ACCOMMODATING SMALL AND LARGE USERS AT ROUNDABOUTS

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TABLE OF CONTENTS

Page

LIST OF FIGURES

1.0 ABSTRACT AND INTRODUCTION

Roundabout designs should be balanced to accommodate the mix of pedestrians, cyclists, and motorized vehicles (such as cars, buses, trucks, oversize loads, etc.) expected to use the intersection. Each user class has different characteristics and time/space requirements, and optimizing the design for one user class often reduces the suitability for other users. The task of the designer is to find the design trade-offs that optimize safety and operations for the entire mix of users of the intersection under consideration.

This paper highlights a variety of issues related to “small” users at roundabouts, principally pedestrians and cyclists, and “large” users at roundabouts, namely trucks.

Issues with pedestrians and cyclists include accommodating pedestrian crossing movements, pedestrian safety, pedestrian education (including an innovative program in the Regional Municipality of Waterloo, Ontario), visually-impaired pedestrians, accommodating cyclists, and cyclist safety.

Issues with trucks at roundabouts mainly involve accommodating trucks within the available geometry, whether to employ circulatory road striping (and the fact that trucks commonly encroach on adjacent lanes in multi-lane roundabouts), and lessening the potential for truck overturning at roundabouts.

2.0 PEDESTRIANS AND CYCLISTS AT ROUNDABOUTS

2.1 PEDESTRIAN CROSSWALKS

In Canada, crosswalks are typically installed at roundabouts where there is a reasonable chance of pedestrian activity. They are usually signed and marked. Caution should be taken in applying signs and markings and making pedestrians feel overconfident (and presumably less vigilant) in areas where pedestrian activity may be unexpected.

2.1.1 Signs and Markings

In most provinces, the sign used is the Pedestrian Crosswalk sign (RA-4) as found in the Transportation Association of Canada (TAC) *Manual of Uniform Traffic Control Devices for Canada* (MUTCDC). Quebec has a similar version of the sign. In Ontario the closest equivalent is the Pedestrian Ahead warning sign, which is why most roundabout crosswalks are not signed. The Regional Municipality of Waterloo, Ontario has installed "Yield Here to Pedestrian" signs at all their roundabouts (as per the United States MUTCD), which emphasize that drivers in Ontario must yield to pedestrians within a roundabout crosswalk. The TAC and Region of Waterloo signs are illustrated in Figure 2.1.

Figure 2.1
TAC Crosswalk Sign and "Yield Here to Pedestrian" Sign

Photo: Alberta Transportation

Photo: Region of Waterloo

Crosswalk markings are parallel, zebra or ladder style. Common practice at roundabouts is to use parallel markings, or none at all, in rural locations, and zebra or ladder markings in more urban locations.

2.1.2 Crossing Locations and Treatments

Crosswalks at roundabouts are located one vehicle length, or a multiple, behind the yield line to separate the driving tasks of looking for pedestrians and looking for oncoming traffic in the circulatory road. Pedestrians can cross in between cars if vehicles are queued at the yield line.

A crosswalk can be straight across the entry and exit, or angled through the splitter island. Examples of both are shown in Figure 2.2. A straight crosswalk results in a shorter walking distances for pedestrians following the road through the intersection, and generally maintains a one-vehicle-length separation from the yield line across multiple lanes. An angled crosswalk results in a shorter crossing distance, especially across multiple lanes, creates a more definitive two-stage crossing, and may better guide visually-impaired pedestrians by enabling them to step off the curb at right angles.

Figure 2.2
Straight and Angled Pedestrian Crosswalks

Photos: Ourston Roundabouts Canada

2.1.3 Pedestrian Signals

It is rare in North America to find pedestrian signals at a roundabout. However there is a series of roundabouts along Route 148 in Gatineau, Quebec that have pedestrian signals. See Figure 2.3. There is one set of signals per entry and exit. The cycle lengths are short because crossing distances are short and each stage is handled separately. The signals rest on green for motorized traffic, and change to red upon actuation. It should be noted that traffic signals elsewhere do not result in good safety records for pedestrians (see following section on Pedestrian Safety), and it is possible that traffic signals at a roundabout may lessen overall pedestrian safety.

Figure 2.3
Pedestrian Signals at a Roundabout Crosswalk

Photo: Ourston Roundabouts Canada

In the U.S. trials are being undertaken with "HAWK" signals that show a blank indication to drivers until actuated, whereby they turn solid red, flashing red, then amber while the pedestrian clears the crosswalk.

2.2 PEDESTRIAN SAFETY

A roundabout is safer for a pedestrian than a traffic signal in many ways. At a roundabout, compared to a signalized intersection:

- A pedestrian has two crossings of one-way traffic moving at slower speeds;
- The driver has more time to judge and react to pedestrians because of the slower speeds;
- The crossing distance is less;
- The pedestrian only has to watch for traffic in one direction at a time;
- With no traffic signal to divert the driver's attention upward, the driver is focused on the vehicles and pedestrians around them;
- The driver is more likely to be looking in the direction of the pedestrian. When turning at a traffic signal, the driver is often watching for conflicting traffic and not where they are going (i.e. looking left while turning right); and
- The driver and pedestrian are more likely to be alert and aware of each other because both have to decide when to go.

There has been some research on pedestrian safety at roundabouts in North America, but most comes from other countries:

- A 1993 study in the Netherlands at 181 intersections found that pedestrian crashes dropped 73% and pedestrian casualties dropped 89%.
- Evaluations in Sweden showed a 78% reduction in injuries at single-lane roundabouts, and little change at multi-lane roundabouts.
- The Melbourne metro area in Australia experiences approximately 1 pedestrian crash per year for every 9 traffic signals, and 1 pedestrian crash per year for every 364 roundabouts.
- A 2002 study of collision experience at the roundabouts in Park City, Vail, West Vail and Avon, Colorado, showed 2 pedestrian crashes before the roundabouts, compared to 1 pedestrian crash after roundabouts (with more than double the total number of vehicle movements).

The Roundabouts Listserv managed by Kansas State University recently polled its members about whether they knew of any collisions involving pedestrians at any roundabouts in North America. Fewer than 10 collisions were reported. This is out of over 1,000 roundabouts known to be in existence in North America.

Pedestrian safety is an issue of perceived versus real risks. Even though pedestrian safety at roundabouts is high based on international experience and growing experience in North America, many do not perceive roundabouts to be safe for pedestrians due to the absence of a positive exchange of right-of-way priority by a traffic signal. More public awareness and education is needed on the relative safety of roundabouts for pedestrians compared to signalized intersections.

2.3 PEDESTRIAN EDUCATION IN THE REGION OF WATERLOO

In Ontario, the Regional Municipality of Waterloo recently embarked on an extensive public awareness and education campaign for their 11 arterial road roundabouts. A main focus of the campaign is to better educate pedestrians (and drivers) about the use of pedestrian crosswalks at roundabouts. This part of the campaign, known as the "Roundabout Dance", features two songs and a TV commercial, and information about pedestrians on the Region's website www.GoRoundabout.ca.

Central to the Roundabout Dance is the idea that pedestrians do not necessarily have to wait for a suitable gap to eventually occur. They can create a gap in traffic with good body language. This good body language includes:

- Coming up to the crosswalk briskly and deliberately (this also shows that they will not make drivers wait a long time for them to cross);
- Scanning for a gap in traffic as they come up to the crosswalk;
- Looking at the drivers;
- If they have to wait, stepping up to the curb or even standing with one foot into the crosswalk;
- Pointing across the crosswalk; and
- Starting to cross as soon as they are sure that the driver intends to slow or stop to yield the crosswalk to them.

Examples of poor body language include:

- 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 music player;
- 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.

Also included are instructions to drivers to the effect that they need to look ahead, yield the crosswalk to pedestrians when entering or exiting a roundabout, not pass other vehicles in the vicinity of the crosswalks, and slow down if they feel they do not have enough time to watch for pedestrians.

The Regional Municipality of Waterloo studied pedestrians crossing at roundabout crosswalks before and after the installation of "Yield Here to Pedestrian" signs. The study recorded more than 900 crossing movements of pedestrians 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. The percentage of pedestrians to whom a driver yielded increased from 37% to 63% with 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. It was observed that body language was an important factor for pedestrians for whom vehicles did not yield.

2.4 VISUALLY-IMPAIRED PEDESTRIANS

Roundabouts provide continuous movement for motor vehicles along curvilinear travel paths. As a result, visually-impaired pedestrians can find it very difficult to visualize the layout of the intersection in their minds, and therefore find where crossings are located and decide when to cross. Much of the eye contact that occurs between normally-sighted pedestrians and drivers is not possible, or is possible only at close distances. Visually-impaired pedestrians require training to cross at a roundabout, similar to the quality of training that they would receive at other intersections.

Treatments that may assist visually-impaired pedestrians find the crosswalk and establish alignment include:

- Grooved lines in the sidewalk and at the start of the crosswalk;
- Low-height landscaping, railings or other architectural features;
- A distinctive edge leading to the crosswalk;
- High-contrast surfaces; and
- Surfaces detectable underfoot, such as truncated domes.

Treatments that may assist in determining when it is appropriate to cross include:

- Crosswalks set more than one vehicle length behind the yield line to further separate entering and exiting traffic from circulating traffic;
- Rumble strips in the road in advance of the crosswalks; and
- Actuated or automatic indications that are audible to the pedestrian and notify drivers when to yield. Typically this means signalization of the crosswalk.

The Canadian National Institute for the Blind (CNIB) and other groups are advocating the latter treatment. Signalization may be effective in assisting visually-impaired pedestrians to decide when to cross, but it is expensive and, if collision experience at other intersections is an indication, it has the potential to actually reduce pedestrian safety. The extra cost associated with signalization of one or more legs may preclude a roundabout in many locations where one could provide significant operational and safety benefits.

2.5 ACCOMMODATING CYCLISTS

Cyclists should have the option of travelling through a roundabout as a vehicle, or dismounting and traversing as a pedestrian. An example of a bicycle lane termination and sidewalk connection is seen in Figure 2.4. The angle of the ramp to and from the sidewalk is important. Too shallow and a cyclist may travel along it at speed without dismounting, and the resulting right angle of the ramp with the curb will be difficult to plough and maintain. Too steep and a cyclist may be forced into conflict with motor vehicles. An angle of 25 to 35 degrees is considered optimal.

In most provinces, the sign used to terminate bicycle lanes is the Reserved Bicycle Lane Ends sign (RB-92) as found in the MUTCDC. TAC is also proposing a new Shared Use Lane Single File warning sign that notifies drivers and cyclists of the merge condition following a bicycle lane termination.

Figure 2.4
Bicycle Lane Termination and Sidewalk Connection

Photo: Ourston Roundabouts Canada

2.6 CYCLIST SAFETY

Cyclists travelling through a roundabout face about the same number of conflicts as drivers or pedestrians. Cyclists as vehicles in a roundabout should be trained to ride in the correct lane and to take over their lane (ride in the centre of their lane). When cyclists ride on the right side of the road they can face additional conflicts when travelling through or exiting a roundabout. This is particularly the case at multi-lane roundabouts.

Cyclists are considered to be the most vulnerable users of roundabouts. Almost half of the collisions involving cyclists occur between an entering vehicle and a cyclist who is already on the circulatory road. In many cases, these crashes occur when a driver does not yield on entry.

There has been little research on cyclist safety at roundabouts in North America. In other countries:

- Data collected in the United Kingdom has shown that cyclists are two to four times as likely to be involved in a collision at a roundabout than a signalized intersection. The data is from the 1970s, when designing for cyclists was not a priority. Further, most complex and high-speed intersections in the U.K. are constructed as roundabouts, leaving traffic signals to control smaller and more urban intersections.
- Studies in the Netherlands have shown that roundabouts decrease cyclist injuries by 44% to 73%. Separate bicycle paths were found to be the safest, while a bicycle lane in the circulatory road was found to be the least safe.
- A study in Sweden at 72 locations concluded that at single-lane roundabouts cyclists were involved in 20% fewer injury crashes. However, at multi-lane roundabouts they were twice as likely to be involved in injury crashes (although these were classified as "light" injury crashes).
- The most comprehensive study overseas was undertaken in western France at 1,238 signalized intersections and 179 roundabouts. The study found that two-wheeled vehicles were involved in crashes more often at roundabouts (+16%), but were involved in injury crashes more often at signalized intersections (+77%).

Caution must be used in drawing conclusions applicable to North America because many of the conditions that resulted in cyclist collisions, such as bicycle lanes in the circulatory road, have since been recognized or mitigated. Single-lane roundabouts and low-speed designs are regarded as the safest for cyclists. In general, collisions involving cyclists are reduced somewhat with roundabouts, particularly in severity, but not to the same extent as for collisions involving motor vehicles or pedestrians. Because of this, the relative benefits of roundabouts can be less for cyclists.

3.0 TRUCKS AT ROUNDABOUTS

3.1 ACCOMMODATING TRUCKS AT SMALL ROUNDABOUTS

Several methods exist to accommodate large vehicles at small roundabouts. They include partially-traversable central islands (truck aprons), fully-traversable central islands (mini-roundabouts), and special features such as gated pass-throughs.

3.1.1 Partially-Traversable Central Islands

Partially-traversable central islands, or truck aprons, are a design compromise to accommodate trucks at small roundabouts while still providing deflection for light vehicles. An example is seen in Figure 3.1. Truck aprons should be capable of being mounted by large vehicles, but be unattractive to car drivers because they are raised and have a slope and/or textured surface.

Figure 3.1
Example Truck Apron

Photo: Ourston Roundabouts Canada

Truck aprons are widely used at roundabouts and most guides depict them. Because of this, roundabout designers may assume that aprons are a required element at all roundabouts. However, if speed control and truck swept paths can be provided without an apron, then no apron is necessary. Further, care is needed in the design of truck aprons so that they provide as much deflection as non-traversable central islands, yet do not create under-clearance or stability problems for trucks (see later section on Vertical Design and Truck Overturning). Pedestrians can also mistake an apron for a sidewalk and wander into the circulatory road.

Observations have shown that truck drivers are reluctant to use truck aprons. Often they are unsure of their purpose, or think they look too nice to be driven over. A yellow edge line around the apron may make them even more reluctant because it reminds them of a road centreline that should not be crossed.

3.1.2 Fully-Traversable Central Islands

If roundabouts become small enough, then the need to accommodate certain vehicles may require that the entire central island be fully traversable. The result is a mini-roundabout. Mini-roundabouts have a domed central island, about 4 to 6 m wide and 100 to 150 mm high, constructed of asphalt and white in colour. Large vehicles overrun the central island, while its speed-hump effect deters other drivers from speeding over it. The example in Figure 3.2 is in a 25 mph speed zone in Michigan.

Figure 3.2
Example Mini-Roundabout

Photo: Ourston Roundabout Engineering, Inc.

3.1.3 Gated Pass-Throughs

An example of a gated crossing of a roundabout central island in the U.K. is shown in Figure 3.3. Gated crossings can be used when oversize loads need to occasionally traverse a roundabout. They are also useful to maintain traffic during future work on the roundabout or approach roads.

Figure 3.3
Gated Pass-Through at a Roundabout

Photo: Ourston Roundabouts Canada

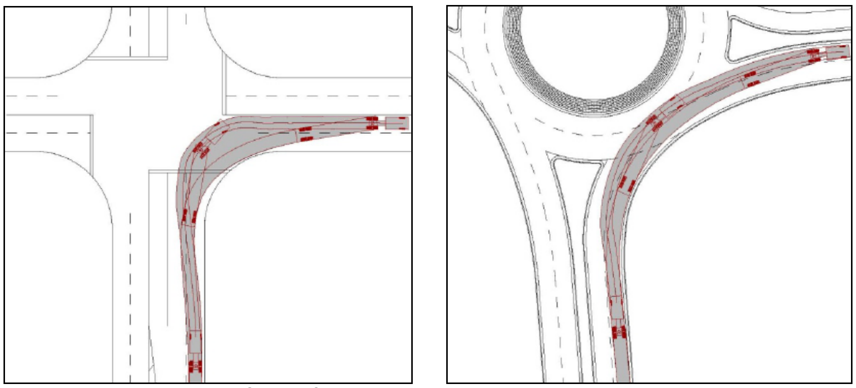
3.2 ACCOMMODATING TRUCK RIGHT TURNS

Several methods exist to specifically accommodate right turns by large vehicles. They include the use of adjacent lanes, widened entries and exits, and by-pass lanes.

3.2.1 Use of Adjacent Lanes

As is often the case at other intersections, large vehicles may need to swing wide and take up adjacent lanes when turning right at a roundabout, as illustrated in Figure 3.4. This is often adequate in situations where trucks are a low-to-average percentage of the vehicle mix. Truck drivers must execute this movement with due caution, and drivers of light vehicles must give way to the larger vehicle.

Figure 3.4
Truck Right-Turn Swept Paths

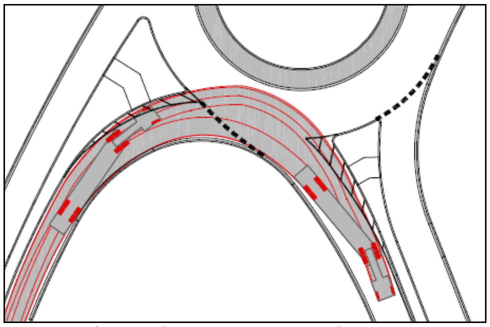


Source: Ourston Roundabout Engineering, Inc.

3.2.2 Widened Entries and Exits

At single-lane roundabouts, trucks can be accommodated by making the entries and exits wide enough for their swept paths, and using pavement markings to visually narrow the road. An example is shown in Figure 3.5. Partially-traversable areas can be used as well. It is preferred to create most if not all of the widening on the exit side, to not compromise speed control on the entry.

Figure 3.5
Right Turn at a Single-Lane Roundabout



Source: Ourston Roundabouts Canada

3.2.3 By-Pass Lanes

By-pass lanes are useful at roundabouts to provide additional right-turn capacity without adding more lanes to the roundabout. They are also useful to allow additional space for truck right turns without making the entire roundabout larger or compromising on certain geometric parameters.

In the roundabout in Figure 3.6, which is in Vail, Colorado, it was not possible for trucks on some approaches to turn right within the roundabout. Here, the west by-pass is free-flow, and the east by-pass is yield-controlled. They both allow a wider and easier turn radius for trucks. In other designs the by-pass lanes can be internal to the roundabout, where entering drivers yield to circulating and exiting traffic and there is no physical channelization. Care should be taken in the design of such by-passes so that drivers in the right lane are not tempted to enter the roundabout.

Figure 3.6
Free-Flow and Yield-Controlled By-Pass Lanes

Source: Google Earth

3.3 CIRCULATORY ROAD STRIPING

In most countries, multi-lane roundabouts have lane striping on the entries and exits, but not in the circulatory road unless special conditions make them necessary. This is analogous to signalized intersections not having lines continue through except to aid certain movements. Circulatory road striping tends to be the rule rather than the exception in the U.S. Circulatory road striping is usually used Canada, but in Waterloo Region and Nova Scotia it is not used except under special conditions. Interestingly, early designs in the U.S. (prior to 2001) did not have circulatory road striping at all.

Advantages of circulatory road striping:

- Lessens the potential for path overlap by reminding drivers to stay in their lane while circulating;
- May result in slower circulating speeds during off-peak times;

- Educates drivers on how to correctly turn left (but only if approach signs and markings correctly assign lane choice); and
- A must for multi-leg configurations with exclusive left turns.

Disadvantages of circulatory road striping:

- Can be tricky to design, and difficult to implement accurately in the field;
- May necessitate truck aprons where not normally required;
- May accentuate inherent path overlap problems;
- Can lessen the potential to yield at entry because striping looks like a continuation of the through road; and
- Where the design does not allow for trucks to maintain their own lane, can encourage passenger car drivers to circulate next to trucks. Roundabouts can be designed to accommodate trucks in their own lane while circulating, but the result is larger designs that are usually less safe for other users.

An effort to counter the tendency for car drivers to circulate next to trucks at a roundabout with circulatory road striping is seen in the British Columbia Ministry of Transportation sign in Figure 3.7.

Figure 3.7
"Give Space to Trucks" Sign

Photo: Ourston Roundabouts Canada

3.4 VERTICAL DESIGN AND TRUCK OVERTURNING

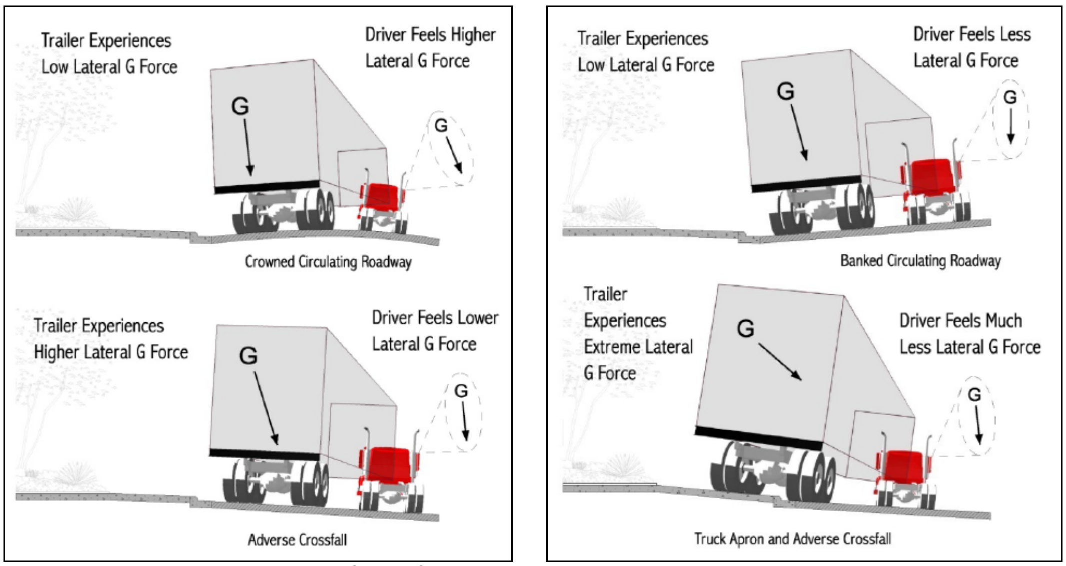
When negotiating tight turns, trucks and other vehicles having a high centre of gravity face the potential of overturning or shedding their loads. Truck rollovers have occurred at a few roundabouts in the U.S. They have been attributed to either excessive entry speed on the part of the truck, or hard braking on the adverse crossfall of the circulatory road after being cut off by an entering car.

As a tractor semi-trailer rounds a tight curve, as in a roundabout, the trailer tracks a tighter curve than the tractor and cab. While doing so, the driver reacts not just to what is seen, but also to what is felt in the "seat of the pants" (see Figure 3.8).

- On a crowned circulatory road, the trailer leans inward compared to the tractor. This places the line of gravitational force more perpendicular to the road surface than that of the tractor. The driver feels more lateral G force than the trailer, and will (presumably) keep a speed within its range of safety.

- On a circulatory road with adverse crossfall, the driver traverses a larger radius and feels less lateral G force than the trailer. For this reason, the driver will sense less danger of tipping than may actually be the case.
- On a banked circulatory road, the driver on the larger radius again feels less lateral G force than the trailer and will feel less danger of tipping than is actually the case.
- What has become common in Canada and the U.S. is continuous adverse crossfall, coupled with a truck apron. From a physics standpoint, this may be the worst possible combination. Aprons are typically elevated 50 to 100 mm above the circulatory road at the curb and designed with an outward slope of 2% or more. This creates far greater lateral G force on the trailer than that experienced by the driver.

Figure 3.8
Circulatory Road Cross Section Comparison



Source: Ourston Roundabout Engineering, Inc.

The preceding comparison considers only the circulating truck, but stability is also a concern while entering and exiting a roundabout. In the absence of significant Canadian or international data, research should be undertaken into the physics of various circulatory road designs for various movements through a roundabout. For now, it is likely inherently safer for the truck driver to feel more lateral G force than the trailer experiences. Therefore, truck aprons should be used with caution at roundabouts.

Vertical clearance is also a concern at roundabouts (and at other intersections). When designing to accommodate "lowboy" truck trailers and car haulers, it is not just the ground clearance of the trailer, but the combination of ground clearance, wheelbase, and vertical elevation of the road that determine whether a truck will run aground. Some lowboy trailers have a ground clearance of only 50 mm. Roundabouts can be designed for these vehicles, and for other trucks with oversize dimensions, but this usually requires compromising on the height of the truck apron or certain geometric parameters. Some responsibility should also be placed on those who manufacture and operate these vehicles.

4.0 CONCLUSIONS

Roundabout designs should accommodate the mix of users (pedestrians, visually-impaired pedestrians, cyclists, cars, buses, trucks, oversize loads, etc.) expected to use the intersection. There are a variety of issues associated with these user classes, and optimizing conditions for “small” users may make them worse for “large” users (and vice-versa).

A number of treatments exist to accommodate pedestrian crossings at roundabouts. One issue relates to pedestrian safety and the use of pedestrian signals. Research has shown roundabouts are safer for pedestrians than signalized intersections. In an effort to make them more accessible it is possible the implementation of signals at a roundabout may lessen overall pedestrian safety. Unfortunately the perception among many is the opposite, that roundabouts are not as safe for pedestrians due to the absence of a positive exchange of right-of-way priority.

Another issue is that of cyclist safety. Cyclists riding on the right side of the road can face additional conflicts compared to drivers when travelling through or exiting a roundabout, particularly a multi-lane roundabout. They are considered to be the most vulnerable users of roundabouts. Research has shown single-lane roundabouts and low-speed designs are the safest for cyclists.

Bigger roundabouts and multi-lane designs are better for trucks and other large vehicles, although a number of treatments exist to accommodate them without making the entire roundabout larger. Trucks commonly encroach on adjacent lanes in multi-lane roundabouts. The use of circulatory road striping can enable a truck to stay in its own lane while circulating, but this does make the roundabout larger and results in other trade-offs. If the roundabout is not made larger, then circulatory road striping can encourage passenger car drivers to circulate next to trucks. Therefore the decision to stripe the circulatory road of a multi-lane roundabout should be made on a case-by-case basis.

A final issue associated with trucks at roundabouts relates to truck aprons and the vertical design of the circulatory road. Truck aprons are a design compromise to accommodate trucks at small roundabouts. They need to be well-designed so that truck drivers use them, that they accommodate lowboy trailers if necessary, and that they provide sufficient deflection for light vehicles. Research has shown truck aprons can contribute to stability problems and truck overturning even at relatively low speeds.

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