Trucks in Roundabouts: Pitfalls in Design and Operations

USING SIMPLE EXAMPLES, CASUAL CASE STUDIES AND SHARED DESIGN EXPERIENCES, THIS FEATURE PRESENTS EMERGING ISSUES REGARDING THE ACCOMMODATION OF TRUCKS IN NORTH AMERICAN ROUNDABOUTS. THE AUTHORS POINT TO THE NEED FOR FURTHER RESEARCH TO IMPROVE AWARENESS OF DESIGN PITFALLS AND TO IMPROVE DESIGN GUIDANCE REGARDING CONTEXT SENSITIVITY IN PLANNING AND DESIGNING ROUNDABOUTS FOR LARGE TRUCKS.

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ROUNDABOUT DESIGN HAS PITfalls that guides cannot easily address. The composition of a roundabout involves trade-offs and optimization for safety, capacity and cost competing within the site context. Large vehicles pose additional challenges even to experienced designers.

SOME NEGATIVE EXPERIENCES

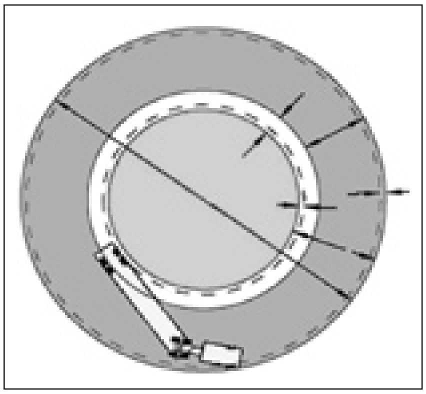
In one project, a developer built three small roundabouts. None of the participants—the developer, the contractor, the street designer, or the city—had experience designing roundabouts. The first hint of a problem was when right-turning trucks dragged their trailers over the outside curb and through the landscaping. (Larger trucks backed up to avoid damage.) The fix required widening the entries and entry radii. Even so, WB-65 trucks were limited to through movements and only WB-50 trucks could turn. The city, developer and contractor shared the $300,000 repair cost.

Another city encountered a vertical design problem. In that case, the layout used granite pavers for the apron and overrun areas. The apron was too high, and lowboy trailers dragged bottom and damaged their undercarriage and the truck apron: another expensive fix.

Truck overturns present a special concern. Contributing factors can be complex and remediation may be expensive.

THE NATURE OF THE TRUCK PROBLEM

Modern roundabouts are compact in comparison to their predecessor: the traffic circle or rotary. As a roundabout's outer diameter shrinks or the design vehicle's wheelbase lengthens, the circulating roadway must widen and the central island must shrink to let trucks turn left (see Figure 1). It gradually becomes difficult to provide entry path deflection for small vehicles, and a truck apron becomes necessary.



Source: Ourston.

Figure 1. Truck dimension considerations.

Eventually, as the circle size decreases further, any raised central island prevents trucks from using the intersection. The central island must become traversable, as with mini-roundabouts.

Measures to Accommodate Trucks

Numerous techniques are used to accommodate trucks in roundabouts. Although not strictly research-based for U.S. design practice, each design technique, which is intuitively rational, involves trade-offs in terms of safety, capacity and cost. Each of the design techniques described applies under different site conditions.

Traversable Islands

At the smallest scale, a roundabout is traversable when space is not adequate for a normal larger-diameter roundabout. The example in Figure 2 is a mini-roundabout in a 25-mile-per-hour zone. It has an outer diameter of 69 feet, and large vehicles overrun the central island. The environment, speed-hump effect and yield control deter other drivers from speeding. At this location in Dimondale, MI, USA, the truck swept paths require use of paint and rumble strips for much of each splitter island. Illuminated bollards (recently updated with U.S. symbols) provide stopping sight distance for the intersection.

Source: Ourston.

Figure 2. Mini-roundabout in Dimondale, MI, USA.

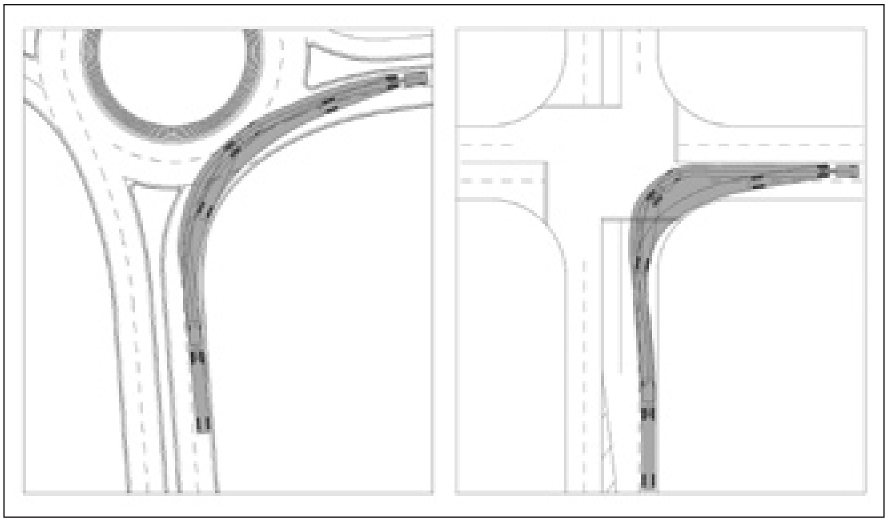


Figure 3. WB-65 right-turn comparison.

Truck Aprons

Truck aprons are a compromise to accommodate large vehicles in a compact circle while preserving entry path deflection for lighter, faster vehicles. Aprons are mountable by trucks but should discourage cars and pedestrians. If the apron is too aesthetic, truck drivers mistake some aprons for landscape area. Aprons do not provide deflection as effectively as a full raised island and, in some circumstances, an apron may cause truck stability or under-clearance problems.

In compact roundabouts, right turns are often tighter than left turns, and trucks are accommodated in several ways, as described in the following sections.

Use of the Adjacent Lane

As at multilane crossroads, trucks often use the adjacent lane to turn right at a roundabout. This can suffice in situations where trucks are a small percentage of traffic. Trucks maneuver with caution, and light vehicles give way to the larger vehicle. Driver responsibility applies equally at roundabouts as at signalized crossroads, as shown in Figure 3.

Widened Entries and Entry Lanes

At higher traffic volumes and with increased truck percentages, trucks may need wider entries to turn without using the adjacent lane. Extra turning space can be added using hatching between entry lanes, providing space for wider right turns. Hatching also aligns paths for light vehicles.

Right-Turn Aprons

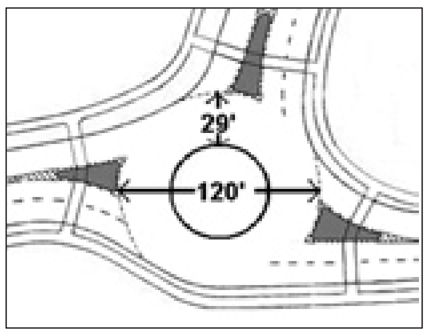
Some road agencies have also used aprons for right turns (blisters). Pedestrian safety is a consideration with this practice. The adoption of blisters is usually evidence that designs are not being properly composed.

Bypass Lanes

A variety of bypass lanes can also be used. Right-turn bypass lanes may be part of the entry and controlled by the yield line, or they can be channelized and either free-flow or yield-controlled. Bypass lanes can be provided upstream if needed.

Use of Full Circulating Roadway Width for Truck Movements

Trucks comfortably use the entire circulating roadway in moderate-diameter roundabouts. In the layout shown in Figure 4, the outer diameter is 120 feet and the unstriped circulating roadway is 29 feet. Trucks use the full width, so a truck apron is not needed. A narrow paved strip on the central island prevents ruts from errant truck tires.



Source: Ingham County Road Commission.

Figure 4. Small roundabout without truck apron.

TRUCKS AND CIRCULATORY LANE STRIPES

Striping the circulatory roadway of compact, four-leg multilane roundabouts is revealing undesirable side effects, including problems for lane discipline with trucks. In roundabouts with circulatory stripes, trucks often straddle lanes, but guidelines currently do not address this. If trucks are required to remain in lane, the designer is forced to enlarge the geometry, often creating imbalance with competing safety objectives. Extra size adds cost and increases entry speeds, associated with increased crash frequency and severity.

Multilane roundabouts built in North America before 2002 did not have stripes or arrows on the circulatory roadway. Many of these remain in service and unmarked, with trucks still using the full pavement width. Car and truck drivers exercise due diligence, and aprons are still not needed. In the past few years, stripes have been used to deter vehicles from turning left from the outside lane. However, like vitamins versus medicine, it is preferable to assign drivers to their correct lane before they arrive at the roundabout rather than correct for wrong entry lane choice because approach information is insufficient.

Depending on roundabout diameter, a truck might travel completely in the outside lane with room for another vehicle. With stripes, observations show drivers tend to circulate next to large vehicles, even if that is unsafe. Trucks may also try to circulate side-by-side, but geometry is rarely designed for that. If a truck in the inner circulating lane must remain in lane, this can force the use of a truck apron.[1]

A CASE STUDY OF TRUCKS, STRIPES AND APRONS

The Interstate 17/Happy Valley Interchange roundabouts in Phoenix, AZ, USA, were built as multilane roundabouts in 2001 but operated as single-lane roundabouts until they were modified in 2005. To add capacity, both roundabouts were reconstructed with wider circulatory roadways in order to facilitate two-lane operation. Spiral lane markings were also added, with truck aprons to aid in truck lane discipline (see Figure 5). By 2007, each carried approximately 2,500 vehicles during peak hours, with truck percentages between 17 and 34 percent.[2]

Ten months of crash data showed increased crash rates (259 percent in the east roundabout and 55 percent in the west roundabout), including five overturned trucks. (See “Truck Overturns” for several possible explanations.) Injuries per year (seven) also doubled, although severity was low. In 2007, the Arizona Department of Transportation directed a study to evaluate the interchange.

Both roundabouts exhibited numerous sideswipes, mostly in the circulating roadway. Drivers drifted into adjacent lanes or abruptly changed lanes to exit the roundabout from the inner lane. Crash patterns suggested that incorrect lane choice at entry and poor geometry at exits were the root causes of the sideswipes.

Figure 5. Happy Valley east roundabout.

Table 1. Survey of 624 trucks at Interstate 17/ Happy Valley Interchange roundabouts.

	Truck Used Apron	Truck Did Not Use Apron	Total
Truck Entered Alone	78 (12.5%)	448 (71.8%)	526 (84.2%)
Truck Entered with Car Adjacent	66 (10.5%)	32 (5.1%)	98 (15.7%)
Total	144 (23%)	480 (77%)	624 (100%)

Source: Lenters, M. Roundabout Apron Use Study. Data collected by United Civil Group, Phoenix, AZ, USA, July 2007.

As expected, adding lanes added conflicts for all vehicles. With two lanes, previously unimportant geometry became critically important to crash and safety performance. The data do not show conclusively whether circulatory lane striping influenced crash frequency. A test would be to operate with and without stripes and compare the two periods. The stripes were upgraded and made wider to reinforce lane discipline. Data were also collected on peak-hour apron use by semis and large single-unit trucks (see Table 1).

Of 624 trucks (single units and semis) entering the roundabouts, 77 percent did not use the apron. Of those that did, two-thirds used it only if a car was in the adjacent lane. Eighty-four percent of trucks drove through alone. (Field staff reported most trucks entered using both lanes in spite of placement of wide entry path hatching, preventing cars from traveling beside them at the entry where it was wide enough.) Future research on semis is suggested.

OBSERVATIONS REGARDING STRIPES AND TRUCKS

Most multilane roundabouts do not need aprons if circulatory stripes are not applied. At Happy Valley, 77 percent of trucks do not use the apron even with stripes. The United States recently began building aprons on multilane roundabouts because of excessive lane discipline and cars getting in the way of trucks. Stripes are apparently a contributing factor. Among unstriped U.S. roundabouts in service for more than 10 years and those built recently, none have this problem. Examples include the first modern roundabout interchanges in Vail and Avon, CO, USA.

Better geometry and approach signage can preclude stripes in many cases. Striping was intended to deter incorrect entry lane use and delineate exclusive left-turn lanes or double lefts. Practitioners did not foresee that circulatory stripes would introduce serious new problems, such as the extreme case of requiring two WB-67 trucks to track side-by-side through a striped roundabout. Side-by-side trucks seem excessive within a roundabout or any other intersection. More research is needed on the safety implications of excessively wide entries and lane discipline for trucks.

Example Corrective Measure

Drivers should not drive adjacent to or pass trucks in roundabouts. Where needed, it may help to post warning signs to advise motorists. The British Columbia, Canada, Ministry of Transportation uses signs to warn drivers not to circulate next to trucks. No data are available regarding the effectiveness, but early reports from traffic engineers in those jurisdictions suggest a positive effect.

TRUCK OVERTURNS

In roundabouts, as at horizontal curves, vehicles with a high center of gravity can overturn or shed their loads if they fail to reduce speed adequately.

In most cases, truck overturns at U.S. roundabouts have been attributed to excessive speed or hard braking on adverse superelevation. The U.S. roundabout crash sample is small and the commercial driver population is still inexperienced with roundabouts. However, the United Kingdom has about 20,000 roundabouts and 50–60 injury crashes per year involving truck overturns. Most are low-speed and do not cause serious injury. The Transport Research Laboratory (TRL) reports five common characteristics of roundabouts with truck overturns: [3]

1. long, straight, high-speed approach;
2. inadequate entry deflection;
3. low circulating flow past the entry;
4. clear visibility to the left (U.S. left); and
5. significant tightening of radius part way around the roundabout.

The U.K. Highways Agency adds three features that may contribute to overturns:[4]

1. excessive grade breaks/cross-fall changes on circulatory roadway or exits;
2. excessive adverse superelevation on the outside lane of the circulatory roadway; and
3. excessive entry path deflection.

Trucks have sometimes tipped at very low speed (10–15 miles per hour), and the physics are not due to a single radius. A combination of speed, mass, center of gravity and successive curves rocks the suspension at a critical frequency.

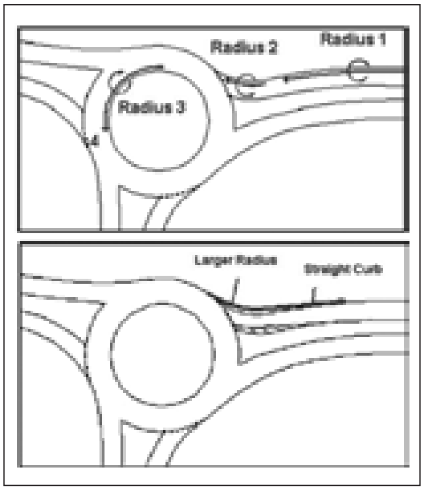
Successive reverse curves introduced a rocking motion that increased as trucks traversed the curves, leading to overturn at point 4 (see Figure 6). Timing of the rocking depended on the speed of the vehicle and the harmonics of the suspension. The speed that matches the harmonic may be low, so a faster or slower speed would not cause tipping.

The countermeasure proposed by Crown is to introduce a short tangent section after radius 1—stabilizing the truck suspension before radius 2. Increasing radius 2 then reduces rocking at that turn, dampening the harmonic. One other installation has benefited considerably from this treatment.

CIRCULATING ROADWAY CROSS-SECTION

What cross-section is best for truck stability—crowned, banked, apron, or adverse super? Opinions are plentiful, but controlled data—corrected for exposure and local conditions—are not. This is another area where further research is needed.

TRL calculates that different cross-slopes have little effect on speed: deflection slows vehicles before entering, and there is little time to accelerate in the roundabout. A TRL trucker survey on the Dover, England to Calais, France, ferry found that drivers respected roundabouts—whether crowned, as in the United Kingdom, or outward sloping, as in France.



Source: Crown, R. Accidents on the A50 Blythe Bridge Roundabout. Stoke-on-Trent, United Kingdom, 2007.

Figure 6. Truck harmonic overturn and countermeasure.

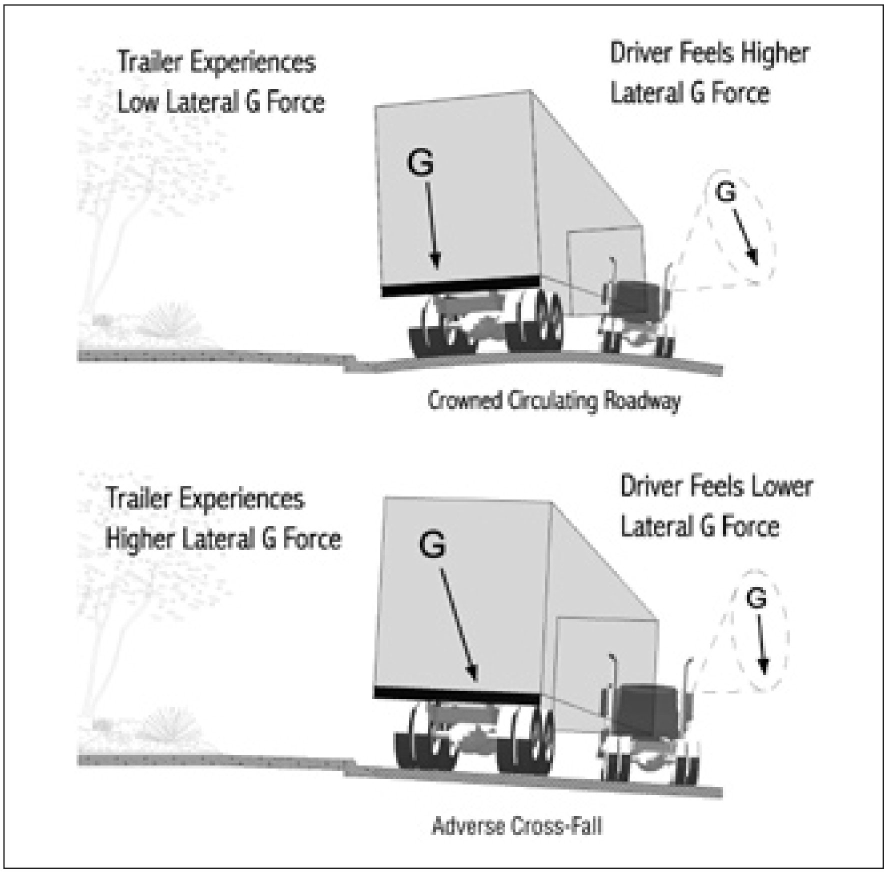
Safe speed depends on the height of the trailer's center of mass and the type of load, and choice of speed depends on how drivers react to the roundabout. In the absence of conclusive data, intuition and casual interviews with truckers reveal a supposed pattern of behavior and physics. As a semi rounds a curve or a roundabout, the trailer tracks a tighter radius than the tractor. The driver reacts to what he/she sees, and to "seat of the pants" gravity. The driver in the cab follows a larger radius than the trailer and may experience less lateral force than the trailer.

Properly designed cab suspensions roll more than the trailer suspension, increasing the driver's seat of the pants sense, but drivers may become used to that sensation. Physics ultimately dictate when and where a load shift occurs or if a truck tips.

The following comparison considers only the circulating roadway and predominantly left-turning trucks. Stability is also a concern while entering and exiting. In the absence of field data, research into the physics of various designs is recommended.

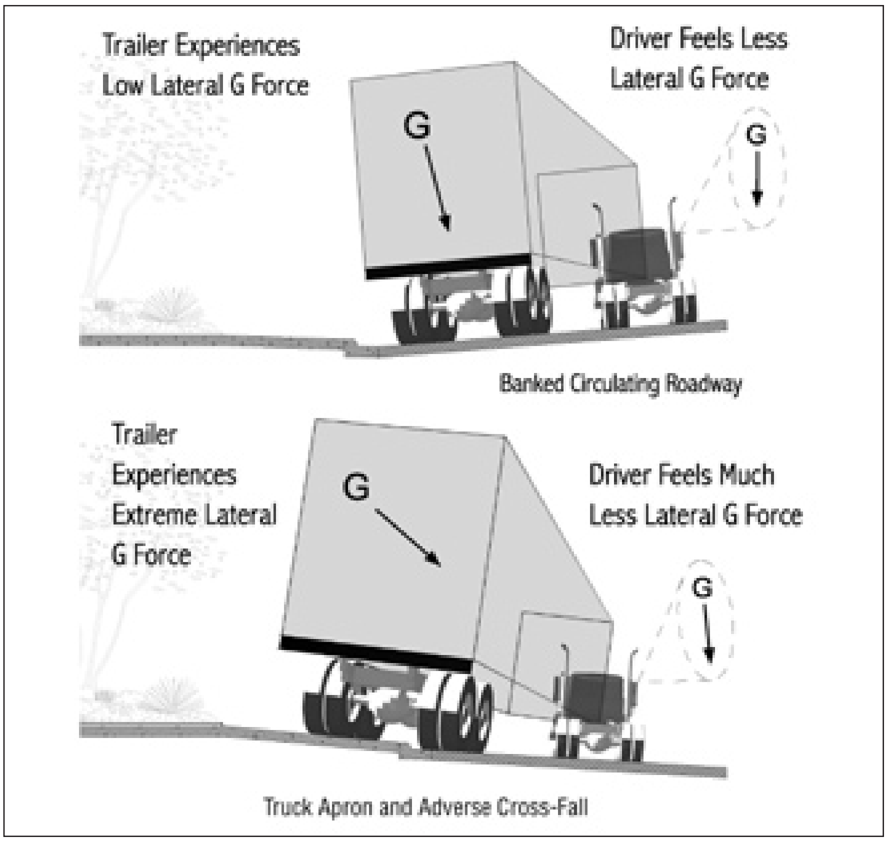
Circulatory Roadway Crowned Condition

On a crowned circulatory roadway, the trailer leans inward compared to the cab, and the lateral force on the trailer is closer to perpendicular with the road surface than for the cab. Because the cab experiences more lateral force than the trailer, the driver will presumably operate within the safe speed range for the trailer. Inward slope would counter the roll moment created by the circulating



Source: Ourston.

Figure 7a. Truck seat-of-the-pants sense.



Source: Ourston.

Figure 7b. Truck seat-of-the-pants sense.

vehicle. The top of Figure 7a illustrates this condition. U.K. roundabout design guidelines have promoted this design for all roundabouts since 1993 with no evidence to change practice to date.

Adverse Circulatory Cross-Fall

With adverse cross-fall (bottom of Figure 7a), the cab experiences less lateral force than the trailer. The driver may sense less danger of tipping than is actually the case. Both the vehicle suspension and the air suspension on the cab will experience the same slope, providing consistent feedback to the driver. However, constant adverse cross-fall when coupled with a smooth entry transition may have advantages if drivers slow adequately as they enter.

Inward Sloping Circulatory Cross-Fall

On a circulating roadway banked inward (see Figure 7b, top), the cab traverses the circulatory on the larger radius, again experiencing less lateral force than the trailer.

Adverse Circulatory Cross-Fall with a Truck Apron

A continuous outward cross-fall with truck apron (see Figure 7b, bottom) has been developed in the United States, but this appears to be the least desirable design combination. Aprons are elevated several inches, with a cross-slope of 2 to 4 percent, raising the left trailer wheel several inches above the circulating roadway. This exacerbates adverse cross-slope for the trailer as compared to the cab. If the trailer is loaded high or enters slightly fast, the potential for load shedding peaks in a left-turn movement.

RECOMMENDATIONS

Designers of modern roundabouts should know design vehicle needs and be aware that truck aprons are a design accommodation for compact geometry.

Stripes have value in many cases (such as dedicated left-turn lanes), but circulatory roadway stripes should not be mandated at all multilane roundabouts. Instead, improved approach guidance comprising correct lane arrows and improved lane designation signs on approaches will clarify correct entry lane choice and reduce the need for lane changes in the circulatory, like taking vitamins instead of medicine.

Highway codes need to emphasize the simple principle of roundabout operation: Vehicles on the left have priority. Police need clear regulations for unambiguous enforcement. Drivers need to understand they must not crowd trucks, regardless of circulatory roadway stripes.

Many agencies are adopting preferences for circulatory roadway cross-section, based on first impressions, habit, or intuition. Cautious design is urged and further research is recommended.

ACKNOWLEDGMENTS

Special thanks to Janet Kennedy of the Transport Research Laboratory, Barry Crown of the United Kingdom and Jim Tipka of the American Trucking Association for providing information for this article. ■

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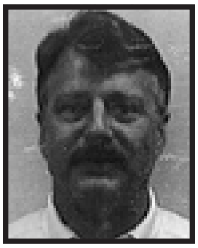

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