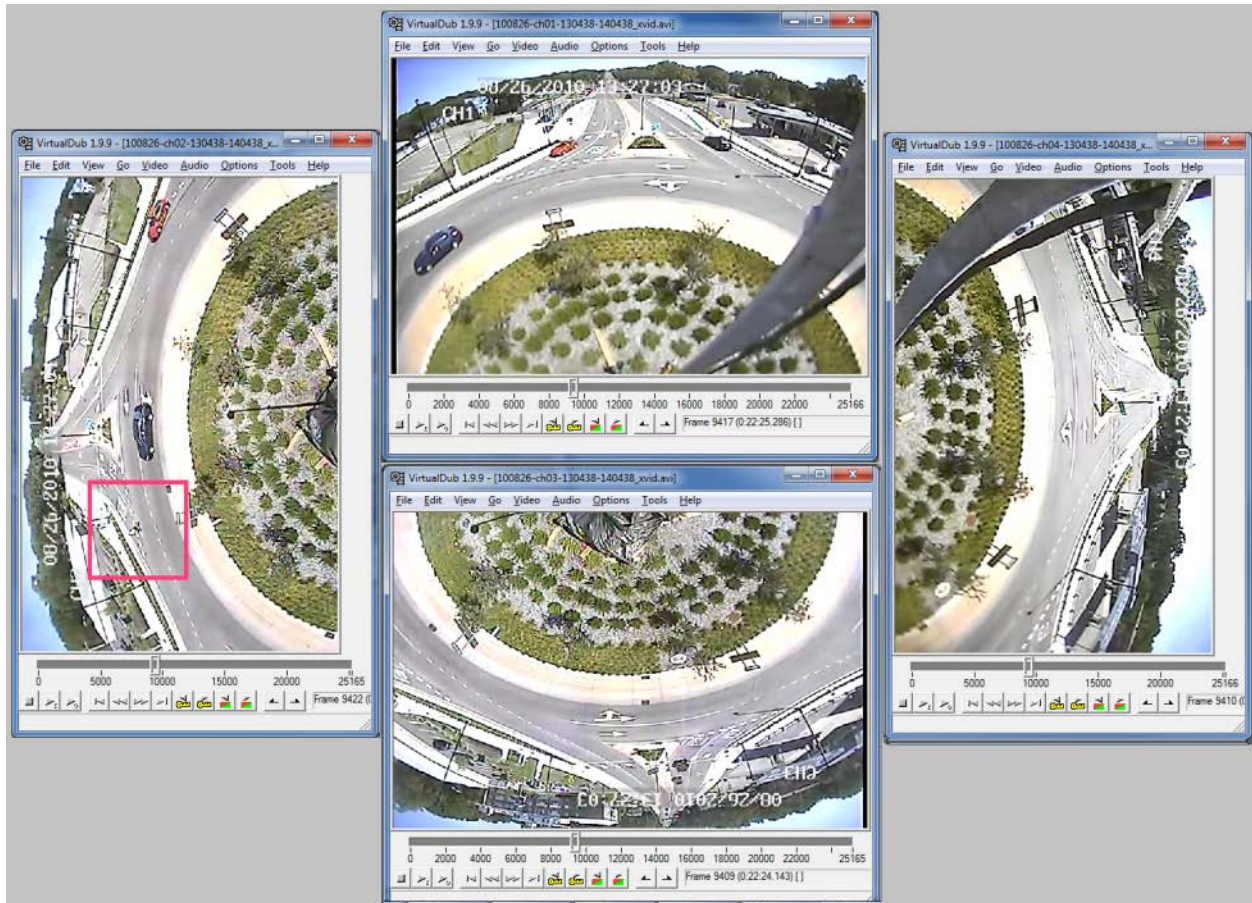
Figure 4-9 Example of a Case where a Bicyclist was Driving inside the Roundabout

Violations

This parameter denotes if the vehicle performed any violations of the roundabout driving rules before it encountered the pedestrian. Such violations include yielding and illegal turn violations.

Table 4-3 Indicator of Violations Performed by Subject Vehicle

Recorded Number	Description
0	No vehicular violations were committed
1	One or more violations were committed

Lane Changes (Richfield Only)

Lane changes are not permitted inside a two lane roundabout. Such violations are marked separately because they most often take place when the vehicle exits the roundabout and in the case of these events encounters the ped/bike.

Table 4-4 Indicator of Illegal Lane Changes Performed by the Subject Vehicle

Recorded Number	Description
0	No lane changes were made
1	One or more lane changes occurred

Vehicle Type

Table 4-5 Vehicle Type Classification

Recorded Number	Description
1	Sedan
2	Motorcycle
3	SUV/minivan
4	Truck
5	Bus
6	Semi-trailer truck

As it is the case with all data reduction activities it was not a priori known which of the extracted information would be pertinent to the project questions and which would not.

As it will be described in the next chapter, several different forms of statistical analysis were performed on the extracted data in the hope that behavioral and traffic related patterns will emerge as relevant to the projects questions.

Chapter 5.   Study of Yielding Behavior at Pedestrian Crossings

Problem Overview

As indicated in Chapter 1, the primary objective of this study was to understand the conditions around pedestrians and bicyclists utilizing crossings on modern urban roundabouts. Given that the most important aspect of the crossing event is the driver's yielding behavior, the project aimed in exploring all influences to this behavior. Because this was an observational study, the identification of influences to driver yielding behavior is constrained to information describing the environment the event is taking place. It is reasonable to expect that other influences to the driver, internal to the vehicle and from their prior driving education, exist but we cannot explore with the data available in this study.

The study followed two parallel tracks. The first track involves a quantitative analysis of the collected information describing trends and populations. The second track involves the use of Logistic Regression as a causal analysis tool to identify the important influences to the driver yielding behavior and determine the effect they have in the probability a vehicle yields to a pedestrian in a roundabout crossing. Following this section, a short description of the use of Logistic Regression for causal analysis is presented.

Logistic Regression: A Summary

Regression methods have become an integral component of any data analysis concerned with describing the relationship between a response variable and one or more explanatory variables. It is often the case that the outcome variable is categorical, taking on two or more possible values. Over the last decade the logistic regression model has become, in many fields, the standard method of analysis in such a situation. In this study, the outcome variable is binary or dichotomous, Yield=1 vs. No-Yield=0 and therefore, logistic regression fits nicely in this problem.

Logit models are commonly used in epidemiology for estimating an individual's risk or probability of a disease as a function of disease risk factors. Logit regression is based on a logistic curve, a symmetric function whose values range between 0 and 1. The logistic transformation or logit of a success probability p is given by $\log\{p/(1-p)\}$, which is defined as logit (p). For n explanatory variables the logit model is given as:

$$p = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n)}$$

(5.1)

or,

$$\log(\frac{p}{1-p}) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n$$

(5.2)

Where,

β_0 =Constant of the logit regression equation

β_i = Coefficient estimate of variable x_i

x_i = Independent variables or predictors.

exp(x) = Exponential function, equivalent to e^x

Fitting a model to a set of data first entails estimating the unknown parameters $\beta_0, \beta_1, \beta_2, ..., \beta_n$ in the model. The most widely used method of estimation is the method of maximum likelihood. In a very general sense, the method of maximum likelihood yields values for the unknown parameters, which maximize the probability of obtaining the observed set of data. Maximum likelihood estimators are consistent, asymptotically efficient, and asymptotically normal.

In order to apply this method, we must first construct a function, called the likelihood function. This function expresses the probability of the observed data as a function of the unknown parameters. The maximum likelihood estimators of these parameters are chosen to be those values that maximize this function. Thus, the resulting estimators are those which agree most closely with the observed data. If y (observation) is coded as 0 or 1 then the expression of p given in equation 5.1 provides the conditional probability that y is equal to 1 given x (explanatory variables). This is denoted as P(y=1|x). It follows that the quantity 1-p gives the conditional probability that y is equal to zero given x, P(y=0|x). Thus, for those pairs (x, y) where y=1, the contribution to the likelihood function is p and for those pairs where y=0, the contribution to the likelihood function is 1-p. A convenient way to express the contribution to the likelihood function for a given pair (x, y) is

$$p^y (1-p)^{1-y}$$

Since the observations are assumed to be independent, the likelihood function is obtained as the product of the above terms:

$$l(\beta) = \prod p^y (1-p)^{1-y}$$

The principle of maximum likelihood states that we use as our estimate of β the value which maximizes the aforementioned expression. However, it is easier mathematically to work with the log of that equation. The expression of log likelihood ($L(\beta)$), is given as

$$L(\beta) = \ln[l(\beta)] = \sum_{i=1}^{N} \{y_i \ln[p_i] + (1-y_i) \ln[1-p_i]\}$$

(5.3)

31

Where,

y$_i$ = Observed value and
p$_i$ = Predicted value for the ith event
N= Number of observations

Estimation of parameters using the aforementioned method is a well known process and is already implemented in several statistical packages like SAS, STATA, SPSS and ARC. ARC was used throughout this study.

Correlation and Causation

The study of causation is central to the understanding of human reasoning. Diagnosis, be it in traffic safety or epidemiology, depends on finding a satisfactory explanation for a given set of observations and the meaning of explanation is intimately related to the notion of causation. Diagnostic methods are generally divided into two categories: observational and experimental.

As Glymour (1987) notes, modern science greatly depends on experimental methods. Even so, many questions cannot be answered by experiments, and many answers did not come from experimental studies. The limitations of experimentation are both practical and ethical. For practical reasons, it is not possible to do experiments with the economies of nations or with the arrangements of galaxies. For ethical reasons, it is not possible to do experiments with humans on the cause of disease or on the causes of pedestrian accidents. Faced with both the urgent need for knowledge and with stringent limitations on the scope of experimentation, researchers resort to observation and statistics. In traffic safety, it is rarely possible to conduct proper randomized experiments; in the majority of cases, observational study of measurements and statistical modeling is the only viable method.

The basic idea behind the application of logistic regression for the identification of important influences or causal factors to the driver yielding behavior, is to treat each individual interaction between a ped/bike and a vehicle as resulting from a set of specified systematic influences related to the driving environment or crossing geometry, plus a random individual difference. The guides in exploring the relationship of each of these influences with the yield or no-yield driver decision are the estimated regression coefficient of each influence representing variable and the Student's T statistic testing the hypotheses that the corresponding coefficient equals zero, i.e. that the predictor makes no significant contribution to model's ability to predict yielding behavior. The latter is also expressed through the p-value for the hypothesis test.

Before proceeding to the analyses for the two study sites, a caution about interpreting the regression results is in order. For observational data such as that collected in this study, the fitted regression models give useful summaries of how model variables are associated, and can be used to predict the yielding behavior of a driver, under conditions similar to those operating when the data were collected. Because it may be possible that other, unobserved, factors may also have been affecting yielding behavior, the regression models should not be used to predict this behavior at other sites, or even at these study sites at times other than those when the data were collected. Regardless, although these models cannot be used to predict the yielding probability of

drivers in other locations the observed correlations and trends can be used in the planning and design of any roundabout.

Phase 1

In Phase 1 the explanatory variables investigated were ones that describe the immediate environment around the crossing event, i.e. crossing location, time, group size, etc. Not all of these variables were explored as predictors to the yielding behavior of drivers. For example, the number of vehicles not yielding was observed in order to understand the level of discomfort of the ped/bike but it is not logical to expect it to have an influence on the decision of the very first vehicle that should had yielded. Such influence is explored with the AFF variable where we explore how the presence of a vehicle just before or after the subject vehicle influences that behavior. Table 5-1 presents all the variables explored during the Phase 1 analysis.

In the following sections, statistics involving the aforementioned variables are presented first followed by the analysis of influence they have on the driver yielding behavior. Each site is presented independently first followed by a combined analysis attempting to explore the effect of the roundabout design. The latter is a very weak attempt since there are a lot of confounding factors involved with the roundabout design that cannot be explored with just two sites in the sample.

Table 5-1 Yielding Behavior Predictors and other Descriptive Variables

Variable	Meaning	Values
Car_Yield	Who yielded, vehicle or ped/bike	1=Vehicle yielded 0=Ped/bike yielded
Time	Time of day	Frames till Midnight
Is_Weekday	Day of the week	1= Monday to Friday 0=Saturday or Sunday
Is_Bicycle	Bicycle or Pedestrian	1= Bicycle 0=Pedestrian
Approach	Intersection Leg	1, 2, 3, or 4 clockwise from East
Ped_Group	Ped/bike Group size	Number of ped/bike in group
Crossing_Start	Island or Sidewalk	1= cross started on island 0=cross started on sidewalk
RB_Direction	Exit or Entrance	1=Traffic entering roundabout 0=Traffic exiting roundabout
Near_Lane	Near or Far lane (Richfield RB only)	1=Vehicle on lane near to pedestrian 0=Vehicle on far lane
AFF	Alone, Following, or Followed	Category 1= Driver alone Category 2= Driver followed Category 3= Driver following
Cars_Not_Yielding	Number of vehicles not yielding	Number of vehicles

Richfield Roundabout

In total, 1437 cases of ped/bike crossings interacting with traffic were recorded at the Richfield roundabout. These cases involved 1,205 pedestrians and 232 involved bicyclists using the pedestrian crossing. The latter does not include bicycles using the roundabout drive lanes.

Table 5-2 describes the general yielding tendencies at the Richfield roundabout. As it can be seen the general yielding percentage is relatively low since only a 41% of drivers sampled who should have yielded actually did. This was even worse in the case of bicycles where this percentage was 36%. The latter can also be attributed to the different behavior of bicycles as compared to pedestrians and the difference is not large enough to draw any concrete conclusions.

Table 5-2 Richfield Roundabout Driver Yielding Percentages

General	41.4% (-4.7% if Bicycle n.s.)
Exiting Roundabout	22.8% (+34.9% if Entering)
Middle Island start	53%
66th St crossings	39.9%
Portland Ave crossings	44.7%

When the driver's yielding behavior is explored separately between roundabout entrances and exits, a large detectable difference is observed. The yielding percentage on the crossings located at the exits from the roundabout is only 22.8% while the same at the entrances to the roundabout is 57.7%. Similar detectable difference can also be observed between crossings starting from the sidewalk or the middle island. Specifically, from all the crossing starting at a middle island 53% percent of cases the driver yielded while for crossings starting at the sidewalk the yielding percentage was only 28.8%. As seen in Table 5-2 the yielding percentages between approaches from/to 66th St and Portland Ave have small difference with a smaller percentage of drivers yielding on the 66th St ones. The latter can be an effect of the higher number of traffic exhibited on these approaches.

In exploring the influence of closely spaced vehicles around the vehicle that interacted with the ped/bike, the analysis showed that over all cases where the vehicle was alone, there is no significant difference. In the cases though were the vehicle was either closely followed or closely following by another vehicle, only approximately 30% of the drivers yielded. As described in the previous chapter, "following" is designated to a vehicle that follows closely another vehicle which though passed the crossing before the pedestrian was in position to be influenced by it. The latter can possibly be explained by a certain pressure the drivers may feel not to stop when they are been "tailgated" by another vehicle. This can have implications on roundabout crossing downstream of signalized intersection where the vehicles arrive at the crossing in platoons.

When the earlier characteristic is explored separately between entrances and exits to/from the roundabout, some different behaviors are observed. As described earlier, the yielding percentage on roundabout entrances in Richfield was 45% but when the vehicle was alone in the road this percentage rose to 63%, while in the same places when it followed or is follows another vehicle, it drops to 41% and 50% respectively. This reinforces the aforementioned possible issue involving roundabouts placed in close proximity to signalized intersections or any other road feature that may prompt vehicles to arrive at the roundabout in dense platoons. On roundabout exits, the percentages of driver yielding when they are alone, followed, or being following are 25%, 21%, and 3%. The last one suggests a tendency from drivers to "sneak by" behind another vehicle and, this way, justify not stopping for the ped/bike. Since the number of vehicles in total not yielding for the ped/bike was recorded, it is interesting to indicate that on the average, only 2.4 vehicles passed before the ped/bike had an opportunity to cross with no difference between

roundabout entrances and exits. Although this statistic can be used as a surrogate to the ped/bike delay, it is compounded to the locations traffic characteristics and therefore not extremely reliable.

The Richfield roundabout is a two lane, two lane exit and entrance roundabout. In an attempt to explore the effect of the two lanes wide crossing, the observations were divided between cases where the yielding or not yielding vehicle was in the near or far lane in respect to the ped/bike. In the cases where the vehicle was in the near lane, the yielding percentage was 44% while the yielding percentage when the vehicle was on the far lane was 38%. The difference is understandable but not substantial. The drivers on the far lane yield less to ped/bikes but not on a magnitude that can drive an argument between one or two lane wide crossings.

As it will be discussed later, the number of ped/bike in the group is a strong influence to the drivers yielding behavior. Specifically, when the ped/bike was alone, the yielding percentage was 38% while for all groups of size two and above the percentage was more than 50% with the percentage specifically on groups of three being 61%. This agrees on earlier studies which showed that there is "safety in the crowd," meaning the bigger the ped/bike group, the more inclined the drivers are to yield. The observations on the size of the group influence on yielding behavior exhibit stable trends when the exits and entrances are considered separately, meaning that a group larger than one on an entrance encounters a higher yielding percentage than a similarly sized group on an exit from the roundabout.

As discussed earlier, the start of the crossing, island or sidewalk has a strong influence on the driver behavior. Explored separately, entrances to the roundabout have a 49% yielding when starting from the sidewalk while experience a 63% yielding if the subject starts from the middle island. On exits from the roundabout, crossings from the sidewalk experience a 16.8% yielding vs. a 31% when the subject starts the crossing from the island.

Although the aforementioned observations of trends are valid and informative, they are not secure until the robustness of the association of each characteristic with the driver yielding probability is established. In addition, confounding between variables cannot be explored through quantitative comparison of cases. The remaining of this section utilizes logistic regression to establish reliable associations between observed variables and driver yielding probability.

Table 5-3 Regression Results Using All Predictors: Richfield Site.

```
                    Binomial Regression
            Response        = Car_Yield

                    Coefficient Estimates
    Label             Estimate      Std. Error      Est/SE    p-value
    Constant         -2.22074       0.357607        -6.210    0.0000
    Approach         -0.0400799     0.0521815       -0.768    0.4424
    Crossing_start    0.937327      0.124599         7.523    0.0000
    Is_Bicycle       -0.367078      0.167696        -2.189    0.0286
    Is_Weekday        0.265416      0.140823         1.885    0.0595
    NearLane          0.578320      0.124705         4.638    0.0000
    Pedestrain_Group  0.325534      0.0849432        3.832    0.0001
    RB_Direction      1.54557       0.126064        12.260    0.0000
    Time              1.345512E-6   6.903567E-7      1.949    0.0513
    AFF              -0.601891      0.101408        -5.935    0.0000
```

Table 5-3 presents the results of the logistic regression analysis of the data collected at the Richfield roundabout. The depended variable was the driver's action of yielding or not to the ped/bike. From the results we observe that there is small difference in the driver yielding behavior between pedestrians and bicyclists. However, this may be an artifact of the small number of events involving bicycles as compared to pedestrians. Even smaller is the effect of the weekend or time of day the crossing is taking place. The latter implies that overall volume on the roadway is not a large influence to the particular probability of a driver yielding to a ped/bike. In difference, the trends involving the start of the crossing, the near/far lane, the pedestrian group size, and the entrance/exit from the roundabout indicate a reliable association to the drivers yielding probability. Specifically, from the signs of coefficients we can verify the following:

- Starting the cross from the middle island increases the probability of the driver yielding to the ped/bike. A possible interpretation to this can be that while for crossing from the sidewalk the driver can pretend that he/she are unsure of the ped/bike intent to cross the street, there is little doubt of this intent when the subject is in the middle island. Another interpretation is that the pedestrians in the island are more visible to the drivers than the ones in the sidewalk.
- When the vehicle is in the lane closest to the ped/bike the probability that it yields is increasing as compared to the case where the vehicle is in the lane farthest from the subject.
- As already discussed the size of the pedestrian group has a positive influence on the driver's yielding probability.
- The location of the pedestrian crossing at the entrance or the exit of the roundabout has the strongest influence to the driver's yielding behavior with the trend as already described. This observation implies that exits from the roundabout require greater scrutiny on the overall design, i.e. have greater need for pedestrian warning devices, greater need for visible indicators that pedestrians have the right-of-way, as well as greater scrutiny regarding their distance from the roundabout. The latter is geometric characteristic this study could not explore due to the limited sample from different sites.
- Although representing weak associations the following can be said:
    - Bicycles experience a reduced probability of yielding.

o During weekdays drivers yield more as compared to their behavior during weekends. A strange observation.

Specifically discussing the strength of the influence each predictor has on the probability a driver will yield to the ped/bike, Table 5-4 shows the influence each of the predictors has on the model deviance when introduced sequentially. The higher the deviance change, the stronger the influence of the variable on the yielding behavior.

Table 5-4 Analysis of Predictor Strength on Yielding Behavior

```
              Binomial Regression
        Response       = Car_Yield

        Sequential Analysis of Deviance
      Predictor            Deviance Change
         RB_Direction           155.803
         Crossing_start         88.3455
         AFF                    37.8693
         NearLane               16.0916
         Pedestrain_Group       14.4358
         Is_Bicycle             3.96854
         Time                   2.95195
         Is_Weekday             1.10953
        Approach                0.110058
```

From the results presented in Table 5-3, we see that there is a strong association between the drivers' yielding behavior and the AFF variable. Because of the non-binary nature of this variable, it is not clear what the effect is. For this reason, an additional step is performed where the AFF variable is introduced to the model as a two level categorical variable. The results are shown in Table 5-5 where it can be observed that the strongest influence is in the case where the vehicle is alone in the encounter with the ped/veh. Specifically, when the vehicle is alone, the probability of yielding is increased while the opposite is observed when the vehicle is followed by another one. It is important to note that the cases where the vehicle was alone are a lot more than the cases where it was followed or following another one. This may be a reason for the weaker association of the AFF2 predictor.

Table 5-5 Regression Results with AFF as Categorical Variable: Richfield Site

```
                    Binomial Regression
              Response      = Car_Yield

                  Coefficient Estimates
Label              Estimate       Std. Error      Est/SE      p-value
Constant           -3.40506       0.355961        -9.566      0.0000
Approach           -0.0433334     0.0522917       -0.829      0.4073
Crossing_start      0.936025      0.124636         7.510      0.0000
Is_Bicycle         -0.361221      0.167893        -2.151      0.0314
Is_Weekday          0.265442      0.140856         1.884      0.0595
NearLane            0.577406      0.124760         4.628      0.0000
Pedestrain_Group    0.326398      0.0850749        3.837      0.0001
RB_Direction        1.54903       0.126222        12.272      0.0000
Time                1.347262E-6   6.908140E-7      1.950      0.0511
{C}AFF[1]           0.599700      0.100367         5.975      0.0000
{C}AFF[2]          -0.126092      0.121088        -1.041      0.2977
```

Minneapolis Roundabout

In total, 12,032 cases of ped/bike crossings interacting with traffic were recorded at the Minneapolis roundabout. These cases involved 4,730 pedestrians and 7,302 involved bicyclists using the pedestrian crossing. As earlier, the latter does not include bicycles using the roundabout drive lanes. The situation in Minneapolis considerably different from the one observed in Richfield both in terms of overall observations as well as the ratio of pedestrians vs. bicyclists. Table 5-6 describes the general yielding tendencies at the Minneapolis roundabout. As it can be seen, the general yielding percentage is much higher as compared to Richfield exhibiting a 83.3% yield percentage. Again, the percentage was smaller for bicycles but only by 1%. Given the plethora of cases involving bicycles this percentage is a reliable observation.

Table 5-6 Minneapolis Roundabout Driver Yielding Percentages

General	83.3% (-1% if Bicycle n.s.)
Exiting Roundabout	81.5% (+3.6% if Entering)
Middle Island start	93.6%

When the driver's yielding behavior is explored separately between roundabout entrances and exits, a detectable difference is observed. The yielding percentage on the crossings located at the exit from the roundabout is 81.4% while the same at the entrances to the roundabout is 85.1%. Similar detectable difference can also be observed between crossings starting from the sidewalk or the middle island. Specifically, from all the crossing starting at a middle island 93% percent of cases the driver yielded while for crossings starting at the sidewalk the yielding percentage was only 73.9%. There was no discernible difference in yielding behavior between entrances on Minnehaha Pkwy and Minnehaha Ave.

In exploring the influence of closely spaced vehicles around the vehicle that interacted with the ped/bike, the analysis showed that over all cases where the vehicle was alone there is no significant difference from the general trend. In the cases where the vehicle was closely followed

by another vehicle, only 79% of the drivers yielded. In difference, to the Richfield roundabout, when the vehicle was closely following another vehicle, the yielding probability increased to 88%, a strange observation. It should be noted that the overall environment is considerably different and there is no signalized intersection anywhere near the roundabout. As described later on the AFF variable exhibited very little influence on driver behavior therefore further breakdown is unnecessary.

As discussed earlier, the start of the crossing, island or sidewalk, has a strong influence on the driver behavior. Explored separately, entrances to the roundabout have a 75.6% yielding when starting from the sidewalk, while experiencing a 94.7% yielding if the subject starts from the middle island. On exits from the roundabout, crossings from the sidewalk experience a 72.2% yielding vs. a 92.3% when the subject starts the crossing from the island. One reason for the very increased percentages of yielding to ped/bikes on the middle island may be the fact that most approaches of the Minneapolis roundabout have a small to non-existing island; the ped/bike is practically standing in the median between lanes.

The group sizes in the Minneapolis roundabout are considerably larger, with groups of two individuals or larger representing more than half of the cases. The yielding percentages related to group size are similar in trend as in Richfield with the same applying when the exits and entrances are explored separately.

As with the analysis of the data collected in Richfield, the remaining of this section utilizes logistic regression to establish reliable associations between observed variables and driver yielding probability.

Table 5-7 Regression Results Using All Predictors: Minneapolis Site

```
                    Binomial Regression
          Response       = Car_Yield


                  Coefficient Estimates
   Label            Estimate       Std. Error      Est/SE      p-value
   Constant         0.182952       0.176912         1.034       0.3011
   AFF              0.0182917      0.0430322        0.425       0.6708
   Approach         0.0680599      0.0230051         2.958       0.0031
   Crossing_start   1.64083        0.0614081        26.720       0.0000
   Is_Bicycle       -0.152349      0.0549824        -2.771       0.0056
   Is_Weekday       0.355899       0.0528638         6.732       0.0000
   Pedestrain_Group 0.177588       0.0316343         5.614       0.0000
   RB_Direction     0.229438       0.0517572         4.433       0.0000
   Time             4.620780E-7    3.778983E-7       1.223       0.2214
```

Table 5-7 presents the results of the logistic regression analysis of the data collected at the Minneapolis roundabout. The depended variable was the driver's action of yielding or not to the ped/bike. From the results, we observed that there was a larger difference in the driver yielding behavior between pedestrians and bicyclists, although still not statistically significant. In difference to Richfield, the effect of the weekend/weekday on driver behavior is strong and statistically significant. This difference did not extend to the time of day the crossing is taking place, which still doesn't seem to play a role in the drivers decision to yield or not. Again, the latter implies that overall volume on the roadway is not a large influence. In difference, the

40

trends involving the start of the crossing, the pedestrian group size, and the entrance/exit from the roundabout indicate a reliable association to the drivers yielding probability. Specifically, from the signs of coefficients we can verify the following:

- Starting the cross from the middle island increases the probability of the driver yielding to the ped/bike.
- As already discussed the size of the pedestrian group has a positive influence on the driver's yielding probability.
- The location of the pedestrian crossing at the entrance or the exit of the roundabout has a strong influence to the driver's yielding behavior with the trend as already described.
- During weekdays drivers yield more as compared to their behavior during weekends. A possible explanation to this trend is the fact that most of the pedestrians during weekdays are joggers regularly using the location for exercise while weekends experience a lot of pedestrians visiting the Minnehaha Falls Park. The latter are much less experienced to roundabout right-of-way rules than the frequent users during weekdays.
- Although representing weaker association, Bicycles experience a reduced probability of yielding. In the case of Minneapolis this effect could be compounded with the group size since there were much larger groups of bicyclists.

From the results presented in Table 5-7, we see that there is a stronger association between the drivers' yielding behavior and the variable describing the approaches of the roundabout. Because of the non-binary nature of this variable, it is not clear what the effect is. For this reason, an additional step is performed where the approach variable is introduced to the model as a three level categorical variable. For reasons similar to the Richfield data analysis, a similar transformation is performed to the AFF variable. The results are shown in Table 5-8 where it can be observed that one particular approach has an effect on the drivers' yielding behavior. This approach is the one on the south of the roundabout on Minnehaha Drive. Although there is nothing seemingly different in that approach as compared to the others, it is the one that leads to the park road, and therefore, has only park user traffic. Also, due to the surrounding foliage, this approach has the worse visibility as compared to all other approaches. Since the model implies a higher yielding rate on this approach, the hypothesis is that drivers are not in a hurry and are exercising more caution in their approach to the pedestrian crossing.

In addition, it is observed that the probability of yielding is decreased when the vehicle is alone in the road or is closely following another vehicle.

41

Table 5-8 Regression Results with AFF as Categorical Variable: Richfield Site

```
                    Binomial Regression
           Response       = Car_Yield

                 Coefficient Estimates
Label            Estimate      Std. Error      Est/SE      p-value
Constant         0.632283      0.182048          3.473      0.0005
Crossing_start   1.64908       0.0616012        26.770      0.0000
Is_Bicycle      -0.147658      0.0563997        -2.618      0.0088
Is_Weekday       0.382818      0.0533458         7.176      0.0000
Pedestrain_Group 0.176332      0.0317057         5.562      0.0000
RB_Direction     0.230176      0.0520411         4.423      0.0000
Time             5.547393E-7   3.803702E-7       1.458      0.1447
{T}AFF[3]       -0.778774      0.112354         -6.931      0.0000
{T}Approach[3]   0.339506      0.0760626         4.464      0.0000
{T}Approach[4]   0.203918      0.0681672         2.991      0.0028
{T}AFF[1]       -0.494413      0.0779519        -6.343      0.0000
{T}Approach[1]   0.0858252     0.0721947         1.189      0.2345
```

Minneapolis and Richfield Combined Analysis

When the two sites are explored together, discussing yielding behavior percentages does not provide any reasonable information. For completeness, the statistical analysis of the yielding behavior predictors is included and provides some reinforcing evidence to earlier observations. Table 5-9 presents the results of the combined dataset. A dummy variable, "Richfield", is introduced to identify the cases originating from the Richfield roundabout. From the results, the difference in yielding behavior between Richfield and Minneapolis is illustrated with the negative sign of the dummy variable, indicating the considerable reduction in yielding probability in the Richfield roundabout. The rest of the significant predictors to yielding probability follow the behaviors described earlier in the individual site analysis.

Table 5-10 uses the deviance change to explore the magnitude of the influence each predictor has on the yielding behavior. The results follow the expected pattern of the variables that are important to both sites having the greatest influence. It is clear that the greatest influence is that of the Crossing Start location with the probability of yielding being much higher when the event starts from the middle island. The influence of the exit from the roundabout is also illustrated, justifying the closer look this study followed on the conditions involving the vehicles trip between its entrance to the roundabout and the time it encounters the ped/bike.

Table 5-9 Combined Regression Analysis of both Sites

```
                    Binomial Regression
              Response       = Car_Yield

                   Coefficient Estimates
   Label            Estimate        Std. Error      Est/SE     p-value
   Constant         0.818094        0.196509          4.163    0.0000
   AFF             -0.0944479       0.0381228        -2.477    0.0132
   Approach         0.0500192       0.0208633         2.397    0.0165
   Crossing_start   1.51513         0.0535814        28.277    0.0000
   Is_Bicycle      -0.178289        0.0518283        -3.440    0.0006
   Is_Weekday       0.343373        0.0490909         6.995    0.0000
   Pedestrain_Group 0.192312        0.0296872         6.478    0.0000
   Richfield       -3.24226         0.199173        -16.279    0.0000
   RB_Direction     0.434360        0.0474667         9.151    0.0000
   Time             6.359017E-7     3.266968E-7       1.946    0.0516
```

Table 5-10 Analysis of Predictor Strength: Combined Model

```
                    Binomial Regression
              Response       = Car_Yield

               Sequential Analysis of Deviance
             Predictor          Deviance Change
                Crossing_start       796.284
                Portland             271.703
                RB_Direction          84.7119
                Approach              73.9984
                Pedestrain_Group      58.6421
                Is_Bicycle            55.3191
                AFF                    4.89709
                Time                   3.77028
                Is_Weekday             0.300069
```

Phase 2

During Phase 2, the relationships of several measurements, descriptive of the driver experience inside the roundabout, with the yielding behavior were explored. The possible descriptors to the driver's yielding probability can be found in Table 5-11. At the same time, we used Phase 2 data to do an analysis of the pedestrian waiting time. The same vessel of causality analysis with the help of logistic regression was used.

The data collected for this phase involved a subset of cases from Phase 1. The exponentially more intense data reduction of the video records only allowed the extraction of 441 crossing event records from Richfield and 581 from the Minneapolis site. Still, a very robust data set, but smaller than the one used in Phase 1. Since the focus was on the influence of the environment of the roundabout proper on the drivers' yielding behavior, all the cases involved crossings on roundabout exits. The cases were selected randomly as described in the previous chapter.

Table 5-11 Yielding Behavior Predictors from Roundabout Proper

Variable	Meaning	Values
Car_Yield	Who yielded, vehicle or ped/bike	1=Vehicle yielded 0=Ped/bike yielded
Approach	Intersection Leg	Category 1, 2, 3, or 4
Is_Bicycle	Bicycle or Pedestrian	1= Bicycle 0=Pedestrian
Crossing_Start	Island or Sidewalk	1= cross started on island 0=cross started on sidewalk
Near_Lane	Near or Far lane (Richfield RB only)	1=Vehicle on lane near to pedestrian 0=Vehicle on far lane
Density	Number of vehicles in the circle	Count
Dens_B	Number of bicycles in circle	Count
Speed	Speed of the vehicle just before the exit	Number of frames to cover a fixed distance
Turn_Value	Degrees between entrance and exit from roundabout	Category 1=90 degree turn, Category 2=180 degree turn, Category 3=270 degree turn, Category 4=360 degree turn
AFF	Alone, Following, or Followed	Category 1= Driver alone Category 2= Driver followed Category 3= Driver following
Cars_Not_Yielding	Number of vehicles not yielding	Number of vehicles
Ped_Group	Ped/bike Group size	Number of ped/bike in group
Lane		Category 1= Inner Lane Category 2=Outer Lane
Merge_against	Number of vehicles 90 degrees to the left at time of entrance	Count
Merging_in	Status of last entrance to the roundabout before exit taken	Category 0= no vehicle present, Category 1=veh present, not moving, Category 2=veh present moving, Category -1= for 90 degree turns
Lane_change	Lane changes performed by the subject vehicle while in the roundabout	1 =changed lanes before exit 0 = no lane change
Violations	Number of violations performed while in the RB	Count
Veh_Type	Vehicle Type	Category 1= sedan, Category 2 = motorcycle, Category 3 = SUV/MiniVan, Category 4 = Truck, Category 5 = Bus, Category 6 = Semi-Trailer

In the remainder of this section, the results from the logistic regression of these possible predictors are presented.

Table 5-12 Phase 2 Regression Results: Richfield Site

```
                    Binomial Regression
         Response          = Car_Yield

                   Coefficient Estimates
```

Label	Estimate	Std. Error	Est/SE	p-value
Constant	-17.9610	99.6491	-0.180	0.8570
Dens_B	-1.87788	33.2125	-0.057	0.9549
Density	0.0473780	0.0812983	0.583	0.5600
Is_Bicycle	-0.436614	0.371965	-1.174	0.2405
Island_start	**0.894853**	**0.271934**	**3.291**	**0.0010**
Lane_change	-2.34997	1.27925	-1.837	0.0662
Merge_against	0.0242117	0.204154	0.119	0.9056
NearLane	**0.918686**	**0.266559**	**3.446**	**0.0006**
Pedestrain_Group	0.253086	0.173766	1.456	0.1453
Speed	0.0404772	0.0224508	1.803	0.0714
Violations	-0.196365	0.752184	-0.261	0.7940
{T}AFF[1]	**3.41182**	**1.03444**	**3.298**	**0.0010**
{T}AFF[2]	**3.24246**	**1.05801**	**3.065**	**0.0022**
{T}AFF[3]	aliased			
{T}Approach[1]	0.0652191	0.392018	0.166	0.8679
{T}Approach[2]	-0.193142	0.425875	-0.454	0.6502
{T}Approach[3]	-0.302044	0.481804	-0.627	0.5307
{T}Approach[4]	aliased			
{T}Lane[1]	0.406574	0.371588	1.094	0.2739
{T}Lane[2]	aliased			
{T}Merging_in[-1]	1.19319	1.05818	1.128	0.2595
{T}Merging_in[0]	0.146061	0.369008	0.396	0.6922
{T}Merging_in[1]	-0.528848	0.515704	-1.025	0.3051
{T}Merging_in[2]	aliased			
{T}Turn_Value[1]	10.1007	99.6337	0.101	0.9193
{T}Turn_Value[2]	9.36760	99.6319	0.094	0.9251
{T}Turn_Value[3]	9.23098	99.6316	0.093	0.9262
{T}Turn_Value[4]	9.31301	99.6351	0.093	0.9255
{T}Turn_Value[5]	aliased			
{T}Veh_Type[0]	13.1537	99.6379	0.132	0.8950
{T}Veh_Type[1]	1.36100	1.13624	1.198	0.2310
{T}Veh_Type[2]	2.37407	1.49851	1.584	0.1131
{T}Veh_Type[3]	1.45123	1.14279	1.270	0.2041
{T}Veh_Type[4]	1.08514	1.20215	0.903	0.3667
{T}Veh_Type[5]	1.31232	1.69407	0.775	0.4385
{T}Veh_Type[6]	aliased			

Table 5-13 Phase 2 Regression Results: Minneapolis Site

```
                Binomial Regression
        Response         = Car_Yield

              Coefficient Estimates
Label            Estimate        Std. Error      Est/SE      p-value
Constant         0.135628        0.714391         0.190      0.8494
Dens_B           0.569782        0.716383         0.795      0.4264
Density          -0.0474170      0.105611        -0.449      0.6534
Is_Bicycle       0.165825        0.247985         0.669      0.5037
Island_start     2.03058         0.292244         6.948      0.0000
Merge_against    -0.0583308      0.203856        -0.286      0.7748
                 NearLane              aliased
Pedestrain_Group 0.429510        0.198291         2.166      0.0303
Speed            0.00113826      0.0262734        0.043      0.9654
Time             -1.445615E-6    1.704303E-6     -0.848      0.3963
Violations       9.95136         63.5467          0.157      0.8756
{F}AFF[2]        0.380761        0.403869         0.943      0.3458
{F}AFF[3]        -0.397256       0.637699        -0.623      0.5333
{F}Approach[2]   0.696206        0.387467         1.797      0.0724
{F}Approach[3]   0.548216        0.340812         1.609      0.1077
{F}Approach[4]   0.436741        0.353381         1.236      0.2165
{F}Merging_in[0] -12.0075        164.264         -0.073      0.9417
{F}Merging_in[1] -11.3079        164.265         -0.069      0.9451
{F}Merging_in[2] -11.5419        164.265         -0.070      0.9440
{F}Turn_Value[2] 11.7813         164.262          0.072      0.9428
{F}Turn_Value[3] 11.8853         164.262          0.072      0.9423
{F}Turn_Value[4] 21.5063         197.321          0.109      0.9132
{F}Veh_Type[2]   -1.63589        0.690576        -2.369      0.0178
{F}Veh_Type[3]   0.269395        0.255587         1.054      0.2919
{F}Veh_Type[4]   0.222944        0.451230         0.494      0.6212
{F}Veh_Type[5]   0.934890        1.14812          0.814      0.4155
```

Unfortunately, none of the Phase 2 variables proved to be statistically important to the yielding behavior. In the Portland site, the previous results from Phase 1emerged again. Regardless, we did notice some interesting trends although they are not significant. For example, vehicles entering the roundabout at a 90 degree angle in respect to the exit they encounter the pedestrian turn to have increased probability of yielding, in difference to vehicles coming from other directions. One can hypothesize that such vehicles have bigger chances noticing the pedestrians even while they are still close to the yield line. The yielding probability is decreasing if there is a vehicle trying to merge into the roundabout at the entrance next to the exit the subject vehicle is going to encounter the pedestrian. In this case, a reasonable hypothesis is that drivers can be distracted when a moving vehicle could enter their trajectory path and do not notice the pedestrians. Finally, the more vehicles in the roundabout, the lower the probability of yielding to pedestrians, while the more bicyclists driving inside the circle, the higher the yielding probability.

As parting thought on the subject of the Phase 2 analysis, we can say that we explored a lot of possible causal factors to the drivers' yielding behavior. Although none can say how exhaustive was the search for factors, we believe we covered most elements that conceivably be attractors of the drivers attention and in extent affect the interaction with the pedestrian. The conclusion of this part of the study is that the build and traffic environment inside the circle of

the roundabout is not a serious influence to the drivers' attention or it is not a causal factor in his/her yielding behavior. Phase 1 showed that there are strong effects from the environment surrounding the pedestrian crossing and the overall analysis, although not robust enough, suggests that two lane roundabouts present greater difficulty for the pedestrians due to lower driver yielding rates. The exits from the roundabouts experience greater issues as compared to the entrances, but it does not seem that these issues have their roots in a particular experience inside the roundabout but rather just the fact that they are the exit from a complex geometry the driver may feel uncomfortable with.

Pedestrian Delay Investigation

Part of Phase 2 analysis was the investigation of the pedestrian delay at the roundabout crossings. The delay was measured as the number of frames in the video sequence the pedestrian waited at the crossing curb for a safe gap or a driver yield. This number is in addition to the normal travel time it takes to cross over the intersection. The travel time for the entire path a pedestrian needs to follow in order to cross, assuming no interaction with traffic, can be calculated based on the roundabout dimensions presented in Chapter 3. Due to limitations in the study data collection the presented results are extremely conservative for the following reasons:

- The pedestrian delay was only measured at the roundabout exits which have lower percentages of drivers yielding.
- The reported delay is on one of the legs of the pedestrian crossing. Doubling the reported number will give a very conservative estimate of the delay involving the entire crossing since the probability the pedestrian encountered traffic on both legs and had to yield twice is smaller than that on a single leg of an exit. The truth is somewhere in the middle but given the numbers reported it did not seem productive to investigate further.
- The measured delays represent only the cases where the pedestrian interacted with traffic. Based on the definition of delay used, crossings that did not encounter traffic have zero delay.

Table 5-14 presents the average delays experienced by pedestrians and bicyclists at the two study roundabouts. Figure 5-1 and Figure 5-2 show the distributions of these delays among the population observed.

Table 5-14 Pedestrian Delays at Study Roundabouts

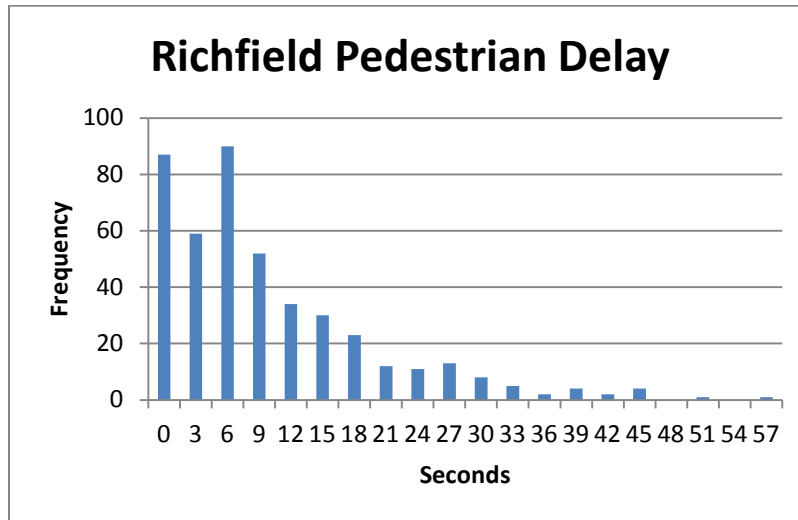|	Average delay at exits with traffic (seconds) (st.d.)	Delay when drivers didn't yield (seconds) (st.d.)	Overall Delay considering cases with no traffic interaction.
Richfield RB	9.04 (10.2)	10.6 (10.6)	2.66
Minneapolis RB	1.6 (3.3)	4.08 (5.1)	0.71

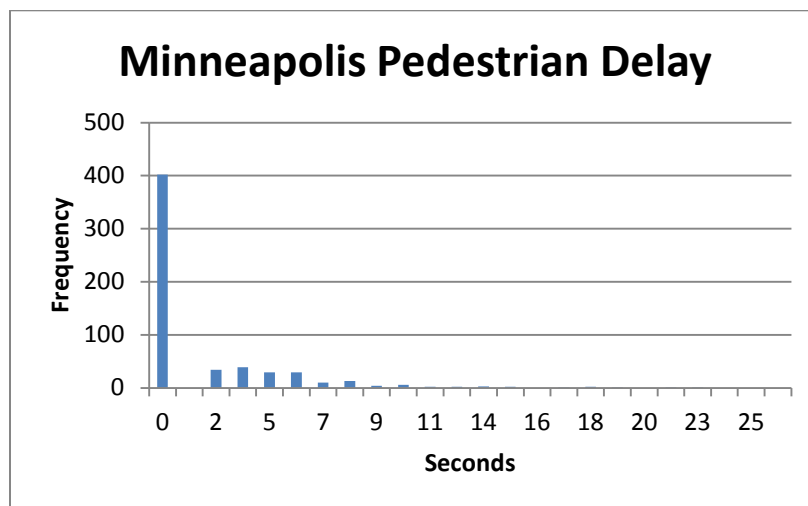**Figure 5-1 Histogram of Pedestrian Delay in Richfield Roundabout**

Figure 5-2 Histogram of Pedestrian Delay in Minneapolis Roundabout

Looking at specific approaches on each roundabout, in the cases where the first vehicle in the scene did not yield for the pedestrian, the average wait time at the curb in the Richfield roundabout varied greatly depending on the roadway the crossing was on. For the two crossings located on 66th St (higher AADT road), the average wait time was 12 seconds while the average wait on the two crossings on Portland Ave was 7 seconds. On the Minneapolis roundabout, one out of four crossings exhibited lower wait times with an average of 2.48 seconds while the other ranged between 3.58 and 5.59 seconds. In cases where the driver yielded, the aforementioned wait times where between 1/3 and half of the non-yield ones.

The numbers describing the delays experienced by pedestrians and bicyclists at the two study roundabouts, if taken literally, describe a situation that is much better than the average experience of a pedestrian at a signalized intersection. For the AADT present at the Richfield roundabout, the typical signalized intersection would have a cycle length of no less than 60 seconds. The typical pedestrian delay at signalized intersection is approximately ½ of the signal cycle. In this case, the average delay would have been 30 seconds as compared to the very conservative 9.04 seconds currently pedestrians experience at the roundabout.

At this point, it would be interesting to note that the numbers taken literally may not describe the perceived delay experienced by the pedestrian. The fact is, the pedestrians have the right-of-way and the, at least rude, non-yielding behavior of the drivers is definitely frustrating. Pedestrians in a signalized intersection do not often interact with traffic; the delay experienced blends in with all the other rules involved with walking in a dense urban environment. On the roundabout, the fact that the pedestrians have to interact with traffic, which in many cases does not yield, intensifies the delay experienced. The research team involved in this project does not have the necessary human factors expertise to investigate this further.

Chapter 6.   Conclusions

General Findings

This report discussed results of a research in the accessibility of modern urban roundabouts for ped/bike. The results, although containing no surprises, highlight the existence of friction between pedestrians and drivers at roundabout crossings. The law in Minnesota states that all vehicles must yield for pedestrians in the crossing. From the results, we can see that the location the crossing starts and the direction the vehicle is driving are important determinants of drivers' yielding behavior. Specifically, a ped/bike crossing that **starts in the island** has a higher probability for a driver yielding, whereas if **the vehicle is exiting the roundabout,** there is a lower probability the driver will yield. We can hypothesize the following explanations: in the case of the pedestrian being in the island any ambiguity of his or her intention to cross is reduced, so drivers are more obliged to yield. In the case of the vehicle direction, the result may be indicative of increased pressure on the part of the driver to clear the roundabout as soon as possible, and therefore selecting not to yield to the pedestrian. The **size of the pedestrian group**, although not a strong predictor, indicated a tendency for drivers to yield to larger groups. More cases of larger groups are needed however to verify this possible effect. In the subcategory analysis utilizing equally-sized cases of pedestrians and bicyclists, there was no distinctive effect on the yielding behavior of the drivers.

During phase 2 we explored the relationships of several measurements related to the driver experience inside the roundabout with yielding behavior and pedestrian waiting time. Although there was no strong correlation between any of the parameters and the probability of a vehicle yielding, we did notice some interesting trends. For example, vehicles exiting the roundabout that have entered at the immediate upstream entrance turn to have increased probability of yielding, in comparison to vehicles coming from other directions. One can hypothesize that such vehicles have a greater chance of noticing pedestrians even while they are still close to the yield line. The yielding probability decreases if there is a vehicle trying to merge into the roundabout at the entrance next to the exit the subject vehicle encounters the pedestrian. In this case, a reasonable hypothesis is that drivers can be distracted when a moving vehicle enters their trajectory path and not notice the pedestrians. Finally, the more vehicles in the roundabout the lower is the probability of yielding to pedestrians.

In cases where the first vehicle in the scene did not yield for the pedestrian, the average wait time at the curb in the Richfield roundabout varied greatly depending on the roadway the crossing was on. For the two crossings located on 66th St (higher AADT road) the average wait time was 12 seconds while the average wait on the two crossings on Portland Ave was 7 seconds. On the Minneapolis roundabout one out of four crossings exhibited lower wait times with an average of 2.48 seconds while the other ranged between 3.58 and 5.59 seconds. In cases where the driver yielded the aforementioned wait times where between 1/3 and half of the non-yield ones.

It is interesting to mention here one of the comments the research team received when discussed the video observations with county and state engineers. It was pointed out that according to the letter of the law the drivers have to yield to pedestrians IN the crossing and

therefore technically they do not have to yield if the pedestrian is standing at the curb. In this research we employed the spirit of the law, accepting that if a pedestrian is standing at the curb facing the crossing it indicates its desire to cross and therefore drivers should yield. Otherwise, it would be irrational to accept that the only way a pedestrian can signal its intention to cross is by first putting his/her safety in danger by stepping into the crossing. Regardless, it is interesting that the law and to some extent driver education material leaves this issue in ambiguity.

Afterthoughts on Safety and ADA Regulations

From the beginning it was the intention of this study to attempt to evaluate the pedestrian experience in roundabout crossings in terms of safety as well as focus on issues involving pedestrians with disabilities. Indeed, one of the reasons this study went in great lengths of to collect long periods of video records and observe tens of thousands of pedestrians and bicyclists using the crossings was so the chances of capturing near-accident events and events involving visually impaired people are maximized. Unfortunately, there were no observations of the latter interacting with traffic and, although fortunate, among the thousands of crossing events there were only three cases that can marginally be considered as close-calls. The study would have been richer if pedestrian accidents were observed but the presented results do not lose any of their value.

The fact that this study was not able to capture any safety compromising situations or observe the interaction of people with disabilities with traffic neither offers evidence that roundabout crossings are perfectly safe nor that visually impaired people have no issues. Indeed as it pertains to the latter, as engineers we believe that there are real problems with the safety and comfort of visually impaired individuals on roundabout crossings. Working only with the fact that on the Richfield roundabout driver yielding rate was at best 45% it is clear that visually impaired individuals cannot assume that drivers see them, are willing to stop, or moving slow which are common safe assumptions made on regular signalized intersections with Turn-on-Red right and permitted left turns. These uncertainties compounded with the other problems reported in the literature do form a negative picture regarding the experience of visually impaired individuals on urban roundabout pedestrian crossings.

References

Ashmead, Daniel H., David Guth, Robert S. Wall, Richard G. Long and Paul E. Ponchillia, "Street Crossing by Sighted and Blind Pedestrians at a Modern Roundabout," *Journal of Transportation Engineering*, Vol. 131, No. 11, ASCE, Reston, VA, 2005.

Bergh, C., Retting, R.A., and Myers, E., (2005). *Continued reliance on traffic signals: the cost of missed opportunities to improve traffic flow and safety at urban intersections*, Insurance Institute for Highway Safety. Arlington VA. September 2005. (http://www.iihs.org/research/paper_pdfs/mf_1848.pdf. Accessed 3/10/11).

Federal Highway Administration (FHWA), (2000). *Roundabouts: An informational guide*, FHWA-RD-00-067, Turner Fairbank Highway Research Center, McLean, VA. (http://www.tfhrc.gov/safety/00068.htm. Accessed 3/10/11).

Glymour, C., Scheines, R., Spirte, P., and Kelly, K. (1987). *Discovering Causal Structure: Artificial Intelligence, Philosophy of Science, and Statistical Modeling*, Academic Press, Orlando, FL.

Harkey, D. and D. Carter. "Observational Analysis of Pedestrian and Motorist Behaviors at Roundabouts in the United States," The University of North Carolina Highway Safety Research Center, presented at the Transportation Research Board Annual Meeting, Washington D.C., January 2006.

Inman, V. W., G. W. Davis, and D. Sauerburger. (2006). *Pedestrian Access to Roundabouts: Assessment of Motorist Yielding to Visually Impaired Pedestrians and Potential Treatments to Improve Access*, Report Number FHWA–HRT–05–080, Federal Highway Administration, McLean, VA.

Minnehaha Park info. http://www.minneapolisparks.org/default.asp?PageID=4&parkid=252. Accessed July 10, 2012.

Minnehaha Regional Trail info. http://www.metrocouncil.org/planning/parks/ParkUseEstimate2010.pdf. Accessed July 10, 2012.

Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. *NCHRP Report 572: Roundabouts in the United States*, National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C., 2007.

Rouphail, N., Hughes, R., and Chae, K. (2005). "Exploratory simulation of pedestrian crossings at roundabouts," *Journal of Transportation Engineering*, 131(3), pp.211–218.

Russell E. (2008). *A Study of the Effects of ADA Accessibility on Kansas Roundabout*, Report no. K-TRAN: KSU-05-4. Prepared for Kansas Department of Transportation, Topeka, KS.

Schroeder, B., and Rouphail, N. (2007). "A framework for evaluating pedestrian-vehicle interaction at unsignalized crossing facilities in a microscopic modeling environment," Transportation Research Board 86th annual meeting, Compendium of Papers CD-ROM, Washington D.C., January 21-25, 2007.

Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities, NCHRP Report 674. Project 3-78 (2011). Transportation Research Board, Washington DC.

Turner, S. A., Persaud, B & Chou, M (2007). "Transferability of Overseas Crash Prediction Models to New Zealand," IPENZ Transportation Conference, Tauranga, New Zealand. http://www.ipenz.org.nz/ipenztg/papers/2007_pdf/A3a_TurnerPersaudChou.pdf.

Appendix A: Site Selection Survey

Site Selection Survey

  Considering the resources available to the project, the number of roundabouts with favorable characteristics is too large to allow deployment on all of them. We developed this little survey to facilitate better communication with the TAP in ranking the roundabouts in order of interest and applicability to the project's goals.

  For each of the roundabouts listed we add some characteristics based on prior discussions and our understanding of the characteristics that are important to the project. Still these are at this point based on engineering judgment since no proper site engineering has been accomplished yet.

  The desired and at the moment feasible data collection method involves a trailer parked in the middle of the roundabout island. The trailer will be equipped with four cameras focused on the four pedestrian crossings (up to four) and a novel panoramic camera that will oversee the entire roundabout with a 360 degree view. The latter is a piece of equipment we are still experimenting with to make sure it is applicable with the intended function.

  Alternatively, if a trailer based deployment is not possible due to restrictions from the right-of-way owner we will deploy solar powered pole mounted cameras focused primarily on the pedestrian crossings and on the roundabout segment leading to each crossing. This is a less desired deployment approach because it will reduce the number of approaches we will be able to observe simultaneously.

  We would appreciate if the TAP members who fill in the survey keep in mind the aforementioned deployment alternatives and provide us with contact information of the people who will be providing assistance and permits.

  At the end of the document please fill rankings on the included roundabouts. Feel free to add any ones we missed.

  The roundabouts are in no particular order.

  Thank you,

  John Hourdos

Minnehaha Falls Park, Minnehaha Pkwy

Right-of-way owner: City of Minneapolis
Number of lanes: 1 (one quarter has almost 2 lanes)
Traffic level: medium
AADT: 5000
Number of pedestrian crossings: 4 (3 have pedestrian potential)
Pedestrian crossing island size: none
Pedestrian frequency: High

Comments:

Permit and assistant contact info:

66th & 17th in Richfield, MN

Alternative name: County road 53
Right-of-way owner: Hennepin co
Number of lanes: 2
Traffic level: high
AADT: 10500
Number of pedestrian crossings: 4
Pedestrian crossing island size: large
Pedestrian frequency: High

Comments:

Permit and assistant contact info:
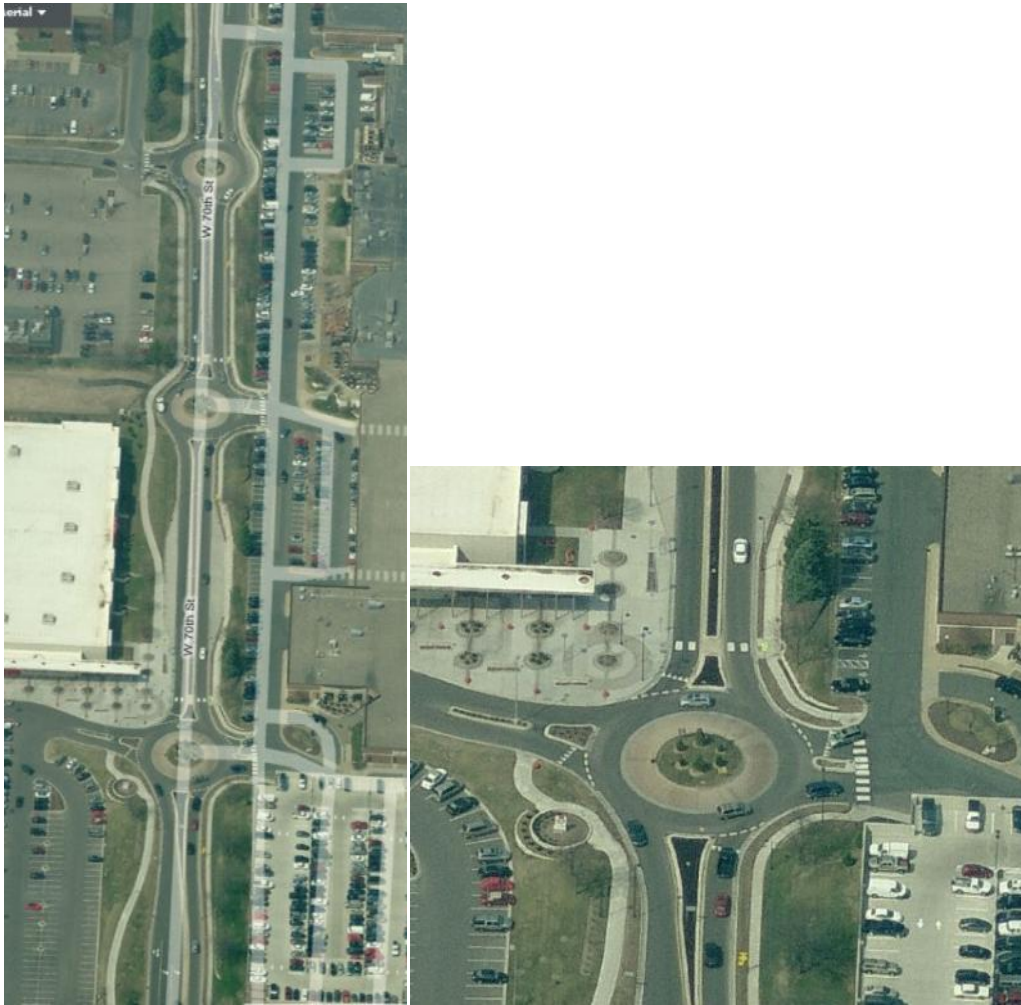
66th & Portland in Richfield, MN

Alternative name: County road 53
Right-of-way owner: Hennepin co
Number of lanes: 2
Traffic level: high
AADT: 10500
Number of pedestrian crossings: 4
Pedestrian crossing island size: large
Pedestrian frequency: High

Comments:

Permit and assistant contact info:

70th St. Edina, MN (Three Small Roundabouts)

Alternative name:
Right-of-way owner: Edina
Number of lanes: 1
Traffic level: high
AADT: 9600
Number of pedestrian crossings: 2
Pedestrian crossing island size: small
Pedestrian frequency: medium

Comments:

Permit and assistant contact info:

Wentworth and TH-52 (Two Roundabouts)

Alternative name: County Road 8
Right-of-way owner: Ramsey co (ramps owned by Mn/DOT?)
Number of lanes: 1
Traffic level: high
AADT: 10000
Number of pedestrian crossings: 4
Pedestrian crossing island size: none
Pedestrian frequency: unknown

Comments:

Permit and assistant contact info:

Jamaica Ave, Cottage Grove (Two Roundabouts)

Alternative name: Highway 61
Right-of-way owner: Mn/DOT and Cottage Grove
Number of lanes: 2
Traffic level: very high
AADT: 20000
Number of pedestrian crossings: 4
Pedestrian crossing island size: large (double in one approach)
Pedestrian frequency: unknown (there is possibly a bike trail)

Comments:

Complex geometry. One is a 6 way and the other is a 4 way.

Permit and assistant contact info:

Denmark Ave, Eagan

Alternative name:
Right-of-way owner: Eagan
Number of lanes: 1
Traffic level: high
AADT: 17100
Number of pedestrian crossings: 4
Pedestrian crossing island size: none
Pedestrian frequency: Medium to high

Comments:

Permit and assistant contact info:

Difley and Rahn, Eagan (No Photo Available)

Alternative name: County road 30
Right-of-way owner: Dakota county
Number of lanes: 1
Traffic level: high
AADT: 17100
Number of pedestrian crossings: 2 (one bike trail crossing)
Pedestrian crossing island size: none
Pedestrian frequency: low?

Comments:

Permit and assistant contact info:

New Prague, MN [Two Roundabouts, One with Potential (Left on the Picture)]

Alternative name: Hwy 19 & Hwy 13
Right-of-way owner: Mn/DOT
Number of lanes: 1
Traffic level: medium
AADT: 9500
Number of pedestrian crossings: 4
Pedestrian crossing island size: large
Pedestrian frequency: ???

Comments:

Permit and assistant contact info:

Setzler Pkwy N and Neddersen Pkwy N, Brooklyn Park

Alternative name:
Right-of-way owner: Brooklyn Park
Number of lanes: 1
Traffic level: low
AADT: 2100
Number of pedestrian crossings: 4
Pedestrian crossing island size: none
Pedestrian frequency: low

Comments:

Permit and assistant contact info:

TH-284 and CR-32, Waconia (Have Not Visited Yet, Future?)

Alternative name: TH-284
Right-of-way owner: Mn/DOT and Hennepin Co
Number of lanes: 1
Traffic level: medium
AADT: 6000
Number of pedestrian crossings: 4
Pedestrian crossing island size: large
Pedestrian frequency: ???

Comments:

Permit and assistant contact info:

CSAH 18 and Fenning Ave, Monticello, MN (Have Not Visited Yet)

Alternative name: CSAH 18
Right-of-way owner: Wright Co
Number of lanes: 2 (almost)
Traffic level: medium
AADT: 7500
Number of pedestrian crossings: 4
Pedestrian crossing island size: large
Pedestrian frequency: ???

Comments:

Permit and assistant contact info:

Roundabout	Rank
Minnehaha Falls park, Minnehaha Pkwy	
66th & 17th in Richfield, MN	
66th & Portland in Richfield, MN	
70th St. Edina, MN (Three small roundabouts)	
Wentworth and TH-52 (two roundabouts)	
Jamaica Ave and TH-61, Cottage Grove (two roundabouts)	
Denmark Ave, Eagan	
Difley and Rahn, Eagan	
New Prague, MN	
Setzler Pkwy N and Neddersen Pkwy N, Brooklyn park	
TH-284 and CR-32, Waconia (future?)	
CSAH 18 and Fenning ave, Monticello, MN	