Improving Pedestrian Performance and Driver Response at Unsignalized Roundabout Crosswalks

Principal Author:

Mark Lenters, P. E., P.Eng. President
Ourston Roundabout Engineering Inc.
Toronto, Canada
and Madison, WI
Phone: 608-249-4545
www.ourston.com

Co-Authors:

Nancy Button, MBA, PhD, P. Eng.
Region of Waterloo, Ontario, Canada

Tom Knostman, P.E., Loveland, Colorado

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TABLE OF CONTENTS

PAGE

TABLES

FIGURES

1.0 ABSTRACT

This paper provides a synopsis of engineering and education measures aimed at improving safety and comfort of pedestrians at roundabouts. A greater emphasis on rigorous pedestrian education is necessary to compliment improved design of crossing treatments for modern roundabouts. Road authorities have proven capability to mandate improved engineered designs for pedestrian crossing treatments, but improving pedestrian assertiveness should also be evaluated for its effectiveness in pedestrian accessibility to roundabout intersections.

The presupposition of the engineering measures is their ability to improve driver response and thereby produce safer pedestrian crossing activity. Examples of preferred design treatments for roundabout crosswalks and related design treatment of roundabout entries are documented herein. Deserving equal consideration is one of the anticipated results of the recent NCHRP 3-78A study of multilane roundabout crosswalk treatments; namely, that the more "assertive" study participants successfully "triggered" more yield events.

Two agencies: Waterloo Region, Canada and Loveland, Colorado developed pedestrian assertiveness campaigns with encouraging results. One pedestrian action, point-and-walk, is emerging as a very effective means of achieving a yield response from drivers at unsignalized roundabout pedestrian crossings. Training pedestrians to step up to the curb and point across the crosswalk to show drivers the intent to cross and continuing to point in the crosswalk is a simple, effective action that deserves more attention from agencies concerned with building roundabouts. The initial observations of these independent campaigns indicate more emphasis on training pedestrians to cross roundabouts merits equal attention with research into traffic control devices that mainly influence the driver.

2.0 BACKGROUND STUDIES AND ISSUES

2.1 A SAMPLE OF PEDESTRIAN COLLISION HISTORY

Maycock and Hall reported one third less pedestrian crashes per million trips entering roundabouts as compared to traffic signals (2). If historical trends abroad and recent local collision history is reliable, then roundabouts will become so numerous in coming years that the current problems with user acceptance and familiarity will become a faint memory.

The Region of Waterloo, Ontario experiences approximately 65 pedestrian collisions per year at its 475 traffic control signals. The average annual daily traffic (AADT) entering the 475 signalized intersections range from 3,000 to 59,000 with an average of approximately 22,000 entering vehicles per day. The AADT vehicular volumes entering their 11 roundabouts range from 6,000 to 23,000 with an average of approximately 14,000 entering vehicles per day. If the sample size of signalized intersections is limited to those with a comparable vehicular volume entering of 23,000 AADT or less, the sample is reduced to 297 signalized intersections with an average of approximately 15,600 AADT. This smaller sample exhibits approximately 30 pedestrian collisions per year (1 pedestrian collision for every 10 signals).

To date, since the first roundabout opened in 2004, the Region of Waterloo has experienced 1 pedestrian collision at its 11 roundabouts. The pedestrian was shortcutting through the central island of the roundabout rather than using the crosswalks. Only minor injuries resulted from the collision. Based on a thorough literature review and a casual survey of experiences from other agencies, this statistic is fairly representative of conditions throughout North America.

2.2 WHY ROUNDABOUTS ARE SAFER FOR PEDESTRIANS

Roundabouts are perceived by some to be less safe for pedestrians; but, compared to traffic signal crosswalks they provide an accurate reading of risk. Crossing of approaches or exits to roundabouts is a simpler process for the pedestrian because the vehicle approaches from one direction and generally in the full view of the pedestrian. When the human factors of crossing roundabouts is compared to crossing at traffic signal controlled intersections the contrast in user task load and task complexity is remarkable. The table below is prescribed by the author for agencies that are comparing the safety of roundabouts to traffic signals in the public spotlight. It compares the tasks, expectancies and conditions associated with crossing a signal controlled intersection or a roundabout using several operating criteria. These in turn affect the perceived sense of safety and the real safety afforded by each device.

Table 1 - Pedestrian Safety Considerations in Selecting Intersection Control – Comparing Traffic Signal Control to Roundabouts

Safety Criteria	Signalized Intersections	Roundabouts
Crossing Distance	Longer crossing distances with multi-lane cross-sections (both directions must be crossed at once).	Shorter crossing distance without turn lanes; one direction is crossed at a time.
Crossing Complexity	Pedestrians must look in more than one direction for oncoming left and right turns at viewing angles that require substantial neck turning.	Pedestrians look in only in one direction per leg of crossing. Speed of approaching traffic is slower, making gap judgments easier.
Number of Conflicts Per Crossing	Seven possible conflicts per 5 lane cross-section including additional conflicts per lane.	One conflict per traveled lane per direction, e.g. four for a four lane crossing but divided by two by a pedestrian refuge on the splitter island.
Speed of Traffic in the Intersection	15 km/h to 90 km/h (10mph to 55mph)	10km/h to 45 km/h (5mph to 25mph)
Pedestrian Expectation (Level of Security)	Higher perceived security but exaggerated sense of safety afforded by crosswalk signal. Pedestrians mistakenly believe they have a guaranteed right-of-way and safe passage with the walk signal.	Accurate sense of safety matched to expectation of safety (actual safety exceeds perceived safety). What you see is what you get – no hidden risks or complex information recognition demands.
Crash Potential	Crosswalk is in front of driver at a stop bar but the driver is looking up at light while the pedestrian arrives from the side.	A driver's eyes are looking ahead where pedestrian will appear, not up at a traffic signal.
Visibility Between Conflicting Users	Left and right turners - > 90 degrees from direction of conflicting vehicle.	The pedestrian sees a vehicle from one straight ahead view at all times. Gaps are easier to judge based on lower approach speeds.
Crash Incidence	Slightly higher than roundabouts (approximately 30% higher in Britain (1)).	Slightly lower than traffic signals.
Crash Severity	High injury severity in most cases owing to higher speed of vehicles in conflict. Through movement failure to yield is often fatal for a pedestrian.	Lower severity owing to low speed of conflicts. Failure to yield is often not fatal or severely injurious.
Crash Incidence Variation: Approach vs. Departure Side	No statistics available but likely equal due to opposing left turns and right turns on red for a symmetrical four leg intersection.	Approximately equal but higher on the entry approach side as compared to exit side according to French and Australian studies (2).

2.3 STATUS OF ACCOMMODATING PEDESTRIANS WITH VISION DISABILITIES

The U.S. Access Board, with authority to enforce provisions of the American Disabilities Act (ADA), initially determined that multilane roundabouts are not accessible by blind pedestrians and drafted proposed guidelines to require additional traffic control devices to improve accessibility for pedestrians at multilane roundabouts. It is possible that if these guidelines become U.S. Federal regulations through the Federal rule making process, and low-cost pedestrian signals are not developed, the growth of roundabouts could diminish greatly throughout the USA. This will, in effect, deny motorists and public transportation organizations a safe, cost-effective means of intersection traffic control, which potentially could result in greater loss through injuries not prevented (3). Once formally adopted, the Access Board's guidelines will become standards that will be applied by U.S. DOT. A final rule is expected sometime in 2010.

Concurrently, several Canadian agencies are consulting with the Canadian National Institute for the Blind on improved accommodation and education of blind pedestrians. In the United Kingdom (U.K.) where roundabouts have been in existence much longer, traffic signal control of pedestrian crosswalks is not mandated for visually impaired pedestrians.

Research is currently underway in the U.S. to test various traffic control devices to provide more positive indication of the need to stop for pedestrians, in particular disabled and visually impaired pedestrians. This is being addressed by The National Academies of Science (U.S.) with their ongoing research project (4). The objective of this research is to recommend a range of geometric designs, traffic control devices, and other treatments that will make pedestrian crossings at roundabouts and channelized turn lanes more useable by pedestrians with vision impairment. It is not the intent of that study to define a 'warrant' for what is accessible.

Researchers presented initial observations at the 2009 TRB Annual Meeting; their presentation was captured as an E-session (http://onlinepubs.trb.org/webmedia/trbmedia/AM2009/794sch/softvnetplayer.htm). These preliminary observations include:

Pedestrian hybrid signal (Figure 1):

- Red-light running was observed.
- Some drivers waited during the flashing red.
- Stopping patterns changed, with drivers stopping as they would at a signalized intersection, providing obvious auditory cues for visually impaired pedestrians attempting to cross.
- Good yield/stop identification by pedestrians.

Raised crosswalk:

- Stopping patterns were like those seen with the pedestrian hybrid signal.
- Seemed to increase yielding.
- Pedestrians commented on the uneven surface of the raised crosswalk.

"Roundabouts can be very challenging for people who are blind and may pose dangers for other pedestrians as well," says Dr. Richard Long, Western Michigan University (WMU) professor of blindness and low vision studies and associate dean of the WMU College of Health and Human Services. "They're challenging because the traffic is not controlled by traffic lights and the traffic often fails to stop for pedestrians," Long says. "Pedestrians themselves have to identify when it is appropriate to cross. It's a task that is rather challenging without vision. Especially when it's a multi-lane roundabout, it's challenging to the point where you sometimes need some type of intervention."

WMU and Dr. Long are part of the investigation reflected in a Michigan Roundabout Lawsuit regarding a court case filed against the Road Commission for Oakland County, Michigan, claiming that the county's roundabouts prevented disabled citizens from safely crossing intersections. Two pedestrian signal treatments, a hybrid activated walk signal (HAWK) and the Rectangular Rapid Flash Beacon were tested on two RCOC roundabouts (See Figure 1). The March 2009 court order that requires testing of pedestrian signal treatments delays the judicial proceedings until approximately August 2010, when a final report of the testing is due.

Figure 1 – Devices being tested under the Oakland County Lawsuit (Source: Road Commission of Oakland County)

2.4 DRIVER AND PEDESTRIAN BEHAVIOR STUDIES

The majority of studies to date only focuses on what treatments could potentially impact the general accessibility concept (5). There has been limited research to measure the effects of pedestrian assertiveness on drivers yielding. In 2006 the Institute of Transportation Research and Education (ITRE) of North Carolina State University conducted an investigation of signalized roundabout crossings employing the microscopic modeling tool VISSIM to estimate impacts on pedestrian and vehicle delay for different crossing geometries and signalization schemes (6). The range of alternate crossing geometries included 'proximal', 'zig-zag', and 'distal' crossings with varying offset distances of entry and/or exit crosswalk from the circulating lane. The modeled signalization options include one-stage and two-stage pedestrian-actuated control, as well as, the use of a hybrid activated walk signal (HAWK) signals. The vehicle models for one- and two-lane roundabouts have been calibrated and were used to conduct sensitivity analyses for a range of pedestrian and vehicle demands for the different scenarios. Their results suggest that the impact of a pedestrian signal at a roundabout is greatest as vehicle volumes approach capacity, but that vehicle delay and queuing can be minimized through innovative signal configurations. This has been shown with implementation of signalized crossings of roundabouts in the U.K. They use gap-out technology and count-down signals to reduce walk phase duration.

A graduate dissertation authored by Bastian Schroeder (7) explored the interaction of pedestrians and drivers at unsignalized crosswalks. Through logistics regression techniques the data were used to derive predictive models for driver yielding and pedestrian crossing behavior. Pedestrian assertiveness was found to be a key variable for promoting yielding behavior and increasing the likelihood of a pedestrian crossing. One of the mid-block model results suggested that an "assertive" pedestrian was 5.6-times as likely to have a driver yield for them, compared to a pedestrian who more passively walked along the sidewalk. Due to a lower sample size, the researcher was unable to replicate this effect for a roundabout yielding model, but hypothesized that with more observations the assertiveness effect would hold up to statistical rigor there as well.

NCHRP Report 572, "Roundabouts in the United States," presented data on roundabout pedestrian crossings for the sites studied (8). No pedestrian crashes and a low level of vehicle/pedestrian conflicts were reported in the study. There were only four conflicts out of 769 pedestrian crossings across the 10 study sites, with a conflict rate of 2.3 conflicts per 1,000 opportunities. An opportunity was defined as any time a pedestrian was either waiting to cross or crossing the leg and a motor vehicle was in the vicinity of the pedestrian. The study did not address the accessibility of roundabouts for pedestrians with visual impairments.

A study published on the Journal of Visual Impairment and Blindness presented the results of an evaluation of drivers' behavior in yielding the right-of-way to sighted and blind pedestrians (9). The pedestrians stood at different stopping distances from the crosswalk lines at entry and exit lanes at two different roundabouts.

Findings include:

- Drivers' willingness to yield to pedestrians is affected by whether they are attempting to cross at the entry or exit to the roundabout and, under some conditions, by the presence of a long cane.

- Getting drivers to yield may require more assertive pedestrian behavior.
- A vehicular speed of 18 mph at an entry lane offers a 9 in 10 chance that a driver will yield.

While more research is still needed these findings are important for inclusion in the discussion of accessibility of roundabouts to pedestrians with vision and mobility impairments where agencies are considering signalization for multilane roundabouts. Until recently the emphasis has been on engineering solutions to indirectly influence and modify driver behavior. The value of pedestrian education to improve pedestrian assertiveness and the historical precedence of enforcement has yet to be explored for modern roundabouts.

3.0 IMPROVED EDUCATION PROGRAMS

Two agencies developed education campaigns to improve driver response and pedestrian vigilance at unsignalized crosswalks, especially roundabouts. Both have employed simple techniques that don't require additional traffic control devices and have the potential to revolutionize the way we educate pedestrians to cross the road. The ideas are so simple it is surprising that they haven't been tried sooner.

3.1 REGION OF WATERLOO, ONTARIO

The Regional Municipality of Waterloo, Ontario, Canada developed an education campaign focusing on pedestrians in roundabouts and launched it in January 2009. The campaign proceeded under the interpretation of the Highway Traffic Act, that drivers are required to yield to a pedestrian in the crosswalk at a roundabout. The campaign message to a pedestrian crossing at a roundabout included these instructions on what to do when crossing at a roundabout:

- Pay attention. Think. Be prepared to make decisions.
- Step up to the curb and point your finger across the crosswalk to show drivers that you intend to cross. Keep pointing until you reach the far side of the road.
- Keep watching all the way across. As you cross a multi-lane roundabout, watch for a driver coming in the next lane. Make sure that the driver sees you.
- Look and listen for a safe gap in the traffic flow before crossing. Do not start to cross if a vehicle is so close that the driver cannot safely yield the right-of-way to you, or if a driver shows by the way that they are driving that they do not intend to stop for you.
- Use the sidewalks and crosswalks around the outside of the roundabout. Do not cut across the middle of the roundabout. The central island is not a pedestrian refuge.
- Use the splitter island. This will let you cross one direction of traffic at a time. Wait on the splitter island if needed.

Examples of behavior on the part of pedestrians in requesting the right-of-way at a crosswalk:

- Slowly ambling up to the crosswalk;
- Not looking at drivers;
- Standing on the sidewalk back from the curb;
- Standing with their hands on their hips;
- Setting down their grocery bags;
- Playing with their cell phone or texting;
- If they are jogging up to the intersection, beginning muscle stretches to fill in the time;
- Not taking advantage of an appropriate gap in traffic to make their crossing;
- Waving drivers on; and
- Hesitating and not starting to cross even when a vehicle is slowing to yield the crosswalk to them.

Further details on the campaign message were provided on the Region's roundabouts website at www.goroundabout.ca. The campaign included a television commercial aired for four weeks in January 2009. Figure 2 illustrates the body language of pedestrians showing their intent to cross in a roundabout crosswalk.

Figure 2 – Waterloo Region Councilors Demonstrating Point and Walk

The Region of Waterloo, Ontario created a song to aid pedestrian training for roundabouts. The author from Waterloo wrote the lyrics and local musician set it to music. The words of the Roundabout Dance song are:

Do the roundabout Dance, point your finger to say, I'm crossing here, I'm walking this way.
In the roundabout dance, watch the traffic flow, 'cause you decide when to step out and go
In the roundabout dance.
In the roundabout dance.
Keep watching those drivers. Are they watching too?
When they slow or stop, there'll be time for you.
In the roundabout dance.
In the roundabout dance.
Source Video: http://roundabout.region.waterloo.on.ca/mediaplayer.php?id=1

They also developed driver training to improve driver responsiveness to pedestrians. A model set of instructions for a motorist at a roundabout to improve responsiveness to pedestrians could be articulated thus:

- Pedestrians go first. When entering or exiting the roundabout, yield the crosswalk to pedestrians.
- Don't pass a vehicle that is slowing down as it approaches a crosswalk – there may be a pedestrian in the crosswalk.
- Don't block the crosswalk.
- If you feel that you don't have enough time to watch for pedestrians, then slow down. Don't accelerate until you are past the crosswalk on your exit.

The initial results of this education campaign are very favourable. Staff conducted periodic field trips to test the point-and-walk technique noting 100% responsiveness on the part of drivers, i.e. yielding to the pointing pedestrian. In follow-up observations the authors' found that rarely do people point but when they choose to the driver response is nearly certain. Training school age pedestrians to make eye contact with the driver is feasible. Without eye contact the pedestrian must learn to judge the car body language, slowing or braking harder versus accelerating. Given that school age children have limited capabilities in judging these subtle interactions, adult crossing guards are usually necessary. This is also common for traffic signal controlled crossings for children age 12 and under.

3.2 CITY OF LOVELAND, COLORADO

The City of Loveland Public Works Department created a new pedestrian education program called "Look Smart". The program helps children remember to be safe, (look smart) when they are in a roadway environment. The goal is to make the pedestrian more alert when crossing a street or driveway and to improve driver response. It is applicable to unsignalized crosswalks including roundabouts.

Training efforts are the focus of Loveland's "Look Smart" program. City representatives teach children what it means to be a safe and alert pedestrian in a roadway environment. This effort centers on the acronym P.E.D. which is short for pedestrian and carries the following message:

P *P*oint and look
E *E*ye contact
D *D*ecide

Figure 3 – Look Smart Training Sessions in Loveland, CO

The intent of this simple memory device is to make the process of crossing a street or driveway more active and to communicate this intent to the motoring public, while reinforcing the need to actively decide if it is safe to cross (have I been seen?). It also provides a brief pedestrian pause prior to physically crossing the roadway reducing unconscious dart-outs into traffic.

The inspiration for this effort was the "Roundabout Dance" education campaign from Waterloo, Canada. This fun training video shows people using this pointing technique to communicate with drivers at pedestrian crossings at roundabouts. "Look Smart" is Loveland's educational outreach program designed to train children to help them and their parents be more confident in their pedestrian skills. "Look Smart" involves the following principles:

1. Reach out to children at an early age to teach non-verbal communication between pedestrian and driver.
2. Use fun, light hearted training approaches through Safe Routes to School (SRTS) program.
3. Use symbols combined with easy to remember acronyms to reinforce critical training messages.
4. Encourage active, non-verbal communication of intent to cross the road through pointing, to prevent misunderstandings with the driving public.

Staff feels that Education and Encouragement, two of the five E's of any safe routes to school (SRTS) program, are critical to building safe alternative modes of transportation. Parents often neglect teaching their children pedestrian safety skills because they are second-nature in the day-to-day experiences of adults. Successfully interacting with one and two-ton chunks of steel traveling at speeds greater than 16km/h (10 mph) is not typical for school age children who must learn how to master this ability successfully. Adults simply forget all the mental calculations made as they interact with drivers when crossing a street. By teaching techniques to non-verbally communicate the pedestrian's intent, this improves driver awareness and prevents drivers ignoring the pedestrian in their driving routine. Secondly, by pointing out one's intent, the pedestrian is cued to actively decide when they can cross in-front of yielding traffic.

Loveland Public Works has a number of outreach efforts with "Look Smart" program. These are focused on SRTS and involve their mascots Smart T. Fox and the robotic Smart T. Jr. Events where Smart T. engages kids include:

- Loveland Public Works Day.
- Loveland Children's Day.
- Walk to School kick off day at each elementary school.

- Summer School Lunch program presentations.
- School Bike Safety Rodeos.

Figure 4 – Field Training in Loveland, CO

These events involve different levels of safety training, but are intended to get the word out and provide young walkers and bike riders' education tips and tools to "Look Smart". The Public Works Day event allows City staff to train elementary children to use the P.E.D. road crossing technique.

The stenciled word "LOOK" on the pavement in school zones, along with the mnemonic device P.E.D. are used together in a coaching opportunity at a raised crosswalk (see Figure 5). The training introduces kids to non-verbal active communication so that they can use this in everyday pedestrian encounters.

Figure 5 – Stenciled Wording to Alert Pedestrians

3.3 OTHER ON-SITE EDUCATION

One Canadian road agency, Ottawa, has begun posting signs to give pedestrians information about crossing conduct and safety at roundabouts. This information is mostly helpful to sighted and mature pedestrians by taking the education message 'to the street'. The large yellow background warning sign is placed on the splitter island and reads in both official languages as follows:

Tips for pedestrians at a roundabout:

1. *Stay on the sidewalk path at all times.*
2. *Never cross the circular roadway to the central island.*
3. *Cross only at designated crosswalks.*
4. *Look in the direction of the oncoming traffic and wait for an acceptable gap before entering the crosswalk.*
5. *Proceed to the splitter islands. Use the splitter island as a refuge. Again, look in the direction of oncoming traffic and again wait for an acceptable gap before proceeding to cross.*

4.0 ROUNDABOUT DESIGN TREATMENTS THAT EMPHASIZE PEDESTRIANS

Concerns about the safety of pedestrians at roundabouts, particularly visually impaired pedestrians, have led some researchers to recommend the installation of traffic signals at roundabouts. Alternatives to signalization that emphasize geometric features and other traffic control devices to increase the safety of both cyclists and pedestrians at roundabouts are available (10). Furthermore, a paper by Harkey, David L; Carter and Daniel L (11) focused on analyzing the interactions between motorists and pedestrians or bicyclists at roundabouts. This research did not find any substantial safety problems for non-motorists at roundabouts based on conflicts or collisions. However, the findings from behavioral observation highlighted some aspects of roundabout design that require additional care to ensure safe access for pedestrians and bicyclists.

4.1 INTRODUCTION OF A CROSSWALK SIGN

To reinforce the campaign message to drivers, Regional of Waterloo, Ontario staff installed additional signs facing drivers just before the crosswalks at roundabout entrances and exits (Figure 6 and Figure 7). The signs conveying "yield here to pedestrian" are promoted in the U.S. Federal Highway Administration Manual of Uniform Traffic Control Devices. Suitable signs for this application have not yet been adopted by Canadian agencies such as the Transportation Association of Canada (TAC) or in the Ontario Traffic Manuals, although Canadian studies are underway that would address this. Sign size may be a factor but speeds near the crosswalks are generally below 50km/h (30mph).

Figure 6 – Crosswalk Yield Sign

Figure 7 – Placement of "Yield to Pedestrians" Signs

Waterloo Region staff sampled the number of pedestrians at roundabouts who either had to wait for a gap in traffic to cross or who were able to cross sooner because of a driver yielding to them, with and without the signs. The study results indicate that a driver either entering or exiting a roundabout is much more likely to yield to a pedestrian waiting at the crosswalk if the signs are present. When approaching a crosswalk when there was no gap in traffic, the percentage of pedestrians for whom a driver yielded was 63% with the signs and 37% without the signs. The signs resulted in a decrease in pedestrian delay and a decrease in the number of vehicles that passed without yielding to a pedestrian waiting at the crosswalk. The data indicated that pedestrians experienced lower delay crossing an entry versus an exit with even less delay when crossing from the splitter island to the roadside.

Noteworthy, is the fact that the majority of crossings took place with very little delay before being able to cross. The majority of the 1713 crossings made experienced less than 6 seconds of delay before starting to cross. This suggests roundabout crosswalks experience less delay than traffic signals where at a traffic signal a pedestrian can easily arrive near the end of the walk cycle.

4.2 CROSSWALK LOCATION

Design and marking of crosswalks requires awareness of the potential for unmatched expectancies of pedestrians and drivers. The appropriate type of crossing treatment ensures that drivers are aware of pedestrians nearby, but that pedestrians do not assume that they have the right-of-way until a driver yields it. Facilities must be provided as close as possible to the desired pedestrian paths to ensure their effectiveness, and their treatment in terms of visibility and design requires knowledge of the frequency of crossings.

Crossing location is fundamental to pedestrian safety, recognizing the driver's need to look left at the roundabout entry and the need to separate conflict areas. Placing the crosswalk one vehicle length removed from the yield line ensures this separation, but does not create unreasonably long walking distances for the whole intersection.

The two figures below show contrasting treatments where the crossing alignment affects the perception of the right-of-way. The angularity of the crossing shown on Figure 8 also minimizes the crossing distance and provides a tactile clue of the refuge. Clear, safe guidance of pedestrians in the crossing area requires clear linkage to the crosswalk, visibility of the refuge area, but not a clear, uninterrupted path from one side of the road to the other (Figure 9). In such cases, bicyclists are tempted to cross without stopping at the refuge area.

Figure 8 - Angled Zebra Crosswalk

Figure 9 – Poor Crosswalk Layout and Alignment

Visibility between drivers and pedestrians was first prescribed by Ourston (12) and later reiterated in the FHWA informational report. (13) Sight of the first exit crosswalk from the driver's position, 15m (50 feet) upstream of the yield line is mandatory. Plantings and fencing or street furniture must not interfere with this safety provision (12).

The use of guiderails and fencing to restrict pedestrian crossing areas is commonly used in the U.K. at intersections with high pedestrian volumes. In our North American climate with snow clearing requirements, fencing is impractical unless farther removed from the edge of pavement. Plantings are preferred and perform the same purpose, while providing improved aesthetics. Whether plantings or fencing is used, heights must be restricted to below 1.05m (3.5 feet) above the pavement surface. In either case, the need should be established where the risk to pedestrians is high.

4.3 CROSSWALK MARKINGS

There are approximately 100 vehicle/pedestrian collisions each year on Region of Waterloo, Ontario roads, of which approximately 92% result in injury or fatality. Most (81%) occur while the pedestrian is crossing the road. Most (58%) occur at signalized intersections. Of those that occur at signalized intersections, most (67%) occur while the pedestrian is in the crosswalk and has the right of way. A traffic control signal does not necessarily provide safety for a pedestrian obeying the signal, especially when the pedestrian is crossing a lane with a permitted vehicular crossing movement, such as a permissive left turn on a green light or a right turn on a red light. The same can be said of a roundabout crosswalk except conditions are more forgiving and less complex for users.

Waterloo Region, Ontario measured the impacts of better defining crosswalks at signalized intersections by undertaking pedestrian conflict studies before and after outlining interlocking brick crosswalks with paint. The study results indicated that a poorly defined crosswalk can result in 4 to 10 times more vehicle / pedestrian conflicts. When drivers can see the crosswalks better, they seem more likely to respect the crosswalks as pedestrian space. In contrast, where pedestrians are supposed to have the right-of-way because of the signal indication then visibility of the roundabout crossing, where there are no traffic signals, is even more important because of the greater reliance on the driver's response without signals.

The literature is consistent in recommending white ladder or zebra style (see Figure 7) stripes as a means to make a crosswalk more visible. In New York City, the replacement of double line crosswalks with ladder or zebra-striped crosswalks reduced vehicle / pedestrian collisions by 42% (New York City Department of Transportation Pedestrian Projects).

One drawback of the zebra marked crossing is potentially poor skid resistance for drivers coming to the yield line. Several agencies have specified skid resistant additives for this type of transverse marking. One well-known manufacturer has developed a pavement marking tape product that is skid resistant.

4.4 THE EFFECTS OF ROUNDABOUT ENTRY/EXIT PATH CURVATURE ON SPEED AND PEDESTRIAN SAFETY

In 2003, Bill Baranowski and Edmund Waddell authored a timely paper entitled: "Alternate Design Methods for Pedestrian Safety at Roundabout Entries and Exits" (14). This paper responded to roundabout designers contending that designing roundabout exits to slow exiting traffic served to protect pedestrians. Many designs were noted as having excessively tight entry and exit radii. Particularly for multi-lane roundabouts, reverse curves near the exits impede driver sight of the crosswalks. This practice resulted in roundabouts with unnecessarily low capacity and high vehicle conflict rates near exits. Their paper made a case for the design of high capacity roundabouts that are safe for pedestrians while optimizing flow efficiency for vehicular traffic.

Two separate studies of pedestrian crash incidence indicated the majority of pedestrian-vehicle crashes occur at roundabout entries versus exits (2). These results indirectly point out the need to control entry speed recognizing that appropriately slowed entries will take care of speed at exits.

Research of the speed curvature relationships was investigated for a modern roundabout built at the intersection of Wilson Street (former Highway 2) and Meadowbrook Road, Ancaster, Ontario in 2002. Spot speed data was collected on six occasions for two-hour periods each, accumulating a total of twelve hours of speed data. Figure 10 shows the roundabout configuration and the locations of speed data collection. The hypothesis regarding the effects of entry speed on exit speed was the same as Baranowski and Waddell (14), that the exit radius does not control the exit speed as much as it is controlled by the entry path curvature and acceleration potential from the circulating roadway.

The speed data results (see Table 2) indicates the differential in entry and exit speeds is low, averaging only 6 km/h (4 mph) for the 85th percentile speed on the high-speed 80 km/h (50 mph) approach, Wilson Street west leg. Although the radius on the exit side of the Wilson Street east leg is flatter than some would prefer; suggesting high exit speed, according to radius friction factors, the actual speed is much lower than calculated. Because the speed reduction occurring at the entry is sustained through the circulating roadway according to the central island radii; and, because the distance from the central island to the exit is too short for excessive acceleration, the exit speed does not increase as one might expect. Similar results were later obtained through a larger U.S. study. (8)

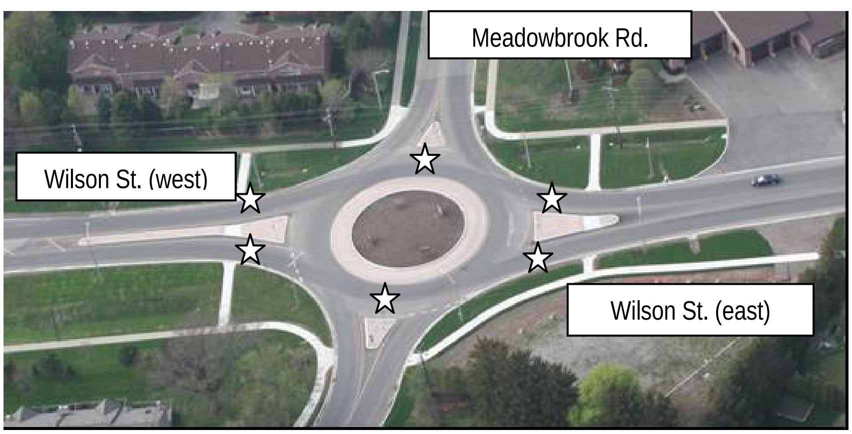

Figure 10 - Spot Speed Observation Points (Lobo and Jamieson, 2003)

Harkey, Carter and Daniel noted that emphasis needs to be placed on designing exit legs to ensure proper sight lines and motor vehicle speeds (11). This finding has been confirmed in practice by the authors with positive results for many years, by making roundabout exit paths flat or nearly tangential.

Table 2 – Overall Results of Spot Speed Observations [km/h (mph)]

Spot Speed Statistic	Wilson Street (East)		Meadowbrook Road		Wilson Street (West)		Circulating
	Entering	Exiting	Entering	Exiting	Entering	Exiting	
Mode	26 (16.1)	38 (23.6)	30 (18.6))	37 (22.9)	35 (21.7)	43 (26.7)	28 (17.3)
Average	26 (16.1)	35 (21.7)	30 (18.6)	36 (22.3)	33 (20.5)	40 (24.8)	28 (17.3)
Standard Deviation	5.4 (3.3)	5.2 (3.1)	6.2 (3.8)	4.9 (3.0)	8.8 (5.5)	5.7 (3.5)	4.9 (3.0)
85th Percentile	31 (19.2)	41 (25.4)	36 (22.3)	41 (25.4)	39 (24.2)	45 (27.9)	33 (20.5)
Maximum	41 (25.4)	48 (29.8)	45 (27.9)	54 (33.5)	46 (28.5)	55 (31)	44 (27.3)
Minimum	12 (7.4)	17 (10.5)	11 (6.8)	23 (14.2)	12 (7.4)	22 (13.6)	12 (7.4)

4.5 LIGHTING

Illumination of the roundabout intersection should be given considerable attention, as positive contrast lighting and vertical luminance is essential for pedestrian and signage visibility. Poor or inappropriate lighting of a roundabout can lead to motorists entering the intersection without adequate information, which can lead to driver confusion, emergency braking and/or loss of control night-time accidents, in addition to delays due to poorly illuminated guidance features.

Recently developed guidelines (15) indicate peripheral lighting is preferred over widespread central flood lighting as the former gives improved positive contrast to important visual elements. Pole placements should respect clear zone requirements for a safer roadside as dictated by the intersection design speed.

Figure 11 - Approach Mounted Lighting 8-250W HPS
(Courtesy: DMD Associates, Canada)

5.0 CONCLUSION

Traditionally, engineers have sought remedy to traffic safety problems mainly from physical solutions. We are reminded with the studies of roundabout driver and pedestrian behavior, documented herein, that improved yielding response is achievable through applying all of the 3-E's of Engineering, Education and Enforcement. No amount of engineering can compensate for a lack of focused education and selective enforcement. A greater emphasis on pedestrian education, including blind pedestrians, is needed otherwise the long term safety and congestion relief benefits of roundabouts, particularly multilane configurations, will be lost because of an overexertion of engineering solutions. In the U.S., if guidelines requiring traffic signals at pedestrian crosswalks become Federal regulations, and low-cost pedestrian signals or other accommodations are not developed, the growth of roundabouts could be stalled throughout the U.S.

Training pedestrians to step up to the curb and point across the roundabout crosswalk to show drivers the intent to cross, and continuing to point in the crosswalk, is a simple and effective action to trigger a yield response from drivers. Independent studies indicate more emphasis on training pedestrians to cross roundabouts merits equal attention with emerging research on alternative traffic control solutions.

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