Road Commission for Oakland County PHB and RRFB Study

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Final Report

by

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Accessible Design for the Blind

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1. EXECUTIVE SUMMARY

This report summarizes the study of two treatments, a pedestrian hybrid beacon (PHB) and a rectangular rapid-flashing beacon (RRFB) system, geared at enhancing accessibility to pedestrians who are blind at multi-lane roundabouts. The study was conducted by Western Michigan University (WMU) and its Department of Blindness and Low Vision Studies (BLS) with support from the Institute for Transportation Research and Education at North Carolina State University (ITRE, NCSU), Accessible Design for the Blind (ADB), and Kittelson & Associates, Inc. (KAI). The focus of the study was on safety and accessibility issues to two multilane roundabout intersections located at Drake and Maple Roads and Farmington and Maple Roads in West Bloomfield, Oakland County, Michigan by individuals who were blind. The impact of the PHB and RRFB on vehicle operations also was investigated.

Blind individuals and a comparison group of sighted individuals participated in the pretest (before installation of the PHB and RRFB) and many returned for the posttest with the PHB or RRFB in place. The posttest further included some participants, who had not participated in the pretest study and therefore represented a group unfamiliar with the test intersection. The studies were conducted at the request of and with financial support from the Road Commission for Oakland County (RCOC), with additional support from a grant from the National Institutes of Health (NIH), National Eye Institute, to Western Michigan University (Project number 5 R01EY012894-07). The research described here was conducted under the overall supervision of Dr. Richard G. Long, Associate Dean of Western Michigan University's College of Health and Human Services.

The study protocol at the Maple and Drake roundabout relied on the help of participants who were blind and who crossed the street independently, but with supervision of a Certified Orientation & Mobility (O&M) Specialist. The study also included some sighted participants, who followed the same study protocol as the blind participants. The O&M Specialist would intervene when the participant started crossing in a risky situation. The rate of occurrence of these O&M *interventions* represents the primary safety measure in this study. Other performance measures include the propensity of drivers to yield, pedestrian and driver delay, vehicle queues, and behavior of pedestrians and drivers with regards of the installed traffic control device.

At the Maple and Farmington roundabout, a revised study protocol was used that replaced actual street crossings with crossing indications, with the study participants raising their hand when they would cross. The decision to modify the study protocol was based on an elevated degree of risk experienced during pilot testing at that roundabout. The resulting performance measures from the indicator study protocol are consistent with the crossing study protocol, with the caveat that interventions were estimated independently by two trained observers.

1.1 Summary of Maple and Drake

The intersection of Maple Road and Drake Road was outfitted with a Pedestrian Hybrid Beacon System. The multi-lane roundabout features three entering and three exiting lanes along Maple Road, and two entering and exiting lanes on the Drake Road approaches. The roundabout has an inscribed diameter of approximately 240 feet. The intersection processes an average daily traffic (ADT) of 41,500 vehicles per

day (vpd) and peak hour flows around 960 vehicles per hour (vph) on the three-lane approaches and 640 vph on the two lane approaches.

The analyses presented in this report offer evidence that the installation of the PHB significantly reduced delay and crossing risk for blind participants at both the two-lane and three-lane crosswalks at the Maple and Drake roundabout. A summary of the key performance measures for blind and sighted study participants is provided in Table 1: Summary of PHB Crossing Performance.

Table 1: Summary of PHB Crossing Performance at Maple/Drake

Measure	Study	Entry/ Exit	Two-Lane Crossings		Three-Lane Crossings	
			Blind	Sighted	Blind	Sighted
Estimated Interventions (%)	Pretest	Entry	1.9%	0.0%	7.7%	0.0%
		Exit	8.7%	0.0%	9.6%	0.0%
	Posttest PHB	Entry	0.0%	0.0%	0.0%	0.0%
		Exit	1.7%	0.0%	0.8%	0.0%
Average Delay (sec.)	Pretest	Entry	15.4	4.7	20.1	9.8
		Exit	19.0	11.1	22.3	9.5
	Posttest PHB	Entry	11.5	7.9	14.2	10.5
		Exit	11.2	9.8	11.7	10.5

The comparison of crossing performance in the pretest indicates that blind participants experienced greater delay at the three-lane crossings and that those crossings occurred at a significantly greater risk. The average intervention rates of 7.7% and 9.6% at the three-lane entry and exit approaches were very high. In fact, these rates were greater than for any other study performed by this research team. The average intervention rate at the two-lane approach exit was also very high in the pretest (8.7%) and was higher than the intervention rate at the two-lane roundabout studied in Golden, CO under NCHRP project 3-78a (TRB, 2010). The results of that NCHRP study (now published in NCHRP Report 674 available online: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_674.pdf) showed a pretest intervention rate of 2.4%, which was decreased to 0.0% for blind pedestrians with the installation of a PHB at a two-lane roundabout approach. Blind participant delay in Golden, CO was 16 seconds in the pretest and 6 seconds in the posttest after the PHB was installed.

For the study at Maple and Drake, sighted participants generally performed much better at both approaches with lower delays and no O&M interventions. Interestingly, sighted participants did not seem to experience notably different levels of delay at the two-lane and three-lane approaches.

The installation of the PHB treatments successfully reduced delay for blind participants, with the larger effect evident at the three-lane approach (due to a higher pretest delay). The range and standard deviation of observed delays also decreased, which indicates more consistent crossing performance across the different blind participants.

The most important effect of the PHB installation was a large reduction in O&M interventions, from 7.7% and 9.6% at the three-lane entry and exit, respectively, to 0.0% and 0.8%. The high intervention

rate at the two-lane exit (8.7%) was also reduced to 1.7%, and the 1.9% interventions at two-lane entry were reduced to zero. In other words, most blind participants in the posttest did not experience any interventions. These results indicate that the PHB installation at the Maple Road and Drake Road multilane roundabout enhanced the crossing safety for participants who are blind through significantly reduced intervention events, and further benefitted through reduced (and more reliable) delay for blind study participants.

However, some concern about the PHB treatment is related to a high rate of red-light running events, especially at the exit legs of the roundabout. A study of driver behavior at the two-lane and three-lane exit legs showed a high rate of drivers that proceeded through the steady red indication at about 13% and 31%, respectively.

1.2 Summary of Maple and Farmington

The intersection of Maple Road and Drake Road was outfitted with a Rectangular Rapid-Flashing Beacon System (RRFB). The multi-lane roundabout features three entering and three exiting lanes along Maple Road, and two or three entering and exiting lanes on the Farmington Road approaches. The roundabout has an inscribed diameter of approximately 250 feet. The intersection processes an average daily traffic (ADT) of 41,700 vehicles per day (vpd) and peak hour flows around 1,120 vehicles per hour (vph) on the three-lane approaches and 700 vph on the two lane approaches.

The analysis of the RRFB treatment at Maple and Farmington showed some promise for improving pedestrian safety at the two-lane approaches to the roundabout, particularly at the entry-leg. However, significant safety concerns remained at the two-lane exit leg, and especially at the three-lane entry and exit legs. A summary of the key performance measures for blind and sighted study participants is provided in Table 2: Summary of RRFB Crossing Performance.

Table 2: Summary of RRFB Crossing Performance at Maple/Farmington

Measure	Study	Entry/ Exit	Two-Lane Crossings		Three-Lane Crossings	
			Blind	Sighted	Blind	Sighted
Estimated Interventions (%)	Pretest	Entry	7.5%	0.0%	12.5%	0.0%
		Exit	23.8%	0.0%	23.2%	0.0%
	Posttest RRFB	Entry	0.0%	0.0%	7.6%	0.0%
		Exit	16.4%	0.0%	18.9%	0.0%
Average Delay (sec.)	Pretest	Entry	20.8	15.9	35.2	21.8
		Exit	22.2	13.9	30.5	23.5
	Posttest RRFB	Entry	17.1	5.7	19.8	11.2
		Exit	18.8	7.3	24.8	16.2
Driver Yielding (%)	Pretest	Entry	57.2%	61.8%	36.5%	34.5%
		Exit	9.5%	11.5%	3.0%	3.7%
	Posttest RRFB	Entry	82.7%	71.2%	73.1%	46.6%
		Exit	49.5%	22.2%	26.9%	15.7%

The RRFB effectively reduced entry-leg estimated interventions from 7.5% to 0.0% at the two-lane entry leg, but still showed a high rate of 16.4% estimated interventions at the two-lane exit. At the three lane crossings, blind participant intervention rates at entry and exit legs remained high at 7.6% and 18.9%, respectively, even after installation of the RRFB. While the measure of estimated interventions is not necessarily exactly comparable with "real" interventions observed at Maple/Drake or in prior research through NCHRP 3-78a (TRB, 2010), the high rates are cause for serious concern for blind pedestrian safety.

By comparison, the pretest intervention rates at the Maple/Drake roundabout were 11.4% at the three-lane crossing and 6.4% at the two-lane crossing. Both intervention rates were reduced to less than 1% in the posttest with the PHB treatment installed. Similarly, at a two-lane roundabout studied previously in Golden, CO (TRB, 2010), a much lower pretest intervention rate was observed at 2.4%, and the installation of the Pedestrian Hybrid Beacon (PHB) treatment reduced interventions to zero.

The fact that posttest exit-leg intervention rates at Maple/Farmington remained at 16.4% and 18.9% at the two-lane and three-lane crossings, respectively, leads to the conclusion that the RRFB did not reduce the likelihood of risky pedestrian crossings at the Maple/Farmington roundabout as much as the PHB did at the Maple/Drake roundabout.

Despite these results, it should be noted that the RRFB showed some benefit towards reducing risky pedestrian crossings. In particular, the treatment did successfully eliminate interventions at the two-lane entry-leg crossing, from a rate of 7.5% in the pretest case. Further, the RRFB significantly increased driver yielding behavior in all crossing environments, and especially at the entry legs to quite high levels of 82.7% and 73.1% at two-lane and three-lane crossings, respectively. The treatments did show some promise at the exit leg as well, but didn't manage to increase yielding above 50% for the two-lane and above 30% for the three-lane crossings.

The RRFB treatment further showed some promise for sighted participants, who didn't experience any interventions in either pretest or posttest. For that population, the RRFB did manage to achieve a reduction in average delay, which is attributable to increased yielding behavior. Any apparent delay improvements for blind participants need to be considered with great care, since many of these seemingly "efficient" decisions ended up being potentially very risky.

In summary, the greatest concern for (blind) pedestrian safety at Maple/Farmington is at the exit legs for both the two-lane and three-lane approaches. The low observed yielding rates are likely attributable to high vehicle speeds leaving the circulatory roadway, concern for rear-end collisions, and ultimately the narrowing of both Maple and Farmington roads to a single lane downstream of the crosswalk. The entrance crosswalk is visible over a longer distance without requiring a driver to also navigate their vehicle. The exit crosswalk is visible over a shorter distance, and the driver is preoccupied with vehicle navigation through the roundabout, and potentially, preparing for the downstream lane-drop merge.

1.3 Summary of Safety Results

A vehicle safety analysis of the intersections of Maple at Drake and Maple at Farmington was conducted to determine the impact of two treatments, the PHB and RRFB, respectively on vehicle collisions. Two

methods of analysis were explored, the Comparison Group (CG) and the Causal Factor (CF) Methodologies, with the former being the preferred method. However, based on tests of the representative comparison groups identified by the county, no good candidate groups could be utilized. Therefore, the team used the CF analysis methodology. The primary shortcoming of this method is that it does not account for historical and seasonal trends such as changing traffic demand or changing weather patterns, and cannot account for regression to the mean.

Collisions were broken into three categories: Rear-end, Sideswipe, and Angle. In addition, collisions were further separated by one of three locations at the roundabout: Within, Exiting, and Entering. The overall findings suggest that fifteen of the eighteen possible collision categories experience no change or a reduction in collisions in a comparison of before and after treatment data. Of the three categories reporting an increase, small sample sizes likely contributed to the apparent increase in collisions and the safety evidence is therefore non-conclusive. Overall, the safety analysis suggests that the treatment installations had no significant adverse effect on vehicle collisions, and may in fact have contributed to making the roundabouts safer.

When reporting safety findings, readers should know that some of the categories had very small samples of collisions. Because of this, standard deviations were very high in many instances, making statistical conclusions difficult. Second, the research team could not account for historical or seasonality trends or regression to the mean as mentioned earlier. Finally, the findings in this analysis include effect from the installation of the treatment AND geometric improvements to the roundabout that occurred during this same construction period.

1.4 **Recommendations**

Our analysis from these studies leads us to conclude that the Pedestrian Hybrid Beacon (PHB, also known as HAWK) installed at Maple and Drake Roads resulted in a statistically significant improvement in the safety of pedestrian crossings for both the two lane segment (Drake Road) and the three lane segment (Maple Road). This improvement can be seen in each of our three measures of safety: intervention rate, vehicle yielding rate and pedestrian delay. Of these measures, intervention rate is a direct measure of safety improvement, while the other two measures are indirect. They could be considered as having a secondary impact on crossing safety (e.g., decreased crossing delay is likely to result in pedestrians initiating crossings at less risky times, but we do not consider it a direct measure of safety). In regard to interventions, the proportion of crossing trials that resulted in interventions by O&M specialists, who shadowed participants during the posttest phases, was less than one percent of all trials with the PHB installed. There was statistically significant reduction in interventions for both the two lane approach and the three lane approach.

In keeping with our earlier studies, we also observed that the intervention frequency overall was higher at the exit lanes than the entry lanes. We observed increases in vehicle yielding (mostly attributable to vehicles yielding to the red indication at the PHB), and significant reductions in pedestrian delay as a result of PHB installation. Because the frequency of interventions was very low at posttest, it may be that additional treatments would yield only marginal increases in safety. However, we are concerned with the high rate of red signal violations noted during the posttest phase of the study. Although these

violations did not result in safety reductions, we believe they could be a significant safety issue, and we recommend that enforcement and education of drivers and pedestrians be considered as means to reduce the violation rate. We recommend that design changes at the intersection be considered to reduce vehicle speed, which likely would result in improved signal compliance and may reduce crash rates as well.

At the intersection of Maple and Farmington Roads, the research team elected to use a crossing indicator method rather than the actual crossing trials method we used at Maple and Drake. This was the case for both pretest and posttest. This decision was based on our perception that the risk of crossing at Maple and Farmington was unacceptably high, regardless of experimental condition, and even when research participants were accompanied by an orientation and mobility specialist. There were no statistically significant safety improvements at the intersection as a result of use of the rectangular rapid flash beacon (RRFB), with the exception of the two lane entry on Farmington Road (there were 7.5 % interventions at pretest at this location and none at posttest). The frequency of risky judgments as measured by estimated interventions (not actual crossings) remained unacceptably high at posttest at the three-lane entrance leg, and was even higher at the two-lane and three-lane exits. We conclude that additional measures are needed at Maple/Farmington to further mitigate the risk to pedestrians with blindness at this intersection. We recommend that consideration should be given to installation of a PHB at this location or to geometric and design changes that result in slower vehicle speed. This could include a reduction to a lower number of lanes entering, exiting, and circulating.

Although we obtained statistically significant differences in vehicle queuing for the exit lanes at Maple and Drake, we do not consider these differences to be operationally significant. The slight differences in queuing at Maple and Farmington likewise are likely not operationally significant. We thus conclude that these treatments likely do not have an impact on the operation of the roundabout.

Why was posttest safety performance at Maple and Drake better than that at Maple and Farmington? In exploring that question, it should be noted that the pretest performance at Maple/Farmington seemed to be more risky than Maple/Drake. While it is not clear what caused the higher perceived level of risk at Maple/Farmington, the team felt strongly about a notably increased level of risk, which ultimately led to the decision to modify the study protocol from crossing trials to indicator trials. With different protocols in place, one should be cautious about directly comparing the two study results, but the rate of interventions at Maple/Drake in pretest was lower than the rate of (estimated) interventions at Maple/Farmington. It is therefore feasible to argue that the treatments were assessed against somewhat different baselines.

But regardless of these differences in pretest performance, the impact of the PHB treatment on pedestrian safety was clearly much larger than the RRFB. In comparing the two treatments, one obvious answer explain this difference is that the PHB appears to be a more effective treatment than the RRFB, because the PHB features a stead red indication, while the RRFB only flashes yellow. However, there are other differences between the two intersections and treatments that could have accounted for some of the variance in performance. A key difference may be in the design of the two installations. The PHB included a mast arm that positioned a signal head over the center lane of the approach, and the side-

mounted heads are mounted high to achieve good visibility. The RRFB was only side mounted with the flashing part at a relatively low mounting height. Further, the PHB installation was associated with a relocation of the exit-portion of the crosswalk, mostly due to the need for adequate sight-distances to the overhead mounted beacon above the center lane. With a relocation of the crosswalk, drivers presumably had more time to react to the traffic control device, although a high incidence of non-compliance remained a concern. These differences could have contributed to performance differences for the two treatments.

Our data support the conclusion that PHB's appear to be an effective treatment at the Maple/Drake roundabout to improve the accessibility of crossings for pedestrians who are blind, although signal violations are a significant concern, especially at the roundabout exit leg. More research is needed to be able to make broader conclusions about the effectiveness of this treatment across the spectrum of multilane roundabouts. Based on the evaluation of the Maple/Farmington roundabout, the RRFB appears to be less effective at Maple/Farmington than the PHB was at the similar Maple/Drake roundabout, with significant concerns regarding the potential for risky crossings for pedestrians who are blind. Broader conclusions should not be drawn until additional research is completed at a broader spectrum of multilane roundabouts. It would be useful to investigate whether changes to the design of the RRFB layout at the Maple/Farmington roundabout, the addition of other treatments tested here (e.g., raised crosswalks, traffic calming, fewer lanes), or testing of these other treatments as stand-alone treatments, may further improve pedestrian accessibility at this location.

Presumably, alternative crossing treatments that would physically limit the speeds of exiting vehicles would have a positive impact on accessibility. In particular, this research team evaluated a raised pedestrian crosswalk at a two-lane roundabout in Golden, CO, which successfully eliminated interventions in the posttest case (reduction was from a pretest intervention rate of 2.8%; TRB, 2010). In fact, the Golden, CO raised crosswalk showed very similar performance to a PHB installed at a different approach to the same roundabout, but at a significantly reduced installation and maintenance cost. At a vertical elevation of 3 inches above pavement level and a 1:15 transition slope, the Golden, CO raised crosswalk did not result in significant impediments to the driving population in the absence of pedestrians, especially since roundabout speeds should be low regardless. Given the track record at the Golden, CO roundabout, a raised crosswalk may be a viable treatment to consider in the future, especially in combination with the RRFB.

One important consideration for both roundabouts is a reduction in the number of lanes. The estimate for roundabout entering capacity in the Highway Capacity Manual (TRB, 2010) is 1,130 vph for each lane, with a reduction of this capacity with increasing conflicting circulating traffic. The observed peak-hour volumes at the three-lane approaches for Maple/Drake and Maple/Farmington were on the order of 960 and 1,120 vph, respectively. These demand levels can likely be accommodated in a modified design with only two entering lanes, but a more careful engineering analysis is warranted. Similarly, entering volumes for the studied two-lane approaches at Maple/Drake and Maple/Farmington were measured at 640 and 700 vph, which may be accommodated in a single-lane design, depending on the level of conflicting circulating traffic. Again, more careful analysis is needed, but relatively low observed vehicle queue lengths presented later in this report generally support the hypothesis that a lane reduction is

feasible, especially at the three-lane approaches. Based on past research at roundabouts, and supported by the comparison of two-lane and three-lane approaches in this study, a reduction of the number of lanes at roundabout entries and exits is expected to lead to an improvement in accessibility.

2. INTRODUCTION AND BACKGROUND

Accessibility of modern roundabouts and channelized right-turn lanes at signalized intersections to pedestrians who are blind has been a focus of an NIH and NCHRP (National Cooperative Highway Research Program by the Transportation Research Board, TRB) funded research team since 2000 (NIH, 2010 and TRB, 2010). This team of psychologists, rehabilitation specialists and traffic engineers has conducted studies at six one lane roundabouts, four two lane roundabouts (including the two-lane approach at the Maple and Drake Roundabout in Oakland County), and one three lane roundabout (three-lane approach at the Maple and Drake Roundabout). The team also studied pedestrian access at several channelized turn lanes, which pose challenges similar to that of roundabout intersections. As this work has progressed, the team has developed and refined both equipment for data capture (e.g., video cameras) and measures of pedestrian and driver behavior and risk. The team also conceptualized and described an "accessibility framework" (Schroeder et al., 2009) that is based on a set of performance measures that describe the frequency of crossing opportunities (driver yields and crossable gaps in traffic), the rate of utilization of these opportunities, pedestrian delay, and occurrence of pedestrian-vehicle conflicts as a measure of risk.

As a result of this systematic and iterative research program, the team has documented that significant access challenges exist for individuals with blindness when crossing at roundabouts (e.g. Long et al., 2005; Guth et al., 2005) and channelized turn lanes (e.g. Schroeder et al., 2006). Roundabouts with multiple lanes have been shown to be particularly problematic. For example, Ashmead et al., 2005, found that blind pedestrians had greater difficulty than did sighted pedestrians when tasked with distinguishing gaps in approaching traffic at a two-lane roundabout that were long enough to cross from those that were not. This study, conducted in Nashville, Tennessee, also involved (for the first time by this research team) the use of a safety performance measure; i.e., the frequency of interventions by an orientation and mobility (O&M) instructor, who closely followed the participants as they crossed the street during the trials. An intervention was recorded any time the O&M instructor physically stopped the pedestrian from continuing to cross because of safety concerns. Although interventions occurred in only 6% of the trials, this level of interventions translates to a 99% cumulative probability of a serious pedestrian-vehicle conflict at this intersection if a person who was blind crossed it daily for three months. (A conflict is defined here as a situation in which a crash is likely unless the driver or pedestrian takes immediate evasive action.)

The two treatments in the study—the Pedestrian Hybrid Beacon (PHB, also known as a HAWK signal or HAWK beacon) and the Rectangular Rapid Flashing Beacon (RRFB)—have demonstrated potential as effective treatments to generate high yielding rates by drivers for pedestrians. One of the earliest implementations of the PHB was at midblock and intersection locations in Tucson, Arizona, and was documented to have high rates in yielding in NCHRP Report 562 (Fitzpatrick et al 2006). The RRFB was first implemented at midblock locations in St. Petersburg, Florida, and exhibited high, sustained vehicular yield rates (Shurbutt and Van Houten, 2010). However, with the exception of the temporary implementation of the PHB at a two-lane roundabout in Golden, Colorado, as documented in NCHRP Report 674, neither treatment had been studied for effectiveness for addressing accessibility concerns

at multilane roundabouts, and none had been implemented at roundabouts with three-lane entries and exits.

Although the primary motivation for the study was the installation of the PHB and RRFB at their respective roundabouts, there were other geometric changes, which were made as secondary improvements during this construction period of the pedestrian treatments. Therefore, it should be noted up front that any positive or negative impacts following the installation of these devices will ultimately include the treatment effects along with the geometric improvements during this same construction period.

3. METHODOLOGY

The research for each site comprised a total of three separate studies, *pretest*, diagnostic review, and *posttest* study. The *pretest* represents conditions before installation of the treatments, PHB or RRFB, a *diagnostic review test* was conducted immediately after treatment installation to assure proper operations of the treatment, and the *posttest* was conducted after allowing for a two-week driver adaptation period to the new traffic control device. The data analysis focuses on a comparison of the pretest and posttest, while the diagnostic review merely focused on observing the treatment in operation and on adapting the pretest study protocol (including camera placement) to account for the presence of the treatment. A safety analysis of two intersections was conducted to analyze the addition of the traffic control device, as well as the implementation of various geometric changes conducted in parallel to the treatment. Because of different driver behavior and traffic patterns, two different approaches were used for data collection at the two sites.

3.1 Research Approach for Maple and Drake Intersection

The pretest study at the intersection of Maple Road and Farmington Road was conducted from June 23 – 30, 2009, the diagnostic review was conducted on September 3 and 4, 2009, and the posttest was conducted from September 14 – 21, 2009. Fourteen blind and six sighted individuals participated in the pretest (fifteen and seven participants were scheduled, respectively, with one “no-show” in each category). Three blind individuals participated in the diagnostic review, and fifteen blind and five sighted individuals participated in the posttest. Of the fifteen blind individuals participating in posttest, nine had participated earlier in the pretest and six were participating for the first time. This mixture of new and returning participants allowed for comparison of the performance of individuals who had had experience crossing the roundabout previously with the performance of those who had not had experience prior to participation in the posttest. The general procedure used in this study replicated methodologies for field data collection used in previous studies by research team members (NIH, 2010 and TRB, 2010). Participants were recruited via telephone calls from the study recruiter. By using most of the same participants for pretest and posttest data collection, participants served as their own control, which provides more statistical power when analyzing data from a relatively small number of participants.

During all studies, people who were blind, after being familiarized with the roundabout, crossed the street repeatedly at the east crosswalk on Maple Road (three lanes per direction) and the south crosswalk on Drake Road (two lanes per direction). As a safety precaution, they were accompanied on all crossings by a certified orientation and mobility (O&M) specialist. Data were collected from multiple video recordings of the crossings, by coding specific participant and driver behaviors in the field, and during debriefing interviews with participants. The analysis focused on measures of participant delay and safety, measures of driver and participant behavior relative to PHB signal displays, measures of impacts to vehicle operation, and participant comments about the crossings.

Both the pretest and the posttest cases included some blind and some sighted participants, the latter acting as a comparison group. Blind participants were individuals who self-reported as having only minimal light perception or no light perception, and who reported that they had no ability to visually

detect crosswalk lines, poles, objects, or vehicles. Blind participants further reported that they traveled independently using a long cane (sometimes referred to as a white cane) or a dog guide and that they crossed streets independently. Sighted participants were individuals with normal vision with or without corrective aids (eye glasses or lenses), who were able to readily see traffic patterns, roundabout design features, signs and markings.

A local O&M specialist who was familiar with individuals who were blind in southwest Michigan assisted in the recruitment of both blind and sighted participants. Blind participants who were guide dog users also had to be proficient in long cane use, and were asked to use the long cane during the crossings, because repetitious street crossings are confusing and stressful for dog guides. Participants were screened via a phone interview to determine that they met the criteria for the research. Written consent was obtained before any data were collected, using consent materials approved by the Institutional Review Board (IRB) at Western Michigan University. Both sighted and blind participants received a $50 honorarium for each study they participated in, and were provided transportation (via Metro Car service) as needed. Participation was strictly voluntary and participants were allowed to withdraw from the study at any time and for any reason without penalty. The honorarium and transportation assistance was provided regardless of whether a participant completed all trials. No participants in either group discontinued participation before completing the respective study, except for one participant in the pretest who was asked to stop by the research staff due to rain.

Identical procedures were used with participants who were blind and those with normal vision. Each participant made four round trip street crossings at each of two crosswalks. Only one individual participated at a time. As in previous studies, participants were allowed to cross at their own pace. All blind participants used a white cane and all made the decision as to when to begin crossing. All participants (blind and sighted) were accompanied by the O&M specialist who assisted as needed with the tasks of aligning to cross and maintaining alignment during crossings. The O&M specialist intervened (physically, by grasping the participant's arm or shoulder) if he or she perceived the participant to be at significant risk from approaching vehicles. These interventions are a key aspect of the team's safety evaluation and involved situations in which a collision appeared to be imminent during the crossing unless either a driver(s) or the participant took evasive action. Multiple O&M specialists served as "spotters" during the course of the study. The posttest procedure was identical to the pretest procedure, except for changes related to the treatments (for example, the fact that the "spotter" pushed the pushbutton for the pedestrian hybrid beacon during posttest).

3.2 Research Approach for Maple and Farmington Intersection

The initial plan for studying Maple-Farmington roundabout was to apply the same research protocol used for studying Maple-Drake Roundabout where blind study participants crossed the roadway under the supervision of a certified Orientation and Mobility (O&M) specialist. However, initial crossing tests at this second roundabout indicated a challenging and potentially hazardous crossing environment for the blind participants, as well as a high risk of vehicle rear-end collisions, if actual crossings were performed. The research team therefore developed a revised study protocol that utilized an *indicator-based* experimental approach, where the participant indicates when he or she would cross, but then doesn't

actually step into the roadway. A more detailed justification for revising the protocol is given below, followed by a description of the test site, the data collection approach, and the revised performance measures.

3.2.1 Justifying a Modified Protocol

Concerns about the ability of participants to perform actual crossing trials at the Maple/Farmington roundabout were raised by team members as early as the initial scoping trip in March 2010. At the time, the team was divided about its ability to run actual crossing trials due to the level of pretest risk perceived to be present at the Maple/Drake intersection. There was concern at the initial scoping trip that crossing trials at Maple and Farmington would place participants at higher than acceptable risk. Following the scoping trip, the decision was made to keep the actual crossings protocol, but with a reduced sample size (minimum feasible) to reduce exposure. In the scoping meeting, the team concluded that the main motivation for conducting a pretest at Maple/Farmington was to assure that the roundabout was comparable to the earlier study performed at Maple/Drake. It was hypothesized that with the limited sample size (5 days, 8 blind, 4 sighted subjects) the research team would be able to gather sufficient information to compare the two roundabouts in the pretest condition.

However, during the first pilot test at Maple/Farmington on May 10, the research team quickly realized that this intersection appeared to be significantly more challenging for independent crossings by persons who were blind the than Maple/Drake intersection. It is unclear what contributed to these differences in crossing risk, but it is likely a combination of subtle design differences, local context of businesses and background noise, and elevated traffic volumes at Maple/Farmington. The first pilot participant at this second roundabout quickly experienced three interventions and several more “close calls”. The exit legs at the two-lane cross-section on Farmington (north exit) and the three-lane cross-section on Maple Road (east exit) appeared to be very challenging to cross. The high three-lane exit risk was present even with a relatively low eastbound exiting traffic during the PM peak hour when the trial was scheduled. The team expected that with higher volumes (AM Peak) the risk at the exit lane would be higher than acceptable for the study.

In addition to the risk to study participants, the team perceived a high risk of potential rear-end collisions with approaching drivers not expecting pedestrian presence. This represented a serious safety liability for drivers and passengers that the research team would not want to introduce.

The research team discussed alternate study approaches in the form of “indicator trials”, which would significantly reduce the risk to participants and drivers. This option was reflected in the contract between RCOC and WMU/ITRE as an alternative if the risk to participants was considered too high. The team developed a revised data collection protocol, described in more detail below, using indicator-based trials. The team informed RCOC of the decision to change protocol, and obtained approval from the Western Michigan University Institutional Review Board (IRB) to proceed with the revised protocol. IRB approval of the revised protocol was necessary because the initial IRB request described actual crossing studies.

Even with the revised study protocol in place, the researchers were still able to extract a variety of performance measures as described in more detail below, including: participant delay, driver yielding rate, yield utilization rate, vehicular queuing, and estimated interventions. It should be noted that the vehicular queuing measure no longer considers pedestrian crossing time and is therefore considered to underestimate "real-world" queuing impacts. The *estimated intervention rate*, our primary safety measure, was obtained by expert judgment of the Orientation & Mobility specialist and a second expert observer. The measure describes whether the O&M specialist "would have intervened" had the participant actually stepped out in the road.

3.3 **Site Description**

3.3.1 Geometry

The focus of the research project was the two multilane roundabouts, one at the intersection of Maple Road and Farmington Road and one at the intersection of Maple Road and Drake Road in Oakland County, Michigan. The roundabouts are part of the Northwestern Connector project in Oakland County that includes strategic road improvements along the east-west arterial Maple Road, as well as several surrounding streets.

3.3.1.1 Maple and Drake Road

Both Maple Road and Drake Road are two-lane roadways that flare out to multiple lanes at the approaches to the roundabout node. At the crosswalk, the cross-sections on entry and exit legs on Maple Road have three lanes of traffic each. The cross-section along Drake Road, the north-south cross-street, has two lanes at both the entry and exit legs of the crossing. Figure 1 shows a schematic of the roundabout in the pretest condition, overlaid on an aerial view of the intersection before roundabout construction (Source: http://www.nwconnector.com). It should be noted that this figure represents an early design drawing of the roundabout, and one notable change to highlight is the alignment of the crosswalks. For example, the crosswalks in Figure 1 at the north-east corner appear to approach the roundabout at close to a 90-degree angle, when in fact the sidewalk more closely followed the curvature of the circulating lane. The actual sidewalk alignment is more closely represented in Figure 2 (posttest condition) or in the aerial images presented later in Figure 4.

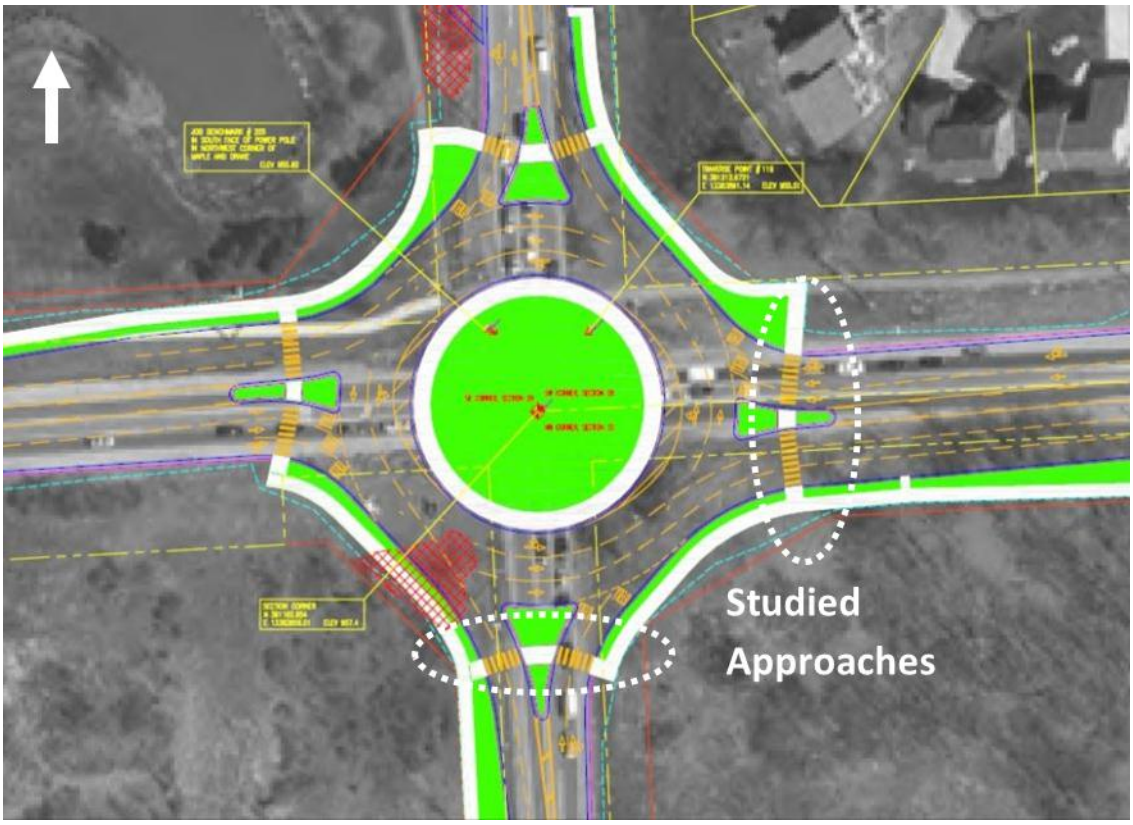


Figure 1: Schematic of Maple and Drake Roundabout in Pretest Condition

With installation of the PHB crossing treatment, the roundabout also went through some geometric modifications. Most notably, the crosswalk alignment was modified to where the exit portion of the crosswalk was moved approximately 40 feet further away from the circulating lane. Accordingly, the pedestrian splitter island between entry and exit legs was widened and extended to accommodate the modified crosswalk geometry. The exit crosswalk modification was primarily motivated by a need to provide at least 40 feet of horizontal distance between the vehicular stop bar line at the signal and the overhead mounted signal head of the PHB to meet the requirements of the MUTCD. The modification was necessary, since the stop bar also needed to be separated from the circulating lane. As a by-product, the modified exit leg geometry provided some additional queue storage before a queue of vehicles stopped at the PHB would spill into the circulating lane. Additional design changes at the roundabout between pretest and posttest involved changes to the stripe markings within the circulating lane. The modified roundabout design for the posttest is shown in Figure 2.

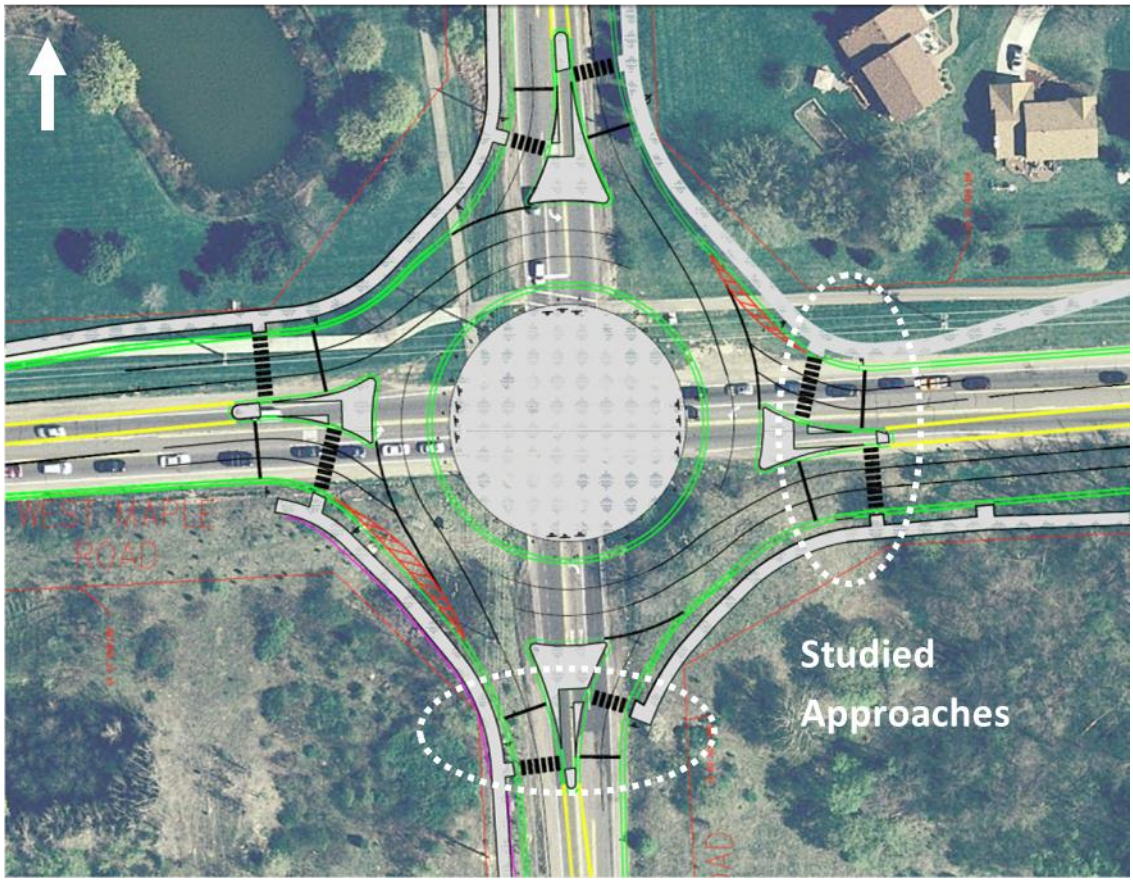


Figure 2: Schematic of Maple and Drake Roundabout in Posttest Condition

3.3.1.2 Maple Road and Farmington Road

Both Maple and Farmington are two-lane roadways that flare out to multiple lanes at the approaches to the roundabout node. At the crosswalk, the cross sections on entry and exit legs on Maple Road have three lanes of traffic each. The cross section along Farmington Road, the north-south cross-street, has two lanes at the entry and exit legs for northbound traffic, and three lanes southbound. In order to assure consistency with the previous study (at Maple/Drake roundabout) the two-lane portions of the northern and southern approaches were used in this study (northbound traffic). Figure 3 shows a schematic of the roundabout in the pretest condition, overlaid on an aerial view of the intersection before roundabout construction (Source: http://www.nwconnector.com). Similar to the discussion above, this figure corresponds to an earlier design drawing of the roundabout. The actual sidewalk and crosswalk geometries of the roundabouts as tested in pretest and posttest are more accurately shown in the aerial image in Figure 4.

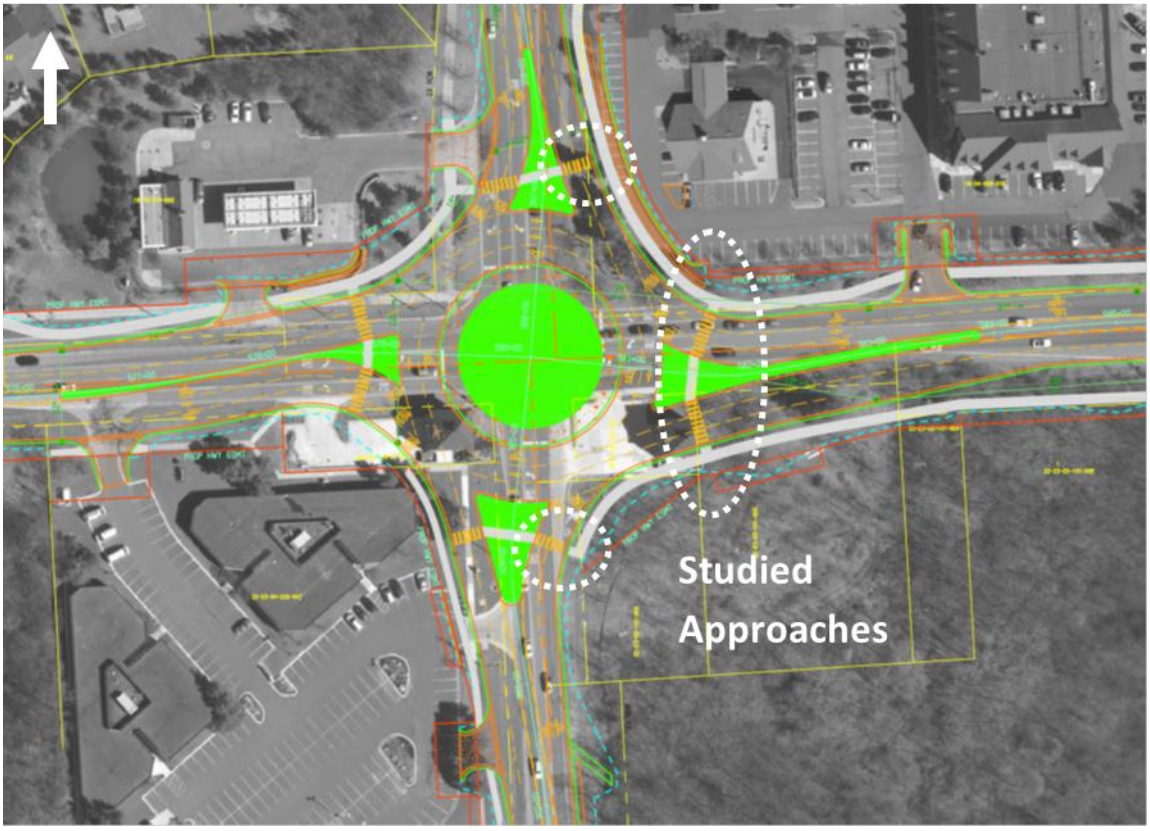
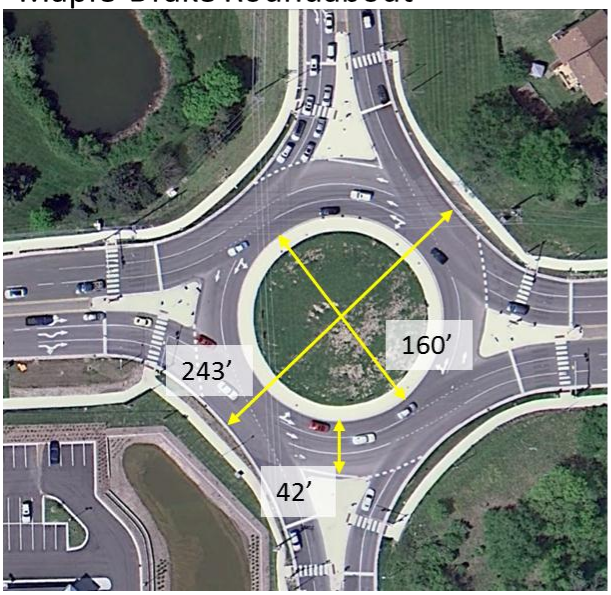


Figure 3: Schematic of Maple and Farmington Roundabout in Pretest Condition

3.3.1.3 Geometry Comparison

A comparison of key dimensions of the two roundabouts is shown in Figure 4. The figures show aerial images taken after installation of both treatments of Google Earth™. The dimensions highlight the inscribed circle diameters for Maple/Drake and Maple/Farmington of approximately 240 and 250 feet, respectively, and central island diameters of approximately 160 feet. The circulating lane width at the three-lane cross-section was approximately 42 feet for both roundabouts. In general, the geometry of the two roundabouts is very similar, with the only difference being a slightly greater inscribed diameter at Maple/Farmington.

Maple-Drake Roundabout



Maple-Farmington Roundabout

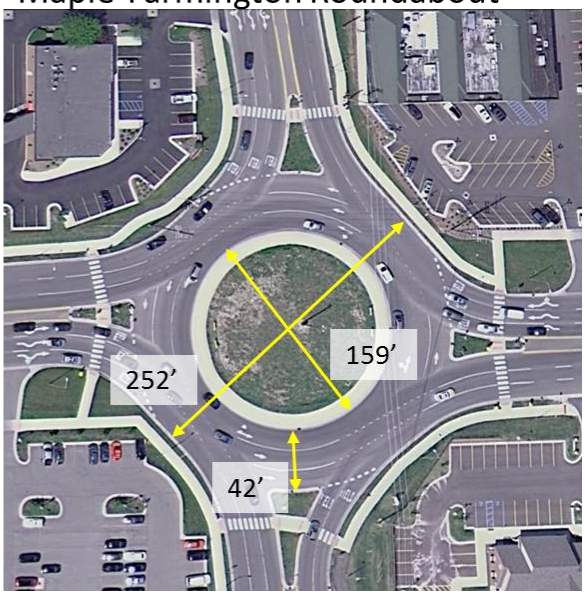


Figure 4: Comparison of Key Geometric Features (Images from Google Earth in Posttest condition)

3.3.2 Traffic Volumes

Entering and exiting approach volume counts were performed by the Road Commission for Oakland County in late June 2009. Table 3 shows the total entering and exiting volumes over a 24-hour period. Figure 5 shows the hourly distribution of entering traffic at the two studied approaches, Maple Road Westbound and Drake Road northbound. The volumes have been proportionally balanced so that total entering volumes match the total exiting volumes.

Table 3: Balanced Total Daily Traffic Volumes at Maple and Drake Roundabout (2-day average)

	NB - Drake Rd.	SB - Drake Rd.	EB - Maple Rd.	WB - Maple Rd.	Total
Entering	6791	7537	15070	12147	**41545**
Exiting	6988	7257	13147	14154	**41545**

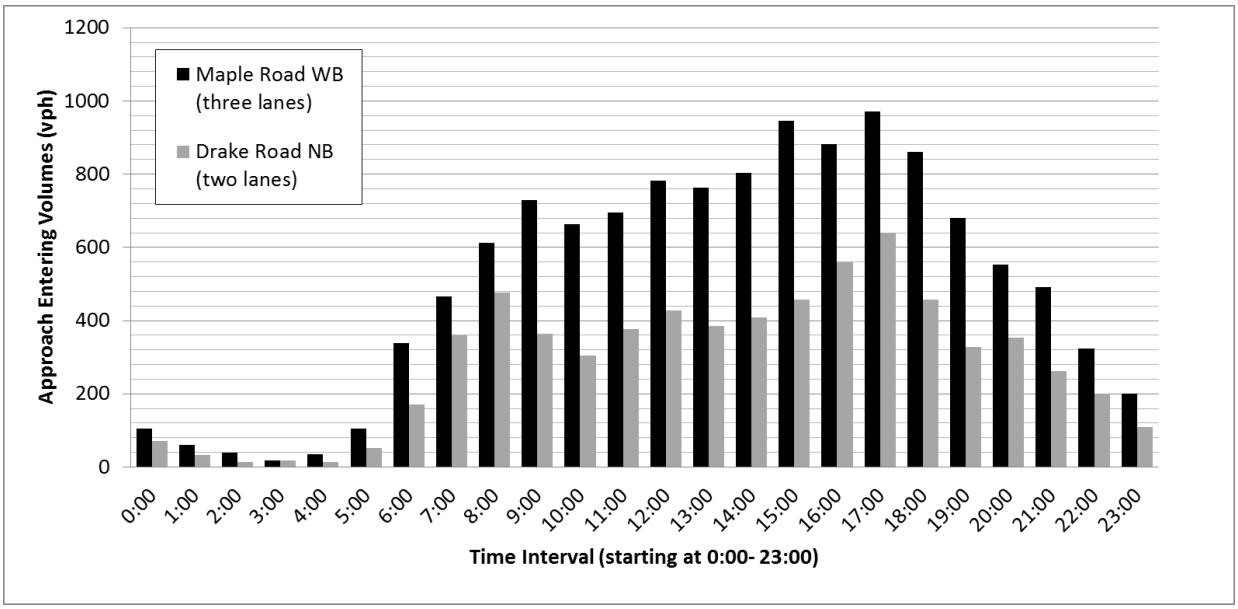


Figure 5: Hourly Distribution of Entering Volumes at Maple and Drake Roundabout

Daily traffic volumes in Table 4 reveal that flows on Maple Road are expectedly higher than along Drake Road. Figure 5 shows that the highest flow period is represented by a peak period from approximately 3-6pm, although traffic volumes are fairly comparable throughout the day. For the analysis of participant crossing behavior, it is hypothesized that crossing challenges are comparable through the daytime conditions from about 8am to 7pm, since no large fluctuations in traffic are evident.

Figure 6 shows the hourly distribution of entering traffic for Maple-Farmington roundabout, at the two studied approaches, Maple Road westbound and Farmington Road northbound.

Table 4: Balanced Total Daily Traffic Volumes at Maple and Farmington Roundabout (06/23/2009)

	NB - Farmington Rd.	**SB - Farmington Rd.**	**EB - Maple Rd.**	**WB - Maple Rd.**	**Total**
Entering	6571	6747	14546	13831	**41695**
Exiting	7923	7074	13692	13005	**41695**

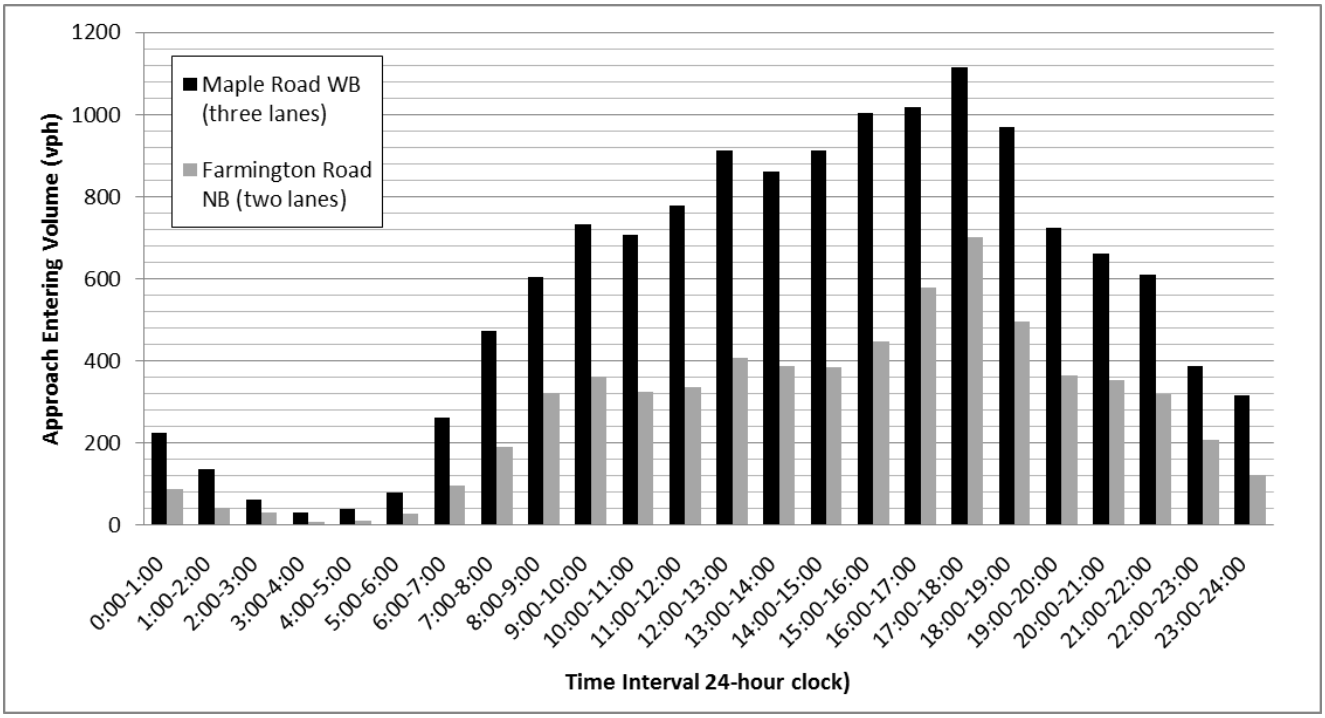


Figure 6: Hourly Distribution of Entering Volumes at Maple and Farmington Roundabout

Daily traffic volumes in Table 4 reveal that flows on Maple Road are expectedly higher than along Farmington Road. Figure 6 shows that the highest flow period is represented by a peak period from 5-6pm, although traffic volumes are high throughout the afternoon.

3.4 Treatment Description

Two different types of treatments have been used in this research. A system of Pedestrian Hybrid Beacons (PHB) was used for the roundabout at Maple Road and Drake Road. For the roundabout at Maple Road and Farmington Road a system of Rectangular Rapid Flashing Beacons (RRFB) was used.

3.4.1 PHB Installation at Maple Road and Drake Road

Each roundabout crosswalk was outfitted with a Pedestrian Hybrid Beacon (PHB), which is also commonly referred to as a HAWK (High-intensity Activated crossWalk) beacon. In total, eight independent PHBs were installed (entry and exit at all four approaches), although only four PHBs were evaluated in this study. Figure 7 shows photographs of the three-lane approach before and after treatment installation (view looking west along Maple Road, roundabout entry lanes). More photographs of the roundabout before and after treatment installation are shown in a photo log include as Appendix A of this report.

Before Treatment Installation

After Treatment Installation

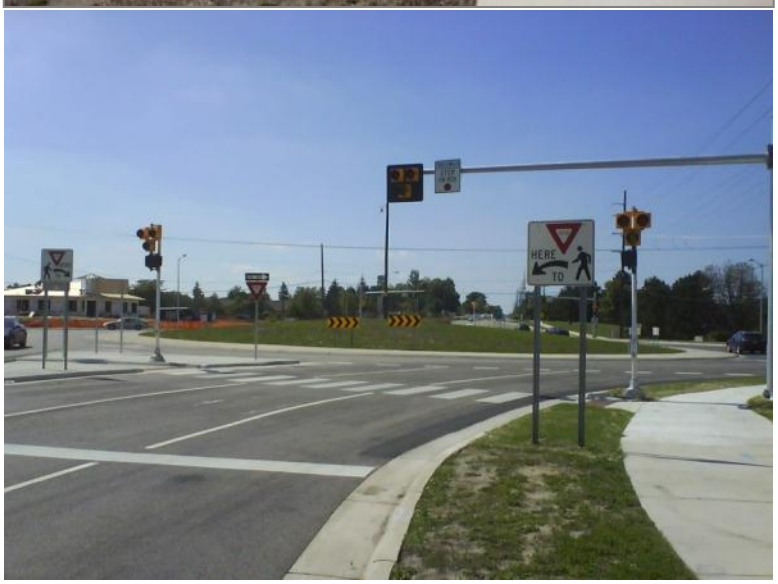


Figure 7: Pretest and Posttest Photos of PHB Treatments at Maple and Drake Roundabout

The PHBs at the roundabout were installed and wired in a manner that allowed all eight legs (entry and exit) at the four approaches to operate independently. All PHBs rested in the "dark" signal display for vehicular traffic and the pedestrian movement, and were activated by pushbutton-integrated accessible pedestrian signals (APS). A pedestrian pushbutton activation at any one of the eight PHB crossings triggered the PHB interval sequence for that crossing leg only. After crossing (for example the entry leg), the spotter accompanying the participant then placed another pushbutton call to cross the next leg (in this case the exit leg). Each pushbutton call triggered the typical PHB interval sequence, which is shown in Table 5, along with the signal timing parameters for each interval. Note that the durations for individual intervals are calculated based on traffic engineering signal timing practice, and therefore differ across the four tested approaches.

Table 5: PHB Signal Timing Sequence and Parameters

Vehicular Interval	Pedestrian Interval	Two-Lane Approach (North-South on Drake Road)		Three-Lane Approach (East-West on Maple Road)	
		Entry-Leg	Exit-Leg	Entry-Leg	Exit-Leg
Dark	Dark	-	-	-	-
Flashing Yellow	Don't Walk	4.0 sec	4.0 sec	5.0 sec	4.0 sec
Steady Yellow		4.3 sec	3.5 sec	4.3 sec	3.5 sec
Steady Red		1.2 sec	2.2 sec	1.2 sec	2.2 sec
	Walk	7.0 sec	7.0 sec	7.0 sec	7.0 sec
Alternating Flashing Red	Flashing Don't Walk	8.0 sec	8.0 sec	12.0 sec	11.0 sec
Dark*	Dark	≥ 40 sec	≥ 40 sec	≥ 40 sec	≥ 40 sec

** The duration of the Dark interval after a pedestrian interval was served is at least 40 seconds, but the signal will rest in this interval in the absence of further pedestrian pushbutton activations*

The appropriate driver behavior is to stop and remain stopped during the vehicle red interval, and to slow down to a stop during the flashing and steady yellow intervals, if it is possible for drivers to do so at their current speed and distance to the crosswalk. The steady red indication means that drivers are not legally allowed to proceed through the crosswalk. Drivers are allowed to *proceed after stopping* during the alternating flashing red interval, but still must yield the right-of-way to pedestrians during that interval.

Figure 1: Photo of APS Installation

Since the pedestrian signal display rests in dark, pedestrians could legally cross without activating the PHB. It should be noted here that the placard above the pedestrian push button does not inform the pedestrian of what to do during the pedestrian dark indication. In this experiment, the PHB was always activated, since the objective was to test the operations of the device. After activating the PHB sequence, pedestrians are therefore expected to wait for the WALK interval to cross. The FLASHING DON’T WALK interval is timed to allow pedestrians who crossed at the end of the WALK interval to complete their crossings. Pedestrians are not expected to begin crossing during the FLASHING DON’T WALK interval.

The PHB installation was outfitted with pushbutton integrated APS (see Figure 7) devices that emitted a constant locator tone in the form of a "tick" sound every second (frequency of 1 Hertz). The tone changed to a "rapid tick" signal at a higher frequency (8-10 Hertz, or 8 – 10 ticks per second) during the pedestrian WALK interval, to alert blind pedestrians that the WALK indication was active.

3.4.2 RRFB Installation at Maple Road and Farmington Road

The roundabout was outfitted with rectangular rapid-flashing beacon (RRFB) systems on all four approaches to the roundabout. In total, sixteen RRFBs were installed in eight pairs (entry and exit at four approaches), although only four RRFBs were evaluated in this study. The evaluation focused on the

three-lane entry and exit legs on the east approach of Maple Road, the two-lane entry leg at the south approach of Farmington Road and the two-lane exit leg at the north approach of Farmington Road.

The RRFBs at the roundabout were installed and wired in a manner that allowed all eight legs (entry and exit) at the four approaches to operate independently. RRFBs consist of two rectangular rapidly flashing amber LED lights. All RRFBs rested in the "dark" display for vehicular traffic and the pedestrian movement, and were activated by pushbuttons. When the button was pushed, the lights began to flash for both beacons in the pair (communication between the button and the RRFB itself was wireless). In addition, when the lights began to flash, a message was played for the pedestrians stating: "The yellow lights are flashing". The RRFB remained active for 20 seconds, after which it returned to "dark" mode. When activated, the two amber indications flash rapidly in an alternating flashing sequence (left light on, then right light on). The rate of flashing of the two yellow LEDs varied from 70 to 80 flashes per minute. Each flashing light had alternating but approximately equal periods of rapid pulsing light emissions and dark operation. Figure 8 shows a picture of RRFB. More photographs of the roundabout before and after treatment installation are shown in a photo log include as Appendix A of this report. The appropriate driver behavior upon RRFB activation is to yield to the pedestrian if there is a pedestrian standing at the crosswalk, although drivers have no legal obligation to yield merely due to the activation of the beacon. Drivers are allowed to proceed through the crosswalk if pedestrians have finished crossing but the RRFB is still active.

Figure 9: Photo of the RRFB Installation at the Maple/Farmington Three-Lane Entry

An important different between the RRFB and PHB installations is that the RRFB is side-mounted on each side of the two- and three-lane approaches, with the flashing beacons mounted approximately 7 feet above the roadway surface. The PHB installations include both post-mounted displays at

approximately 11 feet above the roadway surface and an overhead, mast-arm-mounted installation centered over the approach at approximately 17 feet above the roadway surface. This difference in displays to the driver may contribute to the findings described later in this report, especially for the three-lane approaches.

3.5 **Study Protocol**

Participants met the researchers at a parking lot located on the northwest corner of Maple Road. After consent was obtained, participants were oriented to the roundabout by the O&M specialist. Orientation included exploring a tactile map of the intersection and walking around the roundabout in a counterclockwise direction, beginning at the northwest corner, then turning around and making at least one crossing in a clockwise direction as part of the orientation. The O&M specialist described features, guided participants across the crosswalks, monitored their independent crossings, and provided instruction on the study procedures (e.g., starting point for trials, verbal instructions, safety concerns). Participants were encouraged to ask questions about the layout of the intersection and crosswalks, the traffic movement, the pedestrian facilities available, and any other features of interest. They also asked questions about the study procedures. During the posttest, orientation included a description of the treatment, PHB or RRFB, and their operation.

3.5.1 Pedestrian Crossing at Maple Road and Drake Road

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

Participants were told to begin crossing whenever they believed it was appropriate to do so, using the cues that were available to them (visual cues for sighted participants, the sounds of traffic for blind participants, and additional visual and/or auditory information cues from the PHB during the posttest). They were not requested or required to have any verbal interaction with the spotter prior to initiating the crossing. The entire study from time of arrival at the Jewish Community Center (including familiarization) required approximately two and a half hours for each participant. The starting location (e.g. entry or exit leg at a roundabout) was systematically varied to control for order effects. Trials were blocked, or grouped, by crosswalk to save time and to avoid confusing the participants. For example, all crossings across Drake Road were completed consecutively, and then the team moved to Maple Road and completed all crossings there. The posttest was conducted at the same crosswalks and using the same number of trials as pretesting. The PHB with audible and vibro-tactile rapid ticking indication during the WALK interval was activated during each of the posttest crossings (by the spotter's button press).

For each crossing trial, participants were guided to the middle of the curb ramp and were aligned to face across the crosswalk. While approaching the crossing location, participants were told which lane of the roundabout they were crossing, which direction traffic would approach from, and whether they were crossing from the island or curb. For example: "You are crossing the entry lane of Maple Road from the

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

For the posttest study, the PHB was activated by a pushbutton by the O&M specialist. This was done because the focus of this study was on the task of deciding when it is safe to cross the street, and not on other tasks usually initiated by the pedestrian, including interaction with the push-button. Wayfinding and maintaining alignment was also taken care of by the spotter. The participant was informed that the O&M specialist would push the button at the beginning of each crossing attempt and just prior to telling the participant that they can "cross whenever (they) are ready". The participants were familiarized with the timing sequence of the PHB, and that the *legal* interval for initiating the crossing was the WALK interval, and that this interval could be identified by the rapid tick sound coming from the PHB. However, the participants were also told that they should cross at their own discretion using their judgment of traffic operations, and that they could choose to cross (or not) at *any* time in the signal cycle.

3.5.2 Indicator Study at Maple Road and Farmington Road

The study included total ten (and for some cases twelve) trials for each of the four approaches studied (two-lane entry, two-lane exit, three-lane entry and three-lane exit).

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

In each trial, participants were guided toward the crosswalk, aligned properly and told which approach of the roundabout was in front of them. For example they were told "You are judging the entry lane for Farmington from the curb; traffic will be coming from your left. Raise your hand when you would cross". A trial was concluded by the participant's indication that he/she would cross or by timing-out after two minutes. At that time, the participant was asked to step back from the crosswalk and walk for

a short distance along the sidewalk to allow for traffic to be cleared and then walk back to start a new trial. In addition to the O&M specialist, an independent expert observer would also rate each crossing event as safe, risky, or estimated intervention. These judgments were independently made by the expert observer without seeing the hand signal of the O&M specialist. These two independent risk indicators were then compared later to arrive at an overall risk assessment of the crossing decision. Only the estimated interventions are reported here to quantify the safety of the crossing decision, since those most directly correspond to the safety rating in prior studies, including at the Maple/Drake roundabout.

Each trial was timed-out after two minutes if the participant had not yet indicated his/her crossing intent. During each trial the RRFB was activated as many times as necessary and the participants were informed each time the RRFB was re-activated. After completing each approach, the ground level camera, computers and rest of the equipment were moved to the next approach to set up a new set of trials.

3.6 Data Collection Set-Up

The study combined two approaches for data collection: real-time coding done on a laptop computer in the field and post-processing of data from video recordings in the office. The real-time coding was performed using a Visual Basic macro that records time stamps in a Microsoft Excel spreadsheet whenever the analyst (seated near the crosswalk while the indicator trials were conducted) pushed certain pre-defined keys. For example, in using this computer program to record pedestrian delay, the analyst would push a button when the O&M specialist said "cross whenever you are ready" and another key when the pedestrian indicated they would initiate the crossing. The analyst was able to hear the O&M specialist's instructions to participants through a wireless microphone.

The video camera set-up for this study involved the use of three overhead video cameras and one or two (posttest) ground-level video cameras. The overhead video cameras were installed with the assistance of the Road Commission in the center island of the roundabout. The ground-level camera was positioned at the crosswalk and also recorded sound from the wireless microphone used by the O&M specialist. All camera views were synchronized later in the office and were recorded onto one common DVD with a "split-screen" view of all four video angles. These video discs were used, for example, to record vehicle-related measures such as vehicular queue length. For the posttest, a second ground-level camera was used exclusively to assess pedestrians and driver behavior with regard to the PHB and RRFB phase indication for each site respectively.

3.7 Performance Measures

Measures of participant behavior and measurements of behavior of vehicular traffic/drivers were obtained during this study. Participant measures included measures describing participant delay and safety. Vehicle measures include a distribution of queue lengths in pretest and posttest conditions, as well as an assessment of treatment. For Maple Road and Farmington Road with PHB installation, the performance measures include assessment of participant behavior relative to the PHB signal interval (posttest only). For Maple Road and Farmington Road driver yielding with and without the RRFB

treatment was assessed. Other vehicle measures include the distribution of queue lengths in pretest and posttest conditions. All measures are defined in more detail below.

3.7.1 Participant Measures

3.7.1.1 Maple Road and Drake Road with PHB installation

- *Participant PHB Signal Behavior*, evaluates the behavior of participants with respect to the signal indication of the PHB device. The participant behavior measure presents the distribution of participant crossing initiations during each of the PHB intervals: flashing yellow/DON'T WALK, steady yellow/DON'T WALK, steady red/WALK, and alternating flashing red/FLASHING DON"T WALK.
- *Participant Delay*, measured in seconds and defined as the time from the start of the trial ("cross whenever you're ready") to the moment when the participant initiated the crossing by stepping into the roadway.
- *O&M interventions*, defined as the frequency of events in which the O&M specialist (spotter) physically stopped the participant (after he/she started to cross), because the O&M specialist perceived the risk of the crossing decision to be unacceptably high.
- *Debriefing questions,* which were open-ended or multiple-choice questions asked to all blind participants following each study, and asking about their perceptions and opinions of the crossing task in pretest and posttest.

3.7.1.2 Maple Road and Farmington Road with RRFB Installation

- *Participant Delay* measured in seconds and defined as the time from the start of the trial ("raise your hand when you would cross") to the moment when the participant raised a hand to indicate that he or she would cross.
- *Estimated interventions*, defined as the frequency of events in which the O&M specialist (spotter) would have stopped the participant (if he/she had actually started to cross). In an estimated intervention, the perceived the risk of the crossing decision was unacceptably high.
- *Yield Utilization,* defined as the percentage of driver yield events that were associated with a pedestrian indicating that he or she would cross.

3.7.2 Vehicle Measures

3.7.2.1 Maple Road and Drake Road with PHB installation

- *Driver PHB Behavior*, measured the proportion of drivers who stopped during specific PHB intervals as compared to those who crossed the plane of the crosswalk. The driver behavior measure distinguished between vehicles that are stopped at the end of the signal interval and those who proceeded through the crosswalk during each of the intervals, regardless of whether or not a pedestrian was in the crosswalk.
- *Vehicle Queues*, measured as the maximum queue upstream of the signal caused by the presence of the participant during each trial, summed across all lanes.
- *Time-in-Queue Delay,* defined as the time between when a vehicle joins the back of the queue formed at the crosswalk and the time the vehicle crosses the plane of the crosswalk. This

measure was very time-consuming to collect, and was therefore only obtained for a random subset of participants.

3.7.2.2 Maple Road and Farmington Road with RRFB Installation

- *Driver Yielding Behavior* measured the proportion of drivers who stopped for the waiting pedestrian while the trial was ongoing. Since drivers were not aware of the fact that the participants weren't actually crossing, this measure describes the driver's propensity to yield to a blind pedestrian standing at the curb.
- *Vehicle Queues*, measured as the maximum queue upstream of the signal caused by the presence of the participant during each trial, summed across all lanes.

In addition to the above items, the research team recorded the state of each lane at the time the pedestrian either stepped into the roadway (for Maple Road and Drake Road)or indicated he/she would step into the roadway (for as either having a "stopped vehicle", a "moving vehicle", or being an "empty lane". While the team initially thought that this measure would help quantify pedestrian behavior, we later concluded that the data were not particularly informative because the vehicle state at one instant fails to capture the true dynamic nature of the interaction of vehicles and pedestrians. Similarly, the team explored the use of a sighted expert observer, who indicated by the push of a button on the computer whether or not he/she would cross at any given time. The intent of this measure was to relate the decisions of the blind and sighted participants to that of this expert, but it proved difficult to truly match the (subjective) expert decision to the actions of the study participants. It was ultimately decided that not a lot could be learned from this last measure, and that the other measures were more useful to the analysis.

For the Maple Road and Farmington Road, the team measured the "time-to-collision" (TTC) from the time the pedestrian raised his or her hand to when a vehicle crossed the plane of the crosswalk. TTCs were estimated separately for each lane, and were incorporated in the assessment of estimated interventions. The team previously used this measure to define risky pedestrian decisions, and it proved a valuable metric in this research to justify labeling a pedestrian decision as an "intervention".

3.8 **Research Hypotheses**

The team hypothesized that crossing risk as measured by interventions would decrease during the posttest trials relative to the pretest trials. The team also hypothesized that crossing delay would decrease from pretest to posttest for both types of treatment.

3.8.1 <u>PHB Installation at Maple Road and Drake Road</u>

The PHB is intended to create crossing opportunities by stopping vehicular traffic and to notify pedestrians of the onset of the WALK indication through an audible message. As a result, it was hypothesized that crossing delay would decrease from pretest to posttest. However, delay for sighted participants was hypothesized to increase slightly, assuming that they experienced relatively short delays in pretest, and assuming that they waited for the onset of the WALK indication to cross during the posttest. The team hypothesized that vehicle operation would not be impacted significantly between pretest and posttest, due to the timing characteristics of the PHB. Finally, the team

hypothesized that not all participants and drivers would fully comply with the PHB phase indications, since the traffic control device was new and unexpected by many drivers at a roundabout.

3.8.2 RRFB Installation at Maple Road and Farmington Road

The RRFB is intended to increase motorist yielding behavior, which would presumably create more frequent crossing opportunities. While we realized that not all opportunities would be recognized by individuals who were blind, we were confident that increased opportunities would also result in more frequent indications that it was safe to cross. We also hypothesized that crossing delay would decrease from pretest to posttest. It was hypothesized that the benefits of the RRFB would be more evident for sighted participants, since prior research has shown that blind pedestrians (but not sighted individuals) require several seconds to identify that a vehicle has yielded. The need to identify crossing opportunities in the form of yielding vehicles is crucial for the RRFB effectiveness, where, unlike the PHB at Drake Road, no pedestrian phase exists.

The team hypothesized that vehicle operation would not be impacted significantly between pretest and posttest as a result of the RRFB. The team hypothesized that the RRFB impacts on vehicular traffic would be more pronounced at the entry leg, where yielding is generally higher and where drivers oftentimes have to slow down due to circulating priority traffic in the roundabout. Finally, the team expected that the RRFB would likely be more effective at the two-lane entry and exit legs of the Maple/Farmington roundabout, because the added complexity of a three-lane cross-section was expected to make it more difficult to identify crossing opportunities (due to auditory confusion). Further, it was hypothesized that drivers would be less comfortable to yield due to added traffic in adjacent lanes that requires driver attention when maneuvering the roundabout.

4. Results for Maple Road and Drake Road

The roundabout study included a two-lane and a three-lane approach to the same roundabout, each of which will be discussed separately. The analysis summarizes participant behavior and performance, as well as driver behavior and the impact of the PHB on vehicles negotiating the roundabout.

4.1 Two-Lane Approach

4.1.1 Participant Behavior and Performance

Participant behavior and performance is analyzed in three categories: participant PHB behavior, delay and interventions.

4.1.1.1 Participant PHB Behavior

The first analysis focused on the crossing behavior by blind and sighted participants after the PHB installation. Results are shown in Figure 10 separately for blind and sighted participants. The figure shows a distribution of PHB intervals when participants initiated the crossing, which was defined as stepping off the sidewalk and into the street. The expected signal display to initiate crossings at the PHB was the pedestrian WALK interval, although compliance studies at other intersections suggest that (sighted) pedestrians often cross during crossing opportunities in other intervals. In this study, participants were informed about the legal implication of the WALK interval, but also told that they could cross at their discretion (with or without the WALK interval).

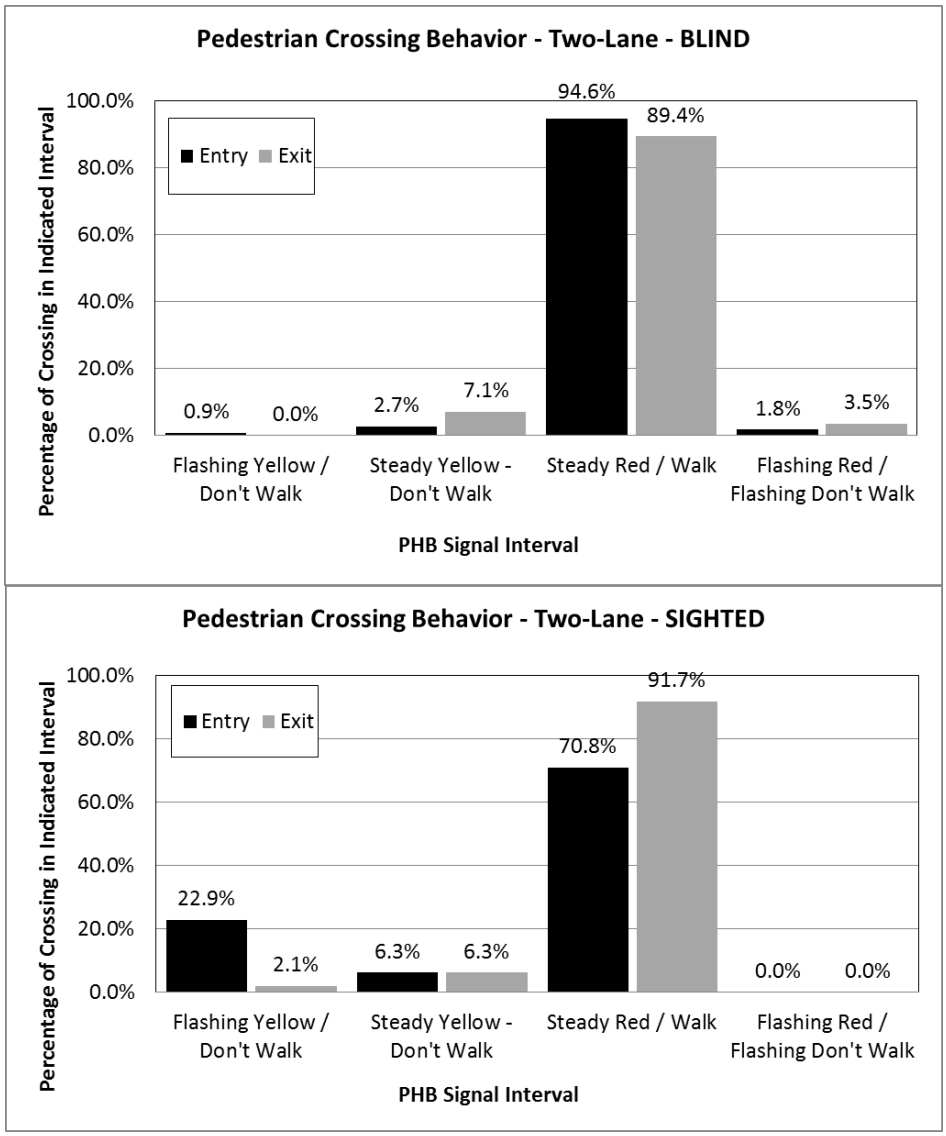


Figure 10: Participant PHB Compliance, Two-Lane Approach

The sample size for blind participants was 225 crossing attempts. The analysis shows that most blind participants initiated crossing during the WALK indication. One blind participant crossed at the entry leg during a flashing yellow interval (no vehicle was approaching at the time). Eleven crossings by blind participants were initiated during the steady yellow interval (eight exit, three entry), as vehicles had likely already come to a stop at the PHB. For six crossing attempts, blind participants didn't initiate crossings until after the WALK interval had elapsed, presumably because they waited to assure that vehicles had in fact come to a full stop.

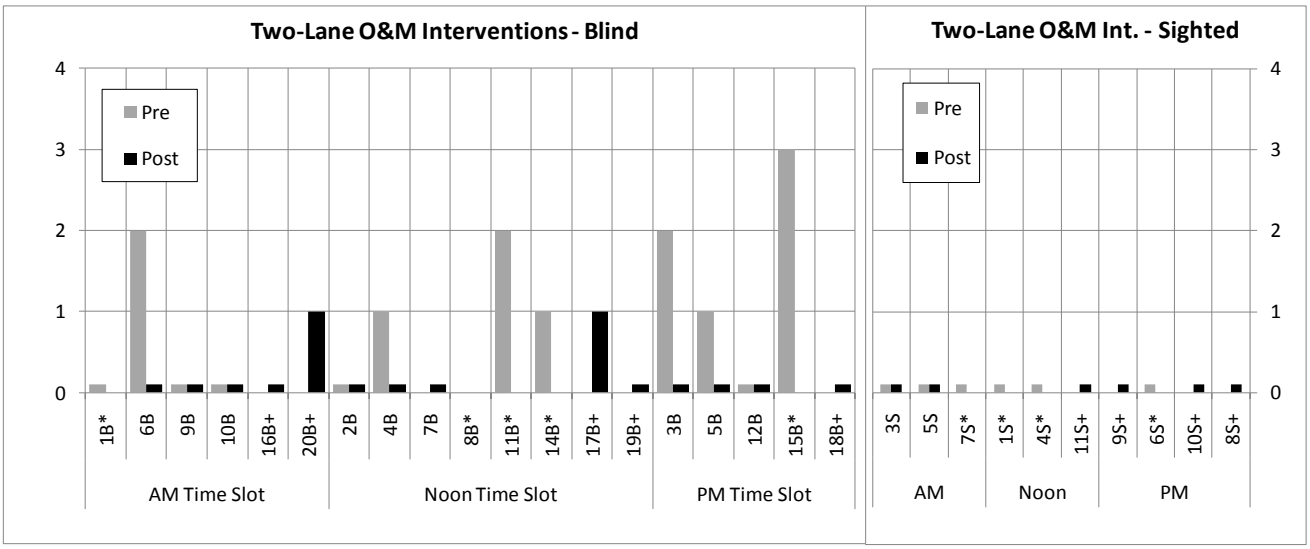
The sample size for sighted participants was 96 crossing attempts. For sighted participants, a higher percentage of crossings were initiated before the onset of the WALK interval. To assure experimental consistency, the PHB was activated for all sighted pedestrians during all crossing attempts. This was especially evident at the entry leg, where only approximately 70% of crossings were initiated during the

WALK interval, compared to just over 90% at the exit leg. Presumably, this is explained by greater uncertainty of traffic patterns at the exit leg, where exiting traffic must be distinguished from circulating traffic. Of those participants who didn't wait for the WALK interval, 6.3% crossed during the steady yellow interval for both entry and exit lane crossings, with the vast majority of the remainder (22.9% at the entry lane crossings) crossing during the vehicle flashing yellow interval. This last category consists of participants who crossed immediately after the onset of the trial, but after the pushbutton was activated. In all cases, the minimum "dark" interval in the PHB cycle had elapsed prior to starting a new trial, so that the flashing yellow interval started immediately after the button was pushed.

4.1.1.2 Interventions

Interventions are a measure of pedestrian risk (see Ashmead et al., 2005). O&M interventions were performed by the orientation and mobility specialist whenever he or she perceived that the pedestrian had made a high risk decision. Interventions occur during risky situations and in situations in which the level of risk is unacceptably high or “too close to call”. They can also be described as situations where evasive action on the part of the driver (braking, swerving) or the participant (running, reversing course) would probably have been necessary to avoid a collision between them. An O&M intervention always resulted in terminating a study trial, and the participant was guided across the street afterwards to start the next trial.

Figure 11 shows the number O&M interventions for each participant in the pretest and posttest conditions. An intervention rate of zero is shown at a value of 0.1 to distinguish it from a data point for participants where no data are available for either pretest or posttest.



*+ No data available for pretest; * No data available for posttest*

Figure 11: Number of O&M Interventions, Two-lane Pretest and Posttest

Figure 11 shows that several blind participants experienced O&M interventions during the pretest at the two-lane approach. The highest number of interventions occurred for participant 15B, where the O&M

specialist intervened 3 times during 16 crossing attempts (a rate of 18.8%). Of the 12 blind participants for which pretest data are available, seven experienced at least one intervention. On the other hand, sighted participants did not experience any O&M interventions in the pretest, although the study protocol was identical for both groups of participants. For blind participants who returned for the posttest after installation of the PHB, the rate of O&M interventions dropped to zero. However, two blind participants who had not participated in the pretest (17B and 20B) experienced one O&M intervention each over the 16 crossing attempts (a rate of 6.3%). No sighted participant interventions were observed in the posttest. Figure 12 shows a comparison of O&M interventions for all participants (blind and sighted) who took part in both the pretest and posttest. It illustrates that none of the returning participants had any O&M interventions in the posttest, including the four (blind) participants with one or more pretest intervention.

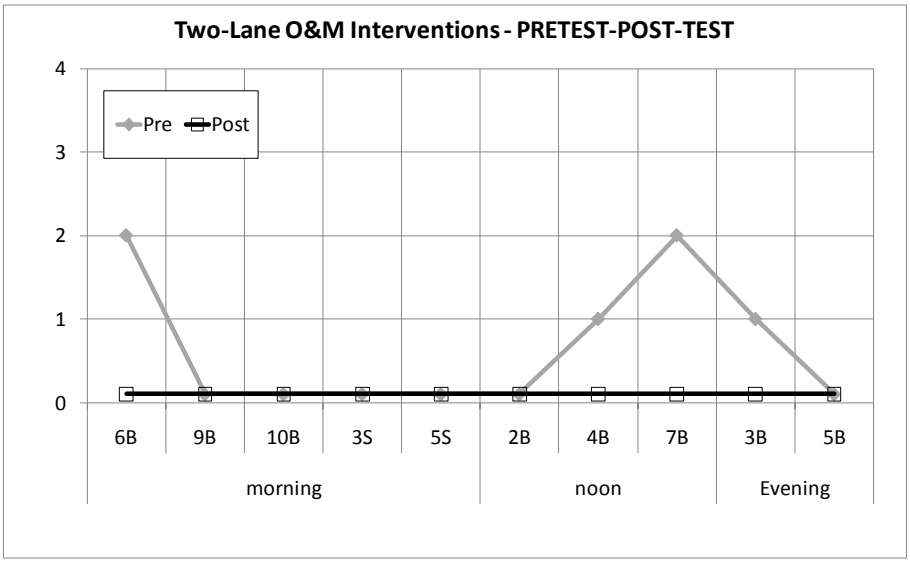


Figure 12: Two-Lane Pretest - Posttest O&M Interventions for Returning Participants

Table 6 shows summary statistics and comparisons for the O&M intervention measure for blind and sighted participants, including average rate per crossing attempt, standard deviation, minimum and maximum. For example, one intervention divided by eight attempted crossings at the three-lane entry corresponds to a rate of 12.5%. The data in Table 6 are based on the individual intervention rates for each participant.

Table 6: O&M Interventions, Two-lane Approach

Study	Subject	Exit/Entry	No. Int.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry (n=97)	2	1.9%	4.7%	0.0%	12.5%
		Exit(n=93)	9	8.7%	11.8%	0.0%	37.5%
	Sighted	Entry (n=46)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=48)	0	0.0%	0.0%	0.0%	0.0%
POST	Blind	Entry(n=103)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=103)	2	1.7%	4.4%	0.0%	12.5%
	Sighted	Entry(n=48)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=48)	0	0.0%	0.0%	0.0%	0.0%

The table illustrates that the average intervention rate for blind participants was significantly reduced from 1.9% at entry to 0% after the installation of the PHB ($p<0.0001$). At the exit, the intervention rate dropped from 8.7% to 1.7%, also a statistically significant reduction ($p<0.0001$). As discussed, the intervention rate for returning blind participants was reduced to zero for pretest participants who returned for the posttest, and the source of the exit interventions observed during the posttest was the two new blind participants who had one intervention each. No sighted participant experienced any O&M intervention in the pretest or posttest.

4.1.1.3 Delay

One of the hypotheses was that the installation of the PHB treatment would decrease blind participants' crossing delay. Participant delay was defined as the time interval between the time a participant arrives at the crosswalk and the time the participant started to cross. Figure 13 shows delay in seconds for each blind and sighted participant for the pretest and the posttest trials. Each bar represents the average (mean) delay of 16 crossings (eight entry-leg and eight exit-leg crossings) for each participant at the two-lane approach (although in a few cases missing data resulted in fewer than 16 crossings). The figure further distinguishes between participants in the AM (9:30 start), early PM (1:30 start), and late PM (4:30 pm start) time slots used for the study. A pretest participant who returned for the posttest was scheduled at the same time of day. A comparison between entry and exit leg crossing performance is given in Table 7.

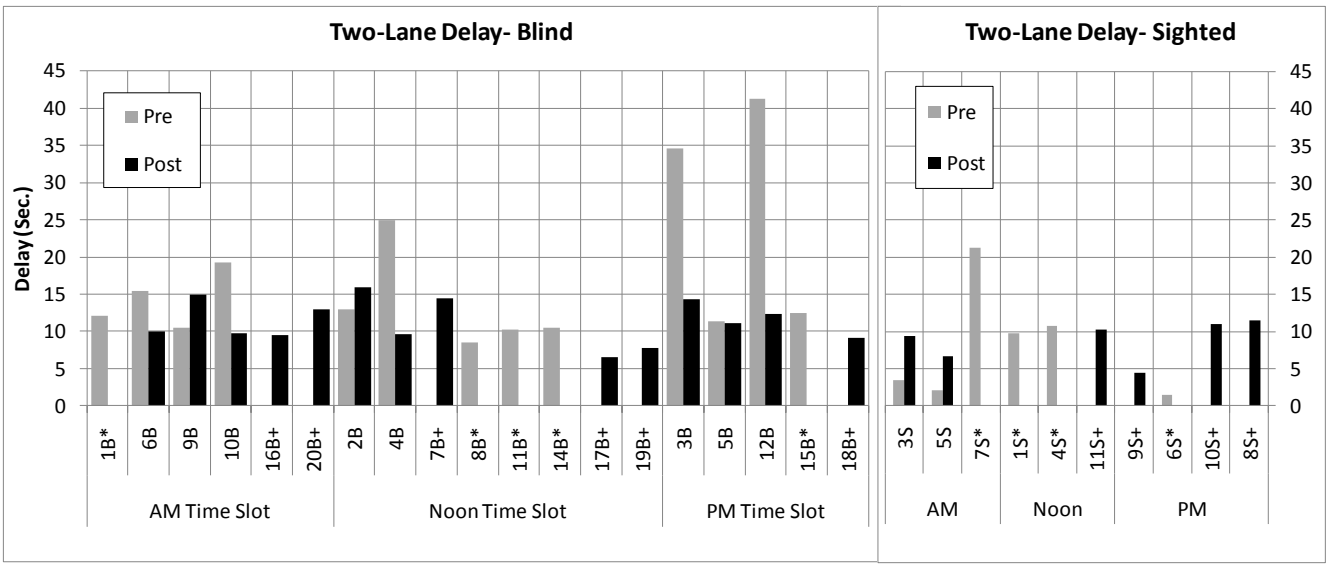


Figure 13: Two-lane Pretest and Posttest Delay

*++ No data available for pretest; * No data available for posttest*

Figure 13 shows that blind participants experienced higher average delays than sighted participants. The highest delays for blind participants in the pretest were observed during the PM study time slot, when traffic volumes were highest. However, the figure also reveals that many blind participants had relatively low average delays at the two-lane approach even in the pretest condition. The figure also shows large variations in average delay across blind participants. It further distinguishes between delay during pretest and posttest. Participants for which no data are available in the pretest are shown with a (+) symbol, and those without posttest data are shown with a (*). For blind participants where both pretest and posttest data are displayed, a decrease in average crossing delay is evident after installation of the PHB, especially for those who experienced high delay in the pretest condition.

Only two sighted participants participated in both the pretest and posttest. For those two, the results indicate increased delay for these participants across these two conditions. For most of the sighted participants, delay in both the pretest and posttest was less than or equal to delay for blind participants in the posttest, with the exception of Participant S7, who exhibited an average delay of greater than 20 seconds per trial. This participant was a very hesitant (sighted) participant, who indicated that he/she usually didn't walk much and didn't have much experience crossing busy intersections. Note that, for all sighted participants, delay increased from pretest to posttest for the entry lane and decreased from pretest to posttest for the exit lane.

Table 7 summarizes the participant delay for the pretest and posttest for the entry and exit lanes and for blind and sighted participants. The numbers are shown in the table as mean delay to cross one leg (or two lanes) of the roundabout. A full crossing of the roundabout approach across Drake Road (entry plus exit) can be interpreted as the sum of the two averages.

Table 7: Delay per Leg for Two-Lane Roundabout

		Blind Participants				Sighted Participants			
		Ave.	StdDev	Min	Max	Ave.	StdDev	Min	Max
PRE	Entry (n=97/46)	15.4	19.1	1.1	104.9	4.7	5.5	0.5	24.8
	Exit(n=93/48)	19.0	15.8	1.0	84.1	11.1	17.2	0.4	89.1
	Total(n=190/94)	17.1	17.6	1.0	104.9	7.9	13.2	0.4	89.1
POST	Entry(n=103/48)	11.5	9.8	3.3	91.1	7.9	4.3	0.5	15.0
	Exit(n=103/48)	11.2	8.4	1.5	67.0	9.8	2.4	2.8	13.9
	Total(n=206/96)	11.3	9.1	1.5	91.1	8.9	3.6	0.5	15.0

**Sample size for blind participants/ Sample size for sighted participants*

During the pretest for blind participants, delay on the exit leg was, on average, greater than that at the entry leg (19.0 and 15.4 seconds, respectively), although this difference was not statistically significant (p=0.1550). For sighted participants, the average exit leg delay (11.1 seconds) was significantly greater than the entry leg delay (4.7 seconds; p=0.0156). The average delay for blind participants in the pretest (17.1 seconds) was significantly greater than for sighted participants (7.9 seconds; p<.0001).

Installing the PHB significantly decreased delay for blind participants from 17.1 to 11.3 seconds per leg (p<0.0001). The PHB resulted in an apparent increase in delay for sighted participants from 7.9 to 8.9 seconds, but this increase was not statistically significant (p=0.5156). The average delay at both exit and entry lane crossings was not significantly different for blind participants (p=0.8314). Interestingly, the entry-exit difference still exists for sighted participants in the posttest (p=0.0061), although the net difference between the legs decreased compared to the pretest, with 9.8 and 7.5 seconds of average delay for the exit and entry lanes, respectively.

The delay figures for the posttest should be interpreted in light of the duration of the PHB intervals as presented in Table 7 and discussed earlier. Following the activation of the pedestrian pushbutton, the PHB cycles through flashing yellow, steady yellow, and all-red clearance intervals before displaying the WALK interval. The duration from pushbutton press (which occurred just before the start of the trial and thus marking the beginning of the delay measurement) was 10.5 and 9.5 seconds for the entry and exit legs, respectively. The average delay for sighted participants of 7.9 seconds at the entry leg, therefore means that participants crossed before the onset of the WALK interval. Since the experimental protocol called for an activation of the PHB for all participants (blind and sighted), it is unclear how many sighted participants would have attempted to cross without pushing the button. This also is reflected in the behavior analysis shown in Figure 10. At the exit leg, the average sighted participant delay of 9.8 seconds more or less matched the phase intervals, and suggests that on average few sighted participants crossed before the onset of the WALK. The average delay times for blind participants were longer than the PHB vehicle clearance intervals, suggesting some uncertainty even after installation of the PHB.

Figure 14 shows the cumulative delay distributions for blind and sighted participants on the two-lane approach in the pretest and posttest. For blind participants, the 85th percentile delay shows a large

decrease for the posttest in comparison with pretest. The decrease was much smaller for sighted participants and, in general, the cumulative delay distribution is relatively tight for this group of participants. One of the major effects of the PHB installation for blind participants was a tightening of the delay distribution in the posttest, resulting in the expected delay for all participants falling closer to the overall observed mean.

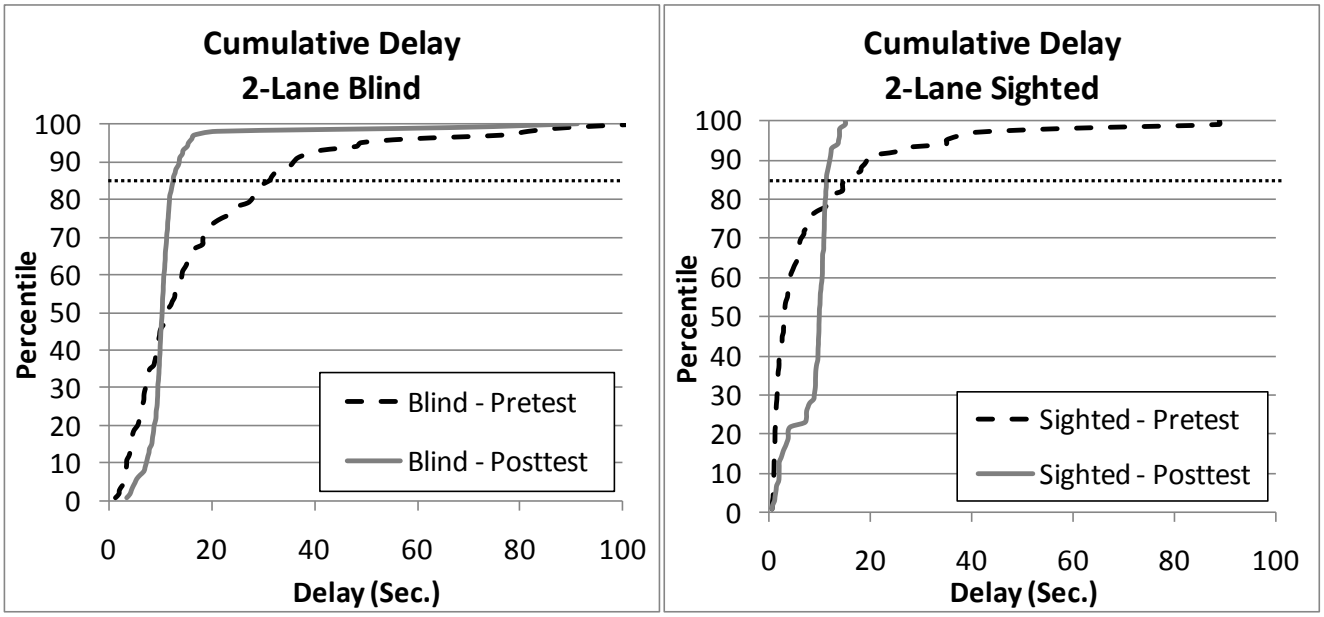


Figure 14: Cumulative Participant Delay Distribution Two-lane Approach

4.1.2 Driver Behavior and Vehicle Impacts

The analysis of the PHB installation also included a focus on vehicle measures, including driver compliance, and vehicle queuing impacts. These measures are described in this section.

4.1.2.1 Driver PHB Behavior

In order to measure driver behavior with the PHB installation, videos taken at the site were manually coded and driver behavior was analyzed during each of the four PHB intervals: steady yellow, flashing yellow, steady red, and alternating flashing red. For each interval, the analyst recorded the number of vehicles stopping (or already in a stopped state) and the number of vehicles proceeding through the crosswalk. The sum of these two categories represents the total number of vehicles observed in each interval, and this number was used to compute the percentage of vehicles stopped/stopping and proceeding. Figure 15 shows the results of the driver behavior study for the two-lane approach, reported separately for entry and exit legs.

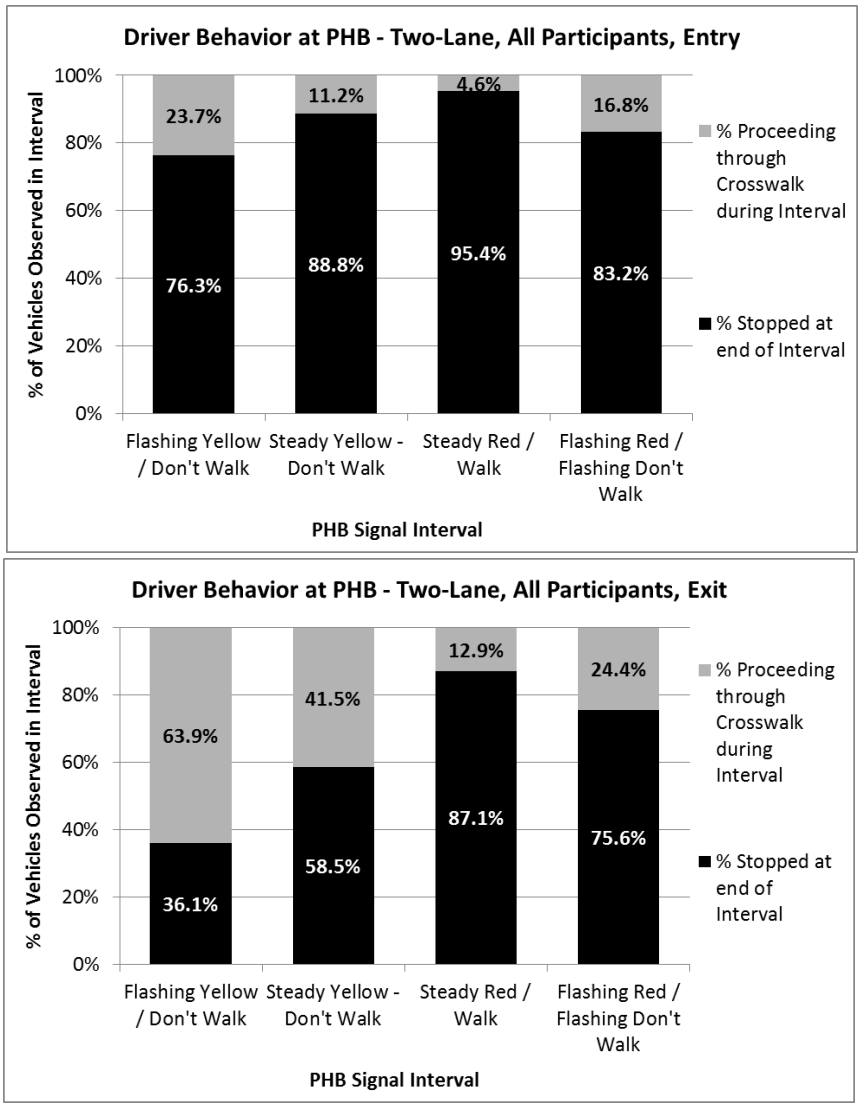


Figure 15: Driver PHB Behavior Results for Two-Lane Approach

The results in Figure 15 indicate that 4.6% of drivers proceeded through the crosswalk during the steady red indication at the entry leg, which is a violation of the PHB traffic control device. In the earlier flashing and steady yellow intervals, approximately 23.7% and 11.2% of drivers proceeded through the crosswalk, respectively, which is allowable. The remaining drivers had already stopped in anticipation of the red signal interval. During the alternating flashing red, 83.2% of drivers remained stopped until the end of the interval, which likely reflects their misunderstanding of the signal interval. Out of these 83% drivers that remained stopped during flashing red phase, at the Entry leg of two-lane approach only about 1% remained stopped because there was still a conflicting pedestrian waiting to cross. The remaining 99% of drivers that remained stopped during flashing red phase, likely, misunderstood the signal indication. For Exit leg of two-lane approach 98% of the drivers that remained stopped during flashing red (out of 223 vehicles or 75.6% of the vehicles observed during flashing red phase) did so even though there was no pedestrian waiting to cross. The PHB is intended to reduce driver delay by allowing

them to move (after stopping) during this interval, but these results suggests that this opportunity was not utilized by many drivers.

The results further reveal a higher rate of red signal violations for exit legs (12.9%) than for entry legs (4.6%). The stopping rate during the flashing and steady yellow intervals was also much lower than at the entry lanes, with 63.9% and 41.5% of drivers proceeding through the crosswalk, respectively. This may suggest that drivers were less aware of the signal presence on the exit leg. During the alternating flashing red interval, 75.6% of drivers did not proceed through the crosswalk until after the signal had returned to dark mode, mirroring the behavior at the entry leg.

The rate of 12.9% of observed vehicles during the steady red interval that proceeded through the crosswalk at the exit leg raises concerns about driver compliance with the PHB traffic control device. These 12.9% of observed vehicles during that interval at the exit leg corresponded to 26 vehicles. The video records showed that in 24 of these events, the vehicle passed in front of the participant. In the remaining 2 events, the pedestrian had already started walking and the vehicle passed behind the pedestrian. For the 24 events with vehicle passing in front of the participant, no event was observed were the pedestrian had set foot into the roadway. Further, of the 24 events, only four events were associated with a vehicle that had previously stopped for the participant, but then proceeded anyways during the steady red interval. The remaining 20 events never stopped for the traffic control device and represent non-stopping red-light running events. This is equals to 9.9% of the 202 vehicles observed during the steady red interval.

In contrast, the 4.6% of vehicles observed to move during the red phase at the entry leg (16 events), 12 crossed in front of the pedestrian and 33% of those (4 events) did previously stop for the pedestrian. Presumably, the drivers proceeded because the pedestrian didn't seem to go during the WALK interval. Of the 347 vehicles observed during steady red at the entry leg, therefore only 1.2% (4 events) represent non-stopping red-light running events in front of the participant.

4.1.2.2 Vehicle Queuing

The vehicle queuing study measured the maximum vehicle queue length caused by the presence of the participant during any given trial. The queue length was defined as the total number of vehicles queued across all lanes. Results for the two-lane roundabout approach are shown in Table 8.

Table 8: Maximum Queue Length Study Results - Two-Lane Approach

Two-Lane Roundabout Queue Lengths (Vehicles.)		Ave.	Median	Std. Dev.	Min	Max
PRE*	Entry (n=152)	1.5	1	1.9	0	9
	Exit (n=152)	0.5	0	0.9	0	4
	Total (n=304)	1.0	0	1.6	0	9
POST*	Entry (n=160)	2.3	2	2.3	0	13
	Exit (n=160)	1.8	1	1.8	0	9
	Total	2.1	2	2.1	0	13

** N refers to the number of trials during which queues were measured*

The results in Table 8 generally show relatively short queues during the trials. The average pretest queue is only 1.0 vehicle with a maximum of 9 vehicles. The median maximum queue length, which is defined as the middle value of the queue length distribution, was only one vehicle at the entry and zero vehicles at the exit. When combining both legs, the median queue length is zero, which means that no queue formed in 50% (or more) of all trials.

In the posttest, the average queue length increased to 2.1 vehicles, with a maximum of 13 vehicles across the two lanes. The median queue was two and one vehicles for entry and exit leg, respectively, and overall, 50% of queues had two vehicles or less. The increase in average queue length after installation of the PHB was statistically significant ($p<0.0001$), but 2.1 vehicles queued across two lanes (on average) is still relatively short. Queues would be most problematic at the exit leg, where they may spill back into the circulating lane. With the stop bar positioned approximately 30 feet from the circulating lane, each lane can comfortably accommodate 1-2 vehicles. The average posttest exit queue of 1.8 vehicles over both lanes is therefore readily contained within the available storage.

Figure 16 shows the cumulative distribution of maximum queue lengths for the approach. The figure shows that while posttest queues are generally larger than pretest queues (evident by a shift of the distribution to the right), the overall queuing impacts are relatively small. The 85th percentile queue at the exit leg in pretest and posttest was 1 vehicle and 3 vehicles, respectively, indicating a somewhat higher likelihood of a queue spilling back into the circulating lanes in the posttest. The 85th percentile entry queue in the pretest of 8 vehicles increased to 11 vehicles in the posttest.

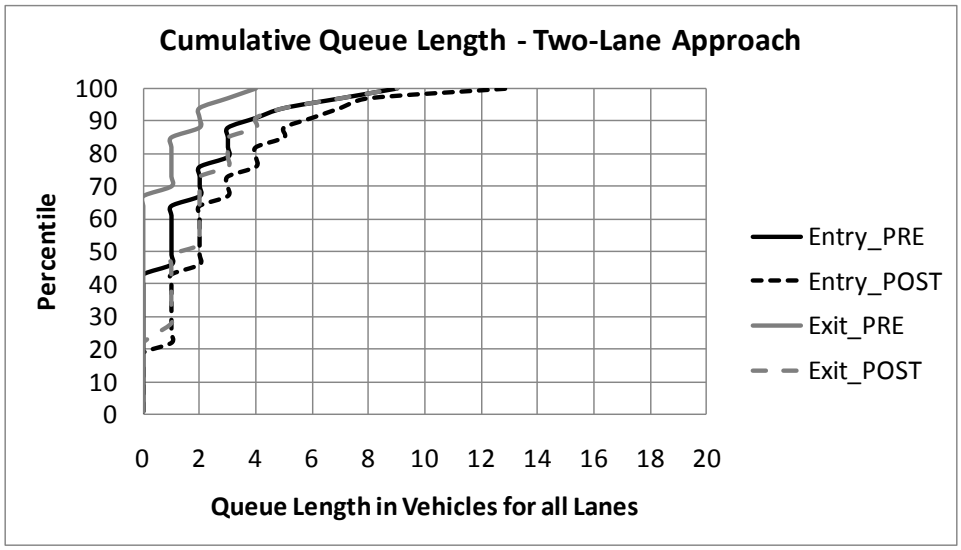


Figure 16: Cumulative Distribution of Maximum Queues - Two-Lane Approach

An analysis of maximum queue lengths by time of day of trials (AM, early afternoon or late afternoon), showed slightly higher posttest queues for the busier early afternoon (average max queue = 2.1 vehicles) and late afternoon time slots (2.5 vehicles), compared to the AM period (1.6 vehicles). The mean maximum exit queues for the respective time slots were 1.7, 1.8, and 1.8 vehicles. All these values are still contained within the available exit queue storage.

Overall, the queuing analysis did not show any significant queuing at the two-lane approach, a fact mostly attributable to the low traffic volumes. Even at the maximum observed entering flow rates of 600 vehicles per hour over two lanes (see Figure 5), the average headway between vehicles in each lane was 12 seconds (3600 sec/hour divided by 300 vehicles/hour in each lane). By comparison, the time needed to cross the 24-foot crosswalk at a walking speed of 4 ft/sec is 6 seconds, and the steady red display for the PHB was 7 seconds. As a result, few vehicles on average arrived while a pedestrian was present. The impact of participant presence on traffic operations is expected to be higher as vehicle (or pedestrian) volumes increase.

4.1.3 Time-in-Queue Delay

In addition to vehicle queue lengths, the research team measured the *time-in-queue (TIQ) delay* for select trials using the methodology described in the Highway Capacity Manual 2000 for signalized intersections. Since no signal was installed at the test location in the pretest, the methodology was adopted to estimate TIQ delay on a per-trial basis.

Following the HCM methodology, the number of vehicles queued at the crosswalk was recorded every 15 seconds from video observations for the duration of the trial (up to two minutes). In addition, the video observer recorded the total number of vehicles observed during the trial (including those that did not stop for the participant and thus weren't delayed). The average TIQ delay is defined as the total number of queued vehicle-intervals multiplied by the analysis interval (15 seconds) and divided by the total number of observed vehicles. The result is the average TIQ delay per vehicle measured in seconds. For example, if a total of five vehicles were observed stopped during four intervals (4*5=20 vehicle-intervals) and overall ten vehicles were observed during the trial (five didn't stop), then the average TIQ delay is: (20*15seconds)/(10 vehicles)=30 seconds per vehicle.

Table 9 shows the results of the TIQ delay analysis for the two-lane roundabout approach on Drake Road, based on a sample of nine pretest and ten posttest participants.

Table 9: Evaluation of Time-in-Queue (TIQ) Delay for Two-Lane Approach (in seconds per vehicle)

Statistic (n=9/10 in pretest/posttest)	**Entry Leg**		**Exit Leg**	
	Pretest	**Posttest**	**Pretest**	**Posttest**
Average (sec/veh)	3.3	4.5	0.5	2.3
Standard Deviation (sec/veh)	1.66	2.22	0.37	1.41
t-test comparison	0.1831		0.0010	
Minimum (sec/veh)	1.2	1.7	0.0	1.1
Maximum (sec/veh)	6.2	7.9	1.2	5.6

The results in Table 9 show an average TIQ delay in the pretest of 3.3 seconds per vehicle at the entry and only 0.5 seconds at the exit leg of the roundabout. With the installation of the PHB, the TIQ delay increased to 4.5 and 2.3 seconds, respectively. This increase is only significant at the exit lane. Even at the posttest delay figures, these estimates fall within the Levels of Service (LOS) A range as defined in the Highway Capacity Manual for signalized intersections. It should be noted that the LOS thresholds in the HCM are based on control delay, which is defined as the TIQ delay plus any delay incurred during

deceleration and acceleration. Typically, this added deceleration/acceleration delay only adds a few seconds to the TIQ delay.

4.2 Three-Lane Approach

4.2.1 Participant Behavior and Performance

Participant behavior and performance were analyzed in the same three categories used for the two-lane approach: participant PHB behavior, delay and interventions.

4.2.1.1 Participant PHB Behavior

The study investigated participant crossing behavior as a function of PHB signal interval. Results are shown in Figure 17, separated for blind and sighted participants. The figure shows the distribution of PHB intervals when participants initiated the crossing, which is defined as stepping off the sidewalk and into the street. The pedestrian WALK signal interval is the legal crossing phase at the PHB although compliance studies at other intersections suggest that (sighted) pedestrians oftentimes cross in adjacent intervals. In this study, participants were informed about the legal implication of the WALK interval, but also that they may cross at their discretion (with or without the Walk interval).

The PHB pushbutton was activated by the O&M specialist for both blind and sighted participants just before the beginning of each trial. The results are therefore not a measure of the rate of activation of the PHB device, since this was controlled in the study. Rather, the objective was to observe behavior in response to the signal indication by both participants and drivers.

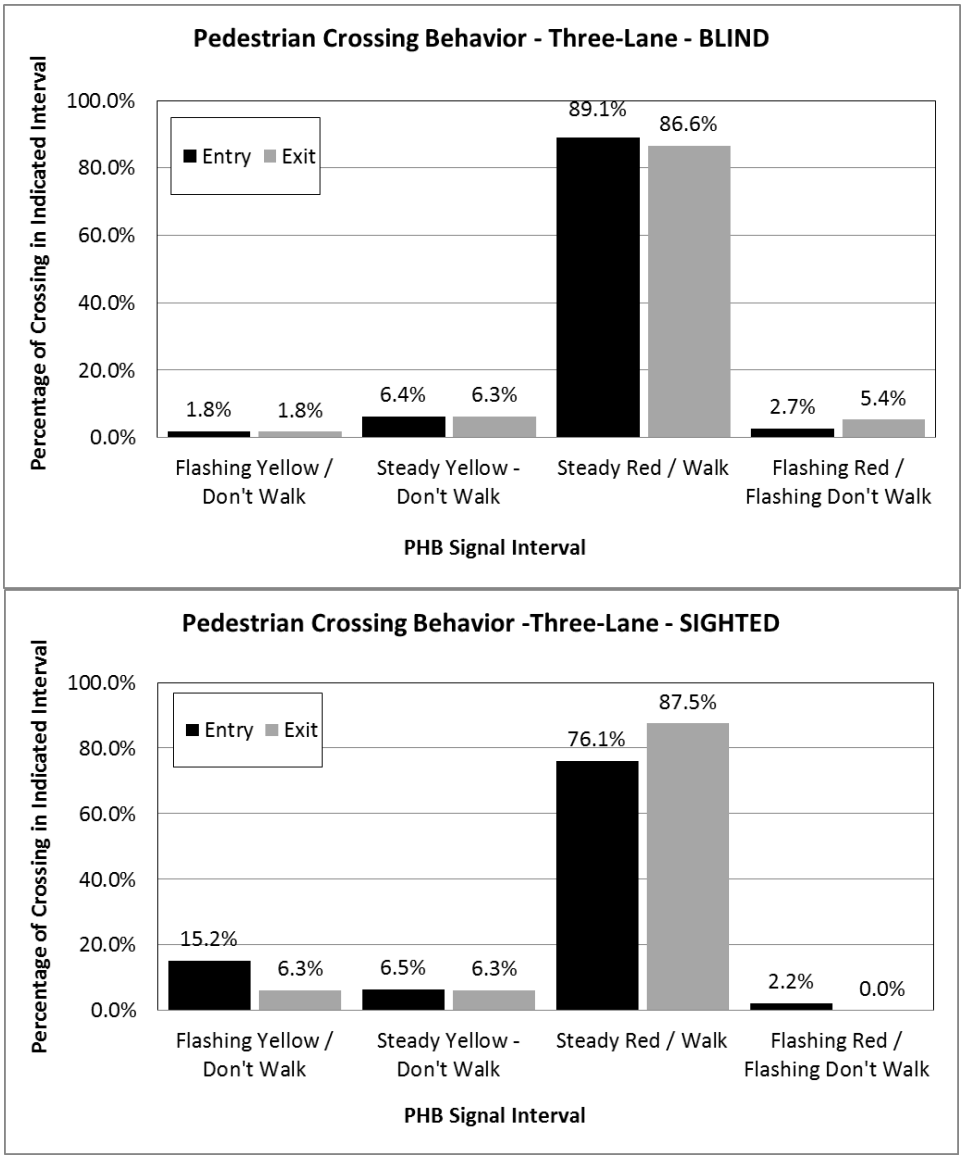


Figure 17: Participant PHB Compliance, Three-Lane Approach

A total of 222 blind participant crossing attempts were observed at the three-lane roundabout approach at entry and exit approach combined. The analysis shows that most blind participants initiated crossings during the WALK indication as intended (195 of 222 crossings), similar to the two-lane results. A small percentage of crossings were initiated during the steady yellow (4 crossings) and flashing yellow interval (14 crossings). Some blind participants didn't initiate crossings until after the WALK interval had elapsed (9 crossings), presumably because they waited to be sure that vehicles had in fact come to a full stop.

A total of 94 sighted participant crossing attempts were observed. A smaller number of sighted participants initiated crossing during the WALK interval on the three lane approach than on the two lane approach, with many participants crossing before the onset of the WALK on the two lane approach. This was more evident at the entry leg, where only 76.1% of crossings were initiated during the WALK interval, compared to 87.5% at the exit leg. Of those participants that didn't wait for the WALK interval,

6.3-6.5% crossed during the steady yellow interval, with the remainder (15.2% at the entry and 6.3% at exit) crossing immediately after the onset of the trial during the vehicle flashing yellow interval.

4.2.1.2 Interventions

Figure 18 shows the number of O&M interventions for each participant in pretest and post cases. Intervention rate of zero are shown in the figure at a value of 0.1 for clarity, and to distinguish them data points in which no data are available for either pretest or posttest.

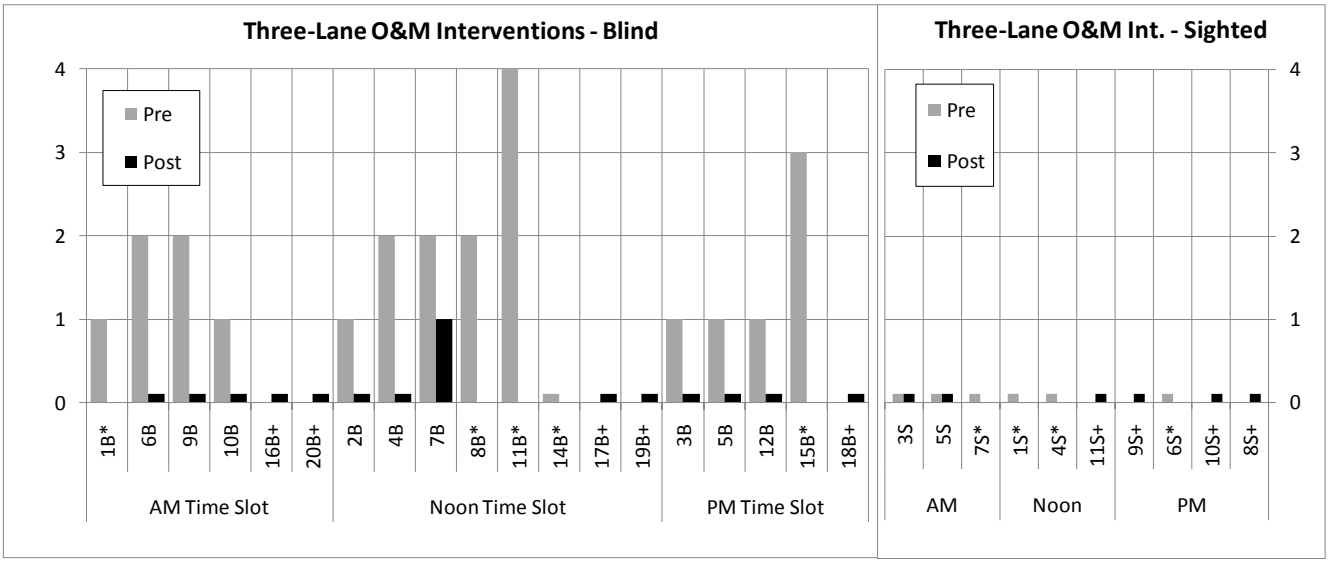


Figure 18: Number of O&M Interventions by subject, three-lane Pretest and Posttest

*+ No data available for pretest; * No data available for posttest*

Figure 18 reveals that many blind participants experienced O&M interventions during the pretest at the three-lane approach. The greatest number of interventions was observed for participant 11B, for whom the O&M specialist intervened 4 times during 16 crossing attempts (a rate of 25.0%). Of the 14 blind participants for whom pretest data are available, all but one experienced at least one intervention. On the other hand, sighted participants did not have any O&M interventions in the pretest (the study protocol was the same for both groups of participants).

For blind participants who returned for the posttest after installation of the PHB, the rate of O&M interventions dropped to zero for all but one participant. This was the only intervention observed during the posttest, compared to a total of 23 intervention interventions in the pretest. No sighted participant interventions were observed in the posttest. Figure 19 shows a comparison of O&M interventions for all participants (blind and sighted) who participated in both pretest and posttest. It illustrates that only one of the returning participants had an O&M intervention in the posttest, but that all other participants experienced zero interventions.

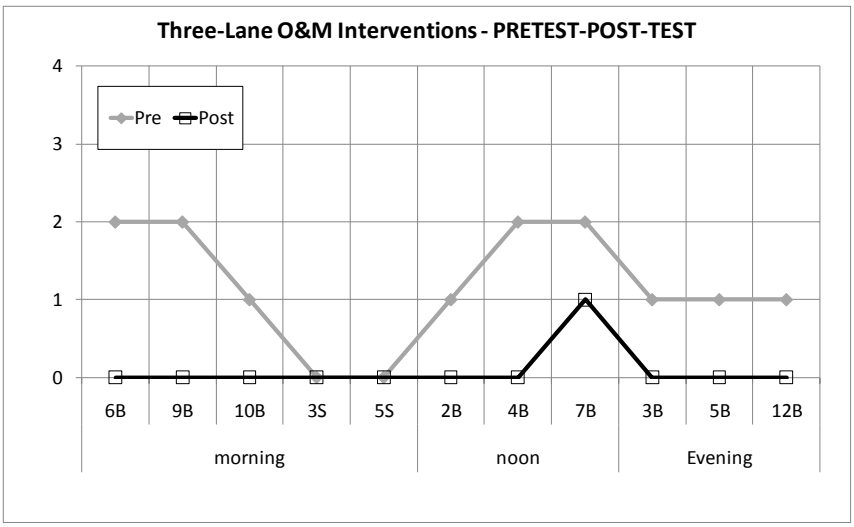


Figure 19: Three-Lane Pretest - Posttest O&M Interventions for Returning Participants

Table 10 shows summary statistics and comparisons for the O&M intervention measure for blind and sighted participants, including average rate per crossing attempt, standard deviation, minimum and maximum For example, one intervention over eight attempted crossings at the three-lane roundabout entry leg corresponds to a rate of 12.5%.

Table 10: Three-Lane O&M Intervention Maple/Drake

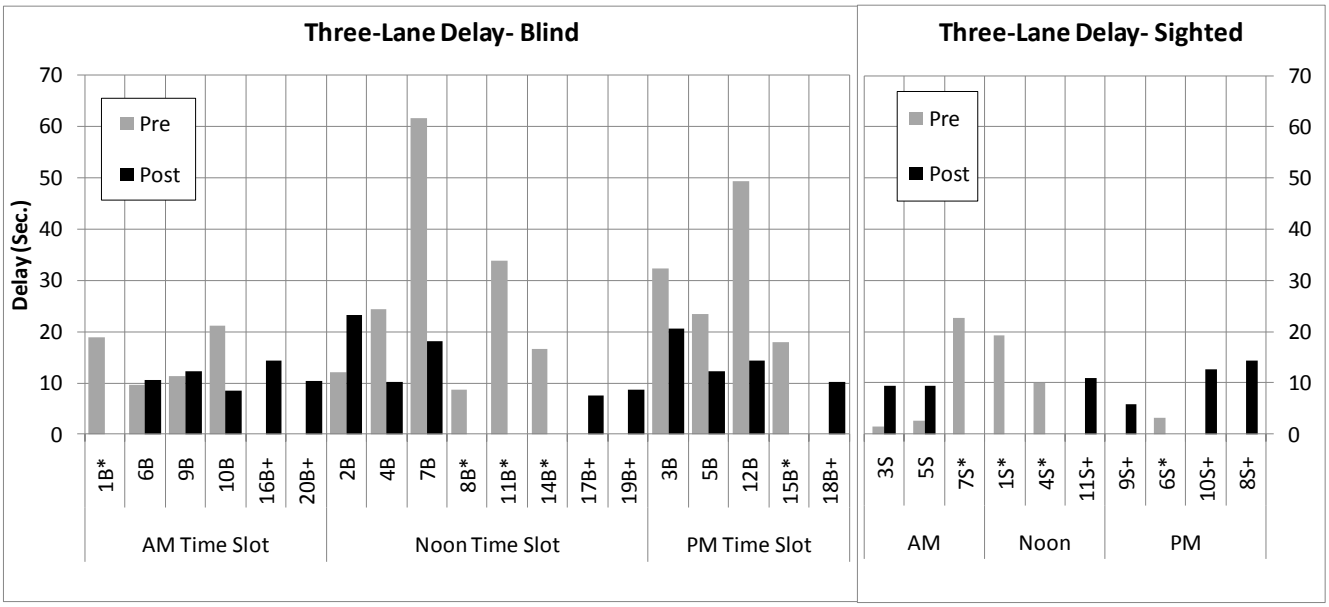
Study	Subject	Exit/Entry	No. Int.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry (n=92)	8	7.7%	8.1%	0.0%	25.0%
		Exit(n=94)	10	9.6%	13.6%	0.0%	50.0%
	Sighted	Entry (n=48)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=46)	0	0.0%	0.0%	0.0%	0.0%
POST	Blind	Entry(n=112)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=112)	1	0.8%	3.2%	0.0%	12.5%
	Sighted	Entry(n=46)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=46)	0	0.0%	0.0%	0.0%	0.0%

The table indicates that the average intervention rate for blind participants at entry was significantly reduced from 7.7% to 0.0% after installation of the PHB ($p<0.0001$.). For the exit leg, the interventions were significantly reduced from 9.6% to 0.8% ($P<0.0001$). A notable fact is that the maximum intervention rate for a subject was reduced from 50% (1 in 2 attempts) to 12.5% (1 in 8 attempts). As noted earlier, no sighted participant experienced any O&M intervention in either the pretest or posttest.

4.2.1.3 Delay

Participant delay is defined as the time interval between the time a participant arrives at the crosswalk and the time he or she starts to cross. Figure 20 shows the delay in seconds for each blind and sighted

participant in during the pretest and posttest. Each bar in the chart represents the average of up to 16 crossings (eight entry-leg and eight exit-leg crossings) for each participant at the three lane approach. The figure distinguishes between participants in the AM, early afternoon and late afternoon time slots used for the study. A pretest participant who returned for the posttest was scheduled at the same time of day for both studies. A comparison between entry and exit leg crossing performance is shown in Table 11.



*++ No data available for pretest; * No data available for posttest*

Figure 20: Three-lane Pretest and Posttest Delay

Figure 20 shows that blind participants generally experienced a higher average delay than sighted participants. For blind participants, higher delays were observed in the pretest during the late afternoon time slot and in some cases during the early afternoon time slot, presumably when traffic volumes were highest. The figure also shows that a number of blind participants experienced relatively low average delays even at the three-lane approach, on the order of 10 seconds or less in the pretest condition. However, similar to the two-lane results, the figure shows high variability in average delay across blind participants.

The figure also distinguishes between delays during the pretest and posttest. Participants for which no data are available during the pretest are indicated with a (+) symbol, and those without posttest data with a (*). For blind participants who participated in both pretest and posttest, a decrease in average crossing delay was evident after the installation of the PHB, in particular for those who experienced high delay in the pretest condition. Blind participants with low pretest delay did not seem to experience a large delay difference in the posttest.

Only two sighted participants participated in both tests. The results show a slight increase in delay, but the sample size is insufficient to draw broader conclusions.

Table 11 shows the average, standard deviation, minimum and maximum values for delay during the pretest and posttest for blind and sighted participants, and for entry or exit legs. The numbers are the average delay to cross one leg (three lanes) of the roundabout. A full crossing of the roundabout approach across Maple Road (entry plus exit) can be interpreted as the sum of the two averages.

Table 11: Delay - Participant Delays for Three-Lane Approach

		Blind Participants				Sighted Participants			
		Ave.	StdDev	Min	Max	Ave.	StdDev	Min	Max
PRE	Entry(n=92/48)	20.1	19.1	0.0	104.1	9.8	16.7	0.4	88.8
	Exit(n=94/46)	22.3	19.6	0.0	100.9	9.5	13.2	0.6	55.2
	Total(n=186/94)	21.2	19.3	0.0	104.1	9.7	15.0	0.4	88.8
POST	Entry(n=112/46)	14.2	13.2	3.9	77.7	10.5	4.9	0.7	20.3
	Exit(n=112/46)	11.7	8.4	2.0	69.5	10.5	3.3	3.0	19.5
	Total(n=224/92)	12.9	11.1	2.0	77.7	10.5	4.2	0.7	20.3

**Sample size for blind participants/ Sample size for sighted participants*

During the pretest the exit leg delay for blind pedestrians was slightly greater than at the entry leg (22.3 and 20.1 seconds, respectively), although this difference was not statistically significant (p=0.4323). For sighted participants, the average exit delay (9.5 seconds) was about that same as for the entry lane (9.8 seconds; p =0.9139). The average delay for blind participants in the pretest (21.2 seconds) was significantly greater than for sighted participants (9.7 seconds; p<.0001).

Installing the PHB significantly reduced delay for blind participants from an average of 21.2 to 12.9 seconds per leg (p<0.0001). The PHB did not result in a statistically significant increase in delay for sighted pedestrians (p=0.6203). The average posttest delay for blind participants at the exit leg is lower than the entry-leg delay (14.2 seconds) at a p-value of 0.8627, which is an unexpected result. The difference between delay for blind (12.9 seconds) and sighted (10.5 seconds) participants was reduced in the posttest, but is still statistically significant at p=0.0047.

The delay figures for the posttest should be interpreted in light of the duration of the PHB intervals as discussed in Table 5. Following the activation of the pedestrian pushbutton, the PHB cycles through flashing yellow, steady yellow, and an all-red clearance intervals before displaying the WALK indication. The duration from pushbutton press (which occurred just before the start of the trial and thus indicated the beginning of the delay measurement) was 10.5 and 9.5 seconds for the entry and exit legs, respectively. The average delay for sighted participants of 10.5 seconds at the entry leg roughly coincided with the onset of the WALK interval. The average delay time for blind participants (12.9 seconds) was slightly higher than the PHB vehicle clearance intervals, which may be attributable to a short time lag between the visible WALK indication and the audible message.

Figure 21 shows the cumulative delay distributions for blind and sighted participants for three-lane approach for pretest and posttest. The 85th percentile delay decreased significantly from pretest to posttest, with a very large reduction in delay evident for blind participants. Both participant groups exhibited a wider delay distribution in the pretest. The installation of the PHB resulted in a tightening of

the distribution for both groups, with the expected delay for each participant falling closer to the overall observed mean.

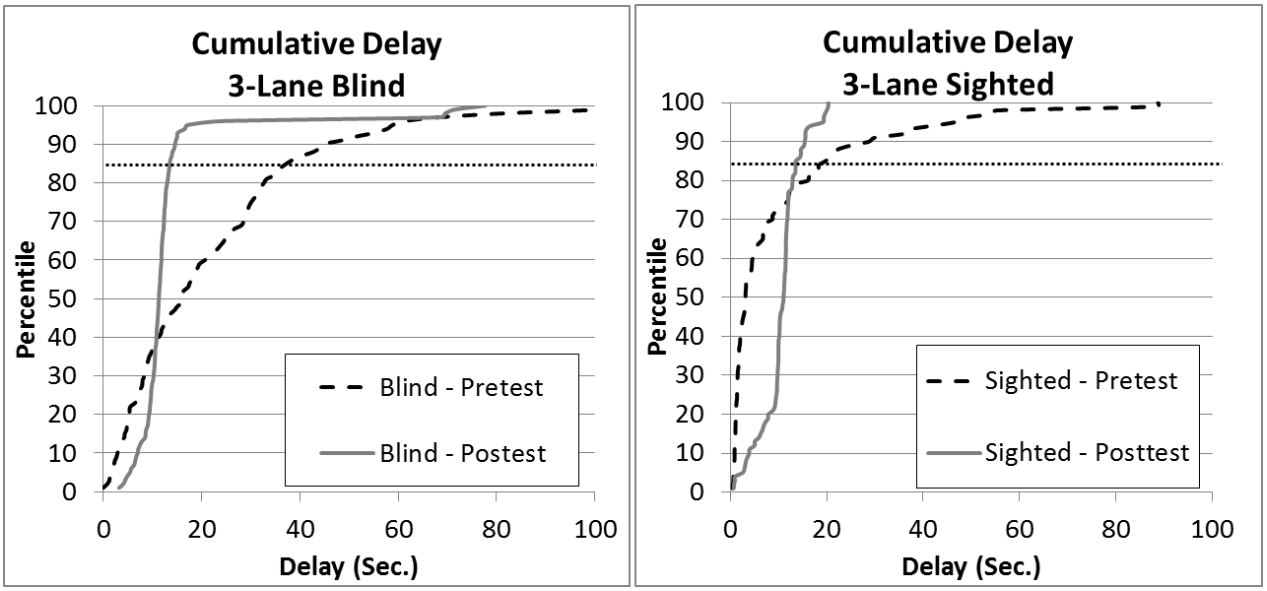


Figure 21: Cumulative Delay Distribution Chart, three-lane, Blind

4.2.2 Driver Behavior and Vehicle Impacts

The analysis of the PHB installation also included a focus on vehicle measures, including driver compliance and vehicle queuing impacts. These measures are described in this section for the three-lane approach.

4.2.2.1 Driver PHB Behavior

Driver behavior with the PHB installation was estimated by noting vehicle behavior for each of the four PHB intervals: steady yellow, flashing yellow, steady red, and alternating flashing red. For each interval, the analyst recorded the number of vehicles stopping (or already in stopped state) and the number of vehicles proceeding through the crosswalk. The sum of these two categories represent the total number of vehicles observed for each interval, which was then used to compute the percentage of vehicles stopped/stopping and proceeding. For each interval, the sum of these two percentages must add up to 100%. Figure 18 shows the results of the behavior study for the three-lane approach, separated by entry and exit leg.

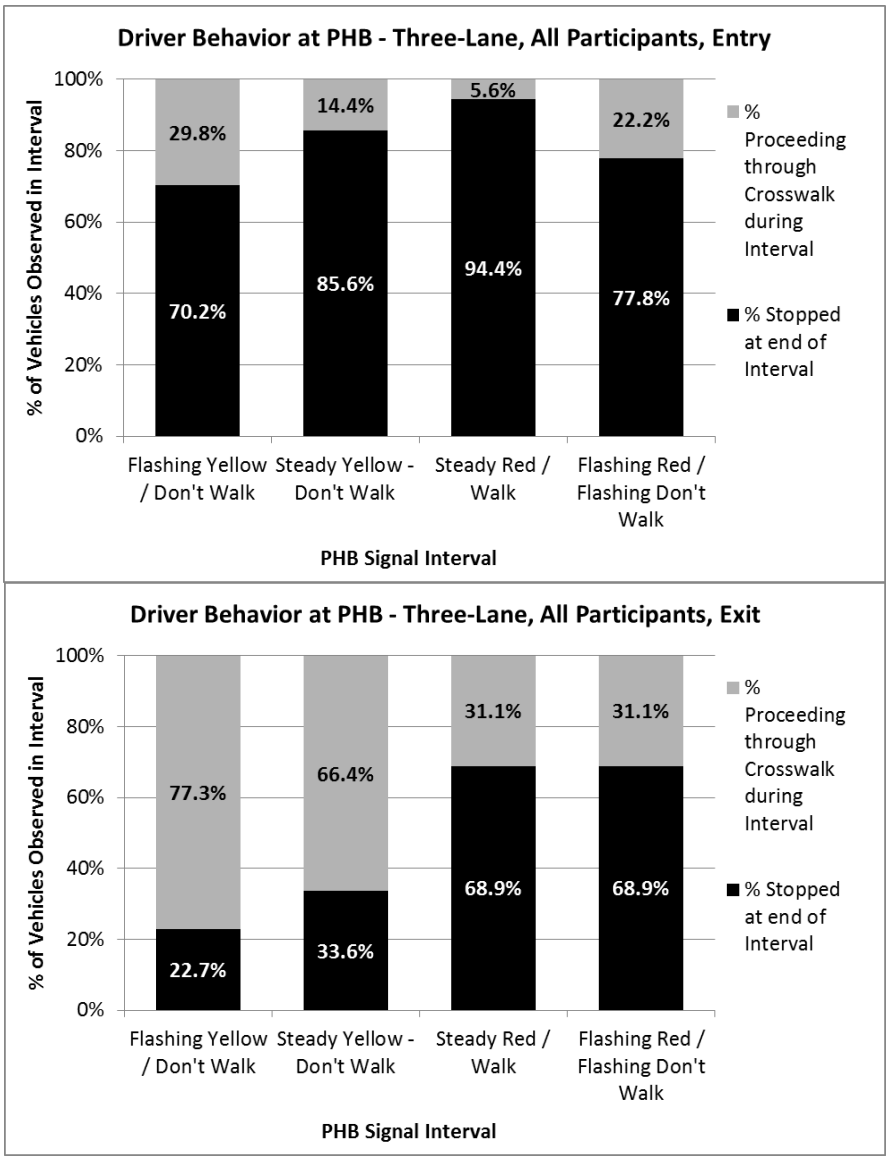


Figure 22: Driver PHB Behavior Results for Three-Lane Approach

The results in Figure 22 suggest that 5.6% of drivers proceeded through the crosswalk during the steady red indication at the entry leg, which is a violation of the PHB traffic control device. In the earlier flashing and steady yellow intervals, approximately 29.8% and 14.4% of drivers proceeded through the crosswalk, respectively, which is permissible. The remaining drivers had already stopped in anticipation of the red signal interval. During the alternating flashing red, 77.8% of drivers remained in the stopped state until the end of the interval, which likely represents a misunderstanding of the signal interval. Out of these 78% drivers that remained stopped during flashing red phase, at the Entry leg of three-lane approach only 3.6% still had a conflicting pedestrian waiting to cross.

Results at the exit leg show a higher rate of red signal violations (31.1 %). The stopping rates during the earlier flashing and steady yellow intervals were also much lower than at the entry leg, with 77.3% and 66.4% of drivers proceeding through the crosswalk, respectively. This suggests that driver were less

aware of the signal on the exit leg. During the alternating flashing red interval, again 68.9% of drivers did not proceed through the crosswalk until after the signal had returned to dark mode. Of these stopped drivers, 95.4% no longer had a waiting pedestrian at the curb and therefore likely misinterpreted the flashing red indication.

Overall, a higher rate of drivers proceeded during red and similarly fewer stopped during other phases at the three-lane approach, compared to the two-lane results. The rates of stopping for all phases at the three lane approach were lower at the exit than at the entry leg.

The rate of 31.1% of observed vehicles that proceeded through the crosswalk at the exit leg during the steady red interval raises concerns about driver compliance with the PHB traffic control device. These 31.1% of observed vehicles during that phase at the exit leg corresponded to 76 vehicles. The video records showed that in 71 of these events, the vehicle passed in front of the participant. In the remaining 5 events, the pedestrian had already started walking and the vehicle went through behind. For the 71 events with vehicle passing in front of the participant, only one event was observed where the pedestrian had set foot into the roadway. For the remaining 70 observations the participant was still standing at the curb. Further, of the 71 events, only one event was associated with a vehicle that had previously stopped for the participant, but then proceeded anyways during the red phase. The remaining drivers never stopped for the traffic control device and represent non-stopping red-light running events. This is equals to 28.7% of the 244 vehicles observed during the steady red interval.

In contrast, the 5.6% of vehicles observed to move during the steady red interval at the entry leg (38 events), 32 crossed in front of the pedestrian, of which 21 previously stopped for the pedestrian. Presumably, the drivers proceeded because the pedestrian didn't seem to go during the Walk interval. Of the 675 vehicles observed during steady red at the entry leg, therefore only 11 events represent non-stopping red-light running events in front of the participant. However, all vehicles that entered the crosswalk during the steady red indication represent a traffic violation.

4.2.2.2 Vehicle Queuing

The study measured the maximum vehicle queue caused by the presence of the participant during each trial. The queue length is defined as the total number of vehicles queued across all lanes. Results for the three-lane roundabout approach are shown in Table 12.

Table 12: Statistics for Maximum Queue Length Study Results - Three-Lane Approach

Three-Lane Roundabout Queue Lengths (Vehicles.)		Ave.	Median	Std. Dev.	Min	Max
PRE	Entry (n=144)	3.6	3	3.9	0	17
	Exit (n=144)	1.3	0	2.2	0	15
	Total (n=320)	2.4	1	3.3	0	17
POST	Entry (n=160)	5.8	5	4.3	0	19
	Exit (n=159)	3.3	3	3.2	0	16
	Total (n=319)	4.6	4	4.0	0	19

The results in Table 12 generally show higher queues at the three-lane approach than at the two-lane approach, which can be attributed to higher traffic volumes. Despite those "higher" volumes, the average pretest queue was only 2.4 vehicles with a maximum of 17.0 vehicles across three lanes. The queuing was higher at the entry approach (3.6 vehicles) than at the exit approach, where the average queue was only 1.3 vehicles. A median queue of zero at the exit shows that 50% or more of pretest crossings didn't result in any queuing.

During the posttest, the average queue length increased to 4.6 vehicles, with a maximum of 19 vehicles across three lanes. Still entry queues (5.8 vehicles) were greater than exit queues with an average of 3.3 vehicles and a median queue of 3 vehicles. The available queue storage of 30 feet at the exit corresponds to 1-2 vehicles in each of the three lanes. Both the median and average queues are therefore contained within the available storage, although some isolated longer queues were observed which spilled back into the circulating lane.

Figure 23 shows the cumulative distribution of maximum queue lengths for the approach. The figure shows generally greater posttest queues compared to the pretest queues (evident by a shift of the distribution to the right). The 85th percentile queue at the exit leg in pretest and posttest was 3 vehicles and 7 vehicles, respectively, indicating a higher likelihood of a queue spilling back into the circulating lane in the posttest. The 85th percentile entry queue in the pretest of 3 vehicles increased to 5 vehicles in the posttest.

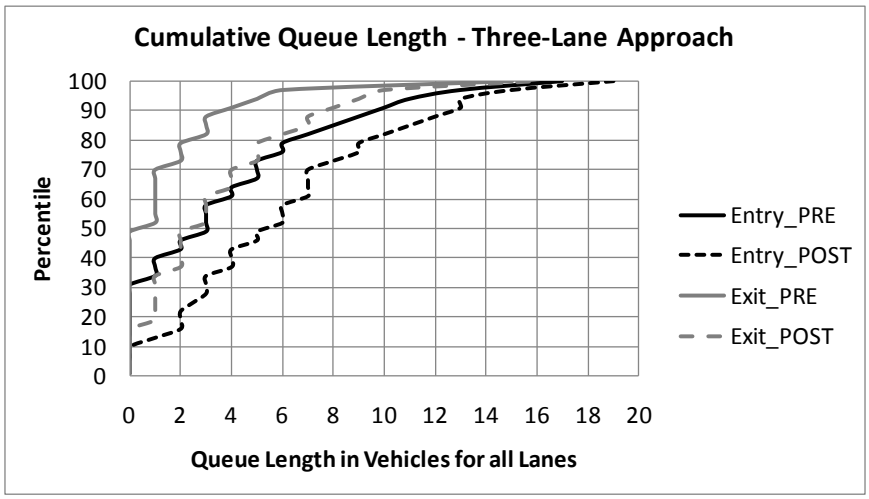


Figure 23: Cumulative Distribution of Maximum Queues - Three-Lane Approach

An analysis of maximum queue lengths by time of day (AM, early afternoon, or late afternoon), showed slightly higher posttest queues during the early afternoon (average max queue = 5.2 vehicles) and late afternoon time slots (4.6 vehicles), compared to the AM period (4.0 vehicles). The mean maximum exit queues for the AM, early afternoon, and late afternoon time slots were 3.5, 3.7, and 2.9 vehicles, respectively, which are all contained within the available exit queue storage.

Overall, the queuing analysis did not reveal the presence of unreasonably high vehicle queues, since most queues were contained within the available queue storage. Field-measured traffic flow rates were

on the order of 800 to 1,000 vehicles per hour over three lanes, which correspond to an average headway of 10.8 to 13.5 seconds between vehicles in each lane. The reason for the observed higher queuing at the three-lane entry was the occurrence of vehicle platooning from an upstream traffic signal. That signal resulted in several "no traffic" periods, during which participants crossed without causing any queues, but also some crossings with high observed queues up to the maximum observed of 19 vehicles over three lanes.

4.2.3 Time-in-Queue Delay

In addition to vehicle queue lengths, the research team measured the *time-in-queue (TIQ) delay* for select trials using the methodology described in the Highway Capacity Manual 2000 for signalized intersections. Since no signal was installed at the test location in the pretest, the methodology was adopted to estimate TIQ delay on a per-trial basis. The procedure for estimating this statistic from video is synonymous for what is described for the two-lane approach above.

Table 13 shows the results of the TIQ delay analysis for the two-lane roundabout approach on Drake Road, based on a sample of nine pretest and ten posttest participants.

Table 13: Evaluation of Time-in-Queue (TIQ) Delay for Two-Lane Approach (in seconds per vehicle)

Statistic (n=9/10 in pretest/posttest)	**Entry Leg**		**Exit Leg**	
	Pretest	**Posttest**	**Pretest**	**Posttest**
Average (sec/veh)	8.8	7.1	0.5	2.3
Standard Deviation (sec/veh)	8.78	2.61	0.53	0.76
t-test comparison	0.5840		0.0000	
Minimum (sec/veh)	1.1	3.4	0.0	1.1
Maximum (sec/veh)	27.7	10.6	1.5	3.6

The results in Table 13 show an average TIQ delay in the pretest of 8.8 seconds per vehicle at the entry and only 0.5 seconds at the exit leg of the roundabout. With the installation of the PHB, the TIQ delay decreased to 7.1 seconds at the entry leg, but this change is not statistically significant. At the exit leg, the average TIQ delay increase significantly to 2.3 seconds. Of the analyst participants, some experienced higher TIQ delay in the pretest at the entry leg, as evident by a high standard deviation and a maximum observed delay of 27.7 seconds per vehicle. These observations were during periods of heavy traffic flow entering the roundabout. Overall, the average delay estimates for all four cases fall within the Levels of Service (LOS) A/B range as defined in the Highway Capacity Manual for signalized intersections, if considering some additional delay incurred for deceleration and acceleration.

4.3 Debriefing Questions

4.3.1 Pretest

In the following, a summary of open-ended responses to the debriefing questionnaire used with participants immediately after the **pretest** crossings at the Maple and Drake Road roundabout in June of 2009 is presented. Interviews were completed with the 13 blind individuals. Some participants did not answer all questions.

All participants reported that they had never crossed at this particular intersection before, and in fact they all reported that they had never crossed at ANY roundabout before. Ten of the thirteen participants reported that they crossed streets where there is no traffic control. They mentioned residential streets, mid-block crossings, the street near their home, and side streets. Two of the thirteen did not respond to this question, and one said he used to cross streets without traffic signal control at intersections or midblock locations. The individuals, who reported crossing streets without traffic controls indicated that they listened to traffic stopping, listened for how far away approaching vehicles were, and listened for the absence of sound altogether. Five individuals reported that they listened for "all quiet" at least some of the time, although these individuals often reported using traffic sounds as well to make crossing judgments.

In regard to the question whether entry or exit crossings were easiest, seven participants said either that the exit was harder, that entry was easier, or both. Three gave the opposite response, and three said crossing entry and exit was about the same difficulty. Participants commented on the fact that the exiting traffic did not stop and that it was difficult sometimes to determine the direction of vehicle movement.

In regard to crossing from splitter to curb or curb to splitter, five of the ten participants who were asked this question said crossing difficulty was the same either way. One participant reported that the crossing from the splitter to the curb was easier, and two reported that crossing from the curb to the splitter island was easier. One participant didn't know (or couldn't tell) and one said crossing Maple was easier, without responding to the question.

When asked to rate their confidence in crossing each of the two roadways on a scale of 1 – 5, with five being very confident and one being not confident at all, eight individuals answered the question in regard to Drake Road (2-lane crossing). There were three "4's" and four "5's", and one individual said "between 3 and 5, because I gained more confidence for the later crossings". For confidence crossing Maple Road (three-lane crossing), there were eleven responses, with a median response of "4".

Ten of twelve participants responded that they would cross Maple Road if it was on their way home from work. Three of the nine qualified their answers by indicating they would "figure out a way to get "off" hours" (presumably assuming that traffic would be lighter), or by indicating Yes, "if I had to" (two respondents). One indicated that it "depended on time (of day) and that he might try to find an alternative route", and another said "If I was on my way to work, I would find another route. People don't yield and drivers consider this a 'rolling' sign".

Seven of ten participants indicated they would cross Drake Road if it was on their way home from work, while one said "maybe". Another reported that Maple and Drake were about the same "except that you have to walk faster on the three lane crossing, plus you are more likely to veer". The final respondent simply indicated that Drake was less risky than Maple Road. Seven of the participants reported that crossing at this intersection is more risky than crossing at an intersection with two lanes of traffic in each direction and a traffic signal. Three said they believed the risk level to be about the same as a signalized crossing, and one reported it was less risky. Eight of nine participants reported they would cross here

rather than at a near-by *unsignalized* midblock crossing, with one reporting he or she would cross midblock. Two participants qualified their answers with comments that indicated their judgment would be affected by which crossing was closer. One participant indicated he or she didn't know the answer to the question. However, when the same question was asked but the word "unsignalized" was changed to "signalized", seven of ten participants indicated they would cross at the signalized midblock crossing, two said they would cross at the roundabout, and one said they'd cross at either one. Finally, in regard to the final question regarding how to make this intersection more accessible and less risky, ten of thirteen recommended a traffic signal, with some mentioning the need for a signal that was accessible to people who are blind. One individual indicated that "you just need to use good strategies", one indicated the need for tactile wayfinding information, and one did not answer the question due to lack of time.

4.3.2 Posttest

Next, a summary of open-ended responses to the debriefing questionnaire used with participants immediately after the **posttest** crossings at the Maple and Drake Road roundabout in September of 2009 is presented. Interviews were completed with the 14 blind individuals. Some participants did not answer all questions.

During the posttest debriefing, the fourteen blind participants all indicated that they had not crossed roundabouts before, except for those who crossed at this intersection during their participation in the pretest. Twelve of fourteen participants reported they crossed streets at locations where there is no traffic control. Only one said they did not do this, and one individual did not respond. The locations where they crossed without traffic controls were very similar to the locations cited in the pretest.

When asked how they decided when to cross the street after the completion of the crossing trials, responses included using the signal, listening to traffic, or both. One participant did not mention traffic in his or her response, and three individuals did not mention the signal, but only mentioned traffic. The remainder of participants mentioned reliance on both the signal and the traffic. Five participants indicated that crossing the entry lane was easier than crossing the exit lane (with one of the five indicating it was not necessarily easier, but safer). Seven individuals indicated that the ease of crossing was about the same at entry and exit, and two participants reported the exit lane crossing was easier due to less traffic. This pattern of response does not differ substantially from the pattern of responses of the pretest debriefing. Six participants indicated Maple Road was easiest to cross, five indicated Drake Road was easiest, and two reported they were the same in regard to ease of crossing. This question was not asked on the pretest debriefing.

Ten participants reported there was no difference in ease of crossing when crossing from curb to splitter island or from splitter island to curb. Two individuals did not respond to the question, one indicated that it was easier to cross from the splitter island to the curb, and one responded that it was easier to cross from the curb to splitter island.

When asked to rate their confidence in their ability to cross at this intersection on a scale of 1 – 5, with one indicating not confident at all and five indicating very confident, the median rating was 4.5, a slight

increase from the pretest median rating. When asked “would you use these crossings if they were on the most direct route home from work”, all respondents said yes. Two qualified their answers, one by saying “if I had to” and the other saying “after practice”. When asked “Overall do you think crossing with the PHB is more risky, less risky, or about the same risk as crossing at an intersection with four lanes of traffic and a traffic signal?”, eleven respondents reported the crossing was less risky, one reported it was the same degree of risk, and two said it was more risky.

Participants then were asked to agree or disagree with the following statements on a scale of 1 – 5, with one indicating strongly disagree and five indicating strongly agree. The statements are followed by the range of values and the median response (Table 14).

Table 14: Summary of Posttest PHB Debriefing Questions

Question	Range of Answers	Median Rating
If there were signals like these, I'd push the button each time I wanted to cross:	4 to 5	5
If there were signals like these, I would always wait to cross until I hear "walk sign is on"	2 to 5	5
These signals helped me know I was near a crosswalk:	1 to 5	4
These signals helped me go straight across the crosswalk:	1 to 4	3
These signals helped me know I was approaching the end of the crosswalk:	1 to 5	3

These responses indicate that, as expected, the accessible pedestrian signals would be used by participants, and that they likely aid in locating the crosswalk. The ratings also indicate that they are perceived to be less valuable as wayfinding aids during the crossing.

Finally, when asked “How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired”, some participants said "nothing," or “nothing really can be done”. Suggestions included making the signals louder to serve as beacons and aligning curb cuts with crosswalks to aid in direction-taking (the ramps were in fact aligned with the crosswalks). Other changes included educating drivers better and enforcing traffic laws.

5. Results For Maple Road and Farmington Road

The study included a two-lane entry and exit leg, and a three-lane entry and exit leg to the same roundabout, each of which will be discussed separately. The analysis summarizes participant behavior and performance, as well as driver behavior and the impact of the RRFB. .

5.1 Two-Lane Approach

Participant behavior and performance is analyzed in three categories: estimated interventions, average delay, and indicated utilization of yield events. Vehicular performance measures include driver yielding behavior and queuing impacts resulting from those yields.

5.1.1 Participant behavior and performance

5.1.1.1 Estimated Interventions

O&M Interventions are a measure of pedestrian risk that has been used in prior research done by this research team, including the Maple/Drake study. Since the protocol was modified to use indicator study, this safety measure was estimated by the O&M specialist in the field ("I would have intervened"), and was confirmed by an expert observer from video. The expert observer primarily evaluated the position of vehicles in the conflicting lanes (relative to the pedestrian) and each vehicle's time-to-collision, which is measured from the time the pedestrian indicates crossing intent to the arrival of the vehicle at the crosswalk.

Figure 24 shows the number of estimated O&M interventions for each participant in the pretest and posttest conditions. An intervention rate of zero is shown at a value of 0.1 to distinguish it from a data point for participants where no data are available for either pretest or posttest.

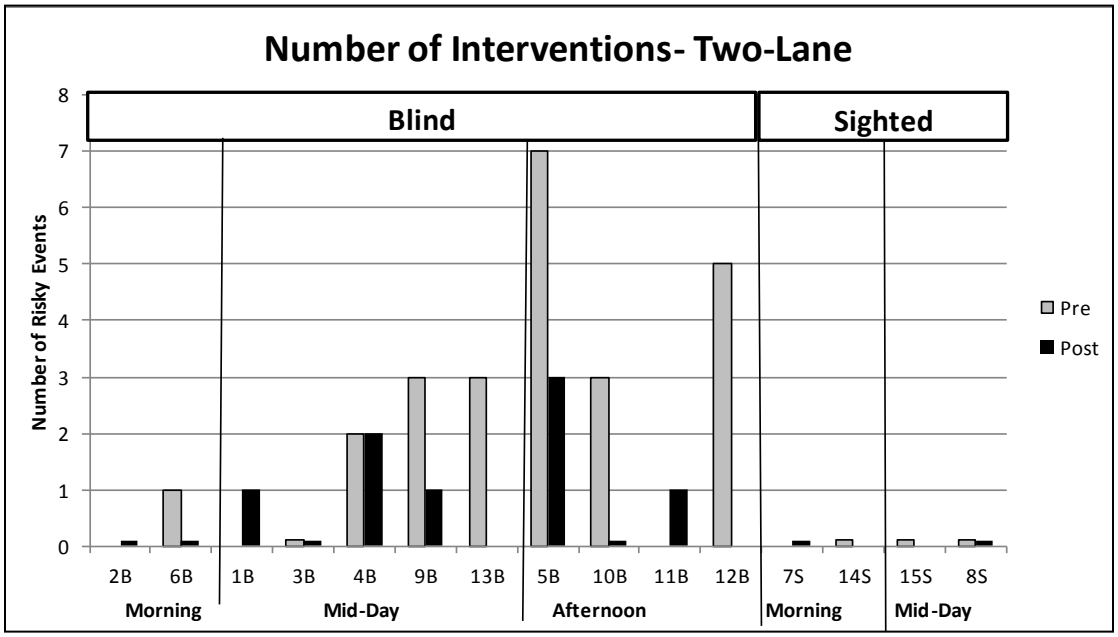


Figure 24: Number of Estimated Interventions per Subject - Pre/Post Comparison - 2-Lane Approach

The results in Figure 24 suggest a rather high rate of occurrence of estimated interventions for most blind participants in the pretest at the two-lane approaches. Not shown in the table are a significant number of other "risky" events that were identified by the research team, but that did not rise to the level of estimated interventions. With the installation of the RRFB, the estimated interventions for most participants did appear to decline somewhat. Four of the nine posttest participants experienced at least one estimated intervention, although all of the posttest estimated interventions occurred at the two-lane exit leg. No posttest estimated interventions occurred at the two-lane entry, compared to six in the pretest, which suggests a potential effect of the RRFB treatment. An overall reduction of estimated interventions was also observed for the two-lane exit from fourteen in the pretest to eight in the posttest. Table 15 below gives more detailed descriptive statistics.

Table 15: Estimated Interventions - Two-Lane Approach

Study	Subject	Exit/Entry	No. Int.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry(n=80)	6	7.5%	8.9%	0.0%	20.0%
		Exit(n=80)	14	23.8%	15.1%	0.0%	40.0%
	Sighted	Entry(n=30)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=30)	0	0.0%	0.0%	0.0%	0.0%
POST	Blind	Entry(n=75)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=75)	8	16.4%	19.2%	0.0%	60.0%
	Sighted	Entry(n=20)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=20)	0	0.0%	0.0%	0.0%	0.0%

Table 15 shows that the average rate of estimated interventions at the two-lane entry leg decreased from 7.5% to 0.0% with the installation of the RRFB (p=0.0302). For the two-lane exit, a slight reduction was evident from 23.8% to 16.4%, although this effect is not statistically significant due to the high variability of interventions across participants (p=0.3883). Even in the posttest, the highest intervention rate for a subject was 60%, which corresponds to three interventions in five trials. Note that for this particular participant the number of trials had to be reduced to five, because of very long delay times that extended the trial too late into the afternoon.

The table further illustrates that no interventions were observed for any sighted participants in either pretest or posttest.

5.1.1.2 Pedestrian Delay

One of the research hypotheses was that the installation of the RRFB treatment would decrease blind participants' crossing delay. Participant delay was defined as the time interval between the time a participant arrives at the crosswalk and the time the participant indicated they would start to cross. Figure 25 and Figure 26 show the average delay for each participant for the pretest and the posttest trials for entry and exit legs, respectively. Each bar represents the average (mean) delay of 10 indicator trials at the two-lane approach. The figure further distinguishes between participants in the morning

(9:30 start), mid-day (1:30 start), and afternoon (4:30 pm start) time slots used for the study. A pretest participant who returned for the posttest was scheduled at the same time of day.

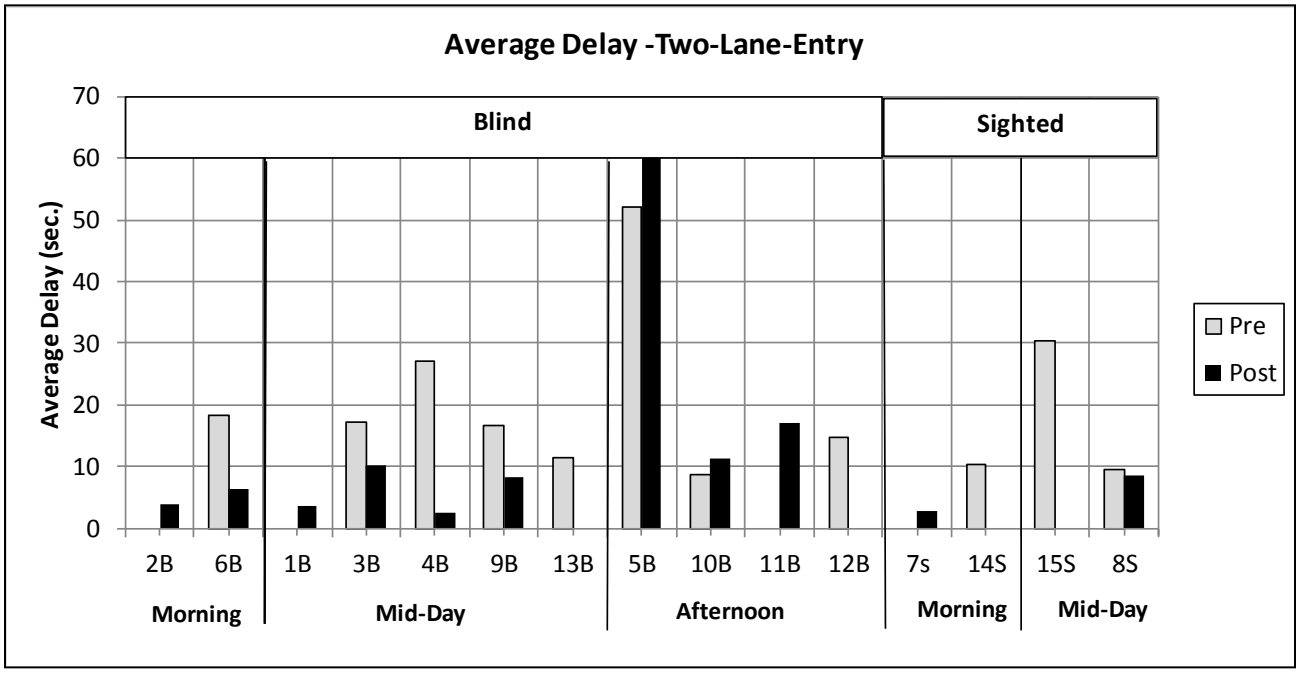


Figure 25: Average Delay per Subject- Pre/Post Comparison - Two-Lane Approach - Entry

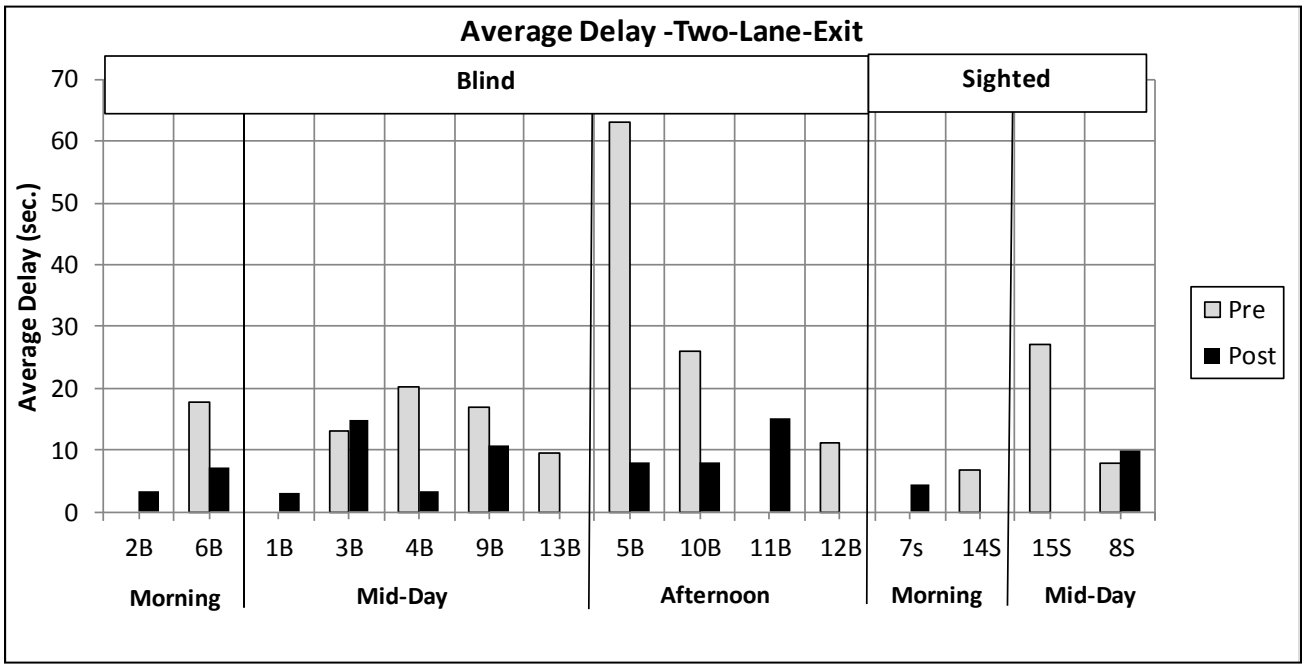


Figure 26: Average Delay per Subject- Pre/Post Comparison - Two-Lane Approach - Exit

The results in Figure 25 and Figure 26 show that several of the blind participants experienced a decrease in delay with the installation of the RRFB. The highest delay was observed for participant 5B in both pretest and posttest with average delay time above 50 seconds to cross the entry leg. Interestingly, delay for that participant at the exit appeared to drop after installation of the RRFB. However, it should

be noted that the same participant had also shown the highest intervention rate of all participants, suggesting overly aggressive crossing indications. Table 16 presents the descriptive statistics for average delay for the two-lane approach.

Table 16: Average Estimated Pedestrian Delay - Two-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	80	20.8	20.2	1.2	97.1
		Exit	80	22.2	20.8	1.2	93.1
	Sighted	Entry	30	15.9	27.6	1.4	114.1
		Exit	30	13.9	16.8	1.1	83.1
POST	Blind	Entry	75	17.1	19.0	0.9	95.3
		Exit	75	18.8	18.5	1.4	79.5
	Sighted	Entry	20	5.7	5.7	0.9	21.4
		Exit	21	7.3	5.6	1.5	18.9

The average delay per blind participant in the pretest was 20.8 and 22.2 seconds, respectively for entry and exit leg. That delay was reduced to 17.1 and 18.8 seconds; which is not a statistically significant reduction (p values equal 0.2417 and 0.2770, respectively). The standard deviations of the delay estimates are high, and the maximum delay for a trial by a blind participant was over 90 seconds for both pretest and posttest. For sighted participants, the delay reduction was from 15.9 to 5.7 seconds at the entry (p=0.0588), and 13.9 to 7.3 seconds at the exit leg (p=0.0530). However, it should be emphasized that only one of the sighted participants returned for the posttest, supplemented by a new participant. The results for sighted participants should therefore be treated with caution, even if they generally suggest a positive impact of the RRFB.

5.1.1.3 Pedestrian Yield Utilization

One of the documented challenges for blind travelers is the utilization of yield events. Prior research has documented that many blind pedestrians may miss or reject yield opportunities, because they either fail to detect them, or because they are uncomfortable crossing in front of presumably stopped cars. The measure of yield utilization defines the percentage of yield events that was associated with a crossing decision. Results are shown in Table 17.

Table 17: Yield Utilization - Two-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	63	39.5%	42.3%	0.0%	100.0%
		Exit	13	38.5%	50.6%	0.0%	100.0%
	Sighted	Entry	20	68.1%	45.9%	0.0%	100.0%
		Exit	5	40.0%	54.8%	0.0%	100.0%
POST	Blind	Entry	55	79.8%	34.8%	0.0%	100.0%
		Exit	32	75.2%	40.6%	0.0%	100.0%
	Sighted	Entry	11	90.9%	30.2%	0.0%	100.0%
		Exit	2	100.0%	0.0%	0.0%	100.0%

The yield utilization results in Table 17 show generally low yield utilization rates for blind participants at the two-lane approaches of around 39% for both entry and exit leg. With the installation of the RRFB, the yield utilization increased significantly to 79.8% and 75.2% for entry and exit, respectively ($p<0.0001$ and $p=0.0311$, respectively). This speaks to a positive impact of the RRFB, where blind participants were more readily able or willing to indicate they would utilize yields. Interestingly, yield utilization also increased for sighted participants at the entry (68.1% to 90.9%, $p=0.1066$) and the exit (40.0% to 100.0%, $p=0.0704$), but at a lower level of significance. The generally higher yield utilization rates for sighted participants support the notion that blind participants were still reluctant to (or were challenged to) utilize yield crossing opportunities as compared with sighted individuals. With posttest yield utilization rates at or close to 100% for sighted participants, the RRFB seems to have given most sighted participants added confidence in indicating they would cross in front of stopped or yielding cars.

5.1.2 Driver Behavior and vehicle Impacts

5.1.2.1 Driver Yielding Behavior

The evaluation of driver yielding behavior is a critical performance measure for the RRFB, a treatment that is principally intended to improve visibility of the crosswalk and the waiting pedestrian. Prior research of the RRFB has consequently shown dramatic increases in driver yielding behavior at midblock crossings. In this analysis, the driver yielding rate was calculated by dividing the number of yielding vehicles (across all lanes), by the total number of vehicles crossing the plane of the crosswalk while the participant was positioned at the curb during a trial. As stated earlier, drivers did not know that the participants in this study weren't going to cross, making the yield observations a valid measure of effectiveness. Because the same protocol was used at the entry and, exit legs, and in the pretest and posttest conditions, reasonable comparisons can also be drawn between the various scenarios. Table 18 presents the detailed yield results.

Table 18: Driver Yielding Propensity - Two-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	76	57.2%	38.0%	0.0%	100.0%
		Exit	64	9.5%	23.9%	0.0%	100.0%
	Sighted	Entry	22	61.8%	42.9%	0.0%	100.0%
		Exit	20	11.5%	25.4%	0.0%	100.0%
POST	Blind	Entry	57	82.7%	32.4%	0.0%	100.0%
		Exit	49	49.5%	44.1%	0.0%	100.0%
	Sighted	Entry	11	71.2%	28.0%	33.3%	100.0%
		Exit	9	22.2%	44.1%	0.0%	100.0%

Table 18 shows a pretest yield rate for blind participants of 57.2% at the entry leg, which was statistically significantly increased to 82.7% with the installation of the RRFB ($p=0.0001$). An increase was also evident at the exit leg, where yielding increased from only 9.5% in the pretest to 49.5% in the posttest ($p<0.0001$). Similar increases were observed for sighted participants, although low sample sizes preclude statistically significant results.

These results further show that yielding was generally higher at the entry leg than at the exit leg, which is consistent with the literature on driver yielding behavior at roundabouts. The fact that both entry and exit leg yielding rates were improved with the RRFB show promise for this treatment at two-lane roundabout entry and exit legs.

5.1.2.2 Vehicle Queuing Impacts

As the final performance measure, the analysis evaluated vehicle queuing impacts in pretest and posttest. Since the RRFB is not associated with the red signal indication of the PHB at Maple/Drake, all pedestrian-induced queues are associated with vehicles yielding to pedestrians. It should be noted however, that queue lengths likely would have increased somewhat had the pedestrians stepped out into the roadway. It should further be emphasized that some of the entry queuing was associated with generally long approach queues waiting to enter the roundabout, and were thus not necessarily fully attributable to the pedestrian. Results of maximum queue length measurements are given in Table 19 for the two-lane approach.

Table 19: Vehicle Queuing Across all Lanes - Two-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	80	3.1	5.2	0.0	25.0
		Exit	80	0.1	0.5	0.0	3.0
	Sighted	Entry	30	0.7	0.9	0.0	4.0
		Exit	30	0.1	0.4	0.0	2.0
POST	Blind	Entry	75	3.4	6.0	0.0	27.0
		Exit	75	1.4	3.5	0	25.0
	Sighted	Entry	20	0.9	1.1	0.0	3.0
		Exit	21	0.2	0.6	0.0	2.0

The average maximum queue lengths in Table 19 are generally quite short, with the longest queues appearing at the entry leg at approximately 3.1 and 3.4 vehicles in pretest and posttest, respectively. The generally shorter queues for sighted participants may be associated with quicker decision-making once a yield has taken place. The maximum queue lengths of 25 or more vehicles at the entry leg were largely attributed to peak hour periods and likely would have been similar without the presence of the pedestrians.

The average maximum queue lengths at the exit leg were much shorter at an average length of less than 1 vehicle. Even the highest observed exit queues were only in the range of 3 to 4 vehicles (across two lanes), suggesting a low occurrence of spillback into the circulating lane.

5.2 Three-Lane Approach

Similar to the two-lane crossings on Farmington Road, participant behavior and performance is analyzed in three categories: estimated interventions, average delay, and indicated utilization of yield events. Vehicular performance measures include driver yielding behavior and queuing impacts resulting from those yields.

5.2.1 Participant Behavior and Performance

5.2.1.1 Estimated Interventions

Estimated interventions correspond to events where the O&M specialist indicated that he or she would have intervened had the pedestrian actually stepped into the roadway. Consistent with the two-lane data, these estimated interventions were confirmed from an independent video-based analysis of an expert observer. Figure 27 shows the resulting frequency of estimated interventions for each participant in the pretest and posttest conditions. An intervention rate of zero is shown at a value of 0.1 to distinguish it from a data point for participants where no data are available for either pretest or posttest.

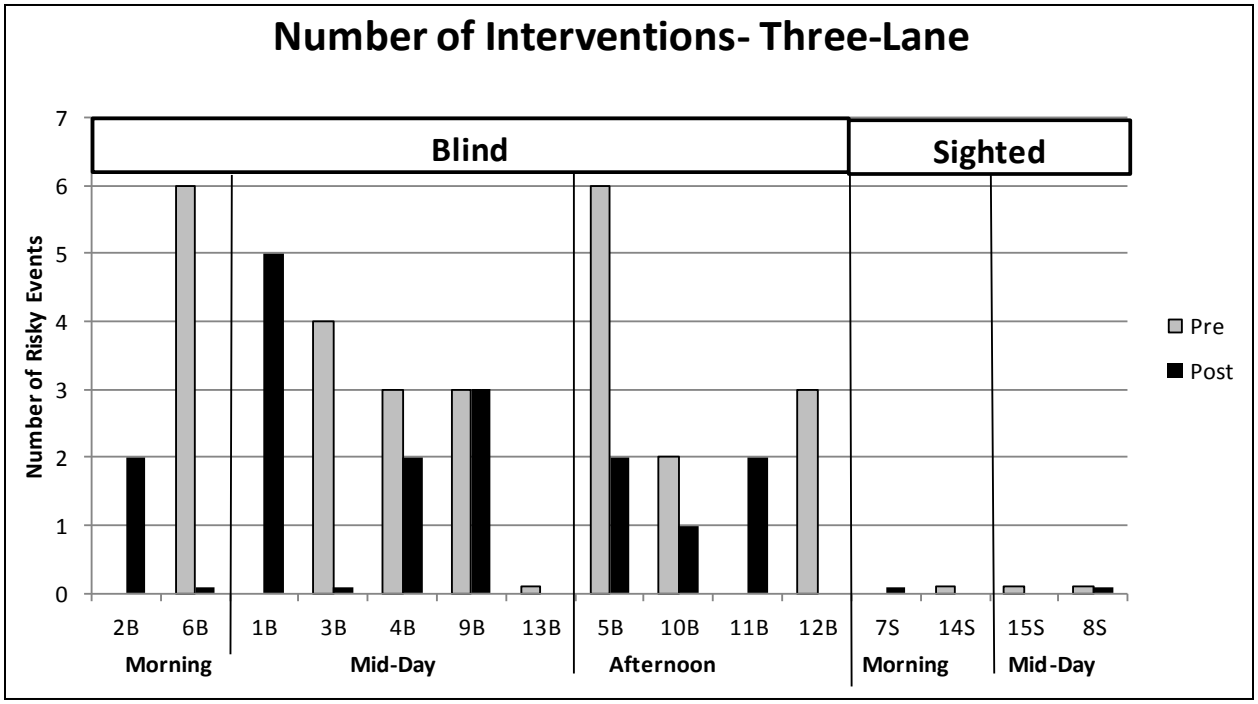


Figure 27: Number of estimated Interventions per Subject - Pre/Post Comparison - 3-Lane Approach

The results in Figure 27 show a high occurrence of estimated interventions at the three-lane crossings. A total of six participants experienced three or more estimated interventions in the pretest condition. In fact, only one of the blind pretest participants (13B) experienced zero interventions. These data confirm the high level of risk at these three-lane crossings. In the posttest condition, the RRFB did not result in a consistent reduction of interventions, with six out of nine blind participants experiencing two or more of these events. None of the sighted participants experienced any estimated interventions. The high intervention rates for blind participants are confirmed by the results in Table 20 below.

Table 20: Estimated Interventions (%)- Three-Lane Approach

Study	Subject	Exit/Entry	No. Int.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry(n=79)	8	12.5%	15.5%	0.0%	36.4%
		Exit(n=80)	19	23.2%	21.3%	0.0%	60.0%
	Sighted	Entry(n=30)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=30)	0	0.0%	0.0%	0.0%	0.0%
POST	Blind	Entry(n=77)	5	7.6%	8.3%	0.0%	20.0%
		Exit(n=75)	12	18.9%	13.6%	0.0%	40.0%
	Sighted	Entry(n=21)	0	0.0%	0.0%	0.0%	0.0%
		Exit(n=20)	0	0.0%	0.0%	0.0%	0.0%

Table 20 shows very high intervention rates in the pretest for blind participants of 12.5% and 23.2% at entry and exit, respectively. These intervention rates are the highest ever observed by this research

team, and in fact are higher than the 11.4% intervention rate observed at the Maple/Drake roundabout. Especially the three-lane exit leg raises significant safety concerns in the pretest condition.

With the installation of the RRFB, a slight reduction of estimated interventions was observed. At the entry, the rate decreased from 12.5% to 7.6%, but this reduction is not statistically significant (p=0.4393). Similarly, the decrease in exit leg interventions from 23.2% to 18.9% was not statistically significant (p=0.63227) due to high standard deviations. Consequently, even after the installation of the RRFB a high level of risk remained at the three-lane crossings, especially at the exit leg. No interventions were observed for sighted participants in either pretest or posttest.

5.2.1.2 Pedestrian Delay

The analysis next explored the impact of the RRFB on delay. Participant delay was defined as the time interval between the time a participant arrives at the crosswalk and the time the participant indicated they would start to cross. Figure 28and Figure 29 show the average delay for each participant for the pretest and the posttest trials for entry and exit legs, respectively. Each bar represents the average (mean) delay of 10 indicator trials at the two-lane approach. The figure further distinguishes between participants in the morning (9:30 start), mid-day (1:30 start), and afternoon (4:30 pm start) time slots used for the study. A pretest participant who returned for the posttest was scheduled at the same time of day.

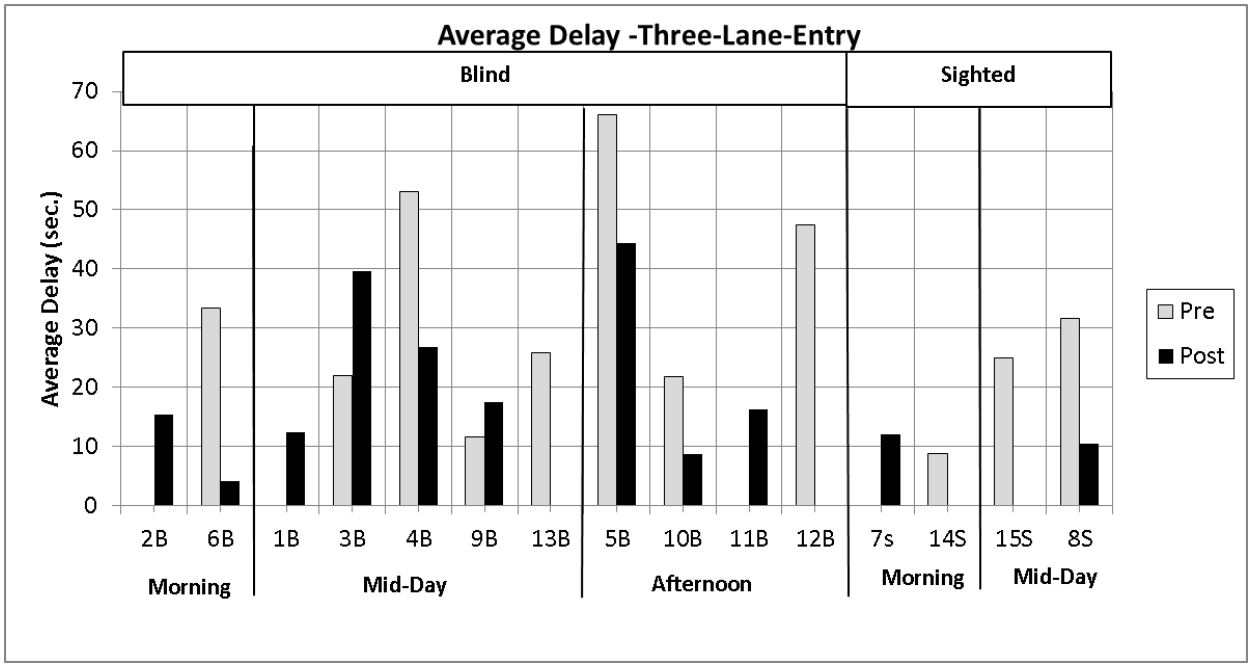


Figure 28: Average Pedestrian Delay - Three-Lane Approach – Entry

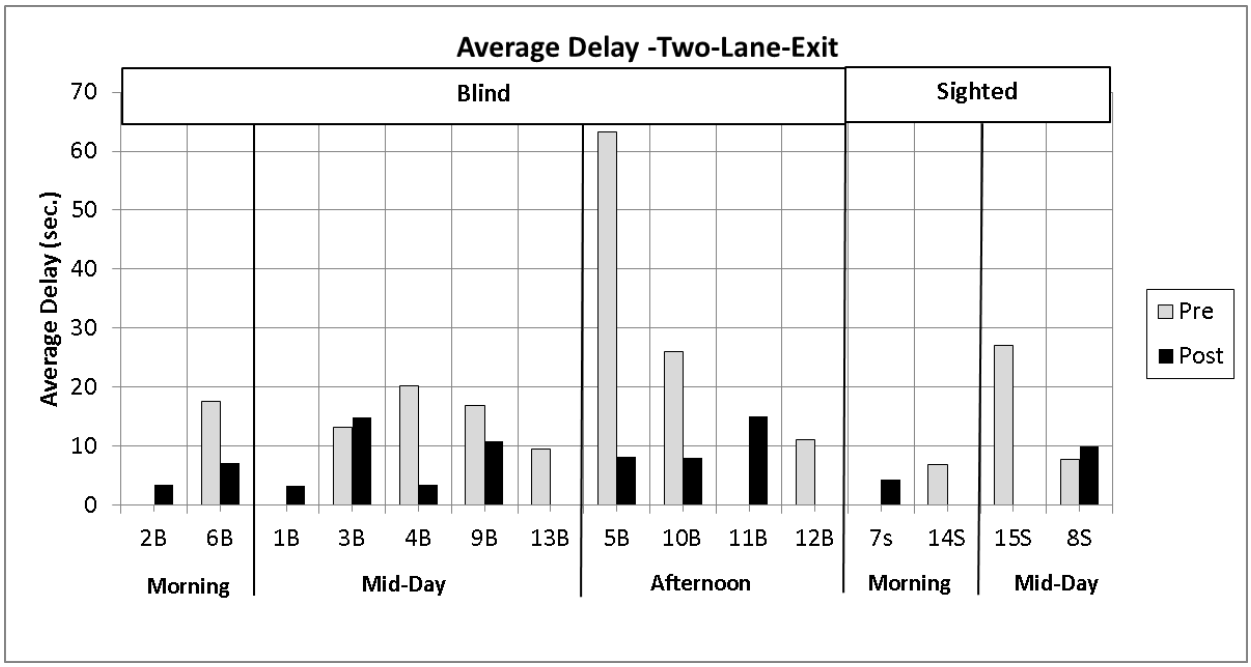


Figure 29: Average Pedestrian Delay - Three-Lane Approach – Exit

The delay results interestingly point to higher delays at the entry leg (Figure 29) with several participants experiencing average delay times of 30 seconds or more. With the exception of one participant (5B) all exit leg delay averages are below 30 seconds per crossing (Figure 28). However, in light of the intervention results discussed previously, these delay figures should be viewed with great care, since these delay estimates for the most part are not associated with safe crossing decisions. The installation of the RRFB did not show a consistent impact on delay. For sighted participants, the average delay times for two participants at the entry were above 20 seconds, pointing to some difficulty even for that pedestrian group to find crossing opportunities at these three-lane crossings. Detailed delay statistics for both groups are shown in Table 21.

Table 21: Average Pedestrian Delay - Three-Lane Approach

Approach	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	79	35.2	30.9	2.5	129.1
		Exit	80	30.5	28.4	1.4	119.3
	Sighted	Entry	30	21.8	28.5	1.2	145.3
		Exit	30	23.5	20.2	2.2	81.4
POST	Blind	Entry	77	19.8	16.5	1.6	77.8
		Exit	75	24.8	21.4	1.0	115.6
	Sighted	Entry	21	11.2	8.8	1.2	37.6
		Exit	20	16.2	18.4	1.8	77.5

Table 21 shows average pretest delays for blind participants of 35.2 and 30.5 seconds at entry and exit, respectively. The total average delay for the entire crossing therefore is well above 60 seconds, which would be considered LOS F in the Highway Capacity Manual for unsignalized pedestrian crossings. For sighted participants, the entry and exit delays in the pretest were 21.8 and 23.5 seconds, respectively. Combined, the total delay for entry and exit leg is therefore also above the 45 second HCM threshold for LOS F in the pretest. It should be emphasized here that the HCM describes a pedestrian LOS F as a crossing with a "high likelihood of risk taking" on the part of the pedestrians.

With the installation of the RRFB, the entry leg delay for blind participants significantly decreased to 19.8 seconds (p=0.0002) and the exit delay to 24.8, though the latter is not significant (p=0.1624). The decrease in delay for sighted pedestrians was to 11.2 and 16.2 seconds at entry and exit, respectively. Statistical testing is not reported because only four sighted participants participated. The RRFB appeared to be associated with decreases in delay for both pedestrian populations. While noteworthy, the results for blind participants need to be interpreted cautiously in light of the high risk that remained in the posttest.

5.2.1.3 Pedestrian Yield Utilization

The measure of yield utilization describes what percentage of yield events was associated with a crossing decision. Results are shown in Table 22.

Table 22: Yield Utilization - Three-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	67	44.9%	41.2%	0.0%	100.0%
		Exit	7	42.9%	53.5%	0.0%	100.0%
	Sighted	Entry	21	57.2%	47.5%	0.0%	100.0%
		Exit	1	66.7%	n/a	66.7%	66.7%
POST	Blind	Entry	69	76.3%	35.0%	0.0%	100.0%
		Exit	37	69.2%	39.1%	0.0%	100.0%
	Sighted	Entry	13	75.0%	48.4%	0.0%	100.0%
		Exit	7	71.4%	40.5%	0.0%	100.0%

The yield utilization rates for blind participants in the pretest condition were about 40-45% for both entry and exit legs. The installation of the RRFB resulted in an increase in yield utilization at the entry leg from 44.9% to 76.3% (p<0.0001). At the exit leg, the increase from 42.9% to 69.2% was not statistically significant (p=0.2544), but nonetheless suggests some improvements. The yield utilization for sighted participants appeared to increase slightly for the entry leg from 57.2% to 75.0%. Changes for the exit lane from pretest to posttest for the sighted participants were low.

5.2.2 Driver Behavior and vehicle impacts

5.2.2.1 Driver Yielding Behavior

The measure of driver yielding behavior evaluates drivers' propensity to yield for the participants waiting at the crosswalk. The driver yielding rate was calculated by dividing the number of yielding vehicles (across all lanes), by the total number of vehicles crossing the plane of the crosswalk while the participant was positioned at the curb. Since the drivers did not know that the participants in this study weren't going to cross, the yield results represent a valid measure of effectiveness. Table 23 presents the detailed yield results for the three-lane crossings.

Table 23: Driver Yielding - Three-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	77	36.5%	32.1%	0.0%	100.0%
		Exit	68	3.0%	14.5%	0.0%	100.0%
	Sighted	Entry	26	34.5%	32.6%	0.0%	100.0%
		Exit	27	3.7%	19.2%	0.0%	100.0%
POST	Blind	Entry	73	73.1%	30.8%	0.0%	100.0%
		Exit	64	26.9%	33.0%	0.0%	100.0%
	Sighted	Entry	18	46.6%	38.5%	0.0%	100.0%
		Exit	17	15.7%	28.3%	0.0%	100.0%

The pretest results in Table 23 point to a low rate of yielding at the entry leg of around 35%. At the exit leg, virtually no vehicles yielded for either blind of sighted participants, at yield rates around 3-4%. The installation of the RRFB resulted in significant increases for yielding to blind participants. At the entry, the yield rate increased from 36.5% to 73.1% ($p<0.0001$), and at the exit the yield rate increased from 3.0% to 26.9% ($p<0.0001$). Increases in yielding were also observed for sighted participants, but again low sample sizes for that population did permit statistical significance testing on these results.

The increase in yielding certainly shows promise for the RRFB treatment, especially at the three-lane entry leg. The results suggest that drivers were responsive to the flashing beacon device and modified their yielding behavior accordingly. The yield rate of 73.1% at the entry leg is lower than was found in previous research on the RRFB at mid-block crossings, but it still represents a notable improvement. The yielding rate at the exit leg, however, remains a concern. Only approximately one in three drivers yielded to participants despite the RRFB device being activated. Also, a single yielding driver does not necessarily result in a safe crossing opportunity. In fact, a near-lane yielding vehicle is oftentimes associated with a *multiple-threat* situation, where a non-yielding vehicle in the far lane(s) is blocked from the sight (and hearing) of the waiting pedestrian. Supported by the high rate of intervention events at the three-lane exit leg, it is concluded that despite a significant improvement, the 26.9% exit leg yield rate with the RRFB is not sufficiently adequate.

5.2.2.2 Vehicle Queuing Impacts

The final performance measures for the three-lane approaches are the maximum vehicle queue lengths observed due to the presence of the study participants. Similar to the two-lane approach, the entry-leg queue lengths should be considered with care, since cars frequently backed up waiting to enter the roundabout during peak times. Results are given in Table 24.

Table 24: Vehicle Queuing Across all Lanes - Three-Lane Approach

Study	Subject	Exit/Entry	n.	Avg.	Std. Dev.	Min	Max
PRE	Blind	Entry	80	4.3	5.4	0.0	26.0
		Exit	80	0.1	0.4	0.0	3.0
	Sighted	Entry	30	2.1	2.7	0.0	9.0
		Exit	30	0.1	0.4	0.0	2.0
POST	Blind	Entry	77	6.4	5.8	0.0	28.0
		Exit	76	1.6	2.2	0.0	9.0
	Sighted	Entry	21	2.1	2.4	0.0	9.0
		Exit	20	0.7	1.6	0.0	7.0

The average back of queue at the entry for blind participants was measured at 4.3 vehicles, with a maximum queue length of 26 vehicles (attributable to general entry-leg congestion). The average queue length of sighted participants was about half that of blind participants, which is explained by faster decisions on the part of the pedestrian and therefore shorter wait times for drivers. Exit-leg queue lengths were generally much shorter and on average only 0.1 vehicles long. These results are expected given the extremely low yield rates observed at the exit leg in the pretest.

With installation of the RRFB, some increases in queue lengths were observed for blind participants at entry (4.3 to 6.4 vehicles) and exit (0.1 to 1.6 vehicles). Some isolated queues were observed up to 9 vehicles across three lanes at the exit, which resulted in spillback into the circulating lane. However, for most trials, the short queues were contained within the available storage at the exit leg.

6. VEHICLE SAFETY ANALYSIS

6.1 Background

A safety analysis of the two intersections, Maple at Drake and Maple at Farmington, was conducted to analyze the installation of the PHB and RRFB, as well as the implementation of various geometric changes conducted in parallel to the treatments. The analysis time period distinguishes a "before" period, defines as the time from which the intersections were initially converted from signals to roundabouts, and an "after" period, defined as the time from the installation of the PHB and RRFB treatments until the time of this study. Table 25 shows the specific dates of these events.

Table 25: Alteration Implementation Dates

Alteration	Maple/Drake	Maple/Farmington
Conversion from Signalized Intersection to Roundabout	April 16th, 2008	October 27th, 2008
Additions of PHB and RRFB along with Miscellaneous Geometric Improvements	July 14th, 2009	July 10th, 2010

6.2 Data Collection

Collisions were categorized based on numerous criteria for analysis, including the type of collision and the location that each collision occurred. Collisions *types* analyzed included Rear-end, Sideswipe, and Angle. Rear-end collisions should reflect how well the PHB and RRFB serve their purpose of making drivers more aware of the upcoming roundabout and crosswalk giving them ample time to slow down, if needed. Sideswipe and angle collisions both reflect the various geometric improvements at the intersections, as well as any erratic maneuvers that may have taken place during a pedestrian crossing. Outlier collisions, such as those that involved loss of control due to weather or that occurred far upstream or downstream, were omitted.

Collisions were also categorized based on the *location* where they occurred. First, collisions were noted by which approach they occurred on, or if they happened within the intersection. Collisions were then categorized based on the destination of the vehicle that caused the incident. These destinations were categorized as: Entering, Exiting, or Circulating. Collisions were categorized as *entering* if the vehicle that caused the collision did so while attempting to enter or approach the intersection, whereas collisions categorized as *exiting* were due to the vehicle attempting to exit the intersection. Collisions were categorized as *circulating* if they occurred within the roundabout and neither vehicle was attempting to enter or exit. Typically, circulating collisions were due to a vehicle crossing the center-line and merging into another vehicle's lane.

6.3 Comparison Group Analysis Method

The comparison group method was initially chosen for our analysis, which involves comparing the collisions at our two treatment sites to that of pre-selected comparison sites *(*Hauer 1997*)*. The team wanted to ensure that a change in collisions at the treatment site was due to the treatment installations

and not just due to an overall (increasing or decreasing) trend caused by events such as seasonal weather or historical patterns such as decreased traffic in the system due to unforeseen events.

Intersections within close proximity and with comparable traffic patterns were provided by the Road Commission for Oakland County staff. More important than traffic patterns, the nearby intersections had similar driver populations and weather patterns, all which are assumed to happen at a similar rate to treatment intersections. The provided comparison sites were then reviewed internally to find the best possible candidates for our comparison group using an odds ratio test.

Proximity to our comparison sites was more important than the actual geometry of the intersection, as the team was more interested in developing an understanding of the trend in traffic throughout the entire area. The team began by identifying a number of candidates for comparison sites and initially narrowed the group to five total intersections; four signalized intersections and one roundabout in the area. The only other roundabout in the area at 14-Mile at Farmington, had to be omitted as a candidate for the comparison group due to an extended construction period that would have impacted much of the collision data in the before period. The four remaining comparison sites were then analyzed further to see if they were credible comparisons.

The collision frequencies before and after treatment installation are provided below in Table 26 and Table 27. For the purpose of these two tables, the category "comparison sites" include the sum of the collisions at each of the four remaining intersections. Separate tables for Maple/Drake and Maple/Farmington are needed due to the treatment sites having different before and after periods. The collision frequencies below correspond to the total occurrence of collisions over the analysis period after removing outlier events such as run-off road collisions and crashes occurring far away from the roundabout

Table 26: Total Collision Frequencies for Maple/Drake

Group	Before Period (Total)	After Period (Total)
Maple/Drake	84	88
Comparison Sites	149	179

Table 27: Total Collision Frequencies for Maple/Farmington

Group	Before Period (Total)	After Period (Total)
Maple/Farmington	87	32
Comparison Sites	209	85

As noted earlier, the before and after periods for the two intersections differed and can be misleading when looking at total collisions over those periods. Yearly collision rates are a better representation of

the trend in traffic throughout the time of analysis. To calculate this, total collisions were first converted to annual rates. These numbers can be seen below in Table 28 and Table 29.

Table 28: Yearly Collision Rates for Maple/Drake

Group	Before Period (Annualized)	After Period (Annualized)
Maple/Drake	66.4	50.3
Comparison Sites	120.8	102.3

Table 29:Total Collision Rates for Maple/Farmington

Group	Before Period (Annualized)	After Period (Annualized)
Maple/Farmington	49.7	42.7
Comparison Sites	119.4	113.3

The yearly values allow for a better comparison in trends, but do not ultimately determine whether a comparison group is able to be used for analysis. Nor do the rates provide any true basis for comparison between before and after periods. Instead, they provide some indication of what might be happening at each site (or group). For the first data set in Table 28, Maple and Drake experienced a reduction of 24%, whereas the comparison sites experienced a reduction of only 15% in yearly collisions. For the second data set, Maple and Farmington experienced a reduction in 14%, whereas the comparison sites experienced a reduction of only 5% in yearly collisions. Although the actual number of collision that were reduced per year is very similar for both sets of data, the percentage of reduction for the treatment sites is larger than the comparison sites due to the smaller sample sizes.

The FHWA Roundabout Informational Guide (second edition) provides intersection-level safety performance models for roundabouts as a function of the number of approaches and the number of circulating lanes. With a daily traffic volume of approximately 42,000 vehicles per day, a four-legged roundabout with three circulating lanes is expected to result (on average) in 36.6 total intersection crashes per year. For two circulating lanes, the estimated crash rate is 11.0 total intersection crashes per year. The observed rates at the subject roundabouts are therefore higher than the annual estimated averages, with higher crash rates evident at Maple/Drake. However, due to the relatively short reporting period, these numbers should be treated with care, especially since the crash rates described here could not be corrected for regression to the mean.

6.4 Odds Ratio Calculation

In attempt to further harvest information from the available crash data, the team conducted an odds ratio test to ensure that the comparison sites are indeed good comparisons and that the data we are using to compare trends in traffic is valid. An odds ratio was calculated using only the before periods

from treatment and comparison sites. Typically, the odds ratio is based on a before period of three or more years, where each year of data leading up to the installation of the treatment is used to calculate an odds ratio. These individual odds ratios are then averaged and a standard deviation is provided. An odds ratio close to 1, with a reasonable standard deviation, would provide sufficient evidence that the comparison group was sufficient for the analysis.

However, the small before period noted earlier was a serious limitation in this analysis. In lieu of using yearly data sets to calculate odds ratio, two alternative binning methods were used, monthly and seasonal, where seasonal provides four individual bins in a given year (January-March, April-June, etc.). An example of the calculation of the seasonal odds ratio – *m(o)*, where "*o*" is the individual odd's ratio calculation and *m(o)* is the average of these observations – for Maple Road and Drake Road (treatment site) and 14 Mile at Drake Road (comparison site) is provided below in Table 30.

Table 30: Seasonal Odds Ratio Sample Calculation

Month	Year	Maple/Drake	Comparison	Total Maple/Drake	Total Comparison	o	m(o)
April	2008	1	0				
May	2008	8	1				
June	2008	4	0	13	1		
July	2008	5	0				
Aug	2008	5	1				
Sep	2008	2	1	12	2	2.000	
Oct	2008	9	1				
Nov	2008	6	0				
Dec	2008	9	1	24	2	0.490	
Jan	2009	4	1				
Feb	2009	9	1				
Mar	2009	7	0	20	2	1.171	
April	2009	5	1				
May	2009	5	0				
June	2009	5	0	15	1	0.645	1.08

The table shows that the comparison site of 14-Mile at Drake Road produces a very satisfactory odds ratio; however, the sample size is very small (causing a high standard deviation) for the comparison site and may cause the value to be misleading. The resulting values from the remaining odds ratio calculations along with the standard deviation are provided below in Table 31 and Table 32. Values were produced comparing each of the treatment sites to each respective comparison site, as well as to the entire comparison group.

Table 31: Odds Ratio and Standard Deviations for Maple/Drake Time Period

Intersection	Seasonal Odds Ratio (Std Dev)	Monthly Odds Ratio (Std Dev)
14 Mile/Drake	1.08 (0.681)	0.51 (0.770)
Maple/Haggerty	1.31 (0.933)	1.12 (0.789)
Maple/Middlebelt	1.51 (1.386)	1.26 (1.127)
Maple/Orchard Lake	1.54 (1.583)	1.57 (1.135)
All Comparison Sites	1.33 (.882)	1.23 (0.770)

Table 32: Odds Ratio and Standard Deviations for Maple/Farmington Time Period

Intersection	Seasonal Odds Ratio (Std Dev)	Monthly Odds Ratio (Std Dev)
14 Mile/Drake	1.49 (1.032)	0.71 (0.790)
Maple/Haggerty	1.22 (0.578)	1.72 (2.729)
Maple/Middlebelt	1.63 (1.564)	0.81 (0.664)
Maple/Orchard Lake	1.01 (0.374)	1.54 (2.093)
All Comparison Sites	1.10 (0.500)	1.62 (2.400)

As noted earlier, typically yearly bins are used when calculating odds ratios; however, the sample size of our data sets were relatively low due to the alterations to the treatment sites from standard signalized intersections to roundabouts occurring so close to the treatment installation. This left only 15 months of data for Maple/Drake and 21 months of data for Maple/Farmington. The small sample sizes are the root of the large standard deviations in our odds ratio calculations in both the monthly and seasonal categories. The intersection of 14-Mile and Drake was also omitted during this analysis method due to a very low sample size, which was most likely due to the fact that the AADT of the intersection was severely lower than any of the others. Referring back to the discussion regarding Table 26, Table 27, Table 28, and Table 29 the trends of each respective treatment site differ a great deal when compared to the comparison sites. Below are charts that depict the trend line that best fits the collisions occurring during the before period for the intersection of Maple and Farmington (Figure 30 and Figure 31).

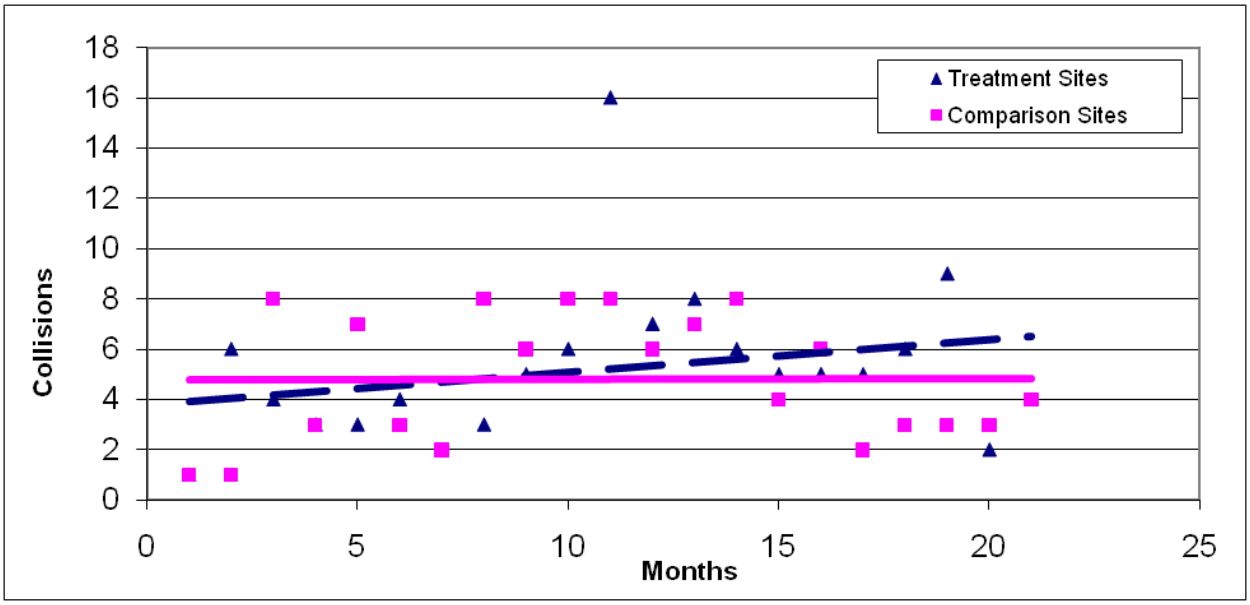


Figure 30: Before Data Trend for Maple/Farmington and Maple/Orchard Lake

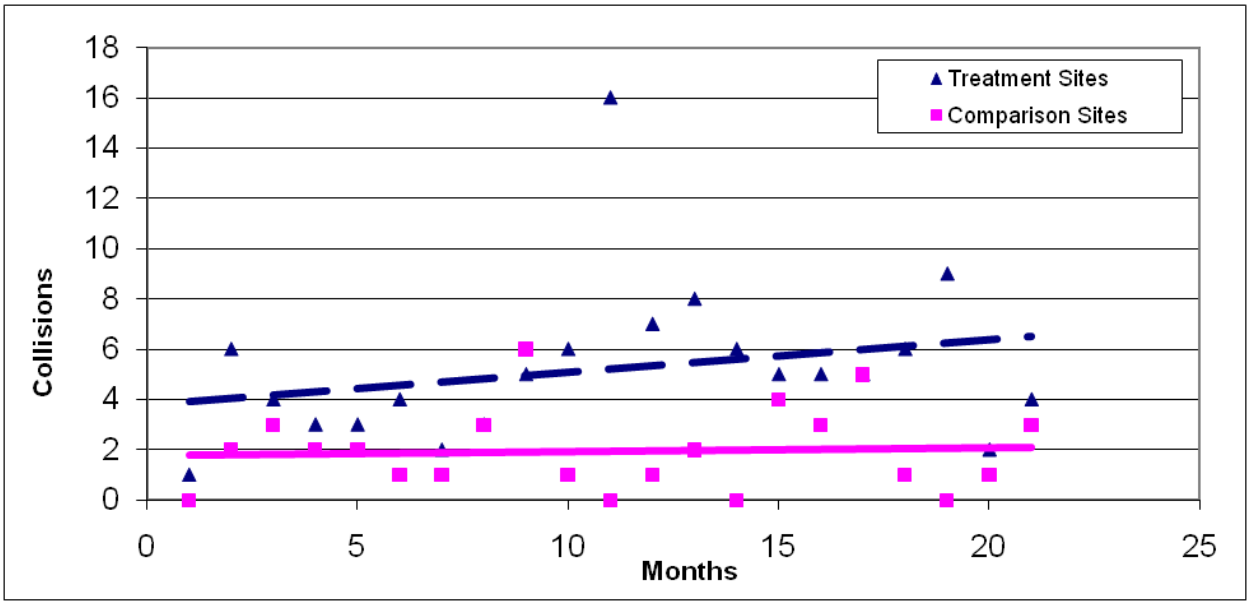


Figure 31: Before Data Trend for Maple/Farmington and Maple/Middlebelt

The charts show that the treatment site tends to increase at a steady rate, while the comparison sites remain relatively flat. The likely reason for this difference in trends is the geometric improvements that were noted as problematic prior to the treatment installation. Recall that the county took the opportunity to make secondary geometric improvements while the PHB and RRFB were installed. Based on the lack of proof that the sites act in a similar manner, these charts along with the high odds ratio and standard deviations suggest that the comparison sites are not useful for analysis. The team therefore decided that the *causal factor analysis methodology* was best suited for this particular set of data. This method, although more problematic, is described in the following section.

6.5 Causal Factor Analysis Method

Unlike the comparison group methodology, this study method is unable to account for seasonality and historical effects by using a comparison group. Instead, this study method only accounts for time duration and traffic flow. Ratios are calculated for both time and traffic from the before to after period. For instance, if traffic flow increased by 10% from the before to after period, we would assume that the likelihood of a collision would also increase by 10%, or a ratio (multiplier) of 1.1 would be used. One similar problem still exist; however, because similar to the other methods the causal factor analysis is unable to distinguish the difference that the secondary geometric changes likely had on the treatment sites.

As mentioned previously, ratios for time duration (r_d) and traffic flow (r_{tf}) were used to calculate an expected number of collisions for the after period. Traffic flow was compensated for by obtaining AADT's for each of the treatment sites before and after the implementation of each treatment, whereas time duration was done through a ratio of the before and after period durations. The AADT's used to calculate r_{tf} are provided in the table below. The values provided are not the entire AADT for the intersection, but are calculated by summing the largest of the minor and major approaches. The before period AADT's for Maple/Drake are from 2008 and 2009 for Maple/Farmington, whereas the after period AADT's for both sites are from 2011.

Table 33: Average Annual Daily Traffic (AADT) of Treatment Sites for Subject Approaches

Intersection	Before	After
Maple/Drake	19060	20813
Maple/Farmington	18820	19410

The ratio of these AADT's was the basis for the r_{tf} calculation. Maple/Drake produced an r_{tf} of 1.09, whereas Maple/Farmington produced an r_{tf} of 1.03.

The calculation used for r_d was done in a similar manner using the ratio of the before and after months. Using the time periods mentioned in Table 25: Alteration Implementation Dates, the r_d calculated for Maple at Drake produced a value of 1.4 and Maple at Farmington produced a value of 0.43. These calculated values, along with the provided before collisions allow us to calculate the expected number of after collisions (π), where

$$\pi = B_o * r_d * r_{tf}$$

and B_0 is the total collisions in the before period for the treatment site being analyzed.

The expected collisions (π) are compared to actual values observed in the after period (λ) to determine the net change. The values for π can be found in the Table 34. The net change (θ) for each treatment

is calculated as the difference between the expected collisions (π) an observed collisions (λ) in the after period, expressed as a percent change.

Table 34: Expected Collisions for Treatment Sites

Intersection	Before Collisions	r_{tf}	r_d	π	λ	θ (% Change)
Maple/Drake	84	1.09	1.40	128	88	-31%
Maple/Farmington	87	1.03	0.43	39	32	-18%

From the table it is evident that the *expected* collisions (π) is greater than the *actual* after collisions in the after period (λ) for both of the intersections. Overall, using the causal factor methodology, the team estimates a reduction of 31% at Maple and Drake and 18% at Maple and Farmington due to the installation of the PHB and RRFB, respectively, along with geometric improvements made during that same time period.

As noted earlier, collisions were categorized by collision type and intersection location to determine the underlying trend for treatment sites for each of the types of collisions. A more descriptive representation of these observed and expected collision by type are provided in Table 35. These values were calculated using the same method mentioned above.

Table 35: Expected Collisions for All Collision Types at Treatment Sites

Intersection	Collision Type	Location	π	λ	θ (%
Maple/Drake	Rear-End	Entering	32	12	-63%
		Exiting	9	2	-78%
		Circulating	5	0	-100%
	Sideswipe	Entering	6	12	100%
		Exiting	28	27	-3%
		Circulating	28	23	-18%
	Angle	Entering	8	9	13%
		Exiting	9	2	-78%
		Circulating	3	1	-67%
Maple/Farmington	Rear-End	Entering	8	6	-25%
		Exiting	1	1	0%
		Circulating	2	1	-50%
	Sideswipe	Entering	7	5	-29%
		Exiting	8	8	0%
		Circulating	7	4	-43%
	Angle	Entering	4	2	-50%
		Exiting	2	3	50%
		Circulating	1	2	100%

From the table it is evident that, in general, there were reductions in all rear-end collisions for the two treatment sites. Some collision types experience an increase in collisions; however, this is most likely due to the small sample size issue as the categories with larger sample sizes all experienced a downward trend. Visual representation of this analysis in appropriate charts is provided below in Figure 32 and Figure 33. From the charts you will see that the underlying trend for both sites is the reduction in rear-end collisions, likely due to the treatment installation of the PHB and RRFB and associated geometric improvements.

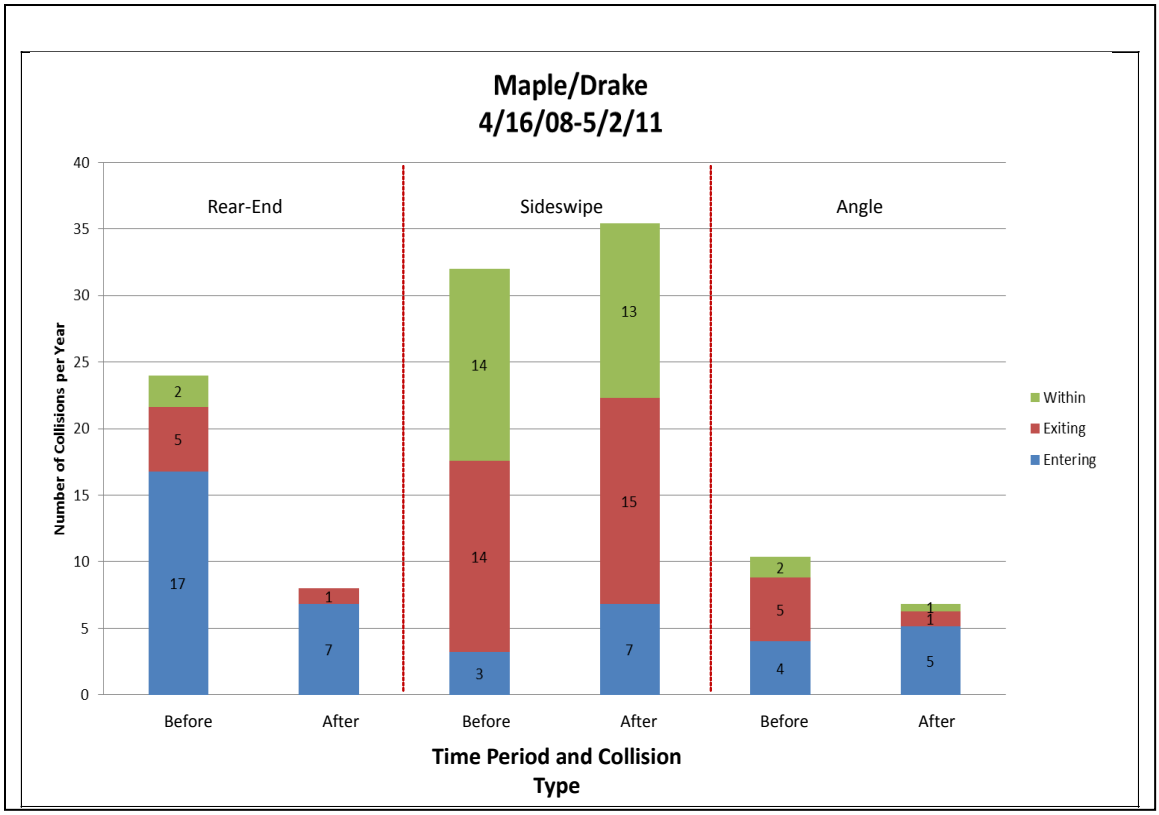


Figure 32: Collisions at maple/Drake by Type

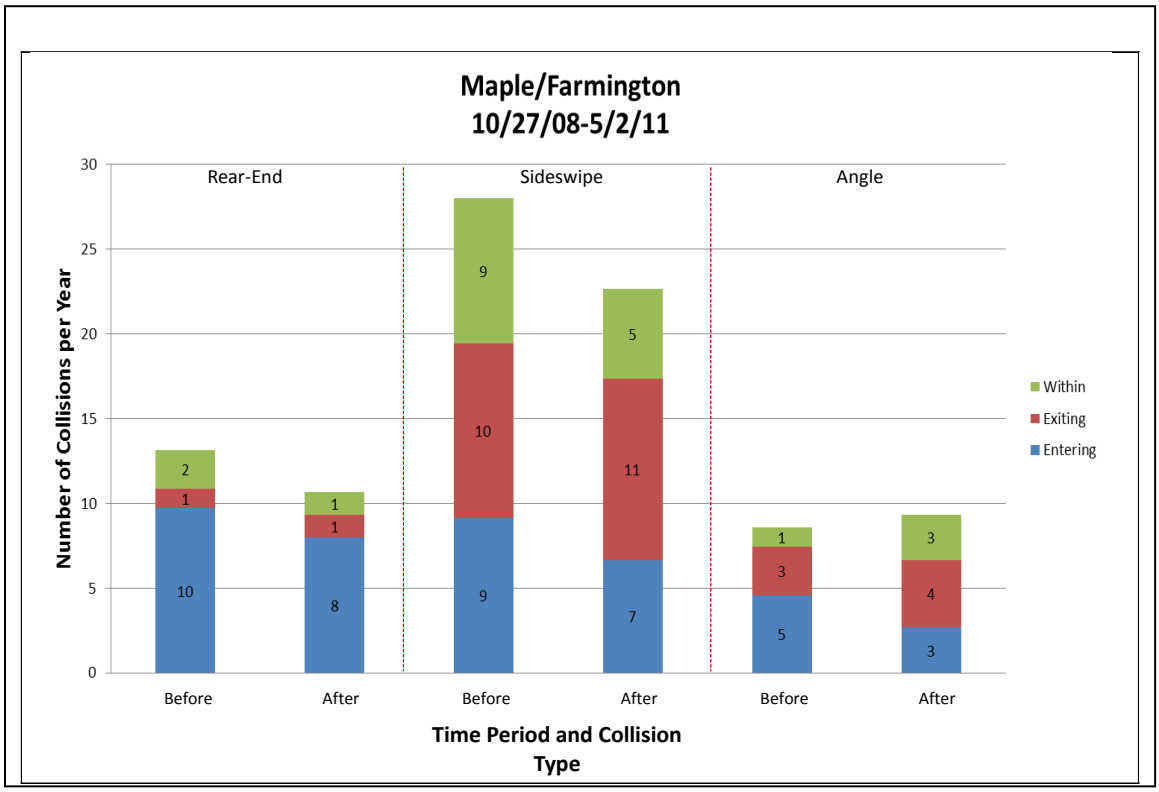


Figure 33: Collisions by Maple/Farmington by Type

7. REFERENCES

Ashmead, Dan, David Guth, Robert Wall, Richard Long, & Paul Ponchillia (2005). Street crossing by sighted and blind pedestrians at a modern roundabout. *ASCE Journal of Transportation Engineering,* Vol. 131, No. 11., November 1, 2005, 812-821

Fitzpatrick, Kay et. Al. (2006), National Cooperative Highway Research Program (NCHRP) Report 562, *Improving Pedestrian Safety at Unsignalized Crossings*, Texas Transportation Institute. College Station, Texas
Guth, David, Dan Ashmead, Richard Long, Robert Wall, & Paul Ponchillia, (2005). Blind and sighted pedestrians' judgments of gaps in traffic at roundabouts. *Human Factors, 47*, 314-331.

Hauer, Ezra. Observations Before/After Studies in Road Safety. Estimating the Effect of Highway traffic Engineering Measures on Road Safety. 20 Jun 1997.

ITE (1994) *ITE Manual of Transportation Studies.* Institute of Transportation Engineers. Washington, D.C., 1994

Long, R.G., Guth, D.A., Ashmead, D. H., Wall, R.S., & Ponchillia, P.E. (2005). Modern Roundabouts: Access by Pedestrians Who Are Blind. Journal of Visual Impairment and Blindness, 99, 611-621.

NIH (2010), National Institutes of Health (NIH)/National Eye Institute (NEI) Bioengineering Research Partnership Grant R01 EY12894-03 (ongoing). Principal Investigator: Dr. Richard Long. Western Michigan University.

Schroeder, Bastian, Nagui Rouphail and Robert Wall Emerson (2006), *Exploratory Analysis of Crossing Difficulties for Blind and Sighed Pedestrians at Channelized Turn Lanes*. Journal of the Transportation Research Board, No. 1956. October 2006

Schroeder, Bastian, Nagui Rouphail, and Ronald Hughes, (in press). *A Working Concept of Accessibility - Performance Measures for the Usability of Crosswalks for Pedestrians with Vision Impairments*. Transportation Research Record: Journal of the Transportation Research Board. Washington, D.C. in press

Shurbutt J. and R. Van Houten, *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks,* Report No. FHWA-HRT-10-043, Federal Highway Administration, Washington, DC. 2010

TRB (2000) Highway Capacity Manual. Transportation Research Board. Washington, D.C. 2000.

TRB (2010), National Cooperative Highway Research Program (NCHRP) Project 3-78 (ongoing). Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Institute of Transportation Research and Education. Raleigh, North Carolina

US Access Board (2006), *Revised Draft Guidelines for Accessible Public Rights-of-Way*. http://www.access-board.gov/prowac/draft.htm. Accessed July 8, 2008

8. APPENDIX A: PHOTO LOG OF OAKLAND COUNTY ROUNDABOUTS

Maple Road at Drake Road Roundabout

and

Maple Road at Farmington Road Roundabout

CONTENTS:

1. Maple @ Drake – Before Case
2. Maple @ Drake – After PHB Installation
3. Maple @ Farmington – Before Case
4. Maple @ Farmington – After RRFB Installation

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September 22, 2011

8.1 **Maple @ Drake Roundabout – Before Case**

Figure 34. View of Three-Lane Entry and Exit legs Maple Rd. Maple at Drake Roundabout, Before Installation of PHB

Figure 35. Close-up View of Three-Lane Pedestrian Crossing at Maple Rd. Maple at Drake Roundabout Before Case

Figure 36: View of Maple Rd. Exit at Maple at drake Roundabout Before Case

Figure 37: View of Two-Lane Entry Drake Rd. at Maple at Drake Roundabout, Before Case

8.2 Maple @ Drake Roundabout – After PHB Installation

Figure 38: View of Three-Lane Entry and Exit Legs at Maple Rd. at Maple at Drake Roundabout. After PHB Installation and Crosswalk Relocation (Zigzag) at Exit Leg

Figure 39: View of Crosswalk Relocation (Zigzag) and Splitter Island (Median) for Pedestrian Crossing at Maple at Drake Roundabout After PHB Installation

Figure 40: View of Maple Rd Three-Lane Exit at Maple at Drake Roundabout, After PHB Installation

Figure 41: View of Three-Lane Entry at Maple Rd. with Two-Stage Pedestrian Crossing, Maple at Drake Roundabout After PHB Installation

Figure 42: View of PHB (Audible) Accessible Pedestrian Pushbutton at Maple at Drake Roundabout, After PHB Installation

Figure 43: Close-up View of PHB at Maple at Drake Roundabout

8.3 Maple @ Farmington Roundabout – Before Case

Figure 44: View of Farmington Rd. Two-Lane Entry and Three-Lane Exit Legs at Maple at Farmington Roundabout

Figure 45: View of Three-Lane Entry Maple Rd. at Maple at Farmington Roundabout, Before Case

Figure 46: View of Three-Lane Exit Maple Rd. at Maple at Farmington Roundabout, Before Case

Figure 47: View of Three-Lane Circulating Lanes and Three-Lane Exit leg Maple Rd. at Maple at Farmington Roundabout, Before Case

Figure 48: View of Three-Lane Exit Maple Rd. at Maple at Farmington Roundabout, Before Case

Figure 49: View of Three-Lane Entry Maple Rd. at Maple at Farmington Roundabout, Before Case

Figure 50: View of Two-Lane Entry Leg Farmington Rd. at Maple at Farmington Roundabout, Before Case

Figure 51: View of Three-Lane Entry and Tow-Lane Exit Farmington Rd. at Maple at Farmington Roundabout, Before Case

8.4 Maple @ Farmington Roundabout – After RRFB Installation

Figure 52: View of Tow-Lane Entry Farmington Rd. at Maple at Farmington Roundabout, After RRFB Installation

Figure 53: View of Three-Lane Exit Maple Rd. at Maple at Farmington Roundabout, After RRFB Installation

Figure 54: View of RRFB Flashing at Exit Leg Maple Rd. at Maple at Farmington Roundabout

Figure 55: Close-up View of RRFB installed at Entry leg of Maple Rd. at Maple at Farmington Roundabout

9. APPENDIX: PARTICIPANT FAMILIARIZATION PROTOCOL

9.1 Maple and Drake - Pretest

Roundabouts - Pedestrians with Vision Disabilities
Protocol for human factors testing at triple lane rbt – Maple and Drake Oakland County, MI
June and September 2009

Paperwork

Review consent, pay them, get signature on consent and receipt

Familiarization

Start along Drake on NW corner, facing rbt, back before crosswalk

Listen to cars on left approaching along road parallel to path - perp street is ahead;

Make sure they hear a couple of cars go by in front of us (going around rbt) before approaching closer

Note the cars coming up parallel street and how some just keep moving and some stop then go, or just slow before moving on

Map

Show them tactile map, and layout of streets and roundabout, (not really mentioning crosswalks at first, but focusing on traffic behavior).

Trace the movement of cars on map on Maple and Drake, going straight, then right, then left. Be sure to explain the center island, the circulatory roadway, the splitter islands and the entry and exit lanes. - mention number of lanes

Be sure to tell them that vehicles can only travel in one direction on the circulatory roadway.

At "corner" near vehicle yield line

Have them walk up to the corner, close to where the corner would be at a signalized intersection.

Listen to vehicles there, and go over the map again if desired, listening to the traffic there. Talk about the curving of the vehicles going around rbt and then straightening out as they continue down the road.

Discuss lanes of traffic, etc. (in terms of traffic movement).

Don't start talking about crossing yet and deflect their questions by saying we'll get to that as we get ready to cross.

Be sure to cover:

- *Yield on entry rule*
- *Lack of a requirement for vehicles to stop if there are no cars in the circulatory roadway (no signals or stop signs)*

Listen to vehicle movement. When person can describe and show the route vehicles have taken, have them walk on up, trailing along the edge of sidewalk or walking SG to find the crosswalk across Maple on west side.

Standing back a little so cars don't stop, listen again to traffic and discuss what cars may do as they approach a crosswalk where a pedestrian is waiting to cross, using the map as needed. Cover:

- *the legal requirement for vehicles to yield to pedestrians in the crosswalk*
- *fact that many vehicles don't*
- *If at multi, will be crossing two or three lanes here, so sound of one car stopping might cover up sound of another approaching and vice versa (cars also block views of other drivers potentially)*
- *Remind them that they are crossing to the splitter island and that they are crossing only traffic coming from the left.*
- *Describe as an exit lane. Remind that cars don't have to stop there for other vehicles.*

Walk across together guided (just say "let's cross now", either in gap or when both lane have yielded.) Note crossing distance – indicate lane as you hit them….

Have them explore splitter island, width in both direction s (direction walking and side to side), edges, curbs, etc.

Get ready to cross the entry lane from the splitter island - guided.

Review vehicle movement and make sure they understand it.

Talk about yield and that yield signs are past the crosswalk, closer to the rbt. Use map if nec.

THEN MOVE AROUND TO DRAKE SOUTHWEST CORNER

Have participant tell me when they'd cross, but don't cross yet. Do several, talk about vehicle behavior as it happens, ie cars just keep moving, cars yield for a couple of seconds, one car yields and others fly by, etc. Then cross together, like last time guided.

Remind them that the task in this experiment is **only** to decide when to cross, that they will be guided to the crosswalk, and basically aligned to cross, and will be corrected if they are veering during the crossing.

GO TO MAPLE SOUTHEAST CORNER

Discuss crossing and practice at each crosswalk, listening to traffic, etc. exit as you would in actual trial, then entry as well.

END OF FAMILIARIZATION UNLESS MORE REVIEW IS NEEDED - DO HALF TRIAL TO GET SET UP FOR STARTING POINT - REGARDLESS OF WHERE IT IS

Before each crossing, tell them which lane of the RAB they will be crossing, and which direction traffic will come from, whether they are crossing to the island or curb. For example:

"You are crossing the entry lane

"You are crossing from the curb to the splitter island

"Traffic will be coming from your left – from your left"

"Cross whenever you're ready."

Always be downstream when final request to cross is given

Explain to them that I'll tell them that info because we'll just be going back and forth and it's kinda hard to keep track of…Obviously would be different if they were crossing this crossing as part of a trip home, etc.

- In providing instructions, remind that I'm telling them when the trial begins, not that it is a safe time to begin crossing. And that after I say "cross whenever you're ready", they should decide when to cross.
- If they don't get a chance to cross, within two minutes, the timer will go off and the trial will be over. Be sure they understand that it's perfectly ok if they don't feel comfortable crossing; that's OK - a time out is OK…

Approach crossing and start trials…

REMEMBER: My position is on the side opposite the direction from which traffic is coming for the crossing.

9.2 Maple and Drake - Posttest

Roundabouts - Pedestrians with Vision Disabilities
Protocol for human factors testing at triple lane rbt – Maple and Drake Oakland County, MI Post – Sept 2009

Paperwork

Review consent, pay them, get signature on consent

Familiarization

Start along Drake on NW corner, facing rbt, North of the crosswalk

Basic Roundabout layout

Traffic movement

We'll begin by standing here for a minute and listening to cars on the street beside us. That road to your left is Drake Road. The roundabout and Maple Road is in front of us. You can hear those cars on Drake beside you, right? You may hear some cars in front of us, on Maple, at the roundabout.

Now I'd like to show you a tactile map of this intersection, and talk with you about how the cars move. I'll hold the map so you can use both hands to explore it. Here is the roadway beside you. At a roundabout, they place a big circle of concrete and grass in the middle of the intersection, called the central island. Here's the central island on the map *[show P the circle and the circulatory roadway]*. Cars have to go around that central island on this road, called the circulatory roadway. So cars approaching the intersection traveling along Drake Road (the road beside you) toward the intersection can go right, straight ahead, or left, but they have to go around the center island on the circulatory roadway. Cars can only go one way on that road around the circle.

[Show them tactile map, and layout of streets and roundabout. FOCUS ON TRAFFIC BEHAVIOR, skip crosswalks; if they ask, say we'll talk about that in a minute. Trace and talk about the path of right turning, straight and left turning cars on the map. Make

sure they hear a couple of cars go by beside and in front of you (going around rbt) before approaching closer.

[Move up to a location near the YIELD SIGN, still standing parallel to Drake]

[NEAR THE YIELD SIGN, STILL STANDING PARALLEL TO DRAKE]

We've moved up to where the corner would be, if this were a typical intersection. Let's just listen to a few cars here and maybe you could show me on the map where the cars are coming from and going. *[Assist them to trace some cars on the map; discuss their paths.]* ..ie… You hear that car going by you now and then off to our right; ..he came from Maple going straight, hear how he moved toward us then curved away as he went around the circle….

Talk about traffic movement/yielding

Now as you hear that car coming up from behind us, notice that he just slowed, then went on, *[or stopped, and waited, then moved again]*. Cars have to yield to traffic in the circle, which means they may stop if there are cars coming, and may just keep moving if there are no cars in the circle. *[listen to a few going by and discuss paths]* Cars do not have to stop if there are no cars in the circle so you'll hear some just speed up as they enter and others come to a full stop.

[Don't start talking about crossing yet and deflect their questions by saying we'll get to that as we get ready to cross. If they hear or have heard the APS locator tone and ask about it, tell them we will talk about it later.]

When person can describe and show the route vehicles have taken, ***have them walk on up, trailing along the edge of sidewalk or walking SG to find the crosswalk across Maple on west side.***

AT CROSSWALK ACROSS MAPLE (NW CORNER FACING MAPLE), BACK FROM CROSSWALK A LITTLE

Let's step back a little from the crosswalk so we can just listen to the traffic and talk a minute. ***[show them the ditch forming there and make sure they don't step back into it]*** You may hear the beeping locator tone on the Accessible Pedestrian Signal here, but we'll talk more about that after this crossing. We're at an exit lane crossing here; the cars are coming out of the roundabout. Remember that they have to yield on entry, as we talked about a minute ago, but as they're exiting the roundabout, they don't have to stop. They're supposed to stop for pedestrians in the crosswalk, but many don't. Here you have three lanes of traffic exiting and three lanes entering the roundabout. Let's just listen a minute. *[Discuss path of cars if person needs it]* When you're crossing, because it's three lanes, you might hear a car stop for you in one lane, but the car in the next lane may not stop, and may not even be able to see you crossing. And the sound of the car that has stopped may keep you from hearing the one approaching in the next lane.

For roundabout crossings, there's what's called a splitter island halfway across the street. You're not supposed to cross all six lanes at once, but just cross the three exit lanes, then stop on the splitter and wait and then cross the three entry lanes. It's what's called a two-stage crossing. They've made some changes to the splitter islands since our earlier research so I want to show you have they're set up. You now have what's sometimes called a 'zigzag crossing' on this island. Let me show you that on this map. *[Show the crosswalk and the zigzag of the splitter]* So let's cross the exit lanes to the splitter island to give you an idea of the crossing. All the traffic for this crossing will be coming from your left.

Walk across together guided after pushing button (and wait for the walk signal) Note crossing distance – indicate each lane as you hit them….

ON THE SPLITTER ISLAND of MAPLE, west crosswalk

Let me show you a little more about the zigzag on this island. You feel the bumpy surface of the detectable warnings under your feet? That's located at the crosswalk, right at the street/island edge. But you don't go straight across for the crossing of the

rest of the street. If you step forward, you'll feel a low curb in front of you. The entry lanes are just beyond that curb; don't step over it. It means you need to turn left here and trail along it until you find an opening to continue your crossing, then turn back to your right to face the street. *[have them do that and explore otherwise if they seem to need to]*

Here you're crossing the entry lanes from the splitter; all traffic is coming from your right for this crossing. Again you have three lanes of traffic; I'll let you know as we cross each lane. ***Walk across together guided after a button push (and wait for the walk signal) Note crossing distance – indicate each lane as you hit them***

THEN WALK AROUND TO the DRAKE crossing (SOUTHWEST CORNER)

AT DRAKE crossing (SOUTHWEST CORNER)

This is the place to introduce the APS and signal. Have them stand near the pushbutton, without pushing the button.

As you know from Amy and the consent form, they've added signals for the pedestrian crossings here. There's also an accessible pedestrian signal or APS installed here. This type of APS may be different from ones you've used before. First, it has what's called a pushbutton locator tone. That's the tone you hear now; it repeats once per second at a fairly quiet volume. It's intended to let you know there's a pushbutton here and to help you find the pushbutton. *[you may want to comment on the fact that it's not very easy to hear in some locations here; call it a problem with adjustment, etc]*

When a pedestrian pushes this pushbutton, the vehicles will have a red light shortly afterward. When the vehicles have a red light, the WALK sign will be on for pedestrians, and you will hear a rapid ticking sound from this pushbutton, not the slow beep you hear now. All the sounds come from the pushbutton, not from overhead speakers like you may have seen in the past. There's also an arrow on the pushbutton, to help you know which way the crosswalk is. That arrow also vibrates when the Walk sign is on. Here, let me show you the button, just don't press it yet so we'll have more time to look at it. Feel the raised arrow here? It's pointing toward the crosswalk that

it's for. *[show them the arrow more, if they don't seem familiar with arrows; many people don't seem to know which end is which]*

Let's just cross now together.

[Push button and cross exit lanes.]

[As the walk indication sounds, say] That's the rapid tick walk sound; that means the vehicles have a red light, but check your traffic too because people do run red lights.

[Go to the next crossing of the entry lanes and say] Let's just cross the entry lanes here*. [push the button and cross with the signal]*

WALK AROUND TOWARD MAPLE AND STOP ABOUT HALFWAY BETWEEN DRAKE AND MAPLE CROSSING.

ABOUT HALFWAY BETWEEN DRAKE AND MAPLE CROSSINGS

Let me tell you a bit more about the signals they've installed here. This is a new type traffic signal, called a HAWK Pedestrian Beacon. It similar to a regular signal in that it activates a red light for traffic, in order to allow pedestrians to cross. It's different in that the signal is dark (not lit) for traffic unless a pedestrian presses the pedestrian pushbutton. When the pedestrian presses the button, the signal starts flashing yellow for drivers, then changes to a solid yellow signal. After a few seconds, the yellow changes to red. When the red signal comes on for drivers, pedestrians have the visual and auditory walk signal. You've heard the APS sound when we crossed the last couple of times. When you press the button, the pedestrian signal begins working too, so there's a don't walk signal until the WALK comes on. Legally, pedestrians are not supposed to begin crossing except during the walk signal.

After a few seconds, the signal for drivers will switch to from red to flashing red for drivers. That means that drivers are supposed to stop, then go, if it is safe to do so. There may still be pedestrians completing their crossing when drivers see signal turn from solid red to flashing red. If there are pedestrians in the crosswalk, drivers are supposed to wait for them.

However, we have seen some vehicles run the red light, or stop and then go on, even when there's a pedestrian there, so you should not assume that everything's clear and all the cars have stopped just because you hear the walk indication. You should use your typical skills in crossing. You can cross today when you hear the rapid tick that means the walk sign is on, or you may cross at any other time after I say "Cross when you are ready".

When we are crossing today, we'll approach the crossing point, with me guiding you. As we approach the crossing point, I'll tell you whether we are crossing an entry lane or an exit lane, and which way the cars are coming from, and whether we're crossing from the curb to the island or island to the curb. When we get to the crossing point, I'll ask you to drop my arm, and then I'll reach over and push the button for the signal. I'll then say "cross whenever you're ready". You may cross at any time after you hear me say that on each trial.

I will always push the button for you. We just need to do that for our procedure to be consistent. If you miss a chance to cross….maybe a car runs the light, or you just can't hear too well….. and want me to push the button again, just ask me to push it again.

We'll tell you the same information each time because we're just going back and forth and it can get a little confusing. Obviously, it would be different if you were crossing this crossing as part of a trip home or something.

Remember that we're telling you when the trial begins, not that it is a safe time to begin crossing. And I say "cross whenever you're ready", you should decide when to cross. After that, you can cross at any time you think it is OK to do so. I'll be right beside you for each crossing and will stop you if it's a time I consider to be too dangerous. Do you have questions??

The task in this experiment is **only** to decide when to cross, you'll be guided to the crosswalk, and basically aligned to cross, and I'll tell you "a little right" or "a little left" if you're veering during the crossing.

WALK UP TO MAPLE CROSSWALK AND DO A PRACTICE CROSSING, OF MAPLE IN EACH DIRECTION, USING PROCEDURE BELOW

CROSS FROM SE TO NE CORNER UNGUIDED WITH ALL PROCEDURES USED,, then return crossing from NE to SE with all procedures (this is the only time they in the orientation that they cross with entry traffic coming from left, and exiting traffic from right; don't leave it out]

AT each crossing, on approach, say:

For this next crossing, we're crossing the exit[entry] lane, from curb to island [island to curb], traffic will be coming from your left [right]. Step up here to the crosswalk, wait…I'm pushing the button, Cross whenever you're ready.

MOVE TO STARTING POINT FOR FIRST TRIAL

Before each crossing, tell them which lane of the RAB they will be crossing, and which direction traffic will come from, whether they are crossing to the island or curb. For example:

"You are crossing the entry lane

"You are crossing from the curb to the splitter island

"Traffic will be coming from your left – from your left"

I am pushing the button

"Cross whenever you're ready."

Always be downstream when final request to cross is given

REMEMBER: Spotter position is on the side opposite the direction from which traffic is coming for the crossing.

9.3 **Maple and Farmington - Pretest**

May 11 2010

Roundabouts: Maple and Farmington pre - INDICATOR TRIALS FAMILIARIZATION

Review consent, pay them, get signature on consent

Familiarization

Start along Farmington Road on NW corner, facing rbt, North of the crosswalk facing south)

Start with Traffic movement

We'll begin by standing here for a minute and listening to cars on the street beside us. That road to your left is Farmington Road. The roundabout and Maple Road is in front of us. You can hear those cars on Farmington beside you, correct? You may also hear some cars in front of us, on Maple, at the roundabout.

Now I'd like to show you a tactile map of this intersection, and talk with you about how the cars move. I'll hold the map so you can use both hands to explore it. Here is the roadway beside you. At a roundabout, they place a big circle of concrete and grass in the middle of the intersection, called the central island. Here's the central island on the map *[show P the circle and the circulatory roadway]*. Cars have to go around that central island on this road, called the circulatory roadway. So cars approaching the intersection traveling along Farmington Road (the road beside you) toward the intersection can go right, straight ahead, or left, but they have to go around the center island on the circulatory roadway. Cars can only go one way on that road around the circle.

[Show them tactile map, and layout of streets and roundabout. FOCUS ON TRAFFIC MOVEMENT, skip crosswalks; if they ask, say we'll talk about that in a minute. Trace and talk about the path of right turning, straight and left turning cars on the map.

Make sure they hear a couple of cars go by beside and in front of you (going around rbt) before approaching closer.

[Move up to a location near the YIELD SIGN, still standing parallel to Farmington]

[NEAR THE YIELD SIGN, STILL STANDING PARALLEL TO Farmington]

We've moved up to where the corner would be, if this were a typical intersection. Let's just listen to a few cars here and maybe you could show me on the map where the cars are coming from and going. *[Assist them to trace some cars on the map; discuss their paths.]* ..ie… You hear that car going by you now and then off to our right; ..it came along Maple and traveled through the intersection from left to right, did you hear how the car sounded like it moved slightly toward us and then curved away – that's because it had to go around the circle in the middle of the intersection….

Talk about traffic movement/yielding

Now as you hear that car coming up from behind us (on Farmington southbound), notice that it slowed, then went on, *[or stopped, and waited, then moved again]*. Cars have to yield to traffic already in the circle, which means they may stop if there are cars in the circle already, and they also may just keep moving if there are no cars in the circle. *[listen to a few going by and discuss paths]* Cars do not have to stop if there are no other cars in the circle - so you'll hear some just speed up as they enter and others come to a full stop.

[Don't start talking about crossing yet and deflect their questions by saying we'll get to that as we get ready to cross]

When person can describe and show the path vehicles have taken, ***have them walk on up, trailing along the edge of sidewalk or walking SG to find the crosswalk across Maple on west side of the intersection. You'll be on the NW corner.***

AT CROSSWALK ACROSS MAPLE (NW CORNER FACING MAPLE), BACK FROM CROSSWALK A LITTLE

Let's step back a little from the crosswalk so we can just listen to the traffic and talk a minute. We're at an exit lane crossing here; the cars are leaving the roundabout, and the cars closest to you are moving from left to right along Maple Road. Remember that they have to yield to other cars when they enter the roundabout, but not when they exit. The cars right in front of us don't have to stop as they exit. They are supposed to stop for pedestrians in the crosswalk, but many don't. There are three lanes of exiting traffic. Let's just listen a minute. *[Discuss path of cars if person needs it]* Because it's three lanes, you might hear a car stop for you in one lane, but the car in the next lane may not stop, and may not even be able to see you crossing. And the sound of the car that has stopped may keep you from hearing the one approaching in the next lane.

For roundabout crossings, there's what's called a splitter island halfway across the street. For example, at this roundabout, you don't cross all six lanes at once. Instead, you cross the three exit lanes first, then stop on the splitter island and wait, and then cross the three entry lanes. Now (GUIDED) let's cross the exit lanes of the roundabout to the splitter island to give you an idea of the width of the crossing, and so we can explore the splitter island. As we make this crossing, the nearest traffic will be coming from our left and exiting the roundabout.

Note crossing distance – indicate each of the three lanes as you hit them….

ONCE ON THE SPLITTER ISLAND of MAPLE, west crosswalk

We are standing on the splitter island in the middle of Maple Road, and protected from traffic by the splitter island. *HAVE THEM EXPLORE CURBING ON BOTH SIDES OF SPLITTER.* NOTE THAT YOU HEAR CARS MOVING BEHIND YOU FROM LEFT TO RIGHT, AND CARS MOVING IN FRONT OF YOU FROM RIGHT TO LEFT. ONE WAY TO KNOW THAT WE HAVE ARRIVED AT THE SPLITTER IS THE DETECTABLE WARNING MATERIAL (SHOW IT TO THEM).

Now we will step forward to the place we need to stand for the next crossing, from the splitter island to the curb. Here we are crossing the entry lanes of the roundabout; all

traffic is coming along Maple Road from your right to your left. These cars are entering the roundabout and they may be stopping here for us as pedestrians, or they may just be slowing and stopping to wait for a gap to enter the roundabout or because there's another car in front of them. Again you have three lanes of traffic; I'll let you know as we cross each lane. ***Walk across together guided across to curb. Note crossing distance – indicate each lane as you hit them…..***

THEN WALK AROUND TO the Farmington crossing (SOUTHWEST CORNER) - Walk sighted guide acr these lanes and tell participant that there are three legs. On splitter – tell them it is wider than the splitter on Maple. Then cross guided to curb – telling them that there are only two lanes here….

THEN GO TO THE STARTING POINT: EITHER FARMINGTON EX, FARMINGTON EN, MAPLE EN, OR MAPLE EX.

Say: We want you to be familiar with how wide the road is before we start the study. In a moment, we want you to cross the road when we ask you to do so. You will be walking independently, but we will be beside you when you cross. Once you have crossed to the splitter island, we'll turn around and cross back to start the study.

Need Chris to ready to record times before we do this. Might be best to have mike on first.

HAVE PERSON WALK ACROSS ON YOUR INSTRUCTION TO GO – MAKE SURE YOU GO WITH THEM - AND YOU MAY ALSO WANT TO SEND ANOTHER PERSON IN FRONT OF THEM.

When we begin the study in a few minutes, your task is to evaluate approaching traffic and indicate when you would begin crossing the street. You will indicate when you would begin crossing by raising your hand, like this. After you raise your hand you will turn around and you and I will walk away from the crossing point, wait a few moments, and then walk back to the crossing point and do another "judgment". We

will approximately 10 crossing judgments at each of four points at the roundabout. We'll do this once for practice.

Say "We are approaching an exit (entry) lane. The vehicles are coming from your left. You are at the curb. Tell me when you think it would be an appropriate time to cross by raising your hand. After you raise your hand, please turn around and we will walk together away from the crossing point and get ready for the next judgment". We won't actually cross the street.

DO THIS ONCE FOR PRACTICE - THEN START THE TRIALs

Do you have questions??

Before each crossing, tell them which lane of the RAB they will be judging, and which direction traffic will come from, and that they are judging from the curb. For example:

"You are judging the entry lane for X Road

"You are at the the curb "Traffic will be coming from your left – from your left"

"Start judging now – raise your arm when you think you could cross safely

Always be downstream when final request to begin judging is given

REMEMBER: Spotter position is on the side opposite the direction from which traffic is coming for the crossing.

DATA COLLECTION:

10 trials of judging at:

1) Southeast side: Curb – Farmington across entrance

2) Southeast side: Curb – Maple across exit

3) Northeast side: Curb – Maple across entry

4) Northeast side: Curb – Farmington across exit

Make sure they raise their hand enough that the camera and the observers can see it

9.4 **Maple and Farmington – Posttest**

Oct 17 2010

Roundabouts: Maple and Farmington POST - INDICATOR TRIALS FAMILIARIZATION

Review consent, pay them, get signature on consent

Familiarization

Start along Farmington Road on NW corner, facing rbt, North of the crosswalk facing south)

Start with Traffic movement

We'll begin by standing here for a minute and listening to cars on the street beside us. That road to your left is Farmington Road. The roundabout and Maple Road is in front of us. You can hear those cars on Farmington beside you, correct? You may also hear some cars in front of us, on Maple, at the roundabout.

Now I'd like to show you a tactile map of this intersection, and talk with you about how the cars move. I'll hold the map so you can use both hands to explore it. Here is the roadway beside you. At a roundabout, they place a big circle of concrete and grass in the middle of the intersection, called the central island. Here's the central island on the map *[show P the circle and the circulatory roadway]*. Cars have to go around that central island on this road, called the circulatory roadway. So cars approaching the intersection traveling along Farmington Road (the road beside you) toward the intersection can go right, straight ahead, or left, but they have to go around the center island on the circulatory roadway. Cars can only go one way on that road around the circle.

[Show them tactile map, and layout of streets and roundabout. FOCUS ON TRAFFIC MOVEMENT, skip crosswalks; if they ask, say we'll talk about that in a minute. Trace and talk about the path of right turning, straight and left turning cars on the map.

Make sure they hear a couple of cars go by beside and in front of you (going around rbt) before approaching closer.

[Move up to a location near the YIELD SIGN, still standing parallel to Farmington]

[NEAR THE YIELD SIGN, STILL STANDING PARALLEL TO Farmington]

We've moved up to where the corner would be, if this were a typical intersection. Let's just listen to a few cars here and maybe you could show me on the map where the cars are coming from and going. *[Assist them to trace some cars on the map; discuss their paths.]* ..ie… You hear that car going by you now and then off to our right; ..it came along Maple and traveled through the intersection from left to right, did you hear how the car sounded like it moved slightly toward us and then curved away – that's because it had to go around the circle in the middle of the intersection….

Talk about traffic movement/yielding

Now as you hear that car coming up from behind us (on Farmington southbound), notice that it slowed, then went on, *[or stopped, and waited, then moved again]*. Cars have to yield to traffic already in the circle, which means they may stop if there are cars in the circle already, and they also may just keep moving if there are no cars in the circle. *[listen to a few going by and discuss paths]* Cars do not have to stop if there are no other cars in the circle - so you'll hear some just speed up as they enter and others come to a full stop.

[Don't start talking about crossing yet and deflect their questions by saying we'll get to that as we get ready to cross]

When person can describe and show the path vehicles have taken, ***have them walk on up, trailing along the edge of sidewalk or walking SG to find the crosswalk across Maple on west side of the intersection. You'll be on the NW corner.***

AT CROSSWALK ACROSS MAPLE (NW CORNER FACING MAPLE), BACK FROM CROSSWALK A LITTLE

Let's step back a little from the crosswalk so we can just listen to the traffic and talk a minute.

[if they hear/mention locator tone, just tell them we'll talk about it after this crossing]

We're at an exit lane crossing here; the cars are leaving the roundabout, and the cars closest to you are moving from left to right along Maple Road. Remember that they have to yield to other cars when they enter the roundabout, but not when they exit. The cars right in front of us don't have to stop as they exit. They are supposed to stop for pedestrians in the crosswalk, but many don't. There are three lanes of exiting traffic. Let's just listen a minute. *[Discuss path of cars if person needs it]* Because it's three lanes, you might hear a car stop for you in one lane, but the car in the next lane may not stop, and may not even be able to see you crossing. And the sound of the car that has stopped may keep you from hearing the one approaching in the next lane.

For roundabout crossings, there's what's called a splitter island halfway across the street. For example, at this roundabout, you don't cross all six lanes at once. Instead, you cross the three exit lanes first, then stop on the splitter island and wait, and then cross the three entry lanes. Now (GUIDED) let's cross the exit lanes of the roundabout to the splitter island to give you an idea of the width of the crossing, and so we can explore the splitter island. As we make this crossing, the nearest traffic will be coming from our left and exiting the roundabout.

Note crossing distance – indicate each of the three lanes as you hit them….

ONCE ON THE SPLITTER ISLAND of MAPLE, west crosswalk

We are standing on the splitter island in the middle of Maple Road, and protected from traffic by the splitter island. *HAVE THEM EXPLORE CURBING ON BOTH SIDES OF SPLITTER.* NOTE THAT YOU HEAR CARS MOVING BEHIND YOU FROM LEFT TO RIGHT, AND CARS MOVING IN FRONT OF YOU FROM RIGHT TO LEFT. ONE WAY TO KNOW

THAT WE HAVE ARRIVED AT THE SPLITTER IS THE DETECTABLE WARNING MATERIAL (SHOW IT TO THEM).

Now we will step forward to the place we need to stand for the next crossing, from the splitter island to the curb. Here we are crossing the entry lanes of the roundabout; all traffic is coming along Maple Road from your right to your left. These cars are entering the roundabout and they may be stopping here for us as pedestrians, or they may just be slowing and stopping to wait for a gap to enter the roundabout or because there's another car in front of them. Again you have three lanes of traffic; I'll let you know as we cross each lane. ***Walk across together guided across to curb. Note crossing distance – indicate each lane as you hit them…..***

THEN WALK AROUND TO the Farmington crossing (SOUTHWEST CORNER) -

Talk about flashers here

Since you were here last, they've installed pedestrian warning flashers. In the sign by the crosswalk, there are some yellow lights that begin flashing as soon as a pedestrian pushes the pushbutton there. These yellow lights flash in a fast alternating pattern meant to attract the attention of the drivers. There's a pushbutton locator tone at the pushbutton to help you find the pushbutton. When the button is pushed, the lights start flashing immediately and an audible message repeats "the yellow lights are flashing" as long as the lights flash. Cars may or may not stop, or yield.

Walk sighted guide acr these lanes and tell participant that there are three legs. On splitter – tell them it is wider than the splitter on Maple. Then cross guided to curb – telling them that there are only two lanes here….

THEN GO TO THE STARTING POINT: EITHER FARMINGTON EX, FARMINGTON EN, MAPLE EN, OR MAPLE EX.

Say: We want you to be familiar with how wide the road is before we start the study. In a moment, we want you to cross the road when we ask you to do so. You will be walking independently, but we will be beside you when you cross. Once you

have crossed to the splitter island, we'll turn around and cross back to start the study.

Need Chris to ready to record times before we do this. Might be best to have mike on first.

HAVE PERSON WALK ACROSS ON YOUR INSTRUCTION TO GO – MAKE SURE YOU GO WITH THEM – say start and that the end.

When we begin the study in a few minutes, your task is to evaluate approaching traffic and indicate when you would begin crossing the street. We'll walk up to the crosswalk together. I'll push the button to activate the yellow flashers. The flashing lights and message are on for 20 seconds. If you haven't found a time to cross when they stop flashing, I'll push the button and activate the lights and message again. You will tell me when you think it would be an appropriate time to cross by raising your hand. We won't actually cross the street.

You will indicate when you would begin crossing by raising your hand. After you raise your hand, we will turn around and walk away from the crossing point, wait a few moments, and then walk back to the crossing point and do another "judgment". We will approximately 10 crossing judgments at each of four points at the roundabout. Let's do this once for practice now.

We are approaching an exit (entry) lane. The vehicles are coming from your left. You are at the curb. [push the button as you say] Raise your hand when you would cross.

Remember to wait to raise your hand until you think it is safe to cross. Don't hurry.

DO THIS ONCE FOR PRACTICE - THEN START THE TRIALs

Do you have questions??

Before each crossing, tell them which lane of the RAB they will be judging, and which direction traffic will come from, and that they are judging from the curb. For example:

"You are judging the entry lane for X Road

"You are at the the curb "Traffic will be coming from your left – from your left"

"Start judging now – raise your hand when you would cross

Always be downstream when final request to begin judging is given

REMEMBER: Spotter position is on the side opposite the direction from which traffic is coming for the crossing.

DATA COLLECTION:

10 trials of judging at:

1) Southeast side: Curb – Farmington across entrance

2) Southeast side: Curb – Maple across exit

3) Northeast side: Curb – Maple across entry

4) Northeast side: Curb – Farmington across exit

2 crossings for speed measurement done at each of crossing segments

1 practice trial at 1st segment only

Make sure they raise their hand enough that the camera and the observers can see it