Unconventional roundabout geometries for large vehicles or space constraints

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Abstract

This paper investigates roundabouts with unconventional geometry (non-circular) that have been proposed during the last decade to address special constraints of space and traffic conditions. The paper presents an unconventional solution we call “two-geometry.” Two-geometry roundabouts have a circular central island surrounded by an oval circulatory roadway. The combination of inner circular and outer oval shapes allow a reduction in carriageway width on the longer section and enhancement of path deflection. The same geometric combination is useful for enlarging the carriageway width corresponding to lower radii of curvature where high-occupancy vehicles require additional turning space. Roundabouts with unconventional geometries are also investigated for better accommodating oversize/overweight large trucks (OSOW) on routes necessary to key industry and the economy. Strategies including paved areas behind curbs, enlarging truck aprons, use of minimum slopes and mountable curbs are presented. Future research is suggested for both data observation and capacity model calibration.

1. UNCONVENTIONAL GEOMETRY

Today, it is known worldwide that modern roundabouts can greatly enhance traffic safety and operations. Conventional modern roundabouts have a circular geometry both for the inscribed circle and the central island, therefore the circulating roadway has a constant width. However, circular geometry is fairly rigid and is sometime unsuitable for skewed intersections or where there is too much distance between complex intersecting roadways. These are cases with special constraints of space and/or traffic condition with the potential to be better addressed by a non-circular layout, a class of the so-called unconventional roundabout. Types of unconventional roundabout are described in the following sections.

1.1. Turbo roundabout

The turbo roundabout layout was firstly implemented in The Netherlands at the end of the last century by Lambertus Furtuijn, a researcher at the University of Delft (Furtuijn and Harte, 1997). The turbo roundabout is now common on the Dutch highway network. See Figure 1 for layout of a typical turbo roundabout.

The turbo roundabout, with its spiraling shape, is an ideal solution for eliminating some of the most severe weaving conflict points that usually arise in multilane roundabouts, where drivers must select proper lane before entering the roundabout. While a conventional roundabout has 16 potential conflict points, the turbo roundabout has 10. This low-speed configuration has been found to allow a higher capacity than the standard two-lane roundabout.

Turbo roundabouts usually have diameters (D) in the range of 40 to 50 meters (131 to 164 feets). Construction costs are similar to those of conventional two-lane roundabouts.

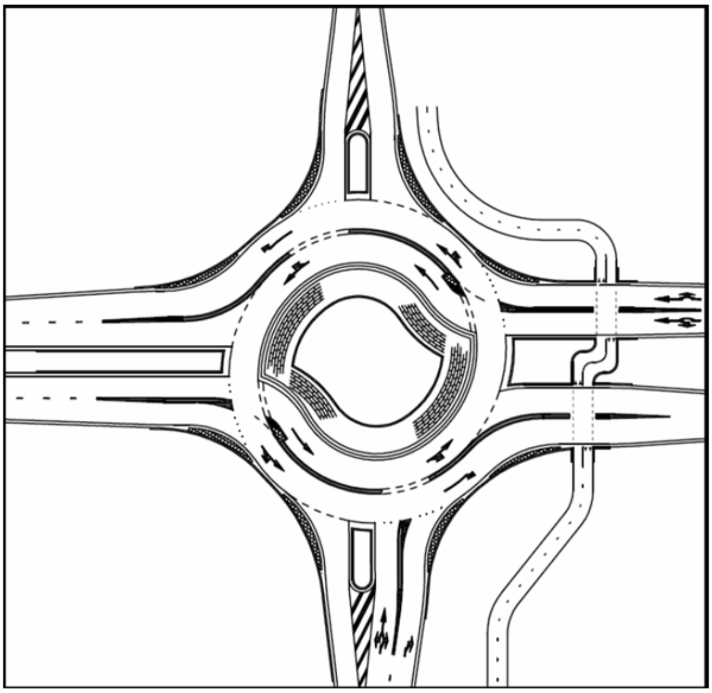

Figure 1. Typical turbo roundabout geometry.

The turbo roundabout was developed to combine the benefits of single- and multi-lane roundabouts, namely:

- no weaving takes place on the circulatory roadway;
- entering right turns need yield to (worry about) only one lane of traffic;
- drivers have clear indication of the lane on which they may exit the roundabout.

Still, the turbo roundabout requires drivers to observe strictly all traffic control and lane channelization to avoid both safety problems and significant disruption to efficiency. Drivers may hesitate (due to confusion, insecurity, etc.) when they enter the turbo roundabout's inside lane, crossing conflict points. They may enter the roundabout very slowly or only when there are large gaps. Therefore, crossing conflict points in a turbo roundabout may have a significantly larger negative effect than expected. Moreover, turbo roundabouts may be more difficult for drivers to "read" than other roundabouts. Desired benefits in safety and capacity may only be achieved if and only if:

- drivers are (very) familiar with the new form; and,
- drivers strictly follow signs and markings for lane choice, both approaching and traveling through the intersection.

Nonetheless, the turbo layout holds a sort of fascination for designers and there are many references in the technical literature related to both theoretical and applied issues. Recently, Slovenian researchers have tried to overcome turbo roundabout drawbacks introducing "depressed" lanes for right-turners (Tollazzi et al., 2011). Other researchers have performed simulation experiments to compare the performance of conventional multilane and turbo roundabouts under similar conditions (Mauro and Branco, 2010)

1.2. Teardrop roundabout

Teardrop, or raindrop, shaped roundabouts are usually associated with locations where certain turning movements cannot be safely accommodated, or at ramp terminals at interchanges. See Figure 2 for an example. Ramp intersections may be configured as a pair of roundabouts to create a so-called “twin roundabout” interchange. A variation known as the “dog-bone” occurs when the roundabouts do not form a complete circle but instead have a "double teardrop" shape (WSDOT, 2011).

Teardrop-shaped central islands eliminate direct U-turn movements (U-turns can be made by circulating around both roundabouts), and reduce yielding conflicts for vehicles entering the teardrop roundabout from the ramps, thus improving capacity and reducing delays and queuing.

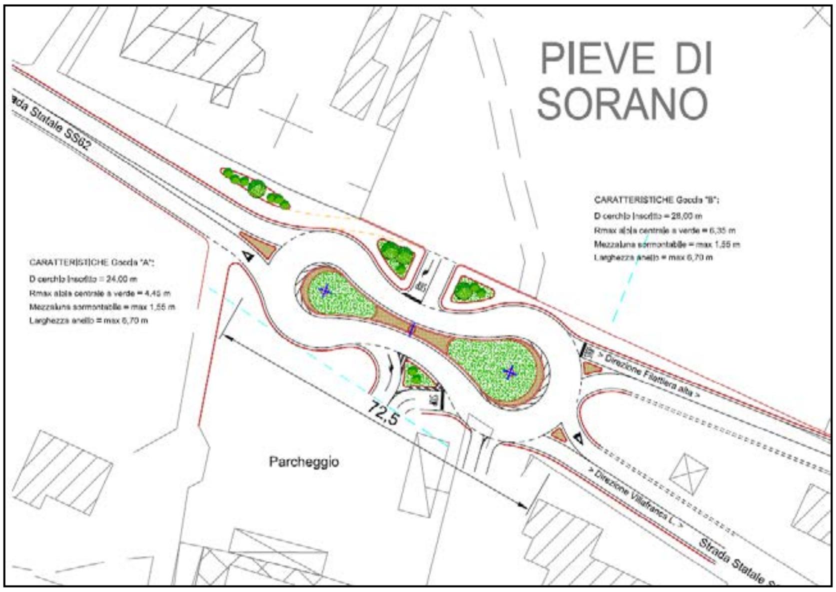

Figure 2. A compact double-teardrop layout designed for a constrained intersection in Filattiera (Italy).

Teardrop geometry is useful for application to ramp terminals where U-Turns are generally unnecessary. Because it does not allow full circulation around the center island, it can be very useful if grades are a design issue eliminating one potential cross-slope constraint. However, teardrop shapes lack operational consistency, because one entry will not be required to yield to any traffic. Because of this, an undesirable increase in speed may occur. Further, if an additional road intersects the ramp terminal, teardrop geometry should not be used.

1.3. Two-geometry roundabout

A two-geometry roundabout is defined when the shape of the external margin is different from that of the central island, e.g. the central island is circular and the external margin is elliptic. In other words, the circulating roadway width is not constant. The advantages of two-geometry roundabouts are the following:

a) two-geometry roundabouts can require less space, and may be more suited to locations with boundary constraints;
b) two-geometry roundabouts guarantee trajectory deflection and foster speed reduction with smaller centerline offsets, as may be common with “T” intersections;
c) two-geometry roundabouts may be more conducive to oversize/overweight large trucks (OSOW) due to varying lane width.

Point b) above is especially important when an approach must be offset to the right of a roundabout's center point where in conventional roundabouts, vehicles will be able to enter too fast, potentially resulting in more crashes between entering and circulating vehicles – see Figure 3 (FHWA, 2000).

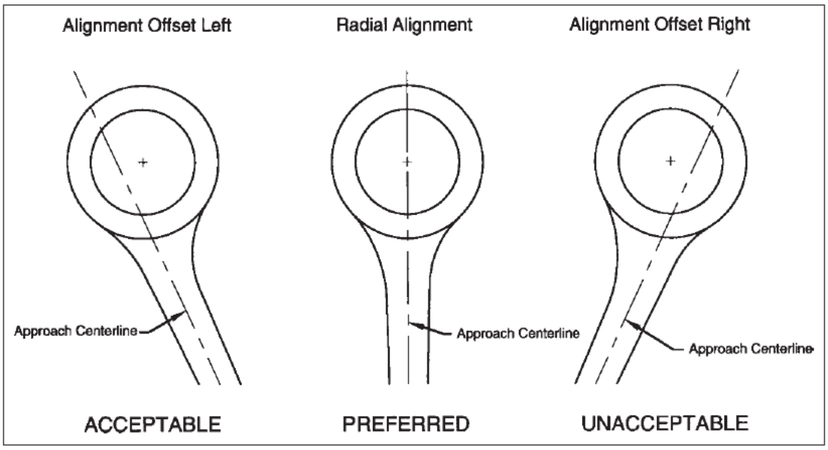

Figure 3. Recommended radial alignment of entries for conventional roundabout (FHWA, 2000).

Two-geometry roundabouts are able to address the problem of the offset to the right of the approach centerline. The minor axis of the external margin ellipse may be aligned in such a manner that the approach centerline offset is balanced and reduced. This way the alignment brings the approach in at an angle and increases the opportunity to provide sufficient entry curvature.

2. CONVENTIONAL VS TWO-GEOMETRY LAYOUT

Conventional and two-geometry roundabouts were compared using traffic flow micro-simulation software AIMSUN 6.1 for T intersections (see Figure 4.) The principal dimensions of the test roundabout can be seen in Table 1.

Each of these solution layouts was considered under different combinations of geometry and traffic as follows:

- *traffic volume*: three different peak hour flow patterns, characterized by prevailing direction of entering flow;
- *approach centerline offset*: two centerline offsets were considered, one with full centerline offset, i.e. tangent, and the other without any offset from the roundabout center, i.e. centered (see Figure 5);
- *traffic composition*: six different percentages (0%, 5%, 10%, 15%, 20% and 25%) of heavy vehicles were considered.

Figure 4. Test intersection layout with full centerline offset, or tangent: conventional roundabout (left) and two-geometry roundabout (right).

	Conventional	Two-geometry
Inscribed diameter	41.0 m (134.5 ft)	min 32.0 m (105.0 ft); max 41.0 m (134.6 ft)
Central carriageway width	6.0 m (19.7 ft)	min 4.5 m (14.8 ft); max 6.50 m (21.3 ft)
Central apron width	1.7 m (5.6 ft)	1.2 m (3.9 ft)
Central island radius	12.8 m (42.0 ft)	10.0 m (32.8 ft)

Table 1. Dimensions of the test roundabouts

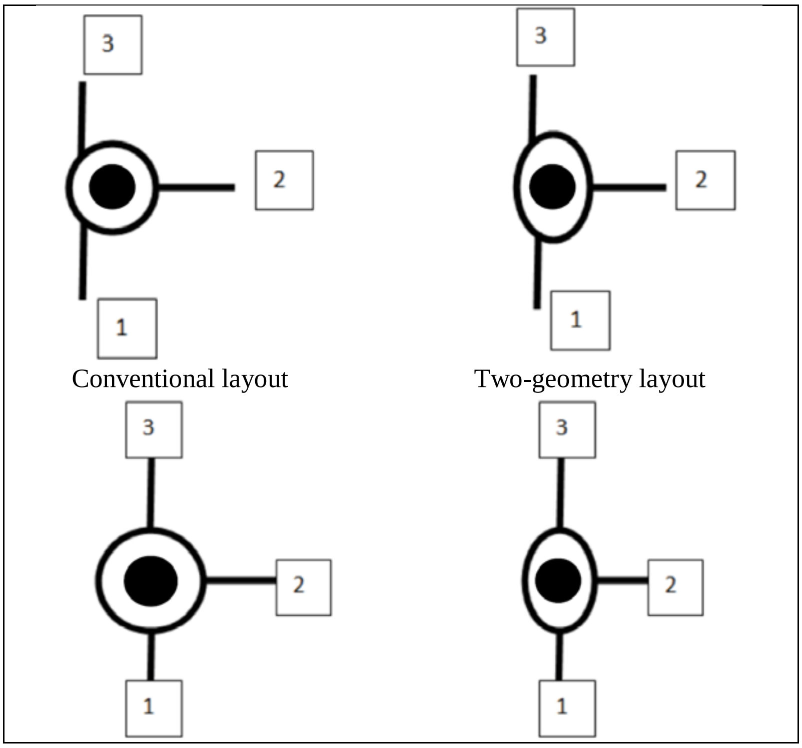

Figure 5. Full approach centerline offset from the roundabout center, on tangent test layouts (top) and approach centerline aligned with roundabout center on centered test layouts (bottom).

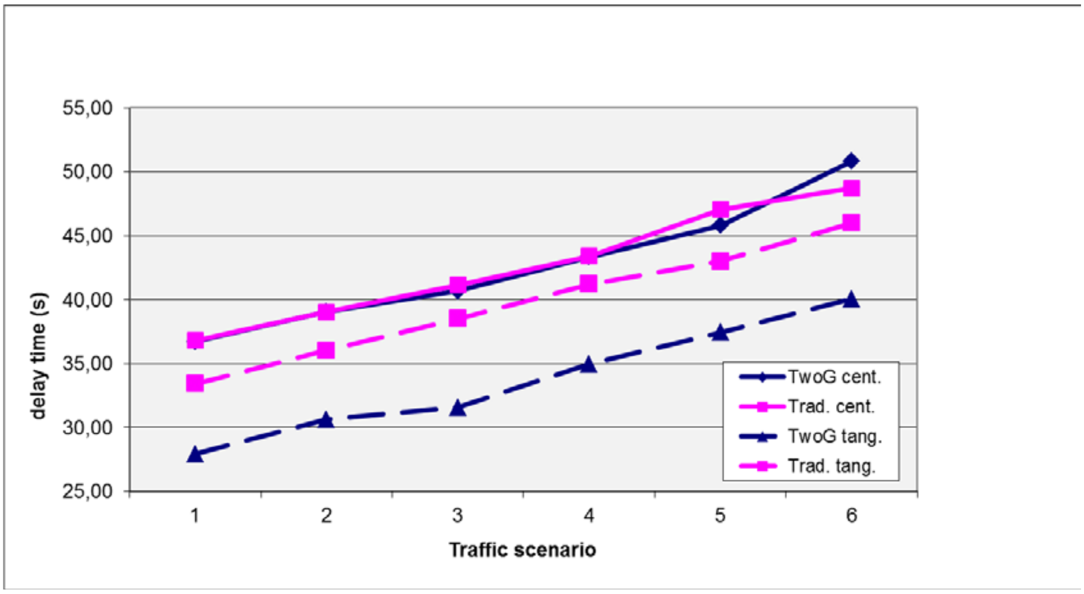

Figure 6. Comparison of average delays.

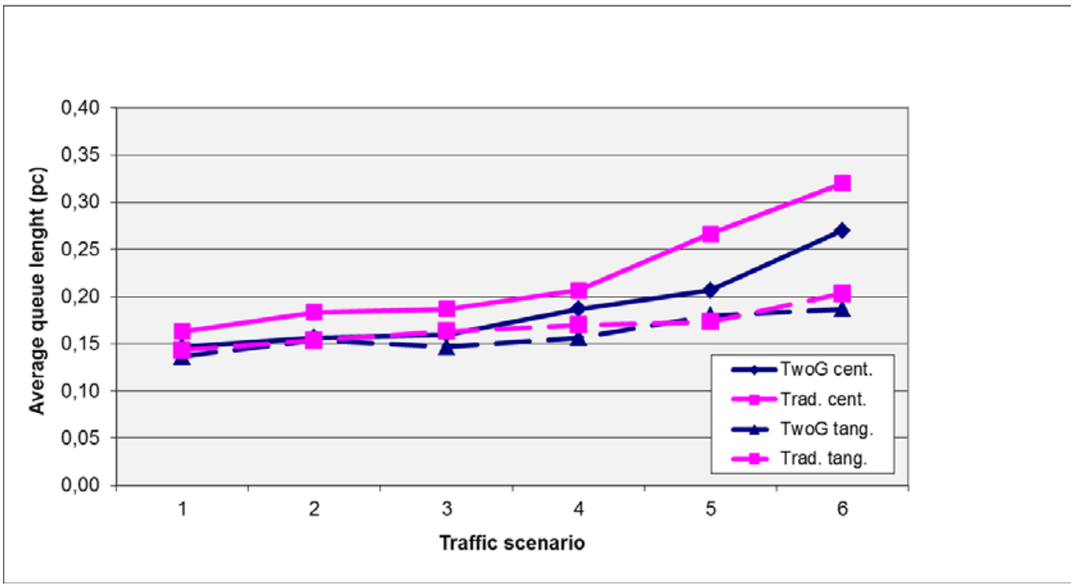

Figure 7. Comparison of average queue lengths.

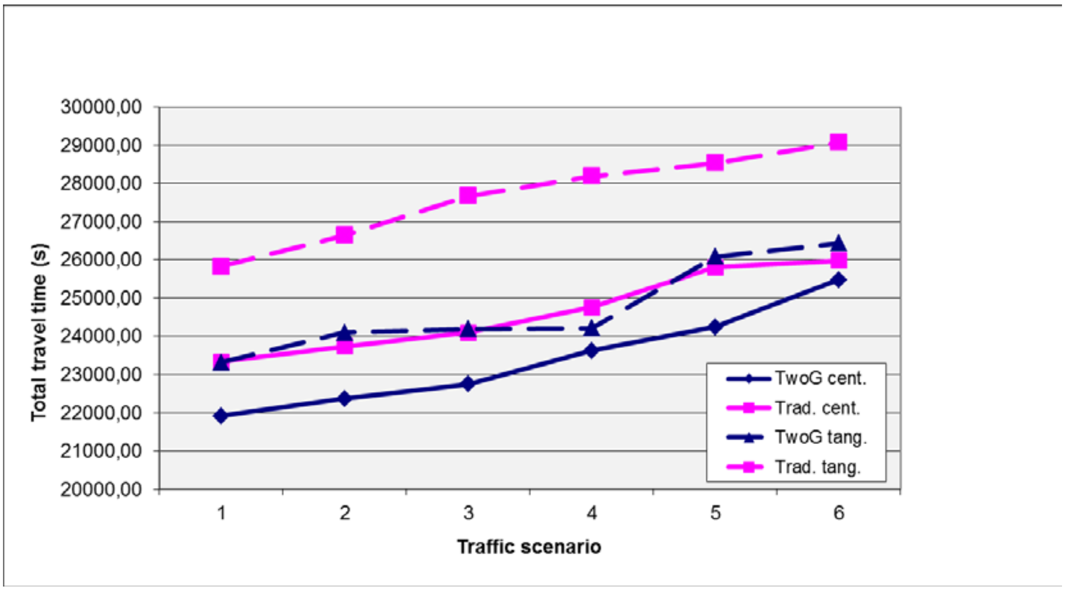

Figure 8. Comparison of total travel times.

Results of the micro simulation are summarized in Figures 6, 7 and 8. These figures show that there are significant differences between the layouts with tangent and centered approach centerline conditions.

Congestion and queue lengths are approximately the same in centered layouts, both for conventional and two-geometry roundabouts (see continuous lines in the figures). But for tangent approach centerline, there are significant differences. The two-geometry solution in tangent conditions provides lower delays when compared to the conventional circular solution, across varying levels of entry flow and traffic composition (see dashed lines in Figure 6, 7 and 8).

These last results provide experimental confirmation of the basic idea underlying the two-geometry roundabout, the concept of variable width of central carriageway. That is, the design offers larger width where curve radius is lower, and smaller widths where the fastest trajectories need to be effectively deflected. “Tangent” conditions, frequently seen at T intersection, demonstrate the enhancing capabilities of the two-geometry roundabouts.

3. OVERSIZE TRUCK ACCOMMODATION PRINCIPLES

Roundabouts in the United States are intentionally designed to operate at slower speeds, with narrow curb to curb widths and tight-turning radio (Russell, Landman and Godavarthy 2012, 2013). Given these conditions, roundabout use by large and oversize trucks may be difficult or even impossible. Therefore, the central issue is how to accommodate these vehicles where necessary without sacrificing the safety and operational efficiency of the roundabout.

An eight-state pooled fund study was conducted to compile current practice and research by various states and countries related to the effects of oversize, overweight vehicles (OSOW) have on roundabout location, design, and accommodation. As stated in the study final report:

> *This research project is necessary to compile current practice and research by various states and countries related to the effects OSOW have on roundabout location, design, and accommodation. Second, the research will attempt to fill in information gaps with respect to roundabout design and operations for these classes of vehicles. Currently there is little information available for accommodating the OSOW vehicle classes in roundabout design.*

To satisfy the objectives of the study, and in addition to an extensive compilation of published and unpublished research worldwide, four surveys were conducted – two with US states and two with industry. Personal contact was also made with several domestic and international designers. Some of the concepts uncovered and reported in the study can be called “unconventional.” A few of the more promising ones are presented below.

3.1 Conclusions from the Industry Surveys

In order to solve the truck accommodation problem, knowledge of the exact nature of the problem is required. The authors teamed up when the American Trucking Research Institute (ATRI) which forwarded a survey to their membership. A second industry survey was conducted with regional managers of the Specialized Carriers and Rigging Association (SC&RA).

Although responses to the survey covered a wide range of issues, a few general concerns that directly relate to the accommodation of OSOW at roundabouts were expressed. One concern stood out and was expressed more times than any other:

> Ground clearance by lowboys is a major problem. This directly relates to just about all vertical elements of a roundabout from the splitter island to outside curbs and truck aprons and associated curbs.

More specifically, responses from the SC&RA survey again brought up the issue of clearance a number of times. This also included horizontal clearance. For example, while it was noted that flowers, ornaments, and statues, etc. can add to the beauty of roundabouts, they can be obstructions to OSOW horizontal clearance. The authors agree that use by OSOW vehicles should be considered and that obstructions should be eliminated or kept to a minimum where OSOW are expected.

Other strategies that the respondents felt had merit in applicable situations were the following:

1. Providing wide truck aprons (12 feet or more) with a minimum slope and mountable curb;

2. Customizing center islands to address known left turns;
3. Tapering center islands to support through movements;
4. Paving the area behind the curb (in the US, right side for off tracking);
5. Installing removable signs of setbacks for permanent fixtures (light poles);
6. Allowing trucks to cross over the median (stamped, depressed or corrugated) before entering the roundabout , in a counter flow direction, to make a left turn in the opposing lane and then cross back over after the turn;
7. Providing right turn lanes (sometimes gated).

The second industries study, distributed by ATRI, concluded that truck drivers dislike roundabouts. However, when asked what specific problems they had with roundabouts their answers were too general and varied to categorize into their responses into specific, constructive accommodation concepts. That said, most comments had to do with either ground clearance, tight radii, narrow lanes (or not being able to stay in a lane) and being crowded or cut off by other drivers. Overall, the respondents' general comments state or infer that they prefer bigger roundabouts and wider lanes.

Of course increasing the size of roundabouts is contrary to the principal objective of roundabouts, that is, safety. Safety with conventional circular modern roundabouts requires a relatively small roundabout with sufficient deflection to control speed; however, on routes which must accommodate large trucks and OSOW some trade-offs may need to be made. Some of the possible trade-offs are covered below.

3.2 Examples from Personal Contact with Designers and Researchers

This section contains a list of ideas and concepts that were obtained from contact with designers and researchers in the US and Europe (Russell, Landman and Godavarthy, 2012). This list was also presented in a paper presented at a TAC meeting in Winnipeg, Canada (Russell, Kandman and Godavarthy, 2013). Only a few are illustrated here (many more are illustrated in the project final report).

1. Kansas state highway roundabouts. These are generally bigger than the typical roundabout but considered appropriate for high-speed state highways with high truck percentages. They accommodate OSOWs traveling on Kansas highways including the WB-67.
2. Where signs need to be removed, easily removable and replaceable types are desired. Off-tracking is a characteristic of large vehicles and most OSOW vehicles need extra space outside of the travel lanes. Considerable discussion of this is included in the project final report.
3. An example from France shows a low-level central island which is composed of stabilized turf which allows OSOW to go straight across. Stabilized turf can also reduce or prevent rutting when wheels go outside of curbs.
4. The authors believe that wide truck aprons, even to the extent that the central island is all or mostly all truck apron (or paved or stabilized soil) have good applicability for accommodating OSOW. Several examples and illustrations are shown in the project final report.
5. In Australia, one of the authors has observed a roundabout with a central island which is essentially a raised level pad of concrete. This would also allow OSOW to go straight across.
6. Truck apron details and examples of curb heights are presented and discussed in detail in the project final report. Several photos of truck apron details are shown. In England and the Netherlands central island elevations can be very low. In these cases, a rumble strip may provide disincentive to encroaching small vehicles, keeping them in the circulating roadway.
7. Another truck apron detail from the Netherlands is to use a rough surface, e.g., cobblestones which would accommodate OSOW but discourage small vehicles because of the roughness.

The advantage of this (and the rumble strip idea from number 5, above) permits low central island elevation.

8. Roundabout operational issues are discussed and illustrated in the project final report. An illustrated concept is to have a narrow or tapered central island allowing space for extra truck aprons as needed for certain movements. Another concept is to allow counter flow, i.e., traveling clockwise around the roundabout or movement against the normal traffic flow for certain portions of certain movements.
9. An example is presented in the project final report where a manufacturer needed the ability to transport 165 foot concrete beams with a haul length of 216 feet. The steps listed appear to be typical for this sort of accommodation:
    - Adding additional tracking pavement to both the central island and outer curb line locations,
    - Creating special truck turning templates in CAD turning software. In this case, the manufacture tested the maneuverability of the design with a scaled model of the beam truck.
    - Locating signage and lighting to avoid conflicts.
    - Installing removable sign sleeves in the splitter islands and outside critical curb areas.
    - Installing mountable curbing for additional truck movements, where needed.
    - Paving island areas for truck tracking ability.
    - Setting subtle grade changes throughout the roundabout intersections to minimize torque stress on the beams.
    - Designing for steerable rear axles. (Josh Stratka, Strand Associates)
10. Roads that may be placed through roundabouts to accommodate through movements are common in Europe. Several examples of these are shown in the final report with photos from the Netherlands and Germany.
11. An example of a temporary accommodation scenario is discussed and illustrated in the project final report. This is a situation where a 531,000 pound, 210.5 foot long, 19 foot high, abatement tower was accommodated through a roundabout in Kansas by laying down mats to protect pavement and areas where off tracking was necessary.
12. Some design ideas, such as using layouts and parking lots and/or moving scale models over drawings to determine proper turning paths are illustrated in the project final report.
13. The Wisconsin Department of Transportation (WisDOT) developed a freight network which included an OSOW sub network on which all segments had to accommodate seven check vehicles. The authors believe all states should consider developing their own. WisDOT conducted a study and developed guidelines, which they immediately put into effect (May 3, 2012), to mitigate low vertical clearance problems, i.e., the global vehicle "hangup" problem, as well as truck apron slope and roadway cross section.

3.3 Some Accommodation Examples

Based on material gathered for this study, surveys and interviews, an ideal theoretical solution for OSOWs would be a large, say 150 feet to 200 feet, roundabout with an elevation no more than 3 inches above the roadway. It should be possible to accommodate OSOW at roundabouts with widened entries and exits, unobstructed central islands with large truck aprons, outer truck aprons, bypass lanes and lanes through the center island, with mountable curbs, no vertical obstructions on the splitter islands, easily mountable curbs 3 inches or less, with signs, light poles etc. outside of the turning paths and/or designed to be easily removed. It would also have some surface treatment for path deflections of small vehicles to reduce their speeds. This is, of course, idealistic and does not take into consideration costs or right-of-way requirements.

Figure 9 illustrates a general overview of many of the concepts presented above, i.e., providing internal and external extra traversable space which could be used by OSOW.

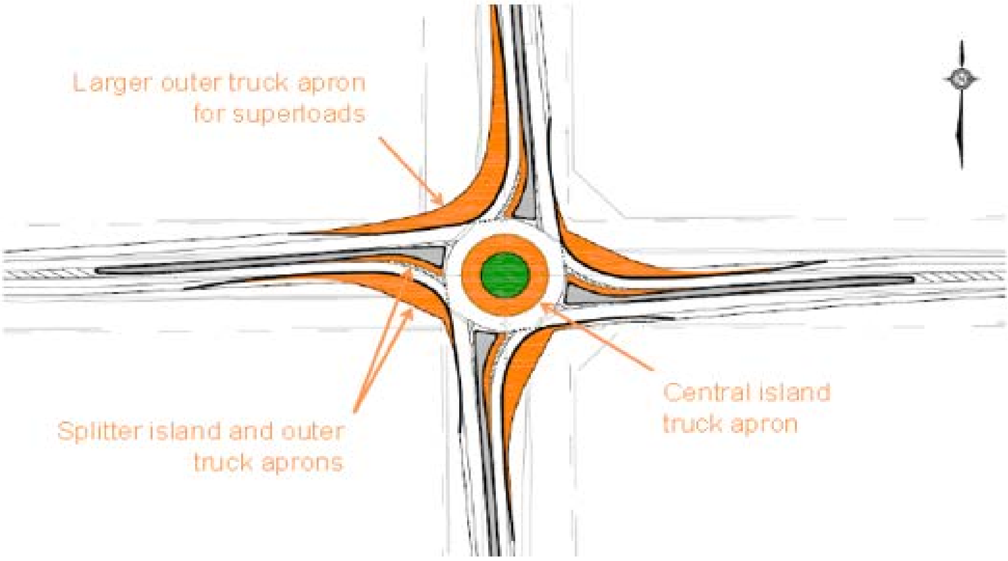

Figure 9. Truck aprons four OSOW; (from a presentation by Phil Weber, Ourston Roundabout Engineering , Canada, at TAC, Edmonton, September 2011)

The authors believe that wide truck aprons – or in some unique or special cases a central island that is essentially all, or almost all, truck apron as shown Figure 10 - can have benefits accommodating OSOW.

Figure 10. Roundabout north of Baltimore - almost all truck apron (photo by Gene Russell, 2000)

Figure 11. Advantage of wide truck apron in Arizona (Photo by Scott Ritchie, RTE, 2011)

It was noted above that one major concern of truckers are low vehicles getting hung up (see Figure 11.) Some examples of low truck aprons and curbs were uncovered. In some cases, rumble strips or cobblestones may be used to keep small vehicles off (see Figure 12).

Figure 12. Low truck aprons in the Netherlands (Top-source LGH Bertus Fortuijn) and the UK (Bottom- Source: Clive Sawyers 2012)

There are also operational concepts that can be incorporated to accommodate all OSOW vehicles through roundabouts. In some cases central islands may have to be provided with extra truck aprons and in other cases there may need to be external truck aprons. However, having all OSOW vehicles travel against the normal flow can cut down these areas. As shown in Figure 13, if vertical clearance is limited in the intended paths, i.e. to 2 to 3 inches, and landscaping obstructions in the center island are kept to a minimum, there is no reason why OSOW vehicles cannot make almost unlimited paths if counter flow is allowed. The green areas show where extra truck aprons (or possibly stabilization) would be necessary. Generally, in many cases, providing for counter flow in and through a roundabout allows sufficient accommodation for OSOW vehicles with a relatively smaller roundabout.

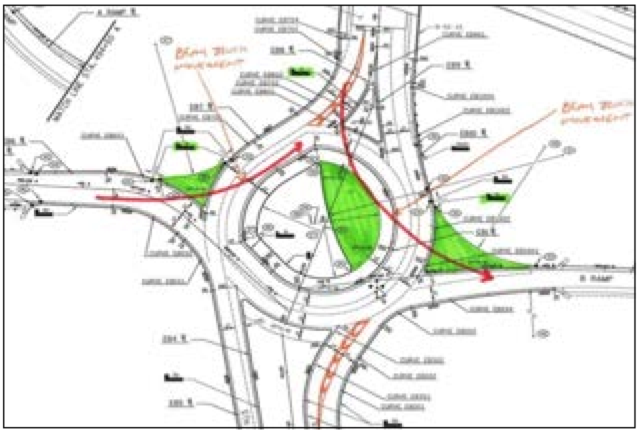

Figure 13. Slide showing schematic of possible OSOW turning movements through a roundabout (Slide from Mark Lenters, Ourston Roundabout Engineering)

Figure 14 shows a more complex double roundabout where accommodation is easily provided by allowing contraflow movements. The extra truck aprons are shown in blue. Contraflow provides a simple solution for required OSOW vehicle movements to be accommodated, while keeping size and cost down.

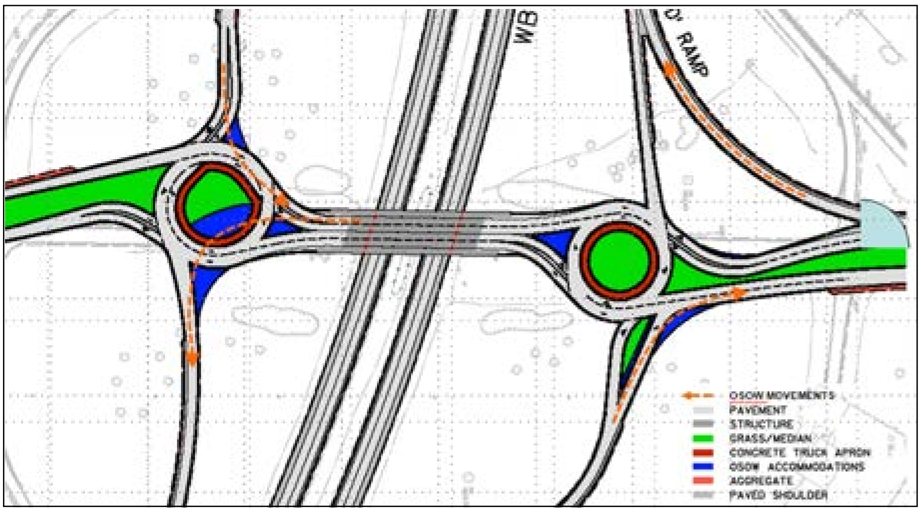

Figure 14. Illustration of accommodating OSOW at roundabouts in an interchange (Illustration provided by Josh Stratka, Strand Associates)

The design concept illustrated in Figure 14 was a design for a Wisconsin interchange. The OSOW accommodation thought process is interesting:

The Wisconsin IH 94/STH 65 interchange was designed with roundabout ramps at the WIS 65 overpass. Both IH 94 and WIS 65 were considered OSOW truck routes. The roundabouts were designed to accommodate an array of typical OSOW trucks. The design included a larger ICD (195'), six foot wide gored entries and additional circulatory roadway width. This interchange was also unique in that a concrete beam manufacturer was located at the northeast corner of the interchange. This manufacture needed the ability to transport up to 165 foot concrete beams with a max haul truck length of 216 feet. To accommodate these trucking movements at these roundabouts, the interchange included the following design details, some of which are from the list above (Josh Stratka, Strand Associates):

1. Additional tracking pavement was provided to both the central island and outer curb line locations

2. The creation of special truck turning templates in CADD turning software. The manufacture also tested the maneuverability of the design with a scaled model of the beam truck.

3. Located signage and lighting to avoid conflicts. Installed removable sign sleeves in the splitter islands and outside critical curb areas.

4. Installed mountable curbing for additional truck movements, where needed.

5. Paved island areas for truck tracking ability.

6. Set subtle grade changes throughout the roundabout intersections to minimize torque stress on the beams (Josh Stratka, Strand Associates).

Figure 15 shows a roundabout in the Netherlands with a road through the center to accommodate OSOW vehicles. Two caveats in regard to this design:

1. It only accommodates straight-through OSOW;

2. The roadway through the center island needs to be barricaded so other vehicles cannot speed through the roundabout.

Figure 15. Roundabout showing straight-through path for large vehicles
(Source: K-State Roundabout sent by L.G.H. (Bertus) Fortuijn. 2012)

A stabilized turf system which allows OSOW vehicles to go straight across the center island in the area circled by red. The photo in Figure 16 was sent by the manager of an OSOW hauling company in the United Kingdom. He pointed out that local engineers design removable road signs, chevron markings, and so forth for roundabout central islands on routes commonly used for heavy transport (OSOW) and he states that:

> *"In some cases, the council simply puts 'grasscrete' (see link for details of one type: http://www.grasscrete.com/docs/paving/grasscrete.html) straight through the RB [roundabout] so that the heavy transport (sic) don't have to navigate around but simply run through. The fact that it is grasscrete means that the grass can grow and looks good, but can support heavy axle loads. Usually these are designed so that no street furniture has to be removed" (Dave Collett, e-mail* 2011).

Figure 16. An example from the UK of a turf-stabilized center island
(photo by David Collett, Collett & Sons Ltd.)

4. CONCLUSIONS

The authors emphasize that the ideas and concepts shown in this paper and (many more in the pooled fund study final report) are just that, i.e., ideas and concepts. No attempt has been made or was ever intended that this report should be a design guide. Based on the examples uncovered the authors conclude the following:

- Wide truck aprons can aid in the accommodation of OSOW vehicles in many cases. A wide truck apron could be installed if it is needed.
- In some special cases where a need is documented, the central island could be all, or almost all, truck apron, pavement, or stabilized turf.
- The central island may have to be narrowed, tapered or adjusted to some "odd" shape allowing for additional apron, pavement, or stabilized turf to accommodate OSOW off tracking.
- Having OSOW vehicles travel counter to the normal flow, in many cases can be more cost-effective than other accommodation measures. In some cases this can be done without additional apron. The authors are unaware of any universal policy or law in any state in regard to the legality of these movements, nor does it seem to be clear if non-police escorts have authority in all states to direct or control traffic as needed. (A TRB synthesis study has been recommended.)
- Not all roundabouts need to accommodate all OSOW vehicle movements. For example, in the case of straight through movements, roads through the center island should be considered. These may require a gate or offset. For right turn movements, a right turn slip lane could be considered. For left turn movements, counter flow movement appears to be more cost-effective than other solutions; however, a fully traversable central island could also be a solution.
- One of the most pressing problems in regard to accommodation of OSOW vehicles is the "hangup" problem. The only relevant study uncovered by the authors has was recently conducted in Wisconsin and immediately put into the Wisconsin DOT's policy and procedures documents. This could be considered by all states.
- The authors further conclude that in regard to the "hangup" problem, some examples from Europe, where rumble strips and or rough surfaces are used, can discourage small vehicle drivers from encroaching on internal and external truck aprons. Rather than raising the island elevation, this could be considered.
- The authors recommend a curb height of three inches (8 cm) should be considered as a reasonable maximum. However, research might be needed to confirm that this has no negative effects on safety.
- Where very large loads are infrequent, using temporary methods such as laying mats to protect pavement and off-track areas, could be considered. An example used by the Kansas DOT clearly illustrates such a procedure.

In conclusion, modern roundabouts do not necessarily need to be strictly circular - some may be elongated to include the combination of multiple intersections. Unconventional roundabout layouts should be considered where space constraints or OSOW vehicle movements are common or expected. In doing so, designers should always consider safety, traffic operations, capacity, right-of-way impacts, and cost. Other factors can also be included in the evaluation if desired and deemed appropriate. In conducting such comparisons, one must bear in mind that an unconventional roundabout is not always the optimal solution, but it can often offer significant benefits for special instances.

The authors suggest that future research for both data observation and capacity model calibration may be needed to fully examine the implications of unconventional roundabout design. Future research will consider several types of roundabouts to enlarge the comparison. Moreover, safety issues have to be consider with observations and simulation trials.

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