DEPARTMENT OF TRANSPORTATION

Pedestrian User Experience at Roundabouts

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16. Abstract (Limit: 250 words)

This study explores the nature and extent of problems related to pedestrian user experience at Minnesota roundabouts. Pedestrian user experience in this study is measured by way of studying driver-yielding rates toward pedestrians at Minnesota roundabout crossings, pedestrian infrastructure design, and pedestrian behavior characteristics at Minnesota roundabout crossing treatments. To gather roundabout candidates for this study, a survey was conducted with Minnesota city and county engineers, as well as with the project Technical Advisory Panel members. Fifteen roundabouts were shortlisted for conducting field observations followed by installing multiple cameras at each roundabout. Eight roundabout locations were shortlisted for conducting case studies and in-depth analysis to study pedestrian user experience. Case study findings have shown that when compared to multi-lane roundabouts, single-lane roundabouts performed well in terms of driver vehicle-yielding rates toward pedestrians. Use of rectangular rapid flashing beacons (RRFBs) at pedestrian crossings has shown better driver-yielding rates while in-roadway signs have shown satisfactory results. Based on the knowledge gathered from previous research by way of literature review combined with Minnesota roundabouts studied in this research effort, a guidance document was developed to help city and county engineers enhance pedestrian user experience at Minnesota roundabouts.

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Pedestrian User Experience at Roundabouts

FINAL REPORT

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EXECUTIVE SUMMARY

Roundabouts can provide numerous pedestrian benefits such as lower vehicle speeds and much lower pedestrian delays compared to other types of intersections. However, transportation agencies in Minnesota and across the U.S. have received feedback from stakeholders indicating that roundabouts, especially larger multi-lane roundabouts, can be difficult to navigate. This study explores the nature and extent of problems related to pedestrian user experience at Minnesota roundabouts. Pedestrian user experience in this study is measured by way of studying driver-yielding rates toward pedestrians at Minnesota roundabout crossings, pedestrian infrastructure design as well as other pedestrian behavior characteristics at Minnesota roundabout crossing treatments. To gather roundabout candidates for this study, a survey was conducted with Minnesota city and county engineers as well as with the project's Technical Advisory Panel members. The survey was primarily aimed to gather pedestrian issues at existing roundabouts in Minnesota, i.e., frequent issues and complaints encountered from pedestrians using the roundabouts and a list of potential roundabouts with existing pedestrian issues that could be examined in the current study. The survey also compiled a list of roundabouts in Minnesota with specialized pedestrian crossing treatments, such as in-roadway signs, rectangular rapid flashing beacons, and others.

Field Observations of Roundabouts:

Fifteen roundabouts were shortlisted for field observations. The shortlisted roundabouts had a combination of "base case" roundabouts and roundabouts with specialized crossing treatments. Base case roundabouts referred to in the study were typically designed with a minimum Manual on Uniform Traffic Control Devices (MUTCD) requirement, and do not have any extra pedestrian crossing treatments. Shortlisted roundabouts were roundabouts with specialized crossing treatments such as rectangular rapid flashing beacon (RRFB), an in-roadway "State law — Stop for pedestrians in crosswalk" sign, or colored crosswalks.

Roundabouts were shortlisted in such a way that the research team had enough roundabouts with the three pedestrian crossing treatments identified, various roundabout configurations (1x1, 2x1, and 2x2 roundabouts), base case roundabouts in each configuration, and roundabouts that were geographically distributed across Minnesota.

Filed observations were conducted for all 15 shortlisted roundabouts, which included visiting each roundabout location, examining the site and roundabout geometry, recording relevant speed limits, finding opportunities for camera installation, and taking site pictures.

Video Data Analysis and Case Studies

Quality Counts LLC assisted the research team in recording video data at all 15 shortlisted roundabout locations. Quality Counts LLC installed cameras at all 15 roundabout locations. At each roundabout, one camera was installed for each leg in such a way that it overlooked the pedestrian crossing for that leg and had enough exposure to study the vehicle-pedestrian interaction at the leg. Each camera recorded

video footage for approximately 50 continuous hours. Therefore, for a 4-leg roundabout, approximately 200 hours of video footage was recorded from four cameras.

Based on the assessment of quality of the video footage recorded for the 15 roundabout locations, eight locations were identified as promising roundabout locations suitable for conducting case study analysis. This decision was also made by considering that the case studies should have a combination of base case roundabouts and roundabouts with various specialized crossing treatments.

The objective for conducting a case study for a roundabout location was to study pedestrian behavior and driver interactions with pedestrians at roundabouts as well as to analyze the driver-yielding behavior toward pedestrians. Eight case studies were conducted, and the list of case study roundabout locations was summarized in Table E1.

Table E1: List of Case Study Roundabout Locations

Case Study	Roundabout Location	City	Configuration	Crossing Treatment
1	Spencer St. and Vierling Dr,	Shakopee, MN	1x1	Base Case/ Paddle Signs
2	Zarthan Ave. S. and Cedar Lake Rd.	St Louis Park, MN	1x1	In-Roadway Signs
3	Richard J. Ames Memorial Highway & Holyoke Ave.	Lakeville, MN	2x1	Base Case
4	Lake Rd. & Woodbury Dr.	Woodbury, MN	2x1	In-Roadway Signs
5	Tracy Ave. & Valley View Ln.	Edina, MN	1x1	RRFB
6	Nicollet Ave. & W66 St.	Richfield, MN	2x1	RRFB
7	College Dr. & Mississippi Pkwy.	Brainerd, MN	2x1	Colored Crosswalk
8	East College Dr. & S. 4th St.	Brainerd, MN	2x1	Colored Crosswalk

During the 50 continuous hours of recorded video footage for each camera, only video data during the day was considered for analysis as a part of the case studies. Video data from 7 am to 8 pm was used as the time during which the research team studied pedestrian actions and pedestrian-vehicle interactions.

For conducting the video data analysis for the case studies, the research team adapted methodologies and procedures used in studies conducted by Schneider et al. (Schneider, et al., 2017) and Harkey and Carter (Harkey & Carter, 2006).

Pedestrian user experience at each case study roundabout is measured by way of studying driver-yielding rates toward pedestrians at roundabout crossings, pedestrian infrastructure design, and

pedestrian behavior characteristics at roundabout crossing treatments. Driver-yielding behavior is characterized as Active Yield (AY), Passive Yield (PY), and No Yield (NY) in the study.

Case study findings for eight roundabout locations has shown that, in general, single-lane roundabouts performed well in terms of vehicle-yielding rates toward pedestrians. A single-lane roundabout at Spencer Street and Vierling Drive in Shakopee, Minnesota, was observed to have an overall driver-yielding rate of 86.1%; a single-lane roundabout with in-roadway signs at Zarthan Avenue South and Cedar Lake Road in St Louis Park, Minnesota, was observed to have an overall driver-yielding rate of 85.7%; a single-lane roundabout with RRFBs at Tracey Ave. and Valley View Lane in Edina, Minnesota, was observed to have an overall driver-yielding rate of 100%. Driver-yielding rates decreased for multi-lane roundabouts. In general, for a roundabout leg, vehicle exit lanes had lower driver-yielding rates when compared to vehicle entry lanes. Vehicle approach speed and advisory speed posted for the roundabout also seemed to effect vehicle-yielding rates. Higher approach speed for a roundabout leg resulted in lower yielding rates.

Use of rectangular rapid flashing beacons (RRFBs) at two different roundabout locations (one 1x1 configuration and one 2x1 configuration) resulted in close to a 100% compliance rate when pedestrians activated the beacon. Therefore, availability of RRFBs for a crosswalk and use of these beacons by pedestrians enhanced the driver-yielding rates by improving the visibility for crossing pedestrians. Use of In-roadway signs at the pedestrian crosswalk yielded satisfactory yielding rates. However, the yielding rates went down as the number of lanes at the crosswalk increased from one to two.

Guidance Document

Knowledge gathered from previous research by way of literature review combined with Minnesota roundabouts studied in this research effort were used to develop guidance to help enhance pedestrian user experience at Minnesota roundabouts. Chapter 5 provided guidance for some important design elements that can enhance the pedestrian user experience at the roundabouts.

CHAPTER 1: BACKGROUND AND INTRODUCTION

Modern roundabouts are well known to be a safer intersection control when compared to other forms of control for at-grade intersections. A significant amount of research has proven that roundabouts decrease fatal and injury crashes when compared to their counterparts. While the safety benefits of roundabouts are definitely applicable to vehicles using the roundabouts, there are still concerns and questions whether these safety benefits also apply to pedestrians. Although roundabouts can provide numerous pedestrian benefits such as lower vehicle speeds and much lower pedestrian delays, transportation agencies in Minnesota and across the U.S. have received feedback from stakeholders indicating that roundabouts, especially larger multi-lane roundabouts, can be difficult to navigate.

Geruschat and Hassan conducted a study for two multi-lane roundabouts in Annapolis, Maryland, to evaluate drivers' yielding behavior to sighted and blind pedestrians (Geruschar & Hassan, 2005). Findings from the study showed that drivers' willingness to yield to pedestrians was related to speed of the vehicle and whether the vehicle was entering or exiting the roundabout. Drivers travelling at low speeds (<15mph) yielded to pedestrians at roundabouts 75% of the time when compared to 50% when travelling at high speeds (>20mph). Further, the study found that drivers at the entry lane yielded 79% of the time to pedestrians when compared to 37% of the time at exit lanes (Geruschar & Hassan, 2005). A similar finding was observed in a study conducted by Ashmead et al. where drivers yielded frequently in entry lanes but not in exit lanes (Ashmead, Guth, Wall, Long, & Ponchillia, 2005). Harkey and Carter conducted a comprehensive study at seven different roundabouts in six states with a goal to analyze interactions between motorists and pedestrians and bicyclists at roundabouts (Harkey & Carter, 2006). While the study did not find any substantial safety problems for pedestrians and bicyclists at roundabouts based on conflicts or collisions, findings from behavioral analysis emphasized that additional care was needed for some aspects of roundabout design to make sure that pedestrians and bicyclists can safely use the roundabout. As for the behavioral analysis, the study found that motorists were less likely to yield to pedestrians on the exit leg when compared to the entry leg, and therefore pedestrians and bicyclists were more likely to hesitate when crossing at the exit leg when compared to the entry leg. The study noted that two-lane approaches were more difficult for pedestrians to cross when compared to a one-lane approaches, since drivers did not yield as much on two-lane approaches. When compared to other types of traffic control at intersections, the study found that roundabouts under yield control had motorist and pedestrian behavior between the behaviors observed at crossings with no control and crossings with signal or stop control. Harkey and Carter concluded that proper care must be taken to design exit legs so that they have enough sight distance and low vehicle speeds. The authors also recommended additional measures (ranging from static warning signs to real-time devices) for safe pedestrian access for multilane roundabouts (Harkey & Carter, 2006).

Safety benefits for pedestrians are possible at roundabouts with good geometric design for the roundabout. A good geometric design can lower vehicular speeds at roundabouts and thereby increase the likelihood of drivers yielding to pedestrians as well as make potential crashes less frequent and less severe (Rodegerdts, et al., 2010). National Cooperative Highway Research Program Report 672, which is commonly known as the second edition of the roundabout informational guide, documents that single-

lane roundabout configurations designed for lower speed operations are the safest treatments possible for at-grade intersections. However, while multilane roundabouts' safety performance is generally better than signalized intersections, particularly for fatal and injury crashes, multilane roundabouts cannot achieve the same level of safety as single-lane roundabouts because drivers needs to make multiple decisions and pedestrians are faced with multiple threats while they cross more than one lane of traffic at multilane roundabout approaches and exits. Some of the design considerations the roundabout guide provides for creating safer roundabout configurations specifically for pedestrians in urban and suburban areas include minimizing travel lanes to simplify roundabout design and enhance pedestrian safety, designing roundabouts for slower speeds, designing sidewalks that are set back from the circulatory roadway, providing well-defined and well-located crosswalks, and providing a splitter island with a crosswalk as least 6-ft. wide (Rodegerdts, et al., 2010).

Madison, Wisconsin, has been building roundabouts for many years. To better accommodate pedestrians and bicyclists along with the motorized traffic at their roundabouts, the city identified a set of design techniques to be adapted from the beginning of the design process. Some of the summarized design techniques intended to improve pedestrian and bicycle safety include reducing the approach and circulating speed to enhance the safety and comfort of all users (motorized and non-motorized), reducing sign clutter at roundabouts that may distract drivers or hide pedestrians, implementing shorter crossing distance for pedestrians, maintaining proper roadway lighting to illuminate critical features of the roundabout, and using landscaping to limit excessive sight distance. When there is still difficulty in crossing for an already constructed roundabout with pedestrian safety concerns, the city identified a low-cost strategy of installing a rectangular rapid flashing beacon (RRFB) crossing treatment to enhance pedestrian crossing experience (U.S.DOT, 2014).

1.1 CHALLENGES FOR PEDESTRIANS WITH VISION DISABILITIES AT ROUNDABOUTS

For pedestrians with vision disabilities, user experience at roundabouts can be challenging, especially since roundabouts typically do not include pedestrian signals at most crossings. Multiple studies that investigate the gap acceptance and delay of sighted and blind pedestrians at roundabouts conclude that blind pedestrians are more reserved when at roundabouts and wait considerably longer to cross when compared to sighted pedestrians (Ashmead, Guth, Wall, Long, & Ponchillia, 2005) (Rouphail, Hughes, & Chae, 2005). Research has shown that the presence of accessible pedestrian signals (APS) at crossings can assist blind pedestrians by providing information about the signal phase so they can better understand traffic patterns, and therefore the presence of an APS at a roundabout crossings can assist blind pedestrians to cross safely. Further, the U.S. Access Board mentions in 2011's *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Rights-of-Way* that roundabouts with multilane pedestrian street crossings (multi-lane roundabout) require a pedestrian-activated APS to comply with the *Manual on Uniform Traffic Control Devices for Streets and Highways* (US Access Board, 2011).

The NCHRP Project 3-78A explored concerns of pedestrians with vision disabilities at intersections with channelized right-turn lanes and modern roundabouts to provide practitioners important information

on increasing accessibility at these facilities by improving safety and reducing delay (Schroeder, et al., 2011). As for the modern roundabouts, this study analyzed accessibility (increased safety and reduced delay) at three single-lane roundabouts and two multilane roundabouts. For this analysis, the research team selected roundabout locations so that the corresponding local road agency was supportive of a potential treatment installation and evaluation. The research team also recruited a pool of blind pedestrians to participate in crossing activity at roundabouts before and after a specific treatment was installed (Schroeder, et al., 2011). For single-lane roundabout configurations, the research team evaluated roundabouts without any crossing treatments and concluded that some blind pedestrians experienced difficulty crossing; however, it was noted that these difficulties were not beyond the difficulties blind pedestrians typically experience at similar signalized intersections, and therefore, single-lane roundabout configurations observed in the study were found to be accessible to blind pedestrians (Schroeder, et al., 2011). The accessibility of single-lane roundabouts for blind pedestrians from the study was linked to four main factors: 1) existence of low vehicle speeds at the crosswalk where speed reduction was achieved through good geometric design of the roundabout, 2) willingness of the majority of drivers to yield to pedestrians, 3) properly installed detectable warning surfaces to help blind pedestrians at the roundabout navigate toward the crosswalk, and 4) availability of a certified orientation and mobility specialist that accompanied the participant for the crossing exercise to explain intersection geometry and expected traffic patterns (Schroeder, et al., 2011). While the single-lane roundabouts analyzed in the study were observed to be accessible to blind pedestrians, the research team concluded that single-lane roundabout locations that have high vehicle speeds, high traffic volumes, and low driver-yielding rates toward pedestrians could still have accessibility concerns, and therefore future research needs to target such sites as well as evaluate the effectiveness of crossing treatments in such scenarios (Schroeder, et al., 2011). For multi-lane roundabouts, accessibility for blind pedestrians was studied using a similar framework at two locations with pre- and post-treatment installation. For post-treatment at the two-lane roundabouts, a pedestrian hybrid beacon (PHB) was tested at one roundabout and a raised crosswalk treatment was tested at the other crosswalk. The research team observed that both treatments resulted in significant decreases in pedestrian delay and crossing risk at the roundabout locations (Schroeder, et al., 2011). It is also important to note that a raised crosswalk resulted in improved pedestrian conditions at a test roundabout that was similar in performance to a more complex PHB treatment. The research team concluded that two-lane roundabouts were challenging for blind pedestrians and two-lane roundabouts can pose an unacceptable level of risk without some form of additional crossing treatment, or a drastic improvement in driver-yielding rates to pedestrians (Schroeder, et al., 2011).

Building on the research conducted as a part of NCHRP Project 3-78A, a study that was later published as NCHRP Report 674, NCHRP Project 3-78B focused on developing a guidebook for the application of crossing solutions at roundabouts and channelized turn lanes for pedestrians with vision disabilities. This project deliverable was geared to provide guidance for engineers and planners to design roundabouts and channelized turn lanes for blind pedestrians' accessibility. NCHRP Project 3-78B was later published as NCHRP Research Report 384 (Schroeder, et al., 2016) (NCHRP Web-Only Document 222, 2016).

While multiple studies researched accessibility of pedestrians with vision disabilities at roundabouts, little is known about the use of roundabouts by pedestrians with cognitive disabilities (Russell, 2008).

1.2 REVIEW OF RELEVANT MINNESOTA DEPARTMENT OF TRANSPORTATION ROUNDABOUT STUDIES

A 2012 Minnesota Department of Transportation (MnDOT) study conducted by John Hourdos investigated the pedestrian and bicycle experience at roundabout crossings in the Twin Cities at two different locations (Figure 1.1), 66th Street and Portland Avenue in Richfield and Minnehaha Parkway and Minnehaha Avenue in Minneapolis (Hourdos, 2012).

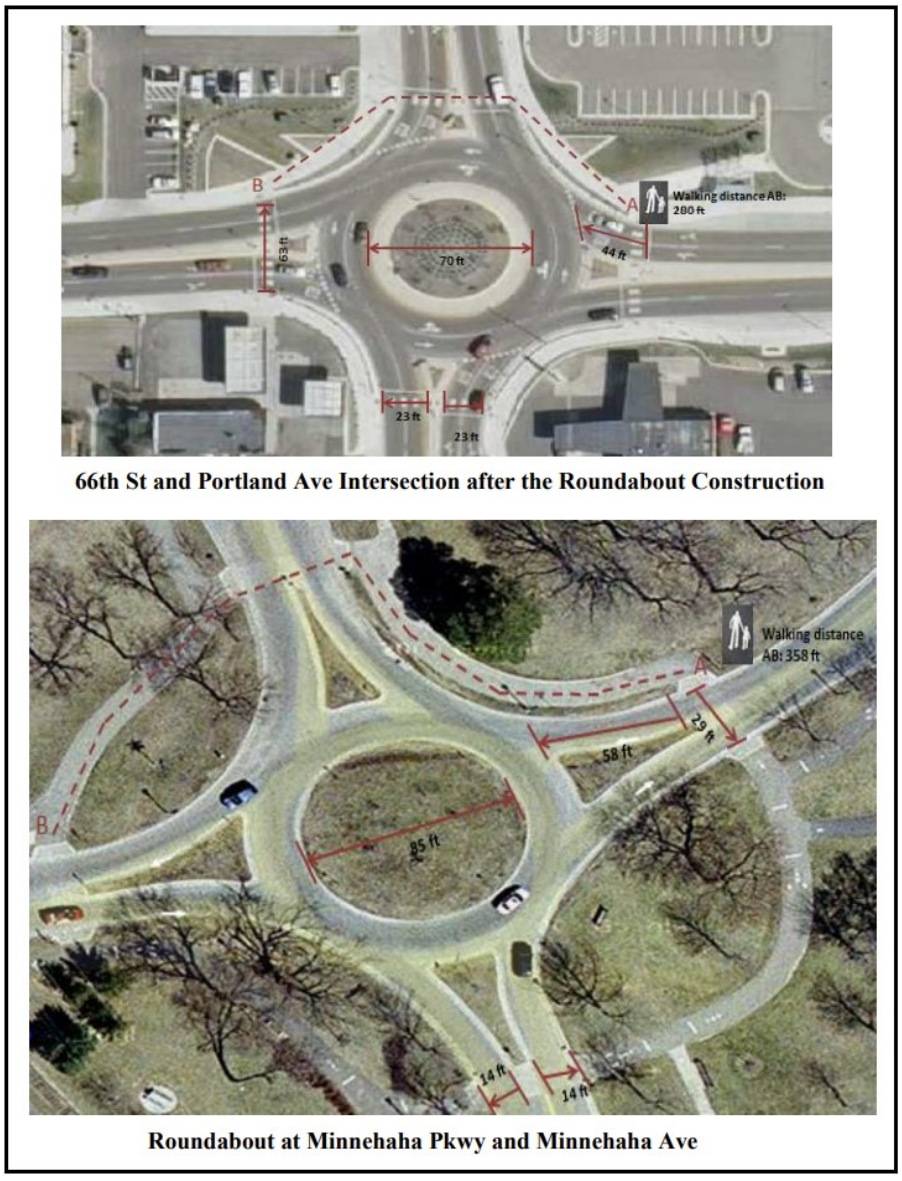


Figure 1.1 Roundabout study site locations for 2012 MnDOT study

Source: (Hourdos, 2012)

Video data was recorded to analyze vehicular traffic, roundabout operations, and bicycle and pedestrian behavior at the two selected roundabouts. Findings from the video data analysis showed that there was friction between pedestrians and drivers at the roundabout crossings studied. Driver yielding at the roundabout was observed at a higher probability when the pedestrian started from the splitter island and at lower probability when the vehicle was exiting the roundabout. Driver-yielding probability was observed to be decreased if a vehicle was present trying to enter the roundabout at the entrance next to the exit the driver wished to take. Furthermore, the probability of yielding for pedestrians decreased as the number of vehicles increased inside the roundabout. While there were some behavioral issues identified at the roundabouts studied, the study was not able to capture any safety compromising situations in the analysis. In addition, the delay for pedestrians observed at roundabouts was much lower than what the delay would have been at a signalized crossing with similar annual average daily traffic (Hourdos, 2012).

Leuer (2017) examined the safety performance of Minnesota roundabouts by comparing crash rates before and after construction at 144 Minnesota roundabouts (Leuer, 2017). The study considered single-lane roundabouts, unbalanced roundabouts, and full multilane roundabouts for its before-and-after crash-rate analysis, and found that roundabouts performed well at crash reduction, particularly for fatal and serious injury crashes with a more than 80% reduction. Table 1.1 shows the crash rates presented in the report for various intersection controls. By studying the crash rate (overall crash rate) and the fatal and serious injury crash rate for various controls, it can be noted that the overall crash rate was lower for single-lane roundabouts when compared to most of the other control methods. The overall crash rate was somewhat higher for unbalanced (partial multi-lane) roundabouts and significantly higher for roundabouts with multi-lane configurations on all sides. When looking at just the fatal and serious injury crash rates, roundabouts had lower crash rates than all other traffic controls (Leuer, 2017).

Table 1.1 Crash rates, fatal, and serious injury crash rates comparing various traffic control devices to roundabouts

Traffic Control Device	Crash Rate	Fatal and Serious Injury Crash Rate
Urban Thru-Stop	0.18	0.33
Rural Thru-Stop	0.25	1.05
Signal - Low Volume/Low Speed	0.52	0.42
All-Way Stop	0.35	0.57
Single Lane Roundabout	*0.32*	*0.31*
Signal - High Volume/Low Speed	0.70	0.76
Signal - High Volume/High Speed	0.45	0.48
Unbalanced Roundabout	*0.76*	*0.15*
Dual Lane Roundabout	*2.18*	*0.00*
All Roundabouts	*0.51*	*0.24*

Source: (Leuer, 2017)

1.3 POTENTIAL SOLUTIONS

A literature review has shown that multilane roundabouts and some single-lane roundabouts can pose threats for pedestrians using the crosswalks due to non-yielding drivers. Improving driver-yielding rates at roundabout crossings, through non-signalized and/or signalized options, could provide improved safety for pedestrians and ultimately improve the user experience for pedestrians at Minnesota roundabouts.

Signalization of pedestrian crossings at roundabouts can be beneficial in the following conditions: 1) at roundabout locations with high vehicular volumes and moderate pedestrian activity leading to insufficient gaps for pedestrians, 2) at roundabout locations with high pedestrian volumes where the crossing activity can negatively impact the vehicle capacity at the roundabout, and 3) at multilane roundabout crossings to provide accessibility where crossing becomes more complicated for regular pedestrians and almost impossible for pedestrians with vision impairments (Rodegerdts, et al., 2010). The U.S. Access Board's latest version of public right-of-way accessibility guidelines (PROWAG) proposes requiring accessible pedestrian signals at all crosswalks across any roundabout approach that has two or more lanes in one direction (US Access Board, 2011). It is important to note that MnDOT voluntarily adopts PROWAG as its departmental standard, with the lone notable exception of the roundabout signalization requirement.

This section focuses on identifying some of the promising crossing treatments that can help improve driver-yielding rates at roundabouts to enhance the pedestrian experience. While this section highlights some of the treatments that could specifically work for multilane roundabouts, there are many other possible non-signalized treatments available that are summarized in NCHRP Report 672 and NCHRP Report 834. This section highlights promising treatments feasible for potential application to Minnesota roundabouts. Much of the information in this section is gathered from the NCHRP Report 834, *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*. The report is a comprehensive effort to identify crossing treatments accessible to blind pedestrians, and there is no doubt that these treatments would also make roundabouts safer for all pedestrians.

1.3.1 Staggered Crosswalk

Staggered crossings at roundabouts can be designed to align the exit crosswalk farther from the roundabout's circulating lane as shown in Figure 1.2 (Schroeder, et al., 2016). Benefits with staggered crossings at roundabouts include availability of increased driver reaction distance to pedestrians while exiting the roundabout, more queue storage of cars, and improved auditory information for blind pedestrians. Some of the challenges for staggered crossings include the possibility of high vehicle speeds caused by locating the crosswalk farther way from the circulatory roadway, and pedestrians turning away from the flow of vehicular traffic they encounter when crossing the street (Schroeder, et al., 2016).

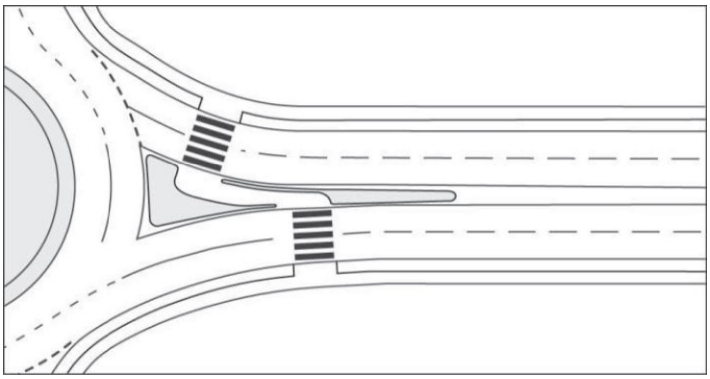


Figure 1.2 Staggered crosswalk with exit crosswalk further from roundabout

Source: (Schroeder, et al., 2016)

1.3.2 Raised Pedestrian Crossings

Non-signalized treatments such as raised pedestrian crossings introduce a vertical deflection for drivers to help reduce speeds and improve the likelihood of drivers yielding to pedestrians (Schroeder, et al., 2016). This traffic calming treatment could cost anywhere between $8,000 and $39,000 not including drainage improvements. Care must be taken to make sure the speed reduction does not significantly reduce the lane capacity and outweigh the benefits attained by speed reduction. Figure 1.3 illustrates a raised pedestrian crosswalk installed at an approach for a two-lane roundabout. Raised pedestrian crossings can be potentially combined with signalized treatments such as a yellow flashing beacon or rectangular rapid-flashing beacon (RRFB) to alert drivers to pedestrians and encourage them to yield (Schroeder, et al., 2016).

Figure 1.3 Raised crosswalk at a two-lane roundabout

Source: (Schroeder, et al., 2016)

It also has to be noted that raised crosswalks present vertical obstructions for emergency vehicles and snowplows, although there are snowfall locations with raised pedestrian crossing treatments (Schroeder, et al., 2016).

1.3.3 Pedestrian Hybrid Beacon

A pedestrian hybrid beacon (PHB), or HAWK signal as it is commonly called, is a traffic-control device to provide drivers information as to when to stop when a pedestrian is present and activates the signal (Schroeder, et al., 2016). Figure 1.4 illustrates a PHB signal at a roundabout crossing in Golden, Colorado, and Figure 1.5 illustrates the sequence of PHB displays for drivers and pedestrians. When compared to regular red/yellow/green signals, PHBs are efficient in that they allow vehicles to move on the pedestrian flashing do-not-walk interval when pedestrians are not in the crosswalk. The cost of installing a PHB is anywhere between $68,000 to $133,000 for the initial leg, and anywhere between $29,000 and $80,000 for each subsequent leg (Schroeder, et al., 2016).

Figure 1.4 Pedestrian hybrid beacon at roundabout in Golden, Colorado

Source: (Schroeder, et al., 2016)

It is important to note that the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) includes PHBs under traffic-control devices and further provides provisions for use of PHBs at roundabouts (MUTCD, 2009). One of the challenges with PHBs is driver familiarity (Schroeder, et al., 2016). Drivers not familiar with the PHB can be confused with the dark phase of the signal (when drivers tend to stop when they instead are supposed to continue driving) and the alternating flashing red phase of the signal (when drivers tend to continue to stay stopped even though there are no pedestrians in the crosswalk).

Therefore, proper care must be taken to install PHBs at locations and in cities where there already are PHBs, or better outreach efforts are made to educate drivers (Schroeder, et al., 2016).

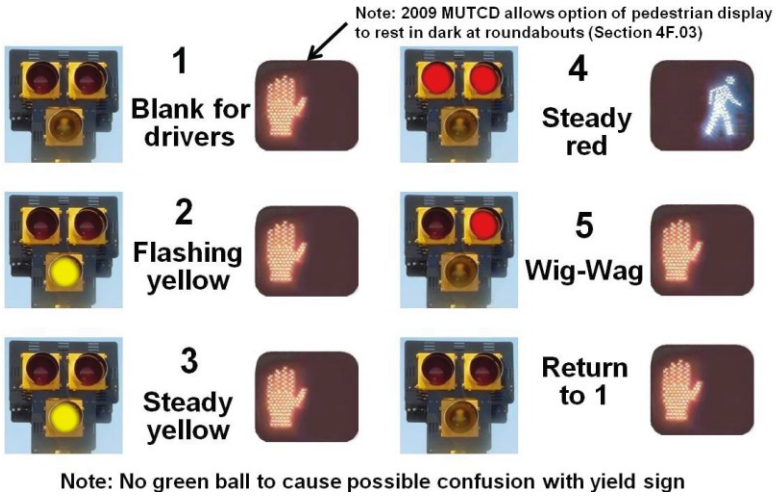


Figure 1.5 Sequence of displays at a pedestrian hybrid beacon

Source: (Schroeder, et al., 2016)

1.3.4 Rectangular Rapid-Flashing Beacon

A rectangular rapid-flashing beacon (RRFB) is a visually enhanced driver-warning device activated by the pedestrian and provided as a supplement for static warning signs (Schroeder, et al., 2016). RRFBs do not have solid-red indicators for motorists or walk indicators for pedestrians, both of which are important characteristics with standard pedestrian signals and PHBs. Figure 1.6 shows an RRFB installed at a two-lane roundabout.

Figure 1.6 RRFB at a two-lane roundabout

Source: (Schroeder, et al., 2016)

An RRFB's primary function is to increase driver awareness of pedestrians crossing or preparing to cross. One of the unique advantages of RRFBs is that they achieve driver-yielding rates similar to traditional signals or PHBs but are much more affordable to install. RRFBs cost anywhere between $26,000 and $49,000 per leg (Schroeder, et al., 2016). As of March 2018, RRFBs received interim approval status from the FHWA for optional use as a pedestrian-actuated, conspicuity enhancement for pedestrian and school crossing warning signs under certain limited conditions (FHWA, 2018).

1.3.5 Flashing Beacon

A flashing beacon is a driver improvement treatment provided in combination with static warning signage. Flashing beacons are installed on overhead signs, in advance of the crosswalk, or on signs at the crosswalk to make the beacon more visible to drivers. Yellow flashing beacons improve driver-yielding rates to pedestrians, and therefore pedestrians can benefit from installations at roundabout crossings. While a flashing beacon improves driver-yielding rates, it is less than what is possible with a RRFB because an RRFB is much more visible to drivers than flashing beacons. Figure 1.7 shows a yellow flashing beacon at a roundabout in Canada.

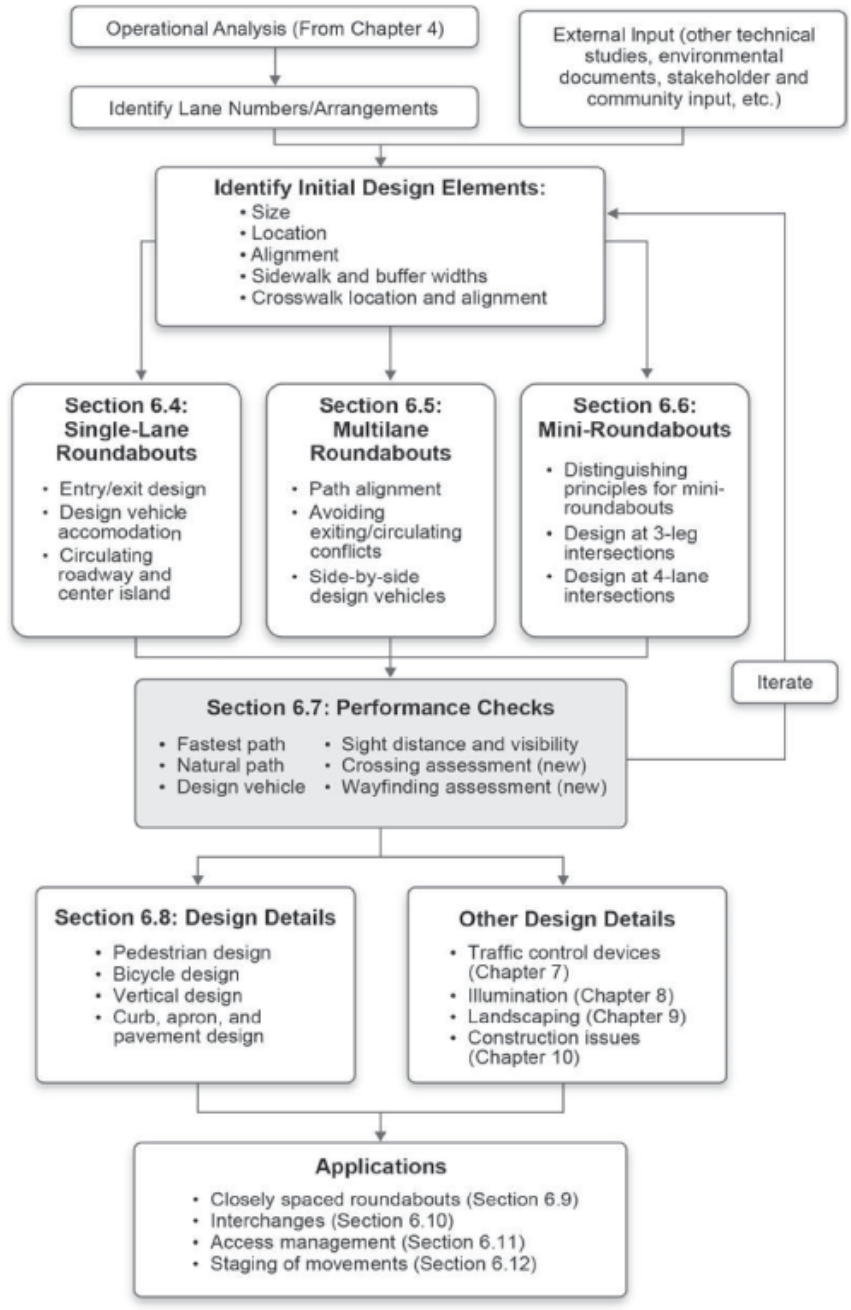
Figure 1.7 Traditional yellow warning beacon at a roundabout in Canada

Source: (Schroeder, et al., 2016)

1.4 EVALUATING POTENTIAL SOLUTIONS

The literature review conducted highlights that a roundabout with good geometric design is key to providing a better user experience for both drivers and pedestrians. NCHRP Report 672 (also referred to as the second edition of the roundabout guide) provides a comprehensive process for designing a roundabout. The key strategy illustrated in this process is starting with an initial design and refining the design in numerous iterations by following multiple checks throughout the design process (Rodegerdts, et al., 2010). The summary of the roundabout design process from the second edition of the roundabout guide is presented in Figure 1.8. As can be seen in the figure, after multiple iterations to develop a suitable roundabout design, two major steps are pedestrian design within the design details step and

traffic control devices in the other design details step. While the NCHRP 672 report provides guidelines for incorporating these two aspects when designing a roundabout for a site, this section focuses on promising solutions and their effectiveness in enhancing pedestrian user experience based on current available literature, including reports from NCHRP projects 3-78A, B, and C.



Note: The chapter and section numbers in this figure refer to *NCHRP Report 672*.

Figure 1.8 Guidance for roundabout design process

Source: (Rodegerdts, et al., 2010)

1.5 PEDESTRIAN ACCESSIBILITY AT ROUNDABOUTS

1.5.1 Single-Lane roundabouts

Single-lane roundabouts typically do not pose pedestrian crossing difficulties at well-designed roundabouts, and this characteristic can be critically linked to factors such as low vehicles speeds achieved due to good geometric design and willingness of a majority of drivers to yield to pedestrians. However, single-lane roundabouts could also have pedestrian accessibility concerns in situations where there is a significant percentage of drivers who drive at higher speeds than the posted speed limits while approaching the crosswalks, resulting in a lower likelihood of drivers yielding to pedestrians. In such scenarios, good design principles or pedestrians crossing treatments can be installed to make drivers more aware and help pedestrians cross safely.

1.5.2 Two-Lane Roundabouts

Two-lane roundabouts can be more challenging for pedestrians primarily due to higher volumes of traffic, higher speed of vehicles and longer crossing distances than with single-lane roundabouts. To account for these pedestrian challenges, the *US Access Board Draft Public Rights-of Way Accessibility Guidelines* (PROWAG), in accordance with the Americans with Disability Act (ADA), specifies a pedestrian-actuated signal, i.e., a pedestrian hybrid beacon (PHB) (US Access Board, 2011), or equivalent, for pedestrian crossings at two-lane or more-lane roundabouts be installed. Other treatments that can facilitate equivalent accessibility would be acceptable.

1.5.3 Treatments to Improve Pedestrian Accessibility at Roundabouts

NCHRP Project 3-78A study identifies 28 promising treatments to improve pedestrian accessibility if the site already meets design standards and accessibility standards (NCHRP3-78a, 2011). These treatments could potentially be implemented at roundabouts to increasing accessibility. These 28 treatments are grouped into six categories and are briefly explained below.

1.5.3.1 Driver Information Treatments: Static pedestrian crossing signs at crosswalks are unlikely to produce higher levels of driver-yielding; therefore, improvements made to these static roadside warning signs may improve driver yielding. Some of the improvements include adding a continuous flashing beacon to a static sign to make it more noticeable, installing in-roadway yield-to-pedestrian signs to increase the impact of the crosswalk, and adding active-when-present flasher treatments, which are similar to a continuous flashing beacon but operated dynamically when a pedestrian pushes a button or when a pedestrian is passively detected.

1.5.3.2 Traffic Calming Treatments: Calming treatments that encourage drivers to reduce speeds can help in achieving higher driver-yielding rates toward pedestrians. Some traffic calming treatments that

can be considered at roundabouts include posting lower regulatory speeds (typically 15-25 mph) and constructing a raised pedestrian crosswalk.

1.5.3.3 Pedestrian Information Treatments: These treatments include systems that provide pedestrians with audible information to help them identify yields and/or gaps to safely cross. Some of the treatments in this category have not been fully developed. Treatments in this category include use of surface alterations such as rumble strips to generate auditory cues for pedestrians to approaching and yielding vehicles, use of in-road sensors or video image processing techniques to detect driver-yielding behavior, use of in-road sensors to help determine a safe crossing time at the crosswalk, and use of hypothetical yield- and gap-detection systems.

1.5.3.4 Crosswalk Geometric Modification: This treatment modifies the usual pedestrian crosswalk location to an alternative crossing location that is farther away from the circulatory roadway, i.e., distal, to separate pedestrian-vehicle interaction that takes place at crosswalks close to the exit of a roundabout. Some of the treatments in this category include installing distal crosswalks, which involves relocating the crosswalk approximately 100 ft. away from the circulating lane to lower the ambient noise at the crosswalk that is caused by vehicles in the circulatory roadway, combining distal crosswalk treatments with some traffic calming measures to reduce speeds, installing medial islands to establish a two-stage crossing at a distal location, and offsetting exit-lane crossings to create a zigzag crossing that promotes a two-stage crossing strategy for pedestrians as well as provides greater queue storage prior to the crosswalk for exiting vehicles.

1.5.3.5 Signalized Treatments with APS: Signals are comparatively costly and an intrusive way of providing safer pedestrian crossing environments. Signals with walk indicators should be outfitted with APS to provide auditory cues to pedestrians. Some of the treatments in this category include a pedestrian scramble phase where all vehicle traffic at a roundabout is stopped to allow pedestrian movement in all directions, pedestrian-actuated traditional red/yellow/green signal, pedestrian hybrid beacons, distal pedestrian actuated signals in a one- or two-stage pedestrian crossing, and a distal PHB treatment at a one- or two-stage pedestrian crossing.

1.5.3.6 Grade-Separated Crossing: Grade separated crossings are typically used in cases where pedestrian volumes are extremely high and where pedestrians need to cross very busy streets or freeways. This treatment allows pedestrians to cross a road without affecting the vehicle flow.

While the long list of treatments synthesized from the literature has some merit to enhance pedestrian accessibility at roundabouts, this study will focus on treatments that have the most cost-effective benefit for enhancing pedestrian accessibility and improving driver-yielding behavior. Furthermore, treatments analyzed in this study will focus on roundabout crossing treatments that are already being used at Minnesota roundabouts so that these candidate roundabouts can be further analyzed for performance.

While signalized crossings are costly and intrusive crossing treatments at roundabouts, they can be beneficial at roundabouts when there is high vehicular volume, high pedestrian volume, or where

needed to provide better pedestrian accessibility at more complex pedestrian crossing situations. Rectangular rapid flashing beacons (RRFB) and pedestrian hybrid beacons (PHB) are electronic treatments that are commonly used at roundabouts that have shown promise to enhance pedestrian user experience as well as to alert drivers to crossing pedestrians. Between these two electronic treatments, PHBs are a costlier pedestrian crossing treatment when compared to RRFBs. PHB displays are sometimes not fully understood by drivers, negating the benefits of reducing driver delay relative to traffic signals. Pedestrian actuated yellow flashing beacon treatments are also found to be somewhat effective crossing treatments for roundabout crosswalk installations. One strategy that multiple roundabout implementations across the U.S. have followed include using raised pedestrian crosswalks with one of the signalized treatments (yellow flashing beacon, RRFB, etc.) to further improve driver compliance than what would have been possible with just an electronic crossing treatment. For roundabouts, signals are usually post-mounted because of their slow-speed environments as opposed to overhead signals that are installed at signalized intersections. Use of a post-mounted PHB or RRFB beacons, or other suitable effective electronic treatments that may be developed at roundabouts also help to significantly reduce the cost of installation (Schroeder, et al., 2016). Chapter 3 and 4 of this study explore all possible roundabout crossing treatments in Minnesota and present case studies for various crossing treatments.

CHAPTER 2: STUDY METHODOLOGY

The study methodology adopted for this research effort was to:

1. Initially develop an understanding of the extent and nature of the problems related to pedestrian user experience at roundabouts through literature review. This effort was documented in Chapter 1.
2. Understand the nature and extent of the problems related to pedestrian user experience at Minnesota roundabouts. To achieve this objective, a survey was conducted with Minnesota city and county engineers, as well as with the project Technical Advisory Panel members. The survey was primarily aimed to gather pedestrian issues at existing roundabouts in Minnesota, i.e., frequent issues and complaints encountered from pedestrians using the roundabouts, and a list of potential roundabouts with existing pedestrian issues that could be examined in the current study. This effort compiled a list of roundabouts in Minnesota with specialized pedestrian crossing treatments such as in-roadway signs, rectangular rapid flashing beacons, etc.,
3. Evaluate the list of roundabouts gathered from the survey and shortlist a final set of roundabouts to be examined in the current study by conducting field observations and case studies.
4. Conduct field observations for the shortlisted roundabouts. Filed observations included visiting each roundabout location, examining the site and roundabout geometry, recording relevant speed limits, finding opportunities for camera installation, and taking site pictures.
5. Install cameras for 15 roundabout locations and record video data for approximately 50 hours per each camera. Evaluate and study the recorded video data.
6. Conduct case studies for eight roundabout locations by studying vehicle-pedestrian interaction metrics at each roundabout.
7. Prepare guidance material to assist city and county engineers in the state of Minnesota to select proper crossing treatments for Minnesota roundabouts.

CHAPTER 3: FIELD OBSERVATIONS OF ROUNDABOUTS

Potential roundabout candidates in Minnesota with known pedestrian issues were identified as a next step of the project to conduct field observations. At this stage, roundabouts in Minnesota with some specialized pedestrian crossing treatments were identified to determine the effectiveness of the crossing treatment in achieving increased drivers yielding rate towards pedestrians, and how they compare with roundabouts with no specialized crossing treatments
To identify roundabout candidates of interest, the research team prepared an online survey questionnaire to gather the needed critical information to help shortlist the roundabouts for conducting field observations. The survey questionnaire is shown in Appendix A. The survey questionnaire was distributed to the project Technical Advisory Panel members, all Minnesota city engineers through the organization "City Engineers Association of Minnesota," and all Minnesota county engineers though the organization "Minnesota County Engineers Association."

A total of 91 survey responses were received. Appendix B summarized the list of roundabouts mentioned as having some pedestrian issues based on the survey responses. These roundabouts were typically designed with a minimum MUTCD requirement, and do not have any extra pedestrian crossing treatments. These roundabouts will be referred to as "base roundabouts" in the study since the driver-yielding rates from roundabouts without any specialized crossing treatments will be considered as a base case to compare with those that have one or more specialized pedestrian treatment(s).

The survey responses and follow-up emails and phone calls with survey respondents were recorded and summarized for specialized crossing treatments at Minnesota roundabouts. Some of the specialized crossing treatments that are being implemented at these roundabouts include rectangular rapid flashing beacon (RRFB), in-roadway "State law - Stop for pedestrians in crosswalk" sign, and colored crosswalks. These crossing treatments were selected for analysis and comparison for driver compliance rates with base case roundabouts. Appendix C summarized the list of roundabouts in Minnesota that has some sort of specialized pedestrian treatment than a minimum MUTCD requirement for a roundabout.

A total of 15 roundabouts were selected from a pool of base case roundabouts and roundabouts with specialized crossing treatments to be analyzed in this study. These 15 roundabouts and their details are summarized in Table 3.1; A Minnesota state map with these 15 locations marked is shown in Figure 3.1. Roundabouts were selected in such a way that the research team had enough roundabouts with the three pedestrian crossing treatments identified, various roundabout configurations (1x1, 2x1, and 2x2 roundabout), have base case roundabouts in each roundabout's configuration, and make sure the roundabouts are geographically distributed across the state of Minnesota.

Table 3.1 List of roundabouts selected for video recording and analysis

S. No.	Roundabout Location	Roundabout Configuration	Crossing Treatment	Quick Google Link to Location
1	Spencer St. & Vierling Dr., Shakopee, MN	1x1 roundabout	Base Case	https://www.google.com/maps/@44.7834751,-93.5197929,242m/data=!3m1!1e3
2	Dakota Rd. 60 & Holyoke Ave., Lakeville, MN	2x1 roundabout	Base Case	https://www.google.com/maps/@44.6561747,-93.242647,362m/data=!3m1!1e3
3	Pioneer Rd. & Twin Bluff, Red Wing, MN	1x1 roundabout	Base Case	https://www.google.com/maps/@44.5430792,-92.5443314,431m/data=!3m1!1e3
4	Lake Road at Woodbury Dr. (County 19), Woodbury, MN	2x1 roundabout	In-Roadway Signs	https://www.google.com/maps/@44.9028459,-92.9042119,303m/data=!3m1!1e3
5	W 66th St. & Lyndale Ave. S., Richfield, MN	2x1 roundabout	RRFB	https://www.google.com/maps/@44.8834153,-93.2887692,17z
6	E 66th St. & Nicollet Ave. S., Richfield, MN	2x1 roundabout	RRFB	https://www.google.com/maps/@44.8834609,-93.2804222,17z
7	E 66th St. & Portland Ave. S., Richfield, MN	2x2 roundabout	RRFB	https://www.google.com/maps/@44.8835825,-93.2700152,17z
8	Zarthan Ave. S. & Cedar Lake Rd., St Louis Park, MN	1x1 roundabout	In-Roadway Signs	https://www.google.com/maps/@44.9650058,-93.3547308,523m/data=!3m1!1e3
9	Highway 7 and Louisiana, St. Louis Park, MN	2x1 roundabout	Base Case	https://www.google.com/maps/@44.9383792,-93.3706521,574m/data=!3m1!1e3
10	Tracy Ave. & Velley View Ln., Edina, MN	1x1 roundabout	RRFB	https://www.google.com/maps/@44.8846497,-93.3699961,428m/data=!3m1!1e3
11	Scandia Trail N. (TH 97) and 8th St./Goodview Ave. N., Forest Lake, MN	1x1 roundabout	RRFB	https://www.google.com/maps/@45.2547726,-92.9858382,675m/data=!3m1!1e3
12	Lake St. (US 61) at Broadway Ave. (County 2), Forest Lake, MN	1x1 roundabout	Base Case	https://www.google.com/maps/@45.2787625,-92.9851491,506m/data=!3m1!1e3
13	Minnesota Highway 22 & Madison Ave., Mankato, MN	2x2 roundabout	Base Case	https://www.google.com/maps/@44.1668461,-93.9483086,516m/data=!3m1!1e3
14	College Dr. & Mississippi Pkwy, Brainerd, MN	2x1 roundabout	Colored Concrete	https://www.google.com/maps/@46.3471646,-94.2124982,394m/data=!3m1!1e3
15	College Dr. & S. 4th St.; Brainerd, MN	2x1 roundabout	Colored Concrete	https://www.google.com/maps/@46.3471646,-94.2124982,394m/data=!3m1!1e4

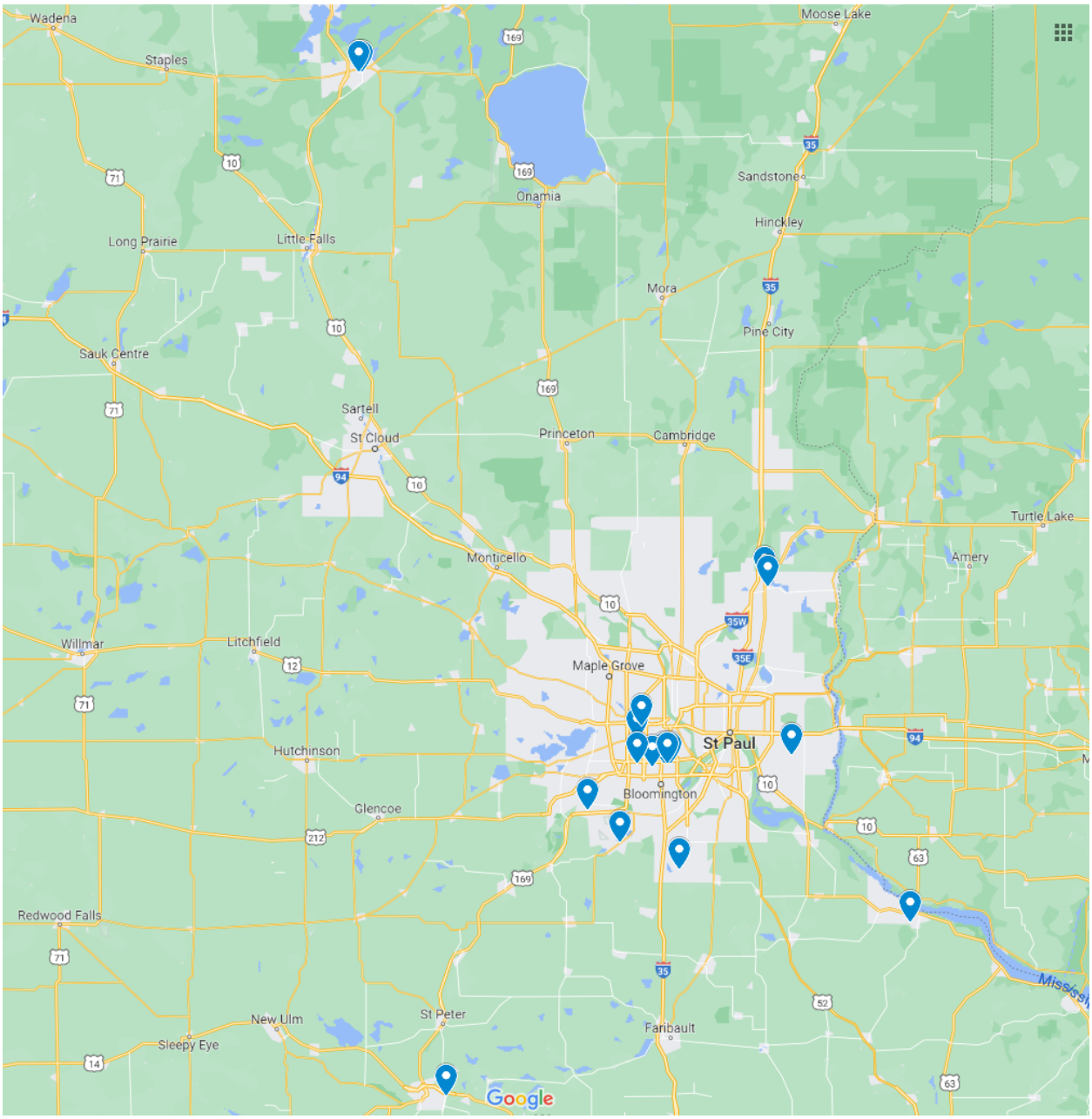


Figure 3.1 Roundabout locations selected for video recording and analysis in the state of Minnesota

3.1 FIELD OBSERVATIONS AND VIDEO DATA RECORDING AT FINALIZED LIST OF ROUNDABOUTS

For the 15 roundabouts shortlisted for the study analysis, apart from the input provided from the survey respondents, the research team had followed-up with the survey respondents as well as other relevant city/county officials via phone/email to gather more details such as design specifications, safety record of the intersections, details of pedestrian challenges faced, etc. Through communications and by examining google maps, the research team gathered as much information as possible on each site. Site

visits were also been conducted to most of the 15 roundabouts finalized for the study in an effort to gather important information for installing cameras for video data collection.

3.2 VIDEO DATA ANALYSIS

Quality Counts LLC was selected as a contractor by the research team to record video data at all the 15 shortlisted roundabout locations. Detailed guidance was provided to Quality Counts team regarding the needs, and requirements of the research team for the video footage at each roundabout leg (Refer Appendix E). At each roundabout, one camera was installed for each leg in such a way that it overlooks the pedestrian crossing for that leg and has enough exposure to study the vehicle-pedestrian interaction at the leg. Therefore, a 4-leg roundabout will have four cameras installed, one on each individual leg. Quality Counts LLC used 'CountCAM 2' cameras for their video data recording purposes. Each camera has recorded video footage for approximately 50 continuous hours. Therefore, for a 4-leg roundabout, approximately 200 hours of video footage is recorded from four cameras. Before the Quality Counts team installed the cameras, representative city, county, and MnDOT officials were contacted to request permission or apply for permit. Needed permissions or permits were received for all the 15 roundabouts before the cameras were installed and video data recording for all the 15 selected roundabouts was conducted in October 2021.

After the research team received the video files from Quality Counts LLC personnel, video footage for each approach was reviewed and an assessment was made on which roundabout locations had good enough quality video data to be useful for a case study analysis. Based on the assessment, eight locations were identified as promising roundabout locations suitable for case study analysis – this decision was also made by considering that the case studies should have a combination of base case roundabouts and roundabouts with various specialized crossing treatments.

Video footage from the rest of the locations were determined as not suitable due to multiple reasons, such as, poor video quality, video footage being hazy or camera having water droplets due to weather events, video footage having a lot of shake due to wind, trees or parked vehicles obstructing the pedestrian crosswalk, and roundabout location being in a construction zone while the video is being recorded. The research team had anticipated these outcomes and a potential loss of roundabout locations due to unforeseen circumstances, and therefore had oversampled the shortlisted 15 locations, with an intention to arrive at final 6-10 case studies. As anticipated, eight locations were identified for the case studies.

CHAPTER 4: CASE STUDIES

4.1 CASE STUDY OBJECTIVES AND METHODOLOGY:

The objective for conducting a case study for a roundabout location is to study the pedestrian behavior, driver interactions with pedestrians at roundabouts, and to analyze the driver-yielding behavior towards pedestrians. Further, the case studies were also intended to determine how various factors, such as approach speed limit, roundabout advisory speed, pedestrian crossing treatments, roundabout location, etc., could influence the pedestrian and driver behavior.

Eight case studies were conducted and the list of case study roundabout locations are shown in Figure 4.1 and summarized in Table 4.1.

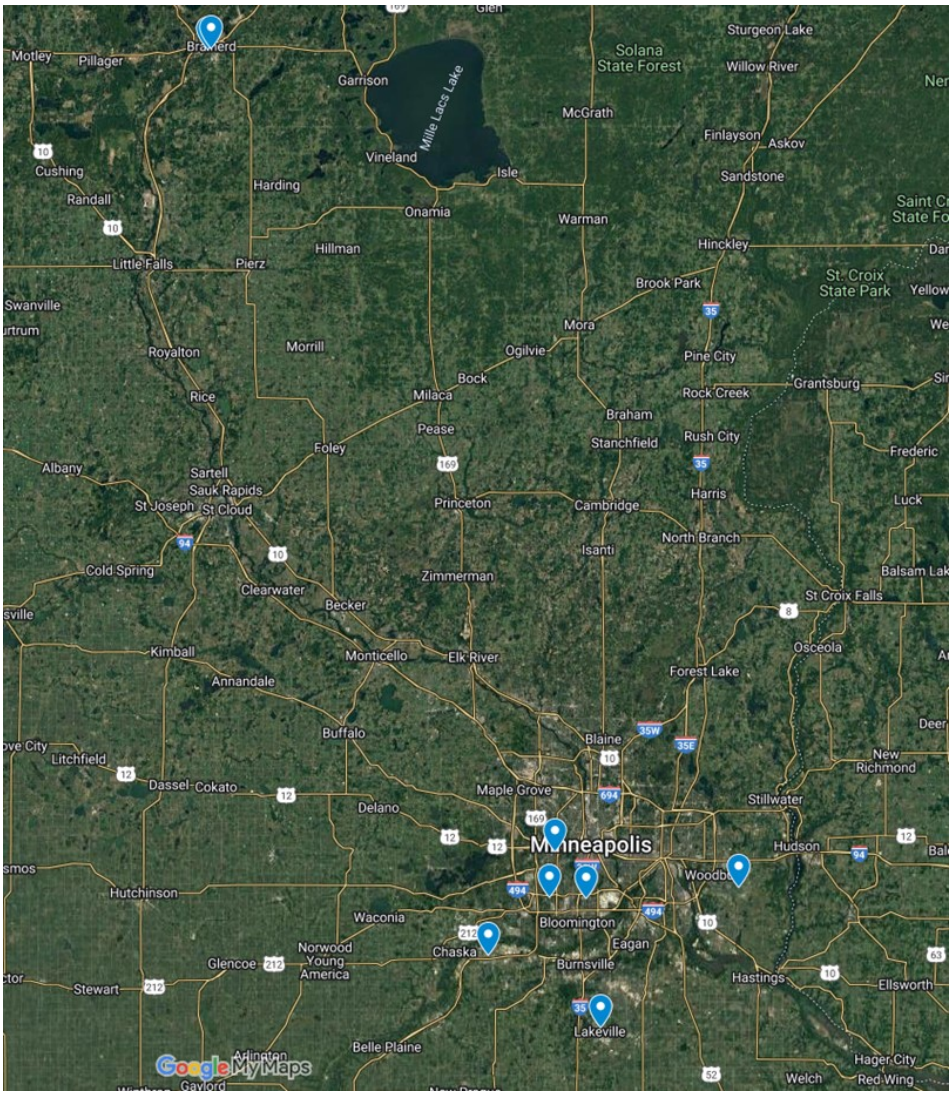


Figure 4.1 Case study roundabout locations in Minnesota

Table 4.1 List of case study roundabout locations

Case Study	Roundabout Location	City	Configuration	Crossing Treatment
1	Spencer St. and Vierling Dr.	Shakopee, MN	1x1	Base Case/ Paddle Signs
2	Zarthan Ave. S. and Cedar Lake Rd.	St Louis Park, MN	1x1	In-Roadway Signs
3	Richard J. Ames Memorial Hwy. & Holyoke Ave.	Lakeville, MN	2x1	Base Case
4	Lake Rd. & Woodbury Dr.	Woodbury, MN	2x1	In-Roadway Signs
5	Tracy Ave. & Valley View Ln.	Edina, MN	1x1	RRFB
6	Nicollet Ave. & W66 St.	Richfield, MN	2x1	RRFB
7	College Dr. & Mississippi Pkwy.	Brainerd, MN	2x1	Colored Crosswalk
8	East College Dr. & S. 4th St.	Brainerd, MN	2x1	Colored Crosswalk

4.2 VIDEO DATA ANALYSIS METHODOLOGY

Each camera generated one recorded video file with approximately 50 hours of video footage from each leg of the roundabout. The 50 hours of video footage is a continuous recording, and therefore video data is recorded for a little over two calendar days, including recording during day and night. The video footage during the night was intended to be used to observe the vehicles using the roundabout, but it was very unreliable to detect pedestrians using the roundabout as well to characterize their behavior at the crossing during the night. Therefore, during the 50 continuous hours of recorded video footage, only video data during the day was considered for analysis as a part of the case studies. Video data during 7am-8pm was used as the time during which the research team studied the pedestrian's actions and pedestrian-vehicle interactions.

For conducting the video data analysis, the research team has adapted methodologies and procedures used in the studies conducted by Schneider et. al (Schneider, et al., 2017), and Harkey and Carter (Harkey & Carter, 2006). While studying the video footage from 7am-8pm, the research team primarily observed for pedestrians at the roundabout leg. Once a pedestrian(s) were spotted, it was categorized as a pedestrian event, and the event was recorded in an excel sheet (Table 4.2 shows a sample excel sheet for a location with data entered for pedestrian interactions) in detail. Initially the date and time of the pedestrian event was recorded. Date and time are available on the video footage as a time stamp, and this information was recorded in the excel sheet. Later, the number of pedestrians using the

crosswalk during the pedestrian event was counted and recorded. The side of the crosswalk at which the pedestrian begins the crossing was also recorded, i.e., – pedestrians can begin crossing at the vehicle entry lane or at the vehicle exit lane. If the crosswalk has specialized crossing treatment such as rectangular rapid flashing beacon (RRFB), the research team observed the video footage to determine if the pedestrian activated the 'Push Button.' Pedestrian delay was measured at the beginning of the crosswalk or while the pedestrian waited at the splitter island. When a pedestrian was waiting to cross or was already crossing, yielding opportunity by vehicles was also determined – this means that when the pedestrian appears about to cross or already crossing, and if a vehicle approaches the crosswalk, there is an opportunity for the vehicle to yield to the pedestrians. For each pedestrian event, when there is a yielding opportunity, the yielding behavior of the vehicles was measured for both the entering vehicles and exiting vehicles for each roundabout leg. Yielding behavior is characterized as Active Yield (AY), Passive Yield (PY), and No Yield (NY) (See the next section, 4.3). Pedestrian crossing behavior is characterized as Normal, Hesitates, Retreats, Runs, and Not Ready. Vehicles using the exit lane(s) for the roundabout leg being recorded could originate from any of the approaches to the roundabout, and to determine the yielding rate of exiting vehicles based on their approach leg, the yielding behavior of the exiting vehicles originating from the adjacent approach and the yielding behavior of exiting vehicles originating from rest of the approaches is measured. Section 4.3 provides more details and specifications about the above-mentioned various data points – section 4.3 also provides the guidelines to the research team members who were involved in analyzing the video footage for the roundabout locations.

Table 4.2 Sample excel sheet showing data entry for pedestrian events from recorded video footage.

Date	Time Stamp	Number of pedestrians crossing	Location the pedestrian/s begins the crossing (E for vehicle entry lane, X for vehicle exit lane, J for jaywalking)	Pedestrian Delay (Measure in seconds)		Pedestrian Yield Opportunity (Y/N)		Driver Yielding Rate (Measure as Active Yield (AY), Passive Yield (PY) or No Yield (NY))						Pedestrian Crossing Behavior					Yielding behavior of exiting vehicles from 'Immediate' approach		Yielding behavior of exiting vehicles from 'Other' approaches		Other special notes or observation for the interaction (two days were analyzed from 7 am to 8 pm)
								1st half of the crosswalk			2nd half of the crosswalk													
				At start	At Splitter Island	1st half of the crosswalk	2nd half of the crosswalk	AY	PY	NY	AY	PY	NY	Normal	Hesitates	Retreats	Runs	Not Ready	Yield	No Yield	Yield	No Yield	
10/14/2021	8:45:54	1	X	0	0	N	N							1									
10/14/2021	12:07:56	1	X	0	0	N	N										1						
10/14/2021	13:01:38	1	E	3	0	Y	Y	1			1			1							1		
10/14/2021	15:17:37	1	E	0	0	N	N										1						Pedestrian is jogging
10/14/2021	16:14:32	1	E	0	0	Y	N	1						1									
10/14/2021	16:19:12	1	E	0	4	N	Y				1			1							1		
10/14/2021	16:37:36	1	X	0	0	N	N							1									
10/14/2021	16:03:15	1	X	0	0	N	N										1						Pedestrian is jogging
10/14/2021	17:30:18	1	J	12	0	N	N											1					Pedestrian crosses the entering lane before reachin
10/14/2021	17:47:02	1	E	0	0	N	N										1						
10/15/2021	7:28:16	1	X	0	0	N	Y				1			1									Pedestrian is riding a bicycle
10/15/2021	7:31:55	1	X	0	0	N	N							1									
10/15/2021	12:25:19	1	X	0	0	N	Y				1			1									Pedestrian is using onewheel
10/15/2021	14:08:52	1	X	0	0	N	N							1									
10/15/2021	14:22:57	1	J	0	4	N	Y				1			1							1		Pedestrian starts crossing the entering lane while st
10/15/2021	15:22:19	1	E	0	0	N	Y				1			1					1				
10/15/2021	15:33:56	1	E	0	3	N	Y				1			1							1		
10/15/2021	15:34:00	1	X	0	0	N	N							1									Pedestrian riding a bicycle and pulling a stroller
10/15/2021	16:01:21	1	X	0	0	N	N							1									

4.3 DESCRIPTION OF VARIOUS DATA MEASURED DURING PEDESTRIAN EVENTS FROM THE VIDEO FOOTAGE:

Date: Date the video is recorded. Available on the video footage.

Time stamp: Exact time in seconds for the pedestrian event being recorded. Available on the video footage.

Number of pedestrians crossing: Group size (number of pedestrians waiting to cross at the same time): Record the group size. This is defined as the total number of pedestrians waiting to cross at one time, as long as at least one person in the group appears intending to enter the crosswalk. If additional pedestrians arrive after the initial pedestrian or pedestrian group passes the roadway centerline, record this additional pedestrian (or group) as a separate observation. Drivers may be more likely to yield for a group of people waiting to cross rather than for a single pedestrian.

Location the pedestrian begins the crossing: E for when pedestrian is at the vehicle entry lane, X for vehicle exit lane, J for jaywalking pedestrian/s.

Did the pedestrian activate the 'Push Button'? (Y/N): This question is applicable to only locations that has RRFBs. For such a location, observe if a pedestrian(s) pressed a push button when they arrived at the pedestrian ramp. When they press a push button, you will be able to see alternating flashing red lights in the video data.

Pedestrian Delay (Measure in seconds): Record whether the pedestrian or leading pedestrian in a group needed to wait before they were able to cross the street – measure the wait time in seconds. This may depend on whether or not drivers yield as well as traffic volumes.

Pedestrian Yield Opportunity (Y/N): Record whether or not there is a car approaching with an opportunity to yield to the pedestrian. If there is, record Yes. If there is not, record No. In both cases, record all other relevant data fields.

Driver-Yielding Rate (Measure as Active Yield, Passive Yield, and No Yield): Record the driver-yielding type for each pedestrian/group of pedestrian's activities. Do this for first half of crosswalk and second half of crosswalk.

- *Active Yield:* The motorist slowed or stopped for a crossing pedestrian or a pedestrian waiting on the curb or splitter island to cross. The pedestrian was the only reason the motorist stopped or slowed.
- *Passive Yield:* The motorist yielded to the pedestrian but was already stopped for another reason. This situation occurs most often when there was a queue of vehicles waiting to enter the roundabout or when the vehicle was already stopped for a prior pedestrian crossing event.
- *No Yield:* The motorist did not yield to a crossing pedestrian or a pedestrian waiting on the curb or splitter island to cross. It should be noted that a behavior of "No Yield", for the purpose of this study, is not necessarily an indication that a safety issue occurred nor that the vehicle driver committed a legal infraction, as areas behind curbs are not considered part of the crosswalk. However, pedestrians may reasonably expect drivers to yield when standing adjacent to the crosswalk, and therefore a lack of voluntary yielding will influence pedestrian's perception of safety.

Pedestrian Crossing Behavior: Record the pedestrian behavior as Normal, Hesitates, retreats, Runs, or Not Ready.

- *Normal:* Crossed the street at a normal pace.

- *Hesitates:* Hesitated on the curb or splitter island because of an approaching vehicle.
- *Retreats:* Began crossing and then retreated to the curb or splitter island because of an approaching vehicle.
- *Runs:* Ran across the approach because of an oncoming vehicle or simple because of a choice made by the pedestrian.
- *Not Ready:* Pedestrian/pedestrians are not in the crosswalk ramp. The reason could be pedestrians are not ready to cross yet, or voluntarily stood back away from the ramp to allow vehicle traffic to clear.

Yielding Behavior of Exiting Vehicles from the Adjacent Approach: This is exclusively for observing yielding behavior of vehicles exiting the roundabout from an adjacent upstream entrance and using the adjacent downstream exit lane for the roundabout leg in the video. If the vehicles that are exiting are arriving from the adjacent upstream approach. Use this category to mention how many vehicles yielded and how many did not.

Yielding Behavior of Exiting Vehicles from Approaches other than the Adjacent Approach: This is exclusively for observing yielding behavior of vehicles exiting the roundabout from any other approach other than adjacent upstream approach and using the exit lane for the roundabout leg in the video. Use this category to mention how many vehicles yielded and how many did not.

4.4 CASE STUDY 1: BASE CASE SINGLE-LANE ROUNDABOUT AT SPENCER STREET AND VIERLING DRIVE, SHAKOPEE, MINNESOTA

A single-lane roundabout (Figure 4.2) on Spencer Street and Vierling Drive in Shakopee, Minnesota, was studied for this case study. The roundabout has a single-lane for the circulatory roadway and all the four approaches have single entry lane and single exit lane (Figure 4.3). All the four approaches have marked pedestrian crosswalks. It was noted that the roundabout is located in a school zone. Adjacent to this roundabout location, at the north-west corner of the roundabout, there is a middle school as well as a high school sporting events field. Apart from the north-west corner, the roundabout could be generally classified as being located in a residential area (Figure 4.2).

Figure 4.2: Roundabout on Spencer St. and Vierling Dr. in Shakopee, Minnesota; Source: Google Maps

Due to the presence of the middle school and high school sporting events field, there is a lot of pedestrian activity along with vehicle-yielding issues that were identified by the survey respondent's observations in the initial stages of the study. Apart from the minimum signing requirements needed for a roundabout based on MUTCD requirements, this roundabout does not have any specialized crossing

treatments, and therefore it was categorized as base case roundabout. However, instead of placing a typical pedestrian yield sign that is generally used at roundabout crosswalks, all the four approaches for this roundabout have pedestrian paddle signs installed at the beginning and end of the crosswalk – as shown in Figure 4.4.

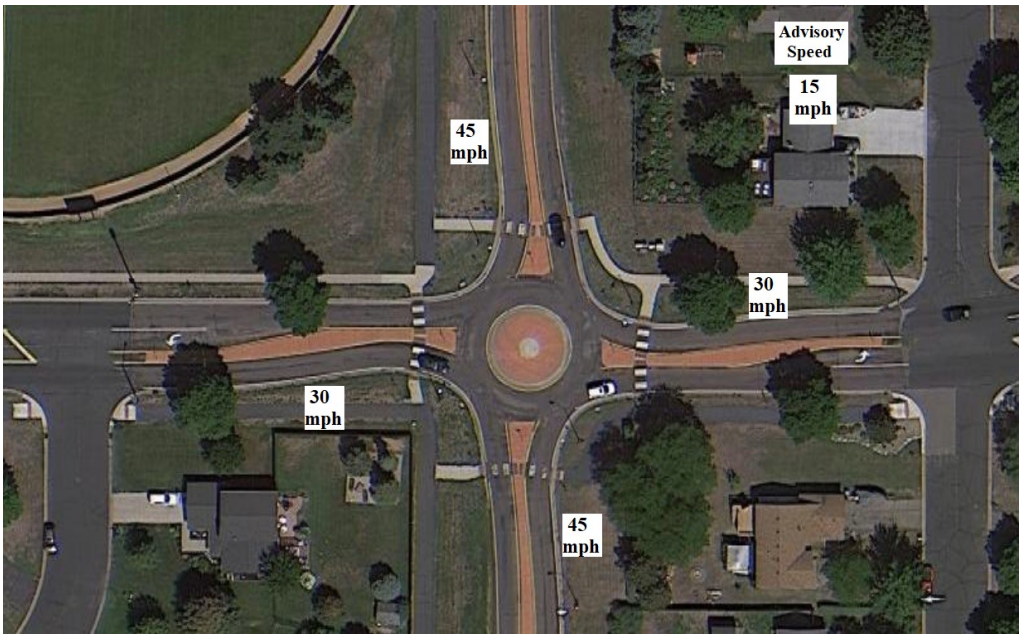


Figure 4.3: Geometry for roundabout on Spencer St. and Vierling Dr.; Source: Google Maps

Figure 4.4: Paddle sign at the beginning of the crosswalk for entry and exit lanes; Source: Google Maps

The speed limit for both the south and north approaches of the roundabout on Spencer Street is 45 mph, and the speed limit for both the west and east approaches of the roundabout on Vierling Drive is 30 mph (Figure 4.3). The advisory speed for the roundabout was posted as 15 mph (Figure 4.5).

For conducting the video data analysis, cameras were installed at all the four legs. Each camera overlooks the pedestrian crosswalk for an individual leg and covers enough length of the leg to study the interaction of pedestrians and both entering and exiting vehicles.

Figure 4.5: Advisory speed for roundabout on Spencer St.

4.4.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for each leg of the case study roundabout during October 27th, 28th, and 29th in 2021. Video footage was analyzed during the daytime (approximately 7am to 8pm during each day) of the recorded video, as the visibility is satisfactory during the daylight for conducting meaningful analysis. Among the video data recorded for all the four legs, all legs except the video of the east leg of the roundabout were analyzed. Video data recorded from the east leg had poor video quality, and therefore a determination was made to not analyze east leg video footage. Findings from the video data analysis for each of the three legs was presented in Table 4.3; further, location summary was also presented in Table 4.3.

Table 4.3: Video data analysis summary for roundabout on Spencer St. and Vierling Dr. in Shakopee, Minnesota

Roundabout Leg			Spencer Street North Leg	Spencer St South Leg	Vierling Dr West Leg	Roundabout Summary
Approach Speed Limit (mph)			45	45	30	45, 30
Advisory Speed (mph)			15	15	15	15
Number of Entry Lanes, Number of Exit Lanes			1,1	1,1	1,1	-
Traffic Count (AADT)			6,800	2,950	3,700	-
Specalized Crossing Treatment			Paddle Signs	Paddle Signs	Paddle Signs	Paddle Signs
Total Nunber of Pedestrians			54	30	145	229
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			2.8	1.8	0.6	1.3
Average Pedestrian Delay at the Splitter Island (seconds)			0.2	0	0.1	0.1
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	92.3%	100.0%	92.6%	93.4%
		AY	57.7%	87.5%	66.7%	65.6%
		PY	34.6%	12.5%	25.9%	27.9%
		NY	7.7%	0.0%	7.4%	6.6%
	Exit Lane	TY (AY+PY)	60.0%	100.0%	85.7%	75.0%
		AY	55.0%	83.3%	78.6%	67.5%
		PY	5.0%	16.7%	7.1%	7.5%
		NY	40.0%	0.0%	14.3%	25.0%
	Overall for the Leg	TY (AY+PY)	78.3%	100.0%	90.2%	86.1%
		AY	56.5%	85.7%	70.7%	66.3%
		PY	21.7%	14.3%	19.5%	19.8%
		NY	21.7%	0.0%	9.8%	13.9%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			25.0%	100.0%	100.0%	75.0%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			68.8%	100.0%	75.0%	75.0%
Pedestrian Crossing Behavior	Normal		59.3%	76.7%	80.7%	75.1%
	Hesitates		0.0%	0.0%	0.0%	0.0%
	Retreats		1.9%	0.0%	0.0%	0.4%
	Runs		35.2%	16.7%	17.9%	21.8%
	Not Ready		7.4%	6.7%	2.1%	3.9%
Jaywalking Pedestrian Events			0.0%	12.5%	0.0%	1.6%

Pedestrian counts were observed as 54 for the north leg, 30 for south leg, and 145 for west leg (Table 4.3). Comparatively more pedestrians were observed for the west and north legs of the roundabout, and this could be attributed to the presence of middle school and high school sporting fields on the north-west corner of the roundabout. When compared to west approach (0.6 seconds) of the roundabout, pedestrian delay observed on north leg and south leg were relatively high (2.8 and 1.8 seconds respectively) – this could possibly be due to the comparatively high number of vehicles observed on the north and south legs and/or the higher speed limit i.e., 45 mph compared to 30 mph on the west leg.

To understand the traffic counts for each leg of the roundabout studied, Average Annual Daily Traffic (AADT) counts measured by MnDOT that are available online (mndot.maps.arcgis.com) are incorporated into the study. Referring to AADT for all the three legs, the north leg has a relatively high AADT value (Table 4.3). The majority of the pedestrians for all the three legs have exhibited normal pedestrian crossing behavior (refer to Table 4.3 for details). However, it was noted that a significant percentage of pedestrians were observed running at the crosswalk. Again, this behavior could be attributed due to the presence of schoolchildren using the roundabout.

To understand vehicle-yielding rate at a more detailed level, for each leg, the vehicle-yielding rate was calculated for the entry lane, the exit lane, and for the overall leg. Vehicle-yielding rates are classified as Total Yield (TY), Active Yield (AY), Passive Yield (PY), and No Yield (NY); Total Yield (TY) is the sum of Active Yield (AY) and Passive Yield (PY). For the north leg of the roundabout (Spencer Street north leg), 92.3% of vehicles yielded in the entry lane and 60% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 78.3% for the overall leg. For the south leg of the roundabout (Spencer Street south leg), 100% of vehicles yielded in the entry lane and 100% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 100% for the overall leg. For the west leg of the roundabout (Vierling Drive west leg), 92.6% of vehicles yielded in the entry lane and 85.7% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 90.2% for the overall leg. Reviewing Table 4.3, it can be seen that the observed driver-yielding rate is very high at all of the legs. It is important to observe that when comparing the yielding rate for the entry lane, yielding rate is comparatively lower for the exit lane. It can be noted from Table 4.3 that 40% of the vehicles that interacted with pedestrians on the north leg did not yield to pedestrians at the crosswalk, and 14.3% of pedestrians that interacted with pedestrians on the west leg did not yield to pedestrians at the crosswalk. To better understand vehicles not yielding at the exit lane, the origin of the vehicles exiting the roundabouts was also observed. This was classified as either a vehicle is entering the roundabout from the adjacent upstream leg of the approach that is being analyzed or a vehicle that entered from any other approaches. Findings for these observations are presented in Table 4.3. For Spencer Street north leg, it is observed that the yielding rate of vehicles entering the roundabout from approaches other than the adjacent leg is 68.8% and the yielding rate of vehicles entering the roundabout from the adjacent leg is 25%. Similar observations for the rest of the two legs can be found in Table 4.3.

4.5 CASE STUDY 2: SINGLE-LANE ROUNDABOUT WITH IN-ROADWAY SIGNS AT ZARTHAN AVENUE SOUTH AND CEDAR LAKE ROAD, ST LOUIS PARK, MINNESOTA

A single-lane roundabout (Figure 4.6) at Zarthan Avenue South and Cedar Lake Road, St Louis Park, Minnesota, was studied for this case study. The roundabout has a single-lane for the circulatory roadway and all the four legs have a single-lane for entry and exit for each leg (Figure 4.7). The roundabout can be categorized as being located in a combination of business and residential area, and it is reported from the initial survey findings that a lot of pedestrian activity is generated between the residential area and businesses located in the southbound of the location. All four legs of the roundabouts have pedestrian crosswalks, and all the crosswalks have in-roadway signs installed at the splitter island (refer Figures 4.6, 4.7, and 4.8).

Figure 4.6: Roundabout on Zarthan Ave. S. and Cedar Lake Rd., St Louis Park, Minnesota

Source: Received from Debra Heiser, Engineering Director, City of St. Louis Park

The speed limit for the west and southeast approaches of the roundabout on Cedar Lake Road is 35 mph, and the speed limit for north approach to the roundabout on Zarthan Avenue South is 30 mph (refer Figure 4.6). The south leg of the roundabout enters into a business complex and has no speed limit posted (Figure 4.6). The advisory speed for the roundabout was posted as 15 mph.

Figure 4.7: South-east leg of roundabout on roundabout on Zarthan Ave. S. and Cedar Lake Rd. showing pedestrian crosswalk with in-roadway signs

Figure 4.8: Close-up view of pedestrian crosswalk – west leg of the roundabout

Three cameras were installed at the roundabout – one on north leg, one on west leg and one on southeast leg. A camera was not installed on the south leg, as there was no way to install the camera to overlook the pedestrian crosswalk to observe the interaction between the pedestrians and vehicles.

4.5.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for each leg of the case study roundabout during October 13th, 14th, 15th and 16th in 2021. Daytime video footage was analyzed (approximately 7am to 8pm during each day) from the recorded video, as the visibility was satisfactory. Video data is analyzed for the north leg, west leg, and southeast leg. Findings from the video data analysis for each of the three analyzed legs, is presented in Table 4.4.

The pedestrian counts were observed to be 19 for west leg, 27 for southeast leg, and 83 for north leg (refer Table 4.4). Very few pedestrians were observed on the west (19) and southeast (27) legs of the roundabout during the two days of videotaping. The north leg however has a higher pedestrian count of 83 pedestrians. Across all the legs studied, average pedestrian delay was less than 2 seconds at the beginning of the crosswalk and at the splitter island. The majority of the pedestrians at all three legs exhibited normal pedestrian crossing behavior (refer to Table 4.4 for details). Further, a smaller portion of pedestrians on all the three legs either were observed as not ready for crossing or were observed running. When compared to the rest of the approaches, the west approach had a significantly higher percentage of pedestrians running in the crosswalk. It has also been noted that a little over 10% of the pedestrians at each of the legs were observed jaywalking.

For the west leg of the roundabout (Cedar Lake Road west leg), 100% of vehicles yielded in the entry lane and 100% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 100% for the overall approach. For the southeast leg of the roundabout (Cedar Lane Road southeast leg), 100% of vehicles yielded in the entry lane and 66.7% of the vehicles yielded in the exit lane which resulted in an average yielding rate of 83.8% for the overall leg. For north leg of the roundabout (Zarthan Avenue north leg), 100% of vehicles yielded in the entry lane and 75% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 82.8% for the overall leg. For all the three legs, while the yielding rates for entry lanes is observed to be 100%, the yielding rates for the exit lanes is observed to be lower for the two legs – 66.7% for southeast leg, and 75% for the north leg. It can be noted from Table 4.4 that 33.3% of the vehicles that interacted with pedestrians on the southeast leg did not yield to pedestrians at the crosswalk, and 25% of the vehicles that interacted with pedestrians on north leg did not yield to pedestrians at the crosswalk.

For Zarthan Avenue North Approach, it is observed that the yielding rate of vehicles entering the roundabout from approaches other than the adjacent leg is 81.8% and the yielding rate of vehicles entering the roundabout from the adjacent leg is 62.5%. Similar observations for rest of the two approaches can be found in Table 4.4.

Table 4.4: Video Data Analysis Summary for Roundabout on Zarthan Ave. S. and Cedar Lake Rd.

Roundabout Leg			Cedar Lake Road West Leg	Cedar Lake Road Southeast Leg	Zarthan Ave North Leg	Roundabout Summary
Approach Speed Limit (mph)			35	35	30	30, 35
Advisory Speed (mph)			15	15	15	15
Number of Entry Lanes, Number of Exit Lanes			1,1	1,1	1,1	-
Traffic Count (AADT)			5,800	5,000	2,300	-
Specalized Crossing Treatment			In-Roadway Signs	In-Roadway Signs	In-Roadway Signs	In-Roadway Signs
Total Nunber of Pedestrians			19	27	83	129
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			0.8	1.8	0.9	1
Average Pedestrian Delay at the Splitter Island (seconds)			0.6	0	0.8	0.6
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	100.0%	100.0%	100.0%	100.0%
		AY	100.0%	83.3%	66.7%	78.9%
		PY	0.0%	16.7%	33.3%	21.1%
		NY	0.0%	0.0%	0.0%	0.0%
	Exit Lane	TY (AY+PY)	100.0%	66.7%	75.0%	76.7%
		AY	100.0%	66.7%	75.0%	76.7%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	0.0%	33.3%	25.0%	23.3%
	Overall for the Leg	TY (AY+PY)	100.0%	83.3%	82.8%	85.7%
		AY	100.0%	75.0%	72.4%	77.6%
		PY	0.0%	8.3%	10.3%	8.2%
		NY	0.0%	16.7%	17.2%	14.3%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			100.0%	100.0%	62.5%	70.0%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			100.0%	33.3%	81.8%	77.8%
Pedestrian Crossing Behavior	Normal		73.7%	81.5%	84.3%	84.1%
	Hesitates		0.0%	3.7%	0.0%	0.8%
	Retreats		0.0%	0.0%	0.0%	0.0%
	Runs		21.1%	3.7%	7.2%	8.7%
	Not Ready		5.3%	7.4%	6.0%	6.3%
Jaywalking Pedestrian Events			10.5%	12.0%	11.7%	11.6%

4.6 CASE STUDY 3: BASE CASE MULTI-LANE ROUNDABOUT AT DAKOTA ROAD 60 AND HOLYOKE AVENUE, LAKEVILLE, MINNESTOA

A multi-lane roundabout (Figure 4.9) at Dakota Road 60 and Holyoke Avenue, Lakeville, Minnesota, was studied for this case study. More specifically, the roundabout can be classified as a 2x1 roundabout; two circulating lanes for the Dakota Road 60 and one circulating lane for Holyoke Avenue (Figure 4.10). The roundabout is located in a region where there are offices, and residential units. Initial survey findings for this location reported vehicle-yielding concerns, especially for the exiting lanes. All four legs have pedestrian crosswalks, and all the crosswalks have minimum MUTCD signage installed at the roundabout crossings, such as yield signs placed at the roundabout entries and pedestrian warning signs at the crosswalks on the roundabout exits.

For the roundabout, the approaching speed limit is 45 mph for the west leg, 40 mph for east leg, 45 mph for north leg and 30 mph for south leg (Figure 4.10). The advisory speed for the roundabout was posted as 15 mph. In can be seen from Figure 4.10 that the east leg of the roundabout has two entry lanes and two exit lanes, the west leg (Figure 4.11) has two entry lanes and two exit lanes, the north leg has one entry lane and one exit lane, and the south leg (Figure 4.12) has one entry lane and one exit lane (Figure 4.10). Four cameras were installed at the roundabout, one at each leg.

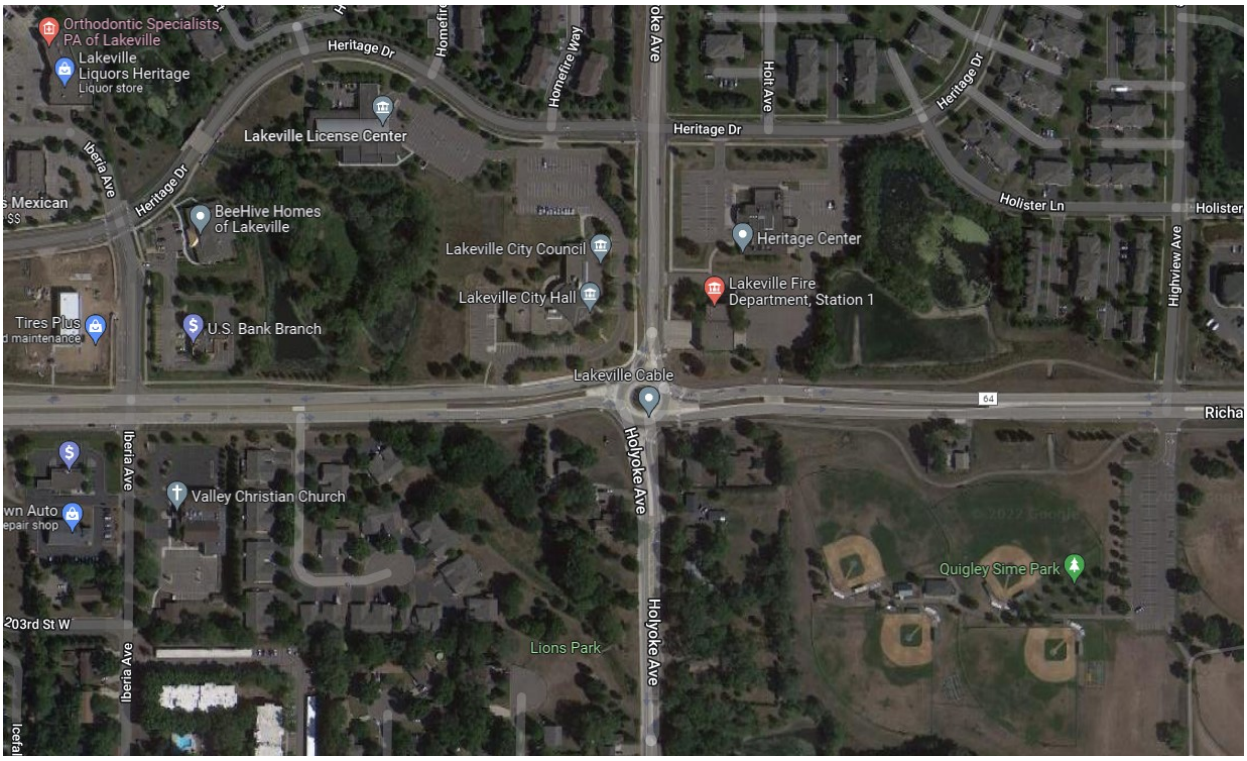


Figure 4.9: Multi-lane roundabout at Dakota Rd. 60 and Holyoke Ave., Lakeville, Minnesota

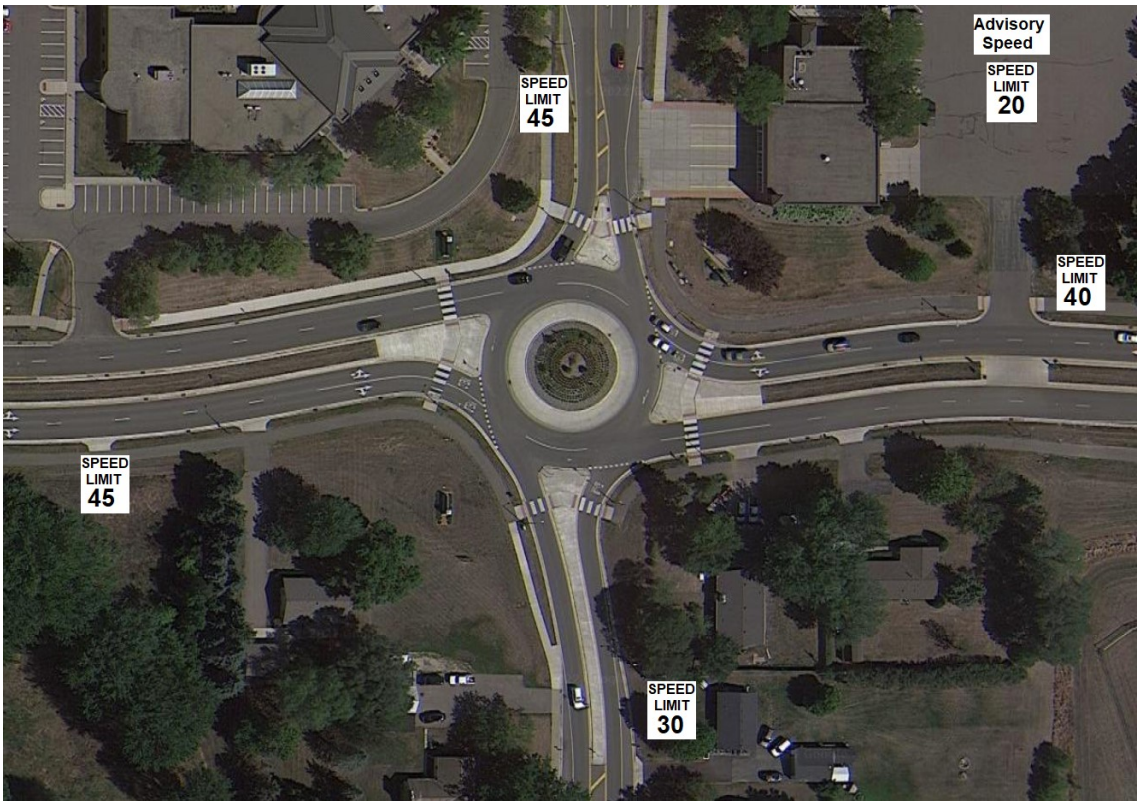


Figure 4.10: Multi-lane roundabout at Dakota Rd. 60 and Holyoke Ave., Lakeville, Minnesota – Close-up view along with speed limits marked

Figure 4.11: View of west leg of the roundabout showing two entry lanes and two exit lanes

Figure 4.12: View of south leg of the roundabout showing one entry lane and one exit lane

4.6.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for each leg of the case study roundabout during October 27th, 28th, 29th and 30th in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Video data was analyzed for the north leg, west leg, and south leg. During the video recording process, the video from the east leg of the roundabout was only recorded for 8 hours during October 27th, and therefore video data for this specific leg was recorded again for 50 hours during November 9th, 10th, and 11th in 2021. During this period, only one pedestrian interaction was observed, and therefore this leg was not considered for further analysis due to the limited pedestrian-vehicle interactions available for analysis. Findings from the video data analysis for each of the three approaches analyzed and for the location as a summary is presented in Table 4.5.

The pedestrian count was observed to be 20 for the north leg, 13 for the south leg, and 37 for the west leg (refer Table 4.5). While the pedestrians at all the three approaches are few, the west leg of the roundabout, which has two entry lanes and two exit lanes, has enough pedestrians (37) to make a meaningful analysis. North and south legs of the roundabout, which both have a single-entry lane and a single-exit lane, have an average pedestrian delay less than one second at both the entry of the crosswalk and at the splitter island. The west leg of the roundabout, which has two entry lanes and two exit lanes, experienced comparatively more average pedestrian delay, i.e., 1.7 seconds at the entry of the roundabout and 3.6 seconds at the splitter island. The majority of the pedestrians on all the three legs exhibited normal pedestrian crossing behavior (refer Table 4.5 for details). However, it was noted that a more than 40% of pedestrians were observed running at two out of the three legs analyzed and about 10% of pedestrians were observed hesitating to cross at two out of the three legs analyzed. Since the roundabout being considered is a two-lane roundabout, pedestrians could have found it challenging

to cross the street with low available gaps, which could be one probable reason for some percentage of pedestrians hesitating to cross.

Table 4.5: Video data analysis summary for roundabout on Dakota Rd. 60 and Holyoke Ave., Lakeville, Minnesota

Roundabout Leg			Holyoke Ave North Approach	Holyoke Ave South Approach	Dakota Road 60	Roundabout Summary
Approach Speed Limit (mph)			45	45	30	30, 40, & 45
Advisory Speed (mph)			20	20	20	20
Number of Entry Lanes, Number of Exit Lanes			1, 1	1, 1	2, 2	-
Traffic Count (AADT)			5800	7900	14000	-
Specalized Crossing Treatment			Base Case Roundabout	Base Case Roundabout	Base Case Roundabout	Base Case Roundabout
Total Number of Pedestrian Events			18	11	32	61
Total Number of Pedestrians			20	13	37	70
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			0.7	0.8	1.7	1.2
Average Pedestrian Delay at the Splitter Island (seconds)			0.3	0.9	3.6	2.2
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	80.0%	80.0%	70.6%	74.1%
		AY	60.0%	40.0%	41.2%	44.4%
		PY	20.0%	40.0%	29.4%	29.6%
		NY	20.0%	20.0%	29.4%	25.9%
	Exit Lane	TY (AY+PY)	42.9%	75.0%	52.4%	53.1%
		AY	28.6%	75.0%	33.3%	37.5%
		PY	14.3%	0.0%	19.0%	15.6%
		NY	42.9%	25.0%	47.6%	43.8%
	Overall Approach	TY (AY+PY)	58.3%	77.8%	60.5%	62.7%
		AY	41.7%	55.6%	36.8%	40.7%
		PY	16.7%	22.2%	23.7%	22.0%
		NY	33.3%	22.2%	39.5%	35.6%
Yielding Rate of Exiting Vehicles originating from the Adjacent Approach			33.3%	66.7%	85.7%	69.2%
Yielding Rate of Exiting Vehicles originating from Approaches other than the Adjacent Approach			50.0%	100.0%	47.0%	52.2%
Pedestrian Crossing Behavior	Normal		41.2%	90.0%	34.4%	45.8%
	Hesitates		0.0%	10.0%	12.5%	8.5%
	Retreats		0.0%	0.0%	0.0%	0.0%
	Runs		41.2%	0.0%	53.1%	40.7%
	Not Ready		17.6%	0.0%	0.0%	5.1%
Jaywalking Pedestrian Events			0.0%	7.7%	0.0%	1.4%

For the north leg of the roundabout (Holyoke Avenue north leg), 80% of vehicles yielded in the entry lane and 42.9% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 58.3% for the overall leg. For the south leg of the roundabout (Holyoke Avenue south leg), 80% of vehicles yielded in the entry lane and 75% of the vehicles yielded in the exit lane which resulted in an

average yielding rate of 77.8% for the overall leg. For the west leg of the roundabout (Dakota Road 60 west leg), which has two entry lanes and two exit lanes, 70.6% of vehicles yielded in the entry lane and 52.4% of the vehicles yielded in the exit lane which resulted in an average yielding rate of 60.5% for the overall leg. For all the three legs, while the yielding rates for entry lanes is observed to be higher (although not in the 90's%), yielding rates for the exit lanes were observed to be lower. For the west leg, which specifically had two entry lanes and two exit lanes, vehicle-yielding rate was lower (60.5%) with the yielding rate being lowest (52.4%) at the exit lanes.

4.7 CASE STUDY 4: MULTI-LANE ROUNDABOUT WITH IN-ROADWAY SIGNS AT LAKE ROAD AND WOODBURY DRIVE, WOODBURY, MINNESOTA

A multi-lane roundabout (Figure 4.13, and Figure 4.14) at Lake Road and Woodbury Drive, Woodbury, Minnesota, was studied for this case study. More specifically, the roundabout can be classified as a 2x1 roundabout; two circulating lanes for the Woodbury Drive and one circulating lane for the Lake Road (Figure 4.14). The roundabout is located in a residential area. Initial survey findings for this location have reported lack of clear gaps for pedestrians to cross the road, vehicle-yielding concerns toward pedestrians, and pedestrians not being clearly visible to drivers, especially for the exiting lanes. All four legs have pedestrian crosswalks. Crosswalks on the Woodbury drive (North and South legs) have in-roadway signs installed (refer Figure 4.15). Crosswalks on the Lake Road (east and west legs) do not have any specialized crossing treatments apart from yield signs placed at the marked crosswalks which are a minimum MUTCD requirement at the roundabout crossings (refer Figure 4.16).

The speed limit is 55 mph for the north and south approaches, 40 mph for east and west approaches (Figure 4.10). The advisory speed for the roundabout was posted as 20 mph. North and South legs of the roundabout have two entry lanes and two exit lanes, and east and west legs of the roundabout have one entry lane and one exit lane (Figure 4.14). Four cameras were installed at the roundabout, one at each leg.

Figure 4.13: Multi-lane roundabout at Lake Rd. and Woodbury Dr., Woodbury, Minnesota

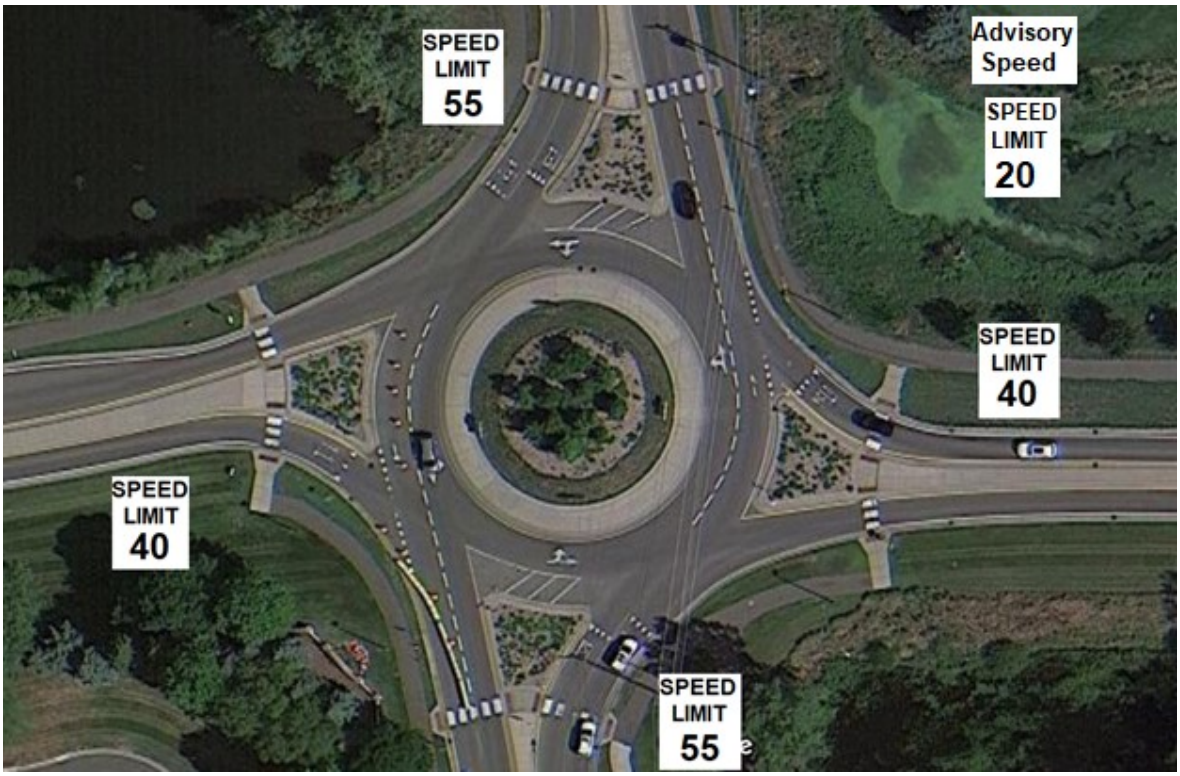


Figure 4.14: Multi-lane roundabout at Lake Rd. and Woodbury Dr., Woodbury, Minnesota – Close-up view along with speed limits marked

Figure 4.15: View of north leg of the roundabout showing two entry lanes and two exit lanes

Figure 4.16: View of east leg of the roundabout showing one entry lane and one exit lane

4.7.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for each leg of the case study roundabout during October 21st, 22nd, and 23rd in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Video data was analyzed for north leg, east leg, and south leg. During the video recording process, the video from the west leg of the roundabout had construction cones installed near the approach and therefore video data for this specific leg was not analyzed as the driver and pedestrian behavior would be a special case, likely biased due to construction cones. Findings from the video data analysis for rest of the three legs and for the location as a summary was analyzed and presented in Table 4.6.

Pedestrian count was observed to be 43 for east leg, 57 for north leg, and 15 for south leg (refer Table 4.6). About 42.9% of the pedestrians for all the three approaches have exhibited normal pedestrian crossing behavior, and the rest of the pedestrians (53.8%) were observed running (refer Table 4.6 for details).

For the north leg of the roundabout (Woodbury Drive north leg) which has two entry lanes and two exit lanes, 81.8% of vehicles yielded in the entry lane and 55.8% of the vehicles yielded at the exit lane, which resulted in an average yielding rate of 67.1% for the overall leg. For the south leg of the roundabout (Woodbury Drive south leg) which has two entry lanes and two exit lanes, 85.7% of vehicles yielded in the entry lane and 42.9% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 64.3% for the overall leg. For east leg of the roundabout (Lake Road east leg) which has one entry lane and one exit lane, 100% of vehicles yielded in the entry lane and 100% of the vehicles yielded in the exit lane, which resulted in an average yielding rate of 100% for the overall leg. Among all the three legs studied, the ones that had two entry lanes and two exit lanes were found to have lower driver-yielding rates and for these legs, the yielding rate was lowest at the exit lanes.

Table 4.6: Video data analysis summary for roundabout at Lake Rd. and Woodbury Dr., Woodbury, Minnesota

Roundabout Leg			Lake Road East Leg	Woodbury Drive North Leg	Woodbury Drive South Leg	Roundabout Summary
Approach Speed Limit (mph)			40	55	55	40, 55
Advisory Speed (mph)			20	20	20	20
Number of Entry Lanes, Number of Exit Lanes			1,1	2,2	2,2	-
Traffic Count (AADT)			9,300	9,700	9,700	-
Specalized Crossing Treatment			Base Case	In-Roadway Signs	In-Roadway Signs	In-Roadway Signs and Base Case Setting
Total Nunber of Pedestrians			43	27	15	115
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			0.2	1.8	0.8	1
Average Pedestrian Delay at the Splitter Island (seconds)			0	0	0.2	0.6
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	100.0%	81.8%	85.7%	86.8%
		AY	92.3%	81.8%	85.7%	84.9%
		PY	7.7%	0.0%	0.0%	1.9%
		NY	0.0%	18.2%	14.3%	13.2%
	Exit Lane	TY (AY+PY)	100.0%	55.8%	42.9%	61.7%
		AY	100.0%	55.8%	42.9%	61.7%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	0.0%	44.2%	57.1%	38.3%
	Overall for the Leg	TY (AY+PY)	100.0%	67.1%	64.3%	73.5%
		AY	95.7%	67.1%	64.3%	72.6%
		PY	4.3%	0.0%	0.0%	0.9%
		NY	0.0%	32.9%	35.7%	26.5%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			100.0%	66.7%	NA	57.1%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			100.0%	60.9%	100.0%	74.3%
Pedestrian Crossing Behavior	Normal		51.4%	37.2%	6.0%	42.9%
	Hesitates		2.9%	4.7%	0.0%	3.3%
	Retreats		0.0%	0.0%	0.0%	0.0%
	Runs		45.7%	58.1%	9.6%	53.8%
	Not Ready		0.0%	0.0%	0.0%	0.0%
Jaywalking Pedestrian Events			0.0%	0.0%	0.0%	0.0%

4.8 CASE STUDY 5: SINGLE-LANE ROUNDABOUT WITH RECTANGULAR RAPID FLASHING BEACONS AT TRACY AVENUE AND VALLEY VIEW LANE, EDINA, MINNESOTA

A three-leg single-lane roundabout (Figure 4.17 and Figure 4.18) at Tracy Avenue and Valley View Lane, Edina, Minnesota, is studied for this case study. The roundabout is located in a residential area. This roundabout location was selected as it has rectangular rapid flashing beacons (RRFBs) installed for pedestrian crosswalks on all three legs of the roundabout. The research team wanted to compare the performance of a roundabout with RRFBs with those that has other or no specialized crossing treatments.

The speed limit is 30 mph for all the three approaches (Figure 4.18). The advisory speed for the roundabout was posted as 15 mph. Each leg of the roundabout has one entry lane and one exit lane (Figure 4.18 and Figure 4.19). Three cameras were installed at the roundabout, one at each leg.

Figure 4.17: Single-lane roundabout at Tracy Ave. and Valley View Ln., Edina, Minnesota

Figure 4.18: Single-lane roundabout at Tracy Ave. and Valley View Ln., Edina, Minnesota – Close-up view along with speed limits marked

Figure 4.19: View of northeast leg of the roundabout showing one entry lane, one exit lane, and RRFBs installed

4.8.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 70 hours for each leg of the case study roundabout during October 13th, 14th, 15th, and 16th in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Video data is analyzed for all the three legs of the roundabout. Findings from the video data analysis for each of the three legs analyzed and for the location as a summary is presented in Table 4.7. Tracy Avenue North leg of the roundabout was observed to have comparatively higher traffic (AADT = 15,100) when compared to the rest of the two legs studied (Valley Lane Northeast Leg AADT = 3,500; Valley View Road South Leg AADT = 9,500).

The pedestrian count was observed to be 152 for north leg, 77 for northeast leg, and 143 for south leg (refer Table 4.7). While all the three legs of the roundabout have RRFBs installed, only a fraction (14.6% for Tracey Avenue North Leg, 14.7% for Valley View Lane Northeast Leg, and 9.8% for Valley View Road South Leg) of pedestrian events at all the three legs were observed to have RRFB activations. Most of the pedestrians did not activate RRFB to use the roundabout crossing. On an average, only 12.9% of total pedestrian events at the roundabout were observed to have RRFB activations. See Table 4.7 for details.

For all the three legs, when pedestrians activated an RRFB, 100% yielding rate was observed. On the contrary, when pedestrians crossed the street without activating an RRFB, driver compliance rate is observed lower but still in 80%-90% range (Refer to Table 4.7 for driver-yielding rate by each leg broken-down by each half of the crosswalk). Some pedestrians' events were observed where a pedestrian or group of pedestrians arrived at the crosswalk ramp, and before the pedestrian pressed the push button to activate the RRFB, a few vehicles did not yield for the pedestrians; however, after the pedestrian activated the RRFB, vehicles yielded for all instances at all the three legs of the roundabout. Such instances when vehicles did not yield to pedestrians when RRFBs were not yet activated were categorized as interactions without RRFB activations.

For the Valley Lane north-east leg and for Valley View Road south leg, for pedestrian crossing events when RRFB was not activated, driver-yielding rates for entry lanes is observed higher (100% and 89.5% respectively) and yielding rates for the exit lanes is observed lower (66.7% and 78.9% respectively).

It can be summarized from the video data analysis of the roundabout at Tracy Avenue and Valley View Lane that pedestrians using RRFB has experienced 100% yielding rate from the drivers. For instances when pedestrians did not use RRFB, the overall driver-yielding rate decreased and stayed below 90%. Most (87.1%) of the pedestrians were observed not using RRFBs while crossing the street.

Table 4.7: Video data analysis summary for roundabout at Lake Rd. and Woodbury Dr., Woodbury, Minnesota

Roundabout Leg			Tracey Ave North Leg	Valley Lane Northeast Leg	Valley View Road South Leg	Roundabout Summary
Approach Speed Limit (mph)			30	30	30	30
Advisory Speed (mph)			15	15	15	15
Number of Entry Lanes, Number of Exit Lanes			1,1	1,1	1,1	-
Traffic Count (AADT)			15,100	3,500	9,500	-
Specalized Crossing Treatment			RRFB	RRFB	RRFB	RRFB
Total Nunber of Pedestrians			152	77	143	372
Percentage of Pedestrians Activating RRFB			14.6%	14.7%	9.8%	12.9%
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			0.4	0.3	0.4	0.4
Average Pedestrian Delay at the Splitter Island (seconds)			0	0	0.1	0.0
RRFB Activated						
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	100.0%	100.0%	100.0%	100.0%
		AY	100.0%	100.0%	100.0%	100.0%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	0.0%	0.0%	0.0%	0.0%
	Exit Lane	TY (AY+PY)	100.0%	100.0%	100.0%	100.0%
		AY	100.0%	100.0%	100.0%	100.0%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	0.0%	0.0%	0.0%	0.0%
	Overall for the Leg	TY (AY+PY)	100.0%	100.0%	100.0%	100.0%
		AY	100.0%	100.0%	100.0%	100.0%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	0.0%	0.0%	0.0%	0.0%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			100.0%	100.0%	NA	100.0%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			100.0%	NA	100.0%	100.0%
RRFB Not Activated						
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	84.2%	100.0%	89.5%	88.1%
		AY	84.2%	100.0%	89.5%	88.1%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	15.8%	0.0%	10.5%	11.9%
	Exit Lane	TY (AY+PY)	91.1%	66.7%	78.9%	84.3%
		AY	91.1%	66.7%	78.9%	84.3%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	8.9%	33.3%	21.1%	15.7%
	Overall for the Leg	TY (AY+PY)	88.0%	85.7%	84.2%	86.1%
		AY	88.0%	85.7%	84.2%	86.1%
		PY	0.0%	0.0%	0.0%	0.0%
		NY	12.0%	14.3%	15.8%	13.9%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			100.0%	NA	33.4%	71.4%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			90.1%	100.0%	87.5%	90.3%
Pedestrian Crossing Behavior	Normal		45.7%	36.8%	33.7%	34.3%
	Hesitates		4.8%	3.5%	1.2%	2.8%
	Retreats		0.0%	0.0%	0.0%	0.0%
	Runs		59.0%	59.6%	98.8%	62.9%
	Not Ready		0.0%	0.0%	0.0%	0.0%
Jaywalking Pedestrian Events			0.0%	0.0%	0.0%	0.0%

4.9 CASE STUDY 6: MULTI-LANE ROUNDABOUT WITH RECTANGULAR RAPID FLASHING BEACONS (RRFBS) AT NICOLLET AVENUE AND W66 STREET, RICHFIELD, MINNESOTA

A four-leg two-lane roundabout (Figure 4.10 and Figure 4.21) at Nicollet Avenue and W66 Street, Richfield, Minnesota, is studied for this case study. More specifically, the roundabout can be classified as a 2x1 roundabout; two circulating lanes for the 66th Street and one circulating lane for the Nicollet Avenue (Figure 4.21). The roundabout is located in a dense business area. This roundabout location was selected as it has RRFBs installed for pedestrian crosswalks on all four legs of the roundabout. The research team want to compare the performance of a roundabout with RRFBs with those that have other or no specialized crossing treatments.

While cameras were installed at all the four legs of the roundabout, only the video footage from Nicollet Avenue south leg was observed as being useful, and therefore only one leg was analyzed from this roundabout location. The video quality from rest of the three legs was very poor or had obstacles such as trees blocking the pedestrian-vehicle activity.

The speed limit is 35 mph for Nicollet Avenue south approach (Figure 4.21). The advisory speed for the roundabout was posted as 15 mph. Nicollet Avenue south leg of the roundabout has one entry lane and one exit lane (Figure 4.21 and Figure 4.22).

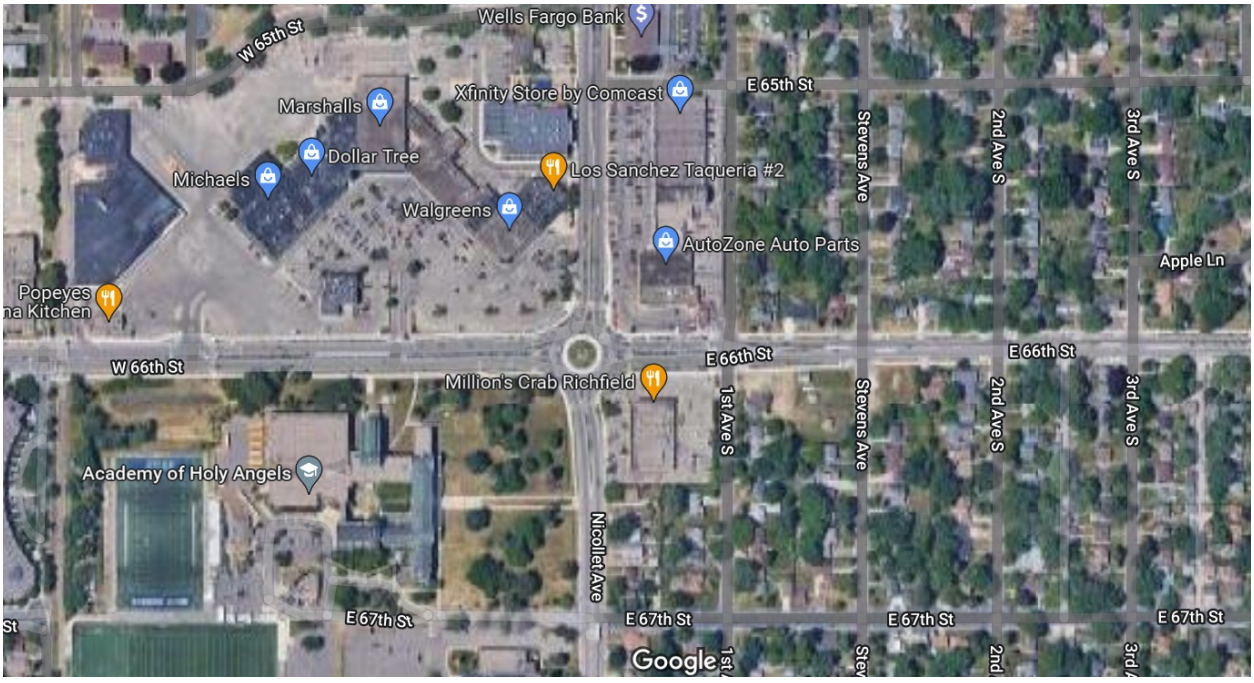


Figure 4.20: Multi-lane roundabout at Nicollet Ave. and W66 St., Richfield, Minnesota

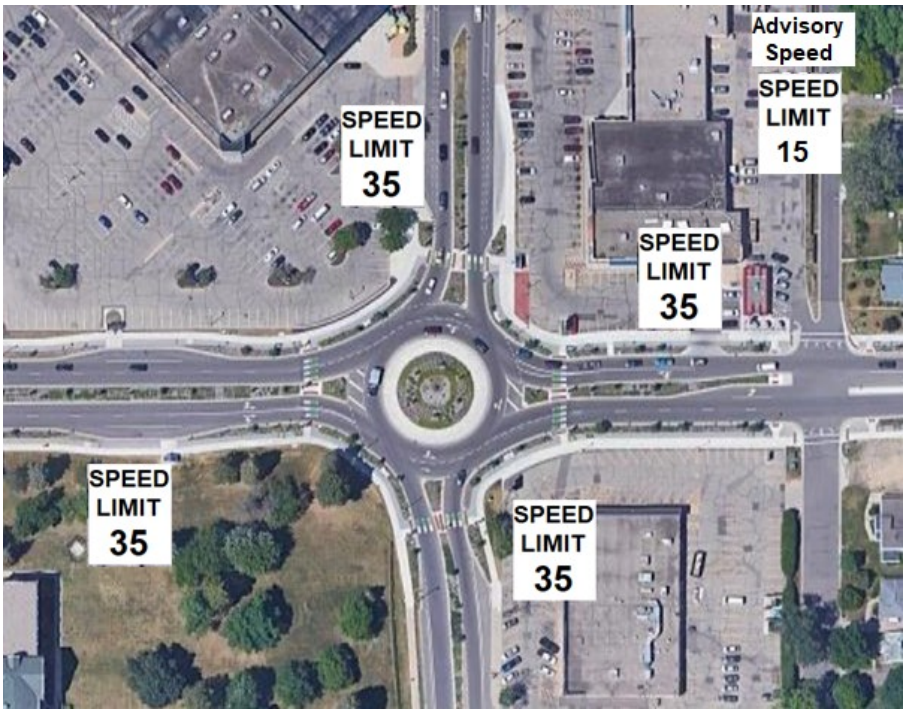


Figure 4.21: Multi-lane roundabout at Nicollet Ave. and W66 St., Richfield, Minnesota–Close-up view along with speed limits marked

Figure 4.22: View of south leg of the roundabout showing one entry lane, one exit lane, and RRFBs installed

4.9.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for Nicollet Avenue south leg during October 13th, 14th, 15th, and 16th in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Findings from the video data analysis for Nicollet Avenue south leg is presented in Table 4.8.

Table 4.8: Video data analysis summary for Nicollet Ave. south-leg of the roundabout at Nicollet Ave. and W66 St., Richfield, Minnesota

Roundabout Leg			Nicollet Avenue South Leg
Approach Speed Limit (mph)			35
Advisory Speed (mph)			15
Number of Entry Lanes, Number of Exit Lanes			1,1
Traffic Count (AADT)			12,100
Specalized Crossing Treatment			RRFB
Total Nunber of Pedestrians			103
Percentage of Pedestrians Activating RRFB			26.2%
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			2
Average Pedestrian Delay at the Splitter Island (seconds)			0.2
RRFB Activated			
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	100.0%
		AY	33.3%
		PY	66.7%
		NY	0.0%
	Exit Lane	TY (AY+PY)	91.7%
		AY	91.7%
		PY	0.0%
		NY	8.3%
	Overall for the Leg	TY (AY+PY)	97.0%
		AY	54.5%
		PY	42.4%
		NY	3.0%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			85.7%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			100.0%
RRFB Not Activated			
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	70.0%
		AY	15.0%
		PY	55.0%
		NY	30.0%
	Exit Lane	TY (AY+PY)	45.2%
		AY	45.2%
		PY	0.0%
		NY	54.8%
	Overall for the Leg	TY (AY+PY)	59.2%
		AY	28.2%
		PY	31.0%
		NY	40.8%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			53.8%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			38.1%
Pedestrian Crossing Behavior	Normal		61.9%
	Hesitates		1.8%
	Retreats		0.0%
	Runs		34.5%
	Not Ready		1.8%
Jaywalking Pedestrian Events			0.0%

The pedestrian count was observed to be 103 for Nicollet Avenue south leg (refer Table 4.8). Most of the pedestrians in the south leg (26.2%) did not activate the RRFB to use the roundabout crossing. Only 26.2% of total pedestrian events were observed to have RRFB activations. When pedestrians activated RRFB, an overall yielding rate of 97% was observed by the drivers. Vehicle entry lane has a better yielding rate (100%) when compared to the vehicle exit lane (91.7%). When pedestrians crossed the street without activating RRFB, overall driver-yielding rate has fell to 59.2%. Vehicle entry lane has a comparatively better yielding rate (70%) than vehicle exit lane (45.2%). Some pedestrians' events were observed where a pedestrian or group of pedestrians arrived at the crosswalk ramp and before the pedestrian pressed the push button to activate the RRFB, vehicles did not yield for the pedestrians; however, after the pedestrian activated the RRFB, vehicles yielded. Such instances when vehicles did not yield to pedestrians when RRFBs were not yet activated were categorized as interactions without RRFB activations.

It can be summarized from the video data analysis for the Nicollet Avenue south-leg that pedestrians using RRFB has experienced closer to 100% yielding rate from the drivers. Overall driver-yielding rate decreased to 59.2% when pedestrians did not use the RRFB. The yielding rate was observed even lower (45.2%) for the exit lane when RRFB was not activated.

4.10 CASE STUDY 7: MULTI-LANE ROUNDABOUT WITH COLORED CROSSWALK AT COLLEGE DRIVE AND MISSISSIPPI PKWY, BRAINERD, MINNESOTA

A four-leg multi-lane roundabout (Figure 4.23 and 4.24) at College Drive and Mississippi Pkwy, Brainerd, Minnesota was studied for this case study. More specifically, the roundabout can be classified as a 2x1 roundabout; 2 circulating lanes for the College Drive and one circulating lane for the Mississippi Pkwy and SW4th Street (Figure 4.24). The roundabout is located in a college and residential area; southwest corner of the roundabout has a college and north of the roundabout has apartment complexes where students reside. This roundabout location was selected as it has a colored crosswalk treatment installed for pedestrian crosswalks on the north and west legs of the roundabout. The south and east legs of the roundabout do not have any marked crosswalk (refer Figure 4.24). The research team wanted to compare the performance of a roundabout with colored crosswalk with those that has other or no specialized crossing treatments.

Figure 4.23: Multi-lane roundabout at College Dr. and Mississippi Pkwy., Brainerd, Minnesota

Figure 4.24: Multi-lane roundabout at College Dr. and Mississippi Pkwy., Brainerd, Minnesota– Close-up view along with speed limits marked

While cameras were installed at all the four legs of the roundabout, only the north and west legs have colored crosswalks that are being studied. Video footage from the west leg was determined to be useful footage to conduct analysis and therefore only one leg was analyzed from this location.

The speed limit is 30 mph for the College Drive west approach (Figure 4.24). The advisory speed for the roundabout was posted as 15 mph. The College Drive west-leg of the roundabout has two entry lanes and two exit lanes (Figure 4.24 and Figure 4.25).

Figure 4.25: View of west-leg of the roundabout showing two entry lanes, two exit lanes, and colored crosswalk installed

4.10.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for College Drive west-leg during October 13th, 14th, 15th, and 16th in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Findings from the video data analysis for College Drive west-leg is presented in Table 4.9.

The pedestrian count was observed to be 29 for the College Drive west-leg (refer to Table 4.9). College Drive west-leg experienced a higher average pedestrian delay – 2.7 seconds at the entry of the roundabout and 5.9 seconds at the splitter island. The majority of the pedestrians on the west-leg exhibited normal pedestrian crossing behavior (refer Table 4.9 for details).

The driver-yielding rates were observed to be low for the College Drive west-leg. Table 4.9 breaks down the driver-yielding rates at entry lane, exit lane, and for the overall College Drive west-leg. Driver-yielding rate is 50% for entry lane, 17.4% for exit lane, and 24.1% for the overall west-leg of the roundabout. Exiting vehicles that are originating from the adjacent leg yielded better (66.7%) to pedestrians compared to vehicles originating from other legs (13.9%).

It can be summarized from the video data analysis for the College Drive west-leg of the roundabout that driver-yielding rates are low (24%) and exiting vehicles' yielding behavior to pedestrians is especially poor (17.4%) with colored crosswalk treatment at the location studied.

Table 4.9: Video data analysis summary for College Ave. west-leg of the roundabout at College Dr. and Mississippi Pkwy., Brainerd, Minnesota

Roundabout Leg			West College Drive West Leg
Approach Speed Limit (mph)			30
Advisory Speed (mph)			15
Number of Entry Lanes, Number of Exit Lanes			2,2
Traffic Count (AADT)			11,400
Specalized Crossing Treatment			Colored Crosswalk
Total Nunber of Pedestrians			29
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			2.7
Average Pedestrian Delay at the Splitter Island (seconds)			5.9
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	50.0%
		AY	50.0%
		PY	0.0%
		NY	50.0%
	Exit Lane	TY (AY+PY)	17.4%
		AY	17.4%
		PY	0.0%
		NY	82.6%
	Overall for the Leg	TY (AY+PY)	24.1%
		AY	24.1%
		PY	0.0%
		NY	75.9%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			66.7%
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			13.9%
Pedestrian Crossing Behavior	Normal		76.5%
	Hesitates		5.9%
	Retreats		0.0%
	Runs		14.7%
	Not Ready		2.9%
Jaywalking Pedestrian Events			9.1%

4.11 CASE STUDY 8: MULTI-LANE ROUNDABOUT WITH COLORED CROSSWALK AT EAST COLLEGE DRIVE AND S 4TH STREET, BRAINERD, MINNESOTA

A three-leg multi-lane roundabout (Figure 4.26 and Figure 4.27) at East College Drive and S 4th Street, Brainerd, Minnesota, was studied for this case study. The roundabout is located near a high school. This roundabout location was selected as it has a colored crosswalk installed for pedestrian crosswalks on the northeast and southeast legs of the roundabout. The west-leg of the roundabout does not have a marked crosswalk (refer Figure 4.27). The research team wanted to compare the performance of a roundabout with colored crosswalk with those that has other or no specialized crossing treatments.

Figure 4.26: Multi-lane roundabout at East College Dr. and S. 4th St., Brainerd, Minnesota

While cameras were installed at all the three legs of the roundabout, only video footage from the northeast leg was observed to be useful footage to conduct an analysis and therefore only this one leg was analyzed from this location.

The speed limit is 30 mph for East College Drive northeast approach (Figure 4.27). The advisory speed for the roundabout was posted as 15 mph. The East College Drive northeast-leg of the roundabout has two entry lanes and two exit lanes (Figure 4.27 and Figure 4.28).

Figure 4.27: Multi-lane roundabout at East College Dr. and S 4th St., Brainerd, Minnesota – Close-up view along with speed limits marked

Figure 4.28: View of northeast-leg of the roundabout showing two entry lanes, two exit lanes, and colored crosswalk installed

4.11.1 Summary of Video Data Analysis:

Video data was recorded continuously for approximately 50 hours for College Drive west-leg during October 13th, 14th, 15th, and 16th in 2021. Daytime video footage was analyzed during 7am to 8pm during each day. Findings from the video data analysis for East College Drive northeast-leg is presented in Table 4.10.

Pedestrian count was observed as 10 for East College Drive northeast-leg (refer Table 4.10). East College Drive northeast-leg has experienced an average pedestrian delay of 1.3 seconds at the beginning of the crosswalk and 4.5 seconds at the splitter island; delay for pedestrians at the splitter island can be categorized as high.

Driver-yielding rates were observed low (11.1%) for the East College Drive northeast-leg. Table 4.10 breaks down the driver-yielding rates at entry lane, exit lane, and for the overall East College Drive northeast-leg. Driver-yielding rate is 50% for entry lane, 6.3% for exit lane, and 11.1% for the overall northeast-leg of the roundabout.

It can be summarized from the video data analysis for the East College Drive northeast-leg of the roundabout that driver-yielding rates are low relative to other roundabouts analyzed in this study, and exiting vehicles' yielding behavior to pedestrians is likewise poor at the colored crosswalk treatment at the location studied. The poor yielding behavior could also be attributed to the fact that the roundabout is located near a high school location.

Table 4.10: Video Data Analysis Summary for College Ave. West-Leg of the Roundabout at College Dr. and Mississippi Pkwy., Brainerd, Minnesota

Roundabout Leg			East College Drive Northeast Leg
Approach Speed Limit (mph)			30
Advisory Speed (mph)			15
Number of Entry Lanes, Number of Exit Lanes			2,2
Traffic Count (AADT)			6,000
Specalized Crossing Treatment			Colored Crosswalk
Total Nunber of Pedestrians			10
Average Pedestrian Delay at the Beginning of the Crosswalk (seconds)			1.3
Average Pedestrian Delay at the Splitter Island (seconds)			4.5
Yielding Rate (TY - Total Yield (AY+PY); AY - Active Yield; PY - Passive Yield; NY - No Yield)	Entry Lane	TY (AY+PY)	50.0%
		AY	50.0%
		PY	0.0%
		NY	50.0%
	Exit Lane	TY (AY+PY)	6.3%
		AY	6.3%
		PY	0.0%
		NY	93.8%
	Overall for the Leg	TY (AY+PY)	11.1%
		AY	11.1%
		PY	0.0%
		NY	88.9%
Yielding Rate of Exiting Vehicles originating from the Adjacent Leg			NA
Yielding Rate of Exiting Vehicles originating from Legs other than the Adjacent Leg			6.7%
Pedestrian Crossing Behavior		Normal	80.0%
		Hesitates	0.0%
		Retreats	0.0%
		Runs	20.0%
		Not Ready	0.0%
Jaywalking Pedestrian Events			0.0%

4.12 SUMMARY OF CASE STUDY FINDINGS

A summary of major findings of each individual leg from all the eight case studies is presented in Table 4.11. This summary table can help visualize the performance of each leg's vehicle-yielding rate towards pedestrians based on various characteristics of the roundabout leg – such as configuration of the roundabout, number of entry and exit lanes, crossing treatment, approach speed, roundabout design speed, traffic count (AADT), and average pedestrian delay. Case study 5 and 6 reviewed the roundabout locations with RRFBs. Since there were scenarios when pedestrians activated the RRFBs to cross the street and scenarios when the pedestrians did not activate the RRFB to cross the street, the case study is presented twice in the summary table. For the scenarios when pedestrians activated the RRFBs to cross the street, the study mentioned the setting as a roundabout with RRFB specialized crossing treatment. For the scenarios when pedestrians did not activate the RRFBs to cross the street, the study mentioned the setting as a roundabout with base case as there were no RRFB beacons to warn the vehicles about the crossing pedestrians.

In general, single-lane roundabouts performed well in terms of vehicle-yielding rates towards pedestrians. A single-lane roundabout at Spencer Street and Vierling Drive, Shakopee, Minnesota, was observed to have an overall driver-yielding rate of 86.1%; a single-lane roundabout with in-roadway signs at Zarthan Avenue South and Cedar Lake Road, St Louis Park, Minnesota, was observed to have an overall driver-yielding rate of 85.7%; a single-lane roundabout with RRFBs at Tracey Avenue and Valley View Lane, Edina, Minnesota, was observed to have an overall driver-yielding rate of 100%. Driver-yielding rates decreased for multi-lane roundabouts. In general, for a roundabout leg, vehicle exit lanes had lower driver-yielding rates when compared to vehicle entry lanes. Visibility of pedestrians decreased for vehicles exiting the roundabouts - this is true for both single-lane roundabouts and multi-lane roundabouts (Refer Table 4.11). Therefore, the vehicle-yielding rates are consistently lower for exit lane/s of a roundabout leg when compared to entry lane/s of a roundabout leg. Vehicle approach speed and advisory speed posted for the roundabout also seemed to have an effect on vehicle-yielding rates. Higher approach speed for a roundabout leg has resulted to lower yielding rates.

Use of rectangular rapid flashing beacons (RRFBs) at two different roundabout locations (one 1x1 configuration, and one 2x1 configuration) resulted in close to 100% compliance rate when pedestrians activated the beacon. On the contrary, when pedestrians did not activate the RRFBs and crossed the street, the overall driver compliance rate decreased by anywhere from 15-18% at Tracy Avenue and Valley View Lane, Edina, Minnesota, and by 38% at Nicollet Avenue and W66 Street, Richfield, Minnesota (Refer Table 4.11). This clearly shows that both availability of RRFBs for a crosswalk and usage of these beacons by the pedestrians enhances the driver-yielding rates by improving the visibility of the crossing pedestrians and clarifying to drivers that the pedestrian is not intentionally waiting for traffic to clear.

Use of In-roadway signs at the pedestrian crosswalk yielded satisfactory yielding rates. However, the yielding rates went down as the number of lanes at the crosswalk increased from one to two. For the single-lane roundabout at Zarthan Avenue South and Cedar Lake Road, St Louis Park, Mjnnesota, the

overall driver compliance rate was observed as 100%, 83.3%, and 82.8% for the three legs studied. For the multi-lane roundabout at Lake Road and Woodbury Drive, Woodbury, Minnesota, the overall driver compliance rate was observed as 67.1% and 64.3% for the two legs studied. It can be noted that approach speed and roundabout advisory speed is higher for the multi-lane roundabout (55 approach speed, and 20 roundabout advisory speed) when compared to the single-lane roundabout (35 and 30 approach speed, and 15 circulatory roadway speed) which might also have contributed towards the decrease in the driver-yielding rate at the multi-lane roundabout.

Table 4.11: Summary of important findings from the eight roundabout case studies

Case Study S.No.	Roundabout	Leg	Rdbt. Configuration	No. of Entry, Exit Lanes	Specalized Crossing Treatment	Approach Speed	Circulatory Roadway Speed	Traffic Count (AADT)	Pedestrian Count	Avg. Ped. Delay - Crosswalk Entry	Avg. Ped. Delay - Splitter Island	Yielding Rate		
												Entry Lane	Exit Lane	Overall
1	Spencer St. and Vierling Dr., Shakopee, MN	Spencer St. North Leg	1x1	1,1	Base Case/ Paddle Signs	45	15	6,800	54	2.8	0.2	92.3%	60.0%	78.3%
1	Spencer St. and Vierling Dr., Shakopee, MN	Spencer St. South Leg	1x1	1,1	Base Case/ Paddle Signs	45	15	2,950	30	1.8	0	100.0%	100.0%	100.0%
1	Spencer St. and Vierling Dr., Shakopee, MN	Vierling Dr. West Leg	1x1	1,1	Base Case/ Paddle Signs	30	15	3,700	145	0.6	0.1	92.6%	85.7%	90.2%
2	Zarthan Ave. S. and Cedar Lake Rd., St Louis Park,	Cedar Lake Rd. West Leg	1x1	1,1	In-Roadway Signs	35	15	5,800	19	0.8	0.6	100.0%	100.0%	100.0%
2	Zarthan Ave. S. and Cedar Lake Rd., St Louis Park,	Cedar Lake Rd. Southeast Leg	1x1	1,1	In-Roadway Signs	35	15	5,000	27	1.8	0	100.0%	66.7%	83.3%
2	Zarthan Ave. S. and Cedar Lake Rd., St Louis Park,	Zarthan Ave. North Leg	1x1	1,1	In-Roadway Signs	30	15	2,300	83	0.9	0.8	100.0%	75.0%	82.8%
3	Dakota Rd. 60 & Holyoke Ave., Lakeville, MN	Holyoke Ave. North Leg	2x1	1,1	Base Case	45	20	5,800	18	0.7	0.3	80.0%	42.9%	58.3%
3	Dakota Rd. 60 & Holyoke Ave., Lakeville, MN	Holyoke Ave. South Leg	2x1	1,1	Base Case	45	20	7,900	11	0.8	0.9	80.0%	75.0%	77.8%
3	Dakota Rd. 60 & Holyoke Ave., Lakeville, MN	Dakota Rd. 60 West Leg	2x1	2,2	Base Case	30	20	14,000	32	1.7	3.6	70.6%	52.4%	60.5%
4	Lake Rd. & Woodbury Dr., Woodbury, MN	Lake Rd. East Leg	2x1	1,1	Base Case	40	20	9,300	43	0.2	0	100.0%	100.0%	100.0%
4	Lake Rd. & Woodbury Dr., Woodbury, MN	Woodbury Dr. North Leg	2x1	2,2	In-Roadway Signs	55	20	9,700	27	1.8	0	81.8%	55.8%	67.1%
4	Lake Rd. & Woodbury Dr., Woodbury, MN	Woodbury Dr. South Leg	2x1	2,2	In-Roadway Signs	55	20	9,700	15	0.8	0.2	85.7%	42.9%	64.3%
5	Tracy Ave. & Valley View Ln., Edina, MN	Tracey Ave. North Leg	1x1	1,1	RRFB Activated (14.6% RRFB Activated)	30	15	15,100	152	0.4	0	100.0%	100.0%	100.0%
5	Tracy Ave. & Valley View Ln., Edina, MN	Valley Ln. Northeast Leg	1x1	1,1	RRFB Activated (14.7% RRFB Activated)	30	15	3,500	77	0.3	0	100.0%	100.0%	100.0%
5	Tracy Ave. & Valley View Ln., Edina, MN	Valley View Rd. South Leg	1x1	1,1	RRFB Activated (9.8% RRFB Activated)	30	15	9,500	143	0.4	0.1	100.0%	100.0%	100.0%
5	Tracy Ave. & Valley View Ln., Edina, MN	Tracey Ave. North Leg	1x1	1,1	RRFB Not Activated/ Base Case	30	15	15,100	152	0.4	0	84.2%	91.1%	88.0%
5	Tracy Ave. & Valley View Ln., Edina, MN	Valley Ln. Northeast Leg	1x1	1,1	RRFB Not Activated/ Base Case	30	15	3,500	77	0.3	0	100.0%	66.7%	85.7%
5	Tracy Ave. & Valley View Ln., Edina, MN	Valley View Rd. South Leg	1x1	1,1	RRFB Not Activated/ Base Case	30	15	9,500	143	0.4	0.1	89.5%	78.9%	84.2%
6	Nicollet Ave. & W66 St., Richfield, MN	Nicollet Ave. South Leg	2x1	1,1	RRFB Activated (9.8% RRFB Activated)	35	15	12,100	103	2	0.2	100.0%	91.7%	97.0%
6	Nicollet Ave. & W66 St., Richfield, MN	Nicollet Ave. South Leg	2x1	1,1	RRFB Not Activated/ Base Case	35	15	12,100	103	2	0.2	70.0%	45.2%	59.2%
7	College Dr. & Mississippi Pkwy., Brainerd, MN	West College Dr. West Leg	2x1	2,2	Colored Crosswalk	30	15	11,400	29	2.7	5.9	50.0%	17.4%	24.1%
8	East College Dr. & S 4th St., Brainerd, MN	East College Dr. Northeast Leg	2x1	2,2	Colored Crosswalk	30	15	6,000	10	1.3	4.5	50.0%	6.3%	11.1%

Case study 7 and 8, which analyzed two different multi-lane roundabouts in Brainerd, Minnesota, with colored crosswalk treatment, resulted in the lowest driver-yielding rates. The west leg of the roundabout at College Drive and Mississippi Pkwy, Brainerd, Minnesota, resulted in an overall driver-yielding rate of 24.1%. The northeast leg of the roundabout at East College Drive and S 4th Street, Brainerd, Minnesota, resulted in an overall driver-yielding rate of 11.1%. For these two locations, the yielding rates for the exit lanes are especially poor which has led to reduction of overall yielding rate for the location. These two roundabouts are located near college and high school areas.

CHAPTER 5: GUIDANCE DOCUMENT

Knowledge gathered from previous research by way of literature review combined with Minnesota roundabouts studied in this research effort were used to develop guidance to help enhance pedestrian user experience at Minnesota roundabouts. Pedestrian user experience in this study is measured by way of studying driver's yielding rate towards pedestrians at roundabout crossings, pedestrian infrastructure design as well as other pedestrian behavior characteristics at roundabout crossing treatments.

Some of the previous comprehensive research efforts have studied the driver's yielding rate with various pedestrian crossing treatments such as in-roadway signs, raised crosswalk, staggered crosswalk, yellow flashers, pedestrian hybrid beacon, rectangular rapid flashing beacons, etc. A combination of two of the above treatments were also studied in previous studies such as a raised crosswalk with the pedestrian hybrid beacon. While there are multiple opportunities to enhance pedestrian user experience at roundabout pedestrian crossings, only some of these opportunities were studied in this research effort due limited implementation of these in the state of Minnesota. Among roundabouts studied in Minnesota, the specialized crossing treatments that are being implemented on Minnesota roundabouts include in-roadway signs, colored crosswalks, and rectangular rapid flashing beacons. Rectangular rapid flashing beacons seemed to be popular among roundabouts in Minnesota that need some form of specialized control to improve driver compliance rate and enhance pedestrian safety. Knowledge from the 'NCHRP 672 - Roundabout: An informational Guide, Second Edition' was also compiled in this chapter to provide guidance on the design elements needed to enhance pedestrian user experience at roundabouts (Rodegerdts, et al., 2010).

In summary, the guidance information provided in this chapter is based on the findings from this research effort and the knowledge that was gathered from previous research efforts. Guidance is provided below for some important design elements that can enhance the pedestrian user experience at the roundabouts. It can be noted that some of the material is from studies to mitigate problems for vision-impaired pedestrians, but there is no doubt that making the crossings safer for them, makes the crossings safer for all pedestrians. In addition, even though the Access Board does not yet have all of these incorporated into enforceable guidelines, they likely will and are currently considered state-of-the-art treatments.

5.1.1 Vehicular Speed

The speed of vehicles entering and traveling through a roundabout is an important design parameter for a roundabout as it contributes towards safety of all users, and more importantly, makes roundabouts easier and safer to use for pedestrians and bicyclists (Rodegerdts, et al., 2010).

NCHRP Project 03-78c studied multiple roundabouts from various states in the U.S. in an effort to understand the effect of the speed of entering vehicles on the yielding rate towards the pedestrians at the roundabout crosswalk. The study summarized that "driver-yielding rates decreased by approximately 12.0% for every one mile per hour increase in the mean average speed at crosswalk (21

mph) (NCHRP Web-Only Document 222, 2016)." While the roundabouts studied in Minnesota do not have a sample size enough to conduct a statistical analysis, the findings followed a similar trend where the driver-yielding rates decreased when the approach speed and advisory roundabout speeds were higher. Therefore, it can be concluded that lower vehicular speeds at roundabout crosswalks could contribute towards better driver-yielding rates.

5.1.2 Sidewalk at the Roundabout

"Wherever possible, sidewalks at roundabouts should be set back from the edge of the roundabout with a landscape strip. Landscape strips provide many benefits, including increased comfort for pedestrians, room for street furniture and snow storage, and a buffer to allow for the overhang of large vehicles as they navigate the roundabout. Two additional important benefits are: 1. the setback discourages pedestrians from crossing to the central island or cutting across the roundabout and, 2. the setback helps guide pedestrians with vision impairments to the designated crosswalks (Rodegerdts, et al., 2010)." Figure 5.1 and 5.2 illustrates two different examples of sidewalk treatments.

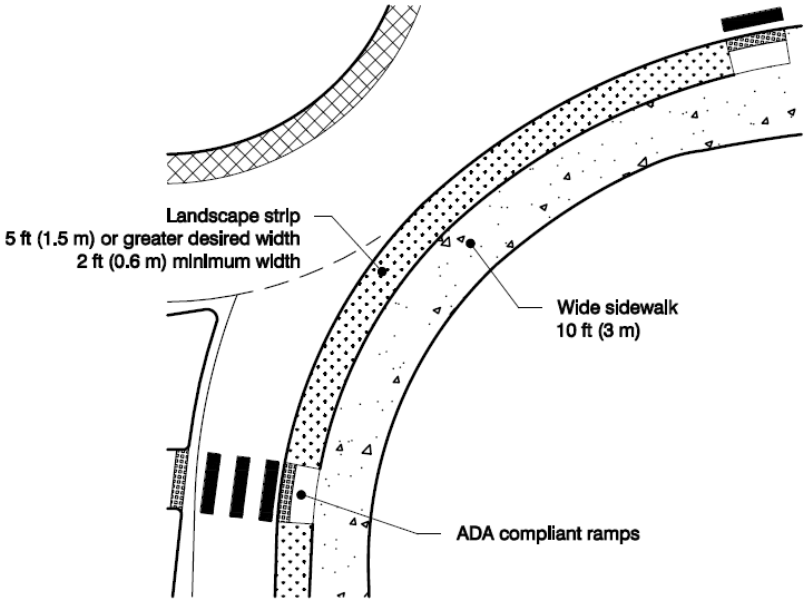


Figure 5.1: Example of sidewalk treatment

Source: (Rodegerdts, et al., 2010)

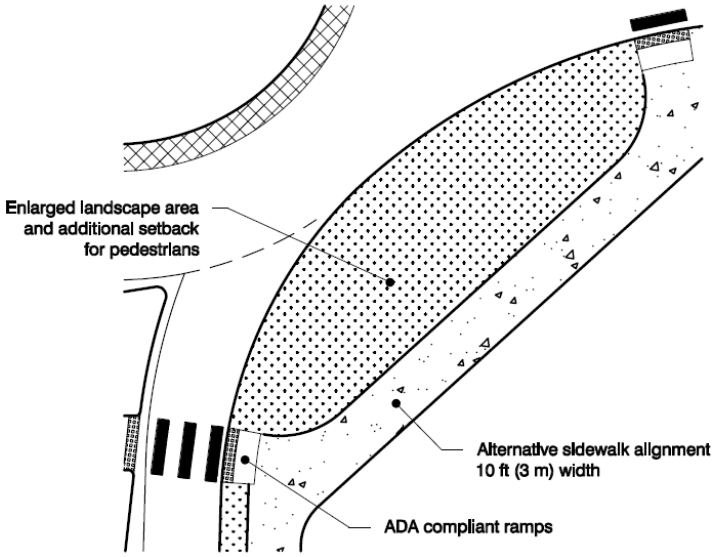


Figure 5.2: One more example of a sidewalk treatment

Source: (Rodegerdts, et al., 2010)

5.1.3 Sidewalk Width

"The recommended sidewalk width at roundabouts is 6 ft. (1.8 m), and the minimum width is 5 ft. (1.5 m). In areas with heavy pedestrian volumes, sidewalks should be as wide as necessary to accommodate the anticipated pedestrian volume. At any roundabout where ramps provide sidewalk access to bicyclists, the sidewalk should be a minimum of 10 ft. (3 m) wide to accommodate shared use by pedestrians and bicyclists (Rodegerdts, et al., 2010)."

5.1.4 Splitter Island

For pedestrians, one key consideration at the initial design stage is to ensure that adequate pedestrian refuge width is provided within the splitter island for wheelchairs. The design width for a refuge area should be a minimum of 6 ft. (1.8 m) to accommodate a typical bicycle or person pushing a stroller (Rodegerdts, et al., 2010).

5.1.5 Design Criteria

Design criteria for potential roundabout users (e.g., bicyclists, pedestrians, skaters, wheelchair users, strollers) should be considered when developing many of the geometric components of a roundabout design (Rodegerdts, et al., 2010). These users span a wide range of ages and abilities and can have a significant effect on the design of a facility. The basic design dimensions for various design users are summarized in Table 5.1.

Table 5.1: Dimensions for non-motorized users at roundabouts

User	Dimension	Affected Roundabout Features
Bicyclist		
Length	5.9 ft (1.8 m)	Splitter island width at crosswalk
Minimum operating width	4 ft (1.2 m)	Bike lane width on approach roadways; shared use path width
Pedestrian (walking)		
Width	1.6 ft (0.5 m)	Sidewalk width, crosswalk width
Wheelchair user		
Minimum width	2.5 ft (0.75 m)	Sidewalk width, crosswalk width
Operating width	3.0 ft (0.90 m)	Sidewalk width, crosswalk width
Person pushing stroller		
Length	5.6 ft (1.70 m)	Splitter island width at crosswalk
Skaters		
Typical operating width	6 ft (1.8 m)	Sidewalk width

Source: (Rodegerdts, et al., 2010)

5.1.6 Signalizing Pedestrian Crossings at Roundabouts

Signalizing pedestrian crosswalks at roundabouts may be beneficial at roundabouts when there are high vehicular volumes, higher pedestrian volumes, or if there is a need for better accessibility at a more complex crossing situation (Rodegerdts, et al., 2010).

In areas with higher vehicular volumes and lower pedestrian activity, available gaps for pedestrians could be insufficient (Rodegerdts, et al., 2010). In areas with high pedestrian activity, there could be a lot of delay for vehicles waiting for pedestrians to cross and therefore could affect the vehicle capacity at the roundabouts. In such scenarios, signalizing a pedestrian crossing could be beneficial. Roundabouts that has more than one lane (multi-lane roundabouts) could face crossing challenges for pedestrians; in such complex scenarios, signalizing the crosswalk could improve the motorist-yielding rate. Some of the options for signalizing the roundabouts include traditional red-yellow-green signals and pedestrian hybrid beacons (Rodegerdts, et al., 2010).

Other displays include yellow flashing warning beacons, and rectangular rapid flashing beacons (RRFBs). RRFBs were found effective at achieving driver-yielding rates compared to yellow flashing beacons and many prior studies have documented the effectiveness of RRFBs towards enhancing driver-yielding rate towards pedestrians. RRFBs were observed to be popular roundabout crossing treatment in the state of Minnesota.

NCHRP Project 03-78c studied multiple roundabouts from various states in the U.S. and found that there is an 8.1% increase in driver compliance rate with a use of RRFB treatment at roundabout crosswalks (NCHRP Web-Only Document 222, 2016). A similar trend is observed among Minnesota roundabouts studied in this research. Minnesota roundabouts that has RRFBs installed as a specialized crossing treatment experienced higher yielding rates when compared to similar roundabout configurations in the base case (refer to Table 4.11). Therefore, pedestrian crossings at roundabouts experiencing low yielding rates should consider implementing RRFBs to enhance driver-yielding rate and improve pedestrian user experience.

5.1.7 Single-Lane Roundabouts vs. Multi-Lane Roundabouts

Prior research suggests that a properly designed single-lane roundabout configuration designed for lower speed operations is the safest treatments possible for at-grade intersections. When applied, RRFB treatments were also found effective in achieving better yielding rates at single-lane roundabouts compared to multi lane roundabouts. As for the entering design speed based on theoretical fastest path, a maximum speed of 20 to 25mph is recommended at single-lane roundabouts (Rodegerdts, et al., 2010). However, it has to be noted that speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approaching roadways. Single-lane roundabouts are easier and safer for pedestrians and therefore multilane roundabout should not be designed at a location when single-lane roundabout is sufficient (Rodegerdts, et al., 2010).

"Multilane roundabouts cannot achieve the same level of safety as single-lane roundabouts because drivers needs to make multiple decisions and pedestrians are faced with multiple threats while they cross more than one lane of traffic at multilane roundabout approaches (Rodegerdts, et al., 2010)." The second edition of the roundabout guide provides some design considerations at multi-lane roundabouts to create safer roundabout configurations; they are: minimize travel lanes to simplify roundabout design and enhance pedestrian safety, design roundabouts for slower speeds, design sidewalks that are set back from the roundabout, providing well-defined and well-located crosswalks, and providing splitter island and at least of 6 ft. width of crosswalk (Rodegerdts, et al., 2010). As for the entering design speed based on fastest path, a maximum speed of 25 to 30 mph is recommended at multilane roundabouts. However, it should be noted that speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approaching roadways (Rodegerdts, et al., 2010).

CHAPTER 6: SUMMARY AND CONCLUSIONS

Transportation agencies in Minnesota and across the U.S. have received feedback from stakeholders that roundabouts, especially larger multi-lane roundabouts, can be difficult for pedestrians to navigate. Past studies have documented that roundabouts, especially multilane roundabouts, pose some challenges for pedestrians, and these challenges could be addressed by implementing proper roundabout geometric, design, low speeds, better design of pedestrian sidewalks and crosswalks, and some sort of specialized pedestrian crossing treatments.

This study focused on exploring the pedestrian user experience at Minnesota roundabouts, identifying how it can be enhanced through various pedestrian crossing treatments, and developing related guidance and decision tools. To achieve these objectives, a survey was conducted with Minnesota city and county engineers, as well as with the project Technical Advisory Panel members. The survey was primarily aimed at gathering pedestrian issues at existing roundabouts in Minnesota, frequent issues and complaints encountered from pedestrians using the roundabouts, and a list of potential roundabouts with existing pedestrian issues that could be examined. Fifteen roundabouts were selected from the pool of base case roundabouts and roundabouts with specialized crossing treatments to be analyzed in this study. Video data was recorded at 15 roundabout locations, and Quality Counts LLC was selected as the contractor by the research team to record video data at the 15 shortlisted roundabouts. At each roundabout, one camera was installed for each leg in such a way that it overlooked the pedestrian crossing for that leg.

After the recorded video data was reviewed at all 15 locations, 8 locations were identified as promising roundabout locations suitable for conducting an in-depth case study analysis. This decision was made by considering that the case studies should have a combination of base case roundabouts and roundabouts with various specialized crossing treatments.

Based on the case study analysis of eight roundabout locations, single-lane roundabouts performed well in terms of vehicle-yielding rates toward pedestrians. Driver-yielding rates decreased for multi-lane roundabouts. In general, for a roundabout leg, vehicle exit lanes had lower driver-yielding rates when compared to vehicle entry lanes. The vehicle approach speed and advisory speed posted for the roundabout also seemed to effect the vehicle-yielding rates toward the pedestrians. Higher approach speeds for a roundabout leg resulted in lower yielding rates.

Use of rectangular rapid flashing beacons (RRFBs) at two different roundabout locations (one 1x1 configuration and one 2x1 configuration) resulted in close to a 100% compliance rate when pedestrians activated the beacon. By contrast, when pedestrians did not activate the RRFBs and crossed the street, the overall driver compliance rate decreased by anywhere from 15% to 18% at Tracy Avenue and Valley View Lane in Edina, Minnesota, and by 38% at Nicollet Avenue and W66 Street in Richfield, Minnesota.

Use of in-roadway signs at the pedestrian crosswalk yielded satisfactory yielding rates. However, the yielding rates went down as the number of circulating lanes increased from one to two. Case study 7 and 8, which analyzed two different multi-lane roundabouts in Brainerd, Minnesota, with colored

crosswalk treatment, resulted in the lowest driver-yielding rates. For these two locations, the yielding rates for the exit lanes were especially poor. which led to a reduction in overall yielding rate for the location. These two roundabouts were located near college and high school areas, which might have partially contributed to lower driver-yielding rates.

Finally, based on the literature review and findings from Minnesota roundabouts, a guidance document was presented to assist planners and engineers in providing needed information and the opportunities available to enhance pedestrian user experience at roundabouts in Minnesota.

6.1 LIMITATIONS OF THE STUDY AND FUTURE RESEARCH NEEDS

1) One of the major limitations of the study was the lack of various specialized pedestrian crossing treatments available in Minnesota to be included in this research effort. Only three specialized crossing treatments (in-roadway signs, RRFBs, colored crosswalks) were available to the research team and therefore results were presented for these three specialized crossing treatments. Other specialized crossing treatments when implemented at Minnesota roundabouts should be studied in future research and should be compared with other crossing treatments for their driver-yielding rates and other metrics applicable for gauging pedestrian user experience.
2) The video data obtained from Quality Count LLC was analyzed by using the daytime footage only. Vehicle-pedestrian interactions during the nighttime, when the visibility was limited, were not studied in this research effort, as quality of the video footage was not sufficient to conduct video data analysis during nighttime. Future research efforts could focus on installing video cameras closer to the roundabout crossing to study vehicle-pedestrian interactions during the night.
3) The research team intended to engage pedestrians at the roundabout crossings by distributing some surveys to pedestrians at the roundabouts to understand their experience using roundabouts. However, MnDOT policies did not allow the research team to distribute surveys to pedestrians on the road.
4) Eight roundabout case studies were conducted covering various roundabout configurations and various specialized crossing treatments. Therefore, there were not enough roundabout candidates in each category (configuration or crossing treatment) to measure the statistical significance of the results observed from each category of roundabout. This was primarily due to the limited scope of this study. A more comprehensive future study for Minnesota roundabouts could help to better learn about the performance of Minnesota roundabouts and how they compare with roundabouts from across the U.S.

CHAPTER 7: REFERENCES

Ashmead, D. H., Guth, D., Wall, R. S., Long, R. G., & Ponchillia, P. E. (2005). Street Crossing by Sighted and Blind Pedestrians at a Modern Roundabout. *Journal of Transportation Engineering, 131*(11), 812-821.

FHWA. (2018, March). Interim Approval 21 Memorandum. Retrieved from https://mutcd.fhwa.dot.gov/resources/interim_approval/ia21/ia21.pdf

Geruschar, D. R., & Hassan, S. E. (2005). Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts. *Journal of Visual Impairment & Blindness, 99*(5), 286-302.

Harkey, D. L., & Carter, D. L. (2006). Observational Analysis of Pedestrian, Bicyclist, and Motorist Behaviors at Roundabouts in the United States. *Transportation Research Record, 1982*(1), 155-165.

Hourdos, J. (2012). *Investigation of Pedestrian/Bicyclist Risk in Minnesota Roundabout Crossings.* St. Paul, MN: Minnesota Department of Transportation.

Leuer, D. (2017). *A Study of the Traffic Safety at Roundabouts in Minnesota.* St. Paul, MN: Office of Traffic, Safety, and Technology; Minnesota Department of Transportation.

MUTCD. (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways.* Washington, DC: FHWA.

NCHRP Web-Only Document 222. (2016). Guidelines for the Application of Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Retrieved from https://nap.nationalacademies.org/login.php?record_id=24675

NCHRP3-78a. (2011). *Supporting Material to NCHRP Report 674 (2011).* Washington, DC: National Cooperative Highway Research Program.

Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., . . . O'Brien, A. (2010). *NCHRP Report 672: Roundabouts: An Informational Guide, Second Edition.* Washington, D.C.: Transportation Research Board.

Rouphail, N., Hughes, R., & Chae, K. (2005). Exploratory Simulation of Pedestrian Crossings at Roundabouts. *Journal of Transportation Engineering, 131*(3), 211-218.

Russell, E. R. (2008). *A Study of the Effects of ADA Accessibility on Kansas Roundabouts.* Manhattan, KS: Kansas Department of Transportation.

Schneider, R. J., Qin, X., Shaon, M. R., Sanatizadeh, A., He, Z., Wykhuis, P., & Block, B. (2017). *Evaluation of Driver Yielding to Pedestrians at Uncontrolled Crosswalks.* Madison, WI: Wisconsin Department of Transportation.

Schroeder, B., Hughes, R., Rouphail, N., Cunningham, C., Salamati, K., Long, R., . . . Myers, E. (2011). *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities.* Washington, D.C.: Transportation Research Board.

Schroeder, B., Rodegerdts, L., Jenior, P., Myers, E., Cunningham, C., Salamati, K., . . . Bentzen, B. L. (2016). *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities - A Guidebook.* Washington, DC: National Cooperative Highway Research Program.

U.S.DOT. (2014). *Making Roundabouts Work for Pedestrians and Bicycles.* Washington, DC: Federal Highway Administration.

US Access Board. (2011, July 26). *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Rights of Way.* Washington, DC: United States Access Board.

APPENDIX A: A SURVEY QUESTIONNAIRE TO GATHER ROUNDABOUT CANDIDATES

Exploring Roundabout Candidates for Roundabout Analysis

Dear Sir/Madam,

We are reaching out to you to gather your input regarding a Minnesota DOT/LRRB research project we are currently conducting. The objective of this research is to understand pedestrian user experience at roundabouts, and determine how pedestrian user experience can be enhanced at roundabouts through various pedestrian treatments. In this regard, we want to gather information on any specific roundabout/roundabouts you are aware of in Minnesota where there are known or perceived negative pedestrian issues. Your input in this regard can help us identify roundabout candidates to shortlist for our research study to conduct further analysis. Our research team would appreciate your input in this regard.

Sincerely,
Dr. Ranjit Godavarthy
Assistant Professor, North Dakota State University

Can you think of any roundabout(s) in your jurisdiction or anywhere else in Minnesota with reported pedestrian crossing issues (such as lack of pedestrian safety, vehicle drivers not yielding to pedestrians, lack of pedestrian compliance, etc.)?

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Can you think of any roundabout(s) in your jurisdiction or anywhere else in Minnesota with report... = Yes

Q3 Can you please provide location details (name of streets, city) of each roundabout with reported pedestrian issues? If you know more than one roundabout with reported pedestrian issues, please provide location details of the roundabouts:

_____

_____

Display This Question:

If Can you think of any roundabout(s) in your jurisdiction or anywhere else in Minnesota with report... = Yes

Q4 Can you briefly explain the reported pedestrian issue(s) at the above identified roundabout(s)?

_____

_____

Display This Question:

If Can you think of any roundabout(s) in your jurisdiction or anywhere else in Minnesota with report... = Yes

Q5 Can we contact you to gather further information about this roundabout(s) so we could study the location in our research? If not, can you provide a contact whom we can reach out to gather more information?

_____

_____

_____

Q6 Do you know of any roundabout(s) in your jurisdiction or anywhere else in Minnesota that has particularly high pedestrian volume? If so, please provide the location of the roundabout(s).

_____

_____

_____

Q7 In addition to finding roundabouts with known or perceived negative pedestrian issues, we want to locate a group of roundabouts with several different crosswalk treatments that are listed below. Do you

know of a roundabout(s) in your jurisdiction or anywhere else in Minnesota that has one or more of the below treatments? *Please check all that apply, and provide location details for each of your selection:*

- ☐ Traditional Signals (Green, Yellow, Red) (1) _____
- ☐ Pedestrian Hybrid Beacon (2) _____
- ☐ Rectangular Rapid Flashing Beacon (3) _____
- ☐ Yellow Flashing Beacon (4) _____
- ☐ Staggered Pedestrian Crossing (5) _____
- ☐ Raised Pedestrian Crossing (6) _____
- ☐ Any other special treatment not listed above (7) _____

Q8 Please provide your details so we can contact you for follow-up information:

- ○ Name: (1) _____
- ○ Title: (2) _____
- ○ Agency Name: (3) _____
- ○ Location: (4) _____
- ○ Best means and time to contact you: (5) _____

APPENDIX B: LIST OF ROUNDABOUTS MENTIONED AS HAVING SOME SORT OF ISSUES FROM THE SURVEY RESPONSES

#	Roundabout Location	Roundabout Configuration	Reported Pedestrian Issues	Quick Google Link to Location
1	Minnesota Highway 22 & Madison Ave., Mankato, MN; Location type: Business area	2x2 lane roundabout	Inability to safely cross multiple traffic lanes without risk	https://www.google.com/maps/@44.1668461,-93.9483086,516m/data=!3m1!1e3
2	Minnesota Highway 22 & Adams St., Mankato, MN; Location type: Business area	2x1 lane roundabout	Inability to safely cross multiple traffic lanes without risk	https://www.google.com/maps/@44.1701788,-93.9485188,729m/data=!3m1!1e3
3	Dakota Rd. 60 & Holyoke Ave., Lakeville, MN; Location type: Residential/Office	2x1 lane roundabout	Concern for yielding - especially for the exiting approach.	https://www.google.com/maps/@44.6561747,-93.242647,362m/data=!3m1!1e3
4	64 & Pilot Knob Rd., Farmington, MN; Location type: Residential/Office	2x1 lane roundabout	Concern for yielding - especially for the exiting approach.	https://www.google.com/maps/@44.6668651,-93.1772428,295m/data=!3m1!1e3
5	TH 169 & CSAH 44, Blue Earth, MN; Location type: Business area	1x1 roundabout	Many (not all) drivers do not stop for pedestrians in the crosswalks. This is not unusual for the city, as drivers typically do not stop for pedestrians in any crosswalk.	https://www.google.com/maps/@43.6520462,-94.0940413,368m/data=!3m1!1e3
6	TH 169 & CSAH 16/E 1st St., Blue Earth, MN; Location Type: Residential area	1x1 roundabout	Many (not all) drivers do not stop for pedestrians in the crosswalks. This is not unusual for the city, as drivers typically do not stop for pedestrians in any crosswalk.	https://www.google.com/maps/@43.6448409,-94.0910613,368m/data=!3m1!1e3
7	TH 169 at CSAH 16/7th St,, Blue Earth, MN; Location Type: Office area	1x1 roundabout	Many (not all) drivers do not stop for pedestrians in the crosswalks. This is not unusual for the city as drivers typically	https://www.google.com/maps/@43.6377374,-94.0907558,309m/data=!3m1!1e3

			do not stop for pedestrians in any crosswalk.	
8	TH 13 & CH 21, Prior Lake, MN; Location Type: Business/residential area	2x1 roundabout	Location has a regional trail crossing the south leg. Vehicles not yielding to pedestrians.	https://www.google.com/maps/@44.7130873,-93.4229518,429m/data=!3m1!1e3
9	Pioneer Rd. & Twin Bluff, Red Wing, MN; Location type: School/ residential	1x1 roundabout	When school is starting and ending, there is a lot of traffic. The pedestrian cross is just outside the splitter islands. With all the traffic, the drivers are noticing the school crossing as they come out of the roundabout. There is a school crossing guard along with a yellow flashing light at the crossing.	https://www.google.com/maps/@44.5430792,-92.5443314,431m/data=!3m1!1e3
10	Lake St. (US 61) at Broadway Ave. (County 2), Forest Lake, MN; Location type: Business area	1x1 roundabout	Concerns are similar at county 2 and county 19 roundabouts- Lack of clear gaps, concern about pedestrians being hidden from view by other vehicles (Multiple-Threat issue), pedestrian concerns that sight distance is insufficient for pedestrians to choose comfortable gaps, that drivers are not voluntarily yielding when the pedestrian is intending to cross but not within the crosswalk. These are both partial multi-lane crosswalks that have both high vehicular and pedestrian volumes compared to other multi-lane roundabouts in the county.	https://www.google.com/maps/@45.2787625,-92.9851491,506m/data=!3m1!1e3
11	Lake Rd. at Woodbury Dr. (County 19), Woodbury, MN; Location type: Residential area	2x1 roundabout		https://www.google.com/maps/@44.9028459,-92.9042119,303m/data=!3m1!1e3
12	3 roundabouts on St. Croix Trail (County 18), Lakeland and Lakeland Shores, MN; Location type: Arterial road?	1x1 roundabout		https://www.google.com/maps/@44.9497148,-92.7705179,428m/data=!3m1!1e3

13	College Dr. in Brainerd, MN (3 roundabout locations). Location type: High-density college housing on one side and the college on the other side.	2x1 roundabout	Complaints regarding 4-lane section, general complaints about narrow escapes. Driver awareness in roundabouts. Complaints about pedestrians and non-compliant vehicles.	https://www.google.com/maps/@46.3476503,-94.2137459,628m/data=!3m1!1e3
14	Highway 7 and Louisiana, St Louis Park, MN; Location type: Freeway ramps	2x1 roundabout	vehicles not yielding, sight lines	https://www.google.com/maps/@44.9383792,-93.3706521,574m/data=!3m1!1e3
15	Spencer St. & Vierling Dr., Shakopee, MN; Location type: School/residential	1x1 roundabout	Both are small roundabouts and don't give drivers time to look ahead for pedestrians when making a right turn through the roundabout. Drivers have to focus on traffic to their left and have limited time to identify pedestrians when making the right turn movement.	https://www.google.com/maps/@44.7834751,-93.5197929,242m/data=!3m1!1e3
16	South Park Dr. & Louisiana Ave., Savage, MN	1x1 roundabout		https://www.google.com/maps/@44.7393324,-93.369258,204m/data=!3m1!1e3
17	Rice St./I-694 Ramps, Shoreview, MN; Location type: Freeway ramps		Cars leaving roundabout on Rice Street to enter WB 694 don't look right to see pedestrians in the marked crosswalk	https://www.google.com/maps/@45.0459243,-93.1051128,604m/data=!3m1!1e3!5m1!1e4
18	3 Roundabouts on 70th St. Between France and York, Edina, MN; Location type: Business area	1x1 roundabout	Cars not yielding to pedestrians or driving too fast	https://www.google.com/maps/@44.8763167,-93.3240675,606m/data=!3m1!1e3!5m1!1e4
19	Diffley and Rahn, Eagan, MN; Location type: Residential	2x1 roundabout	I drive it a few times daily, during rush hour there are always pedestrians and not much compliance for yielding to the pedestrians	https://www.google.com/maps/@44.8047268,-93.2078962,242m/data=!3m1!1e3!5m1!1e4

20	2 roundabouts (north and south junction) - US 61 & TH 97, Forest Lake, MN; Location type: Business/school area?	2x1 roundabout	I walked these two roundabouts at mid-afternoon on a weekday as part of a training-related field exercise. Yielding behavior on the exiting leg of the roundabouts was inconsistent. There are two vehicle movements that present the greatest safety issue/discomfort to pedestrians: - The SB to WB movement at the south roundabout and; - The NB to EB movement at the north roundabout Both of these movements are accommodated with right-turn bypasses that allow vehicles to travel at much higher speeds than a typical right-turn movement at a roundabout. Another issue, at the south junction, is where the SB to WB and NB to WB movements converge. There is a pedestrian "refuge" between these two lanes on a splitter island that is not large enough to act as a refuge.	https://www.google.com/maps/@45.2585079,-92.9825371,1431m/data=!3m1!1e3!5m1!1e4
21	Multiple roundabouts along 66th St. (CSAH 53) in Richfield, MN; Location type: Business area	2x2 and 2x1	The reported issues are that cars do not yield (even where there are RRFBs installed) and they are perceived unsafe for pedestrians. We have learned this is an educational issue for the pedestrian user. We have had success by doing site visits and walking with people to educate them on expectations	https://www.google.com/maps/@44.8832339,-93.2858082,483m/data=!3m1!1e3!5m1!1e4

			and how to cross the roundabouts. This has worked.	

APPENDIX C: LIST OF ROUNDABOUTS IN MINNESOTA WITH SPECALIZED PEDESTRIAN CROSSING TREATMENTS

#	Roundabout Location	Roundabout Category	Crossing Treatment	Quick Google Link to Location
1	W 66th St. & Lyndale Ave. S., Richfield, MN	2x1 roundabout	Rectangular Rapid Flashing Beacon (RRFB)	https://www.google.com/maps/@44.8834153,-93.2887692,17z
2	E 66th St. & Nicollet Ave. S., Richfield, MN	2x1 roundabout	RRFB	https://www.google.com/maps/@44.8834609,-93.2804222,17z
3	E 66th St. & Portland Ave. S., Richfield, MN	2x2 roundabout	RRFB	https://www.google.com/maps/@44.8835825,-93.2700152,17z
4	Zarthan Ave. S. & Cedar Lake Rd., St Louis Park, MN; Location Type: Residential/office	1x1 roundabout	Sign in the median (State law - Stop for pedestrians in crosswalk)	https://www.google.com/maps/@44.9650058,-93.3547308,523m/data=!3m1!1e3
5	Tracy Ave. & Velley View Ln., Edina, MN; Location Type: Residential	1x1 roundabout	RRFB	https://www.google.com/maps/@44.8846497,-93.3699961,428m/data=!3m1!1e3
6	Scandia Trail N. (TH 97) and 8th St./GoodvieW Ave. N., Forest Lake, MN; Location type: School. Residential area	1x1 roundabout	RRFB	https://www.google.com/maps/@45.2547726,-92.9858382,675m/data=!3m1!1e3
7	College Dr. & Mississippi Pkwy.; Brainerd, MN	2x1 roundabout	Colored Concrete	https://www.google.com/maps/@46.3471646,-94.2124982,394m/data=!3m1!1e3
8	College Dr. & S. 4th St.; Brainerd, MN	2x1 roundabout	Colored Concrete	https://www.google.com/maps/@46.3471646,-94.2124982,394m/data=!3m1!1e4

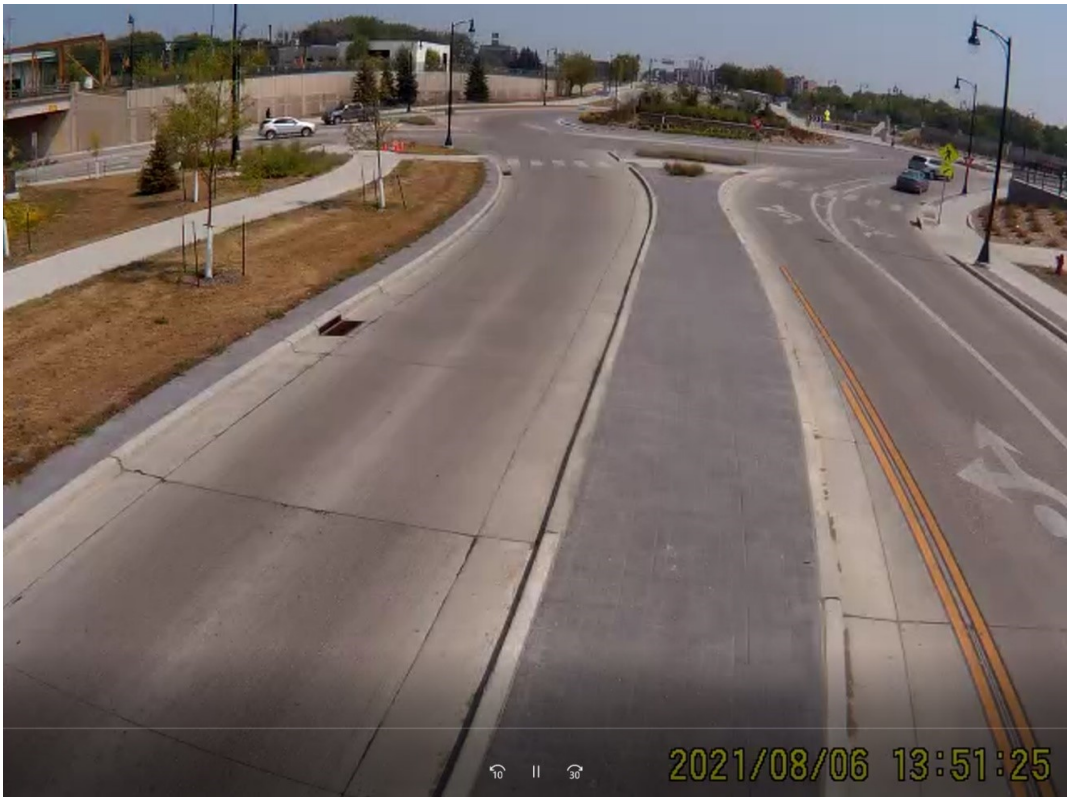
APPENDIX D: CAMERA INSTALLATION GUIDELINES TO QUALITY COUNTS LLC

Camera Installation Guidelines

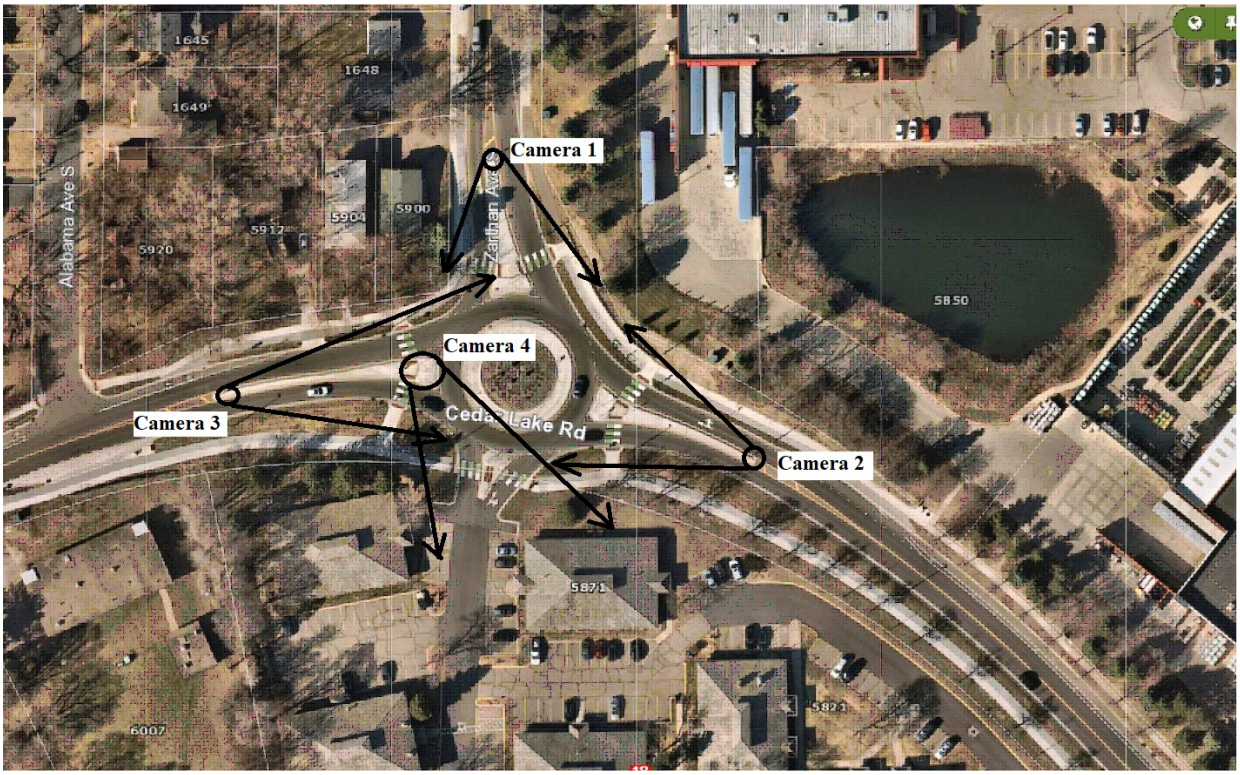
What we need: Video footage of pedestrian crosswalk at each roundabout approach showing the vehicle and pedestrian interaction. We want to see vehicles entering and exiting the roundabout, and how these vehicles interact with pedestrians in the crosswalk.

How far to install the camera from crosswalk. The distance of the camera from the crosswalk could be anywhere in the range 100ft - 250ft. The ideal distance would be approximately 150ft. If the camera is installed in the 100ft-250ft distance range from the crosswalk, we could get a video feed that would be useful for us.

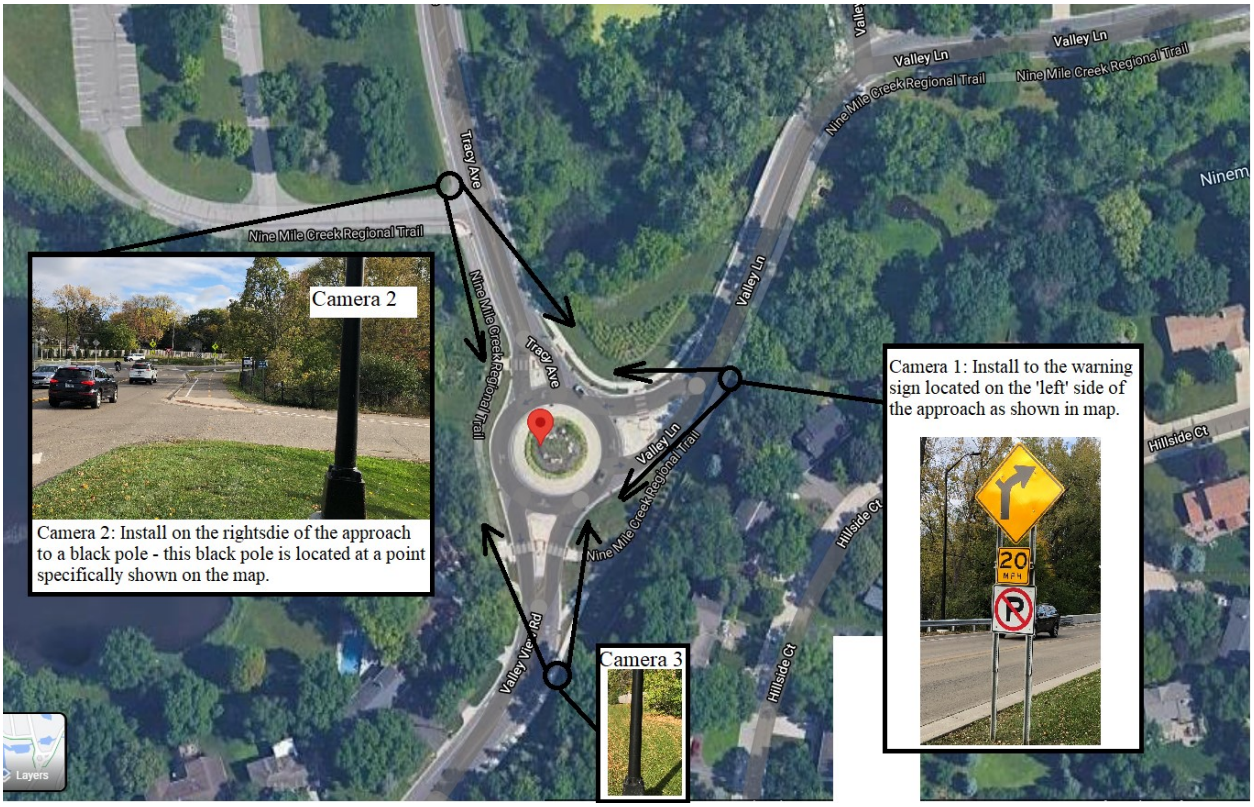
Where to install camera. Typically, there are signs on splitter island for each approach. If these signs were not blocking the view of the crosswalk and in the 100ft-250ft range, they would be perfect. If not, any signs or light poles located on the right- or left-hand side of the approach generating a similar view could also be helpful. Below is the sample camera view that can help you understand what we think is ideal.



Preferred Camera Location and View Area: Zarthan Ave. S. and Cedar Lake Rd., St Louis Park, Minnesota



Camera installation Suggestions and View - Tracy Ave. and Velley View Ln., Edina, Minnesota



Camera installation Suggestions and View – Lyndale Ave. S. and W 66th St., Richfield, Minnesota