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Using vehicle simulations to understand strategies for accommodating oversize, overweight vehicles at roundabouts

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ABSTRACT

There is considerable evidence that roundabouts are the safest and most efficient form of traffic control for most intersections. The potential use of roundabouts with all their inherent benefits may be greatly diminished if they are not able to accommodate oversize/overweight (OSOW) vehicles, sometimes called "Superloads." The problem, therefore, is how to accommodate OSOW vehicles without sacrificing the integrity, safety and other benefits of roundabouts.

This study uses TORUS software to design six standard roundabouts using guidance from the latest Federal Highway Administration (FHWA) roundabout guide. Six OSOW check vehicles from the Wisconsin Department of Transportation's library were used to modify the designs to accommodate these selected check vehicles at the roundabouts. These six OSOW check vehicles were used to conduct swept path analysis using AutoTURN software at the selected six standard roundabouts for right turn, through, and left turn simulations. The space requirements for these maneuvers were analyzed in detail. Various strategies for better accommodating these OSOW check vehicles were suggested and experimented with in this study using AutoTURN software simulations. The effectiveness of using a straight passage through the center island for OSOW vehicles was also addressed in this study and was found to be effective. All the strategies investigated in this study proved to be effective in accommodating OSOW vehicles when compared to conventional ways of using a roundabout. The needed total truck apron was calculated and used as a reference to determine an effective strategy for accommodating OSOW vehicles. This research can be used as guidance for transportation engineers, planners and decision makers to determine possible ways of designing a roundabout at an intersection where certain OSOW vehicles are expected.

1. Background and literature review

The safety and traffic operational benefits of roundabouts for the typical vehicle fleet (automobiles, and small trucks) have been well documented (Russell et al., 2002, 2005; Rodegerdts et al., 2010; Godavarthy and Russell, 2015a; Mandavalli et al., 2008). Although roundabouts have been in widespread use in other countries for many years, their general use in the United

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States began only recently (1990 is generally accepted as the year the first modern roundabouts were built in the USA), but their use is growing at an increasing rate (Rodegerdts et al., 2010; Qin et al., 2013). Roundabouts can offer several advantages over signalized and stop controlled intersection alternatives, including better overall safety performance, shorter delays, shorter queues, better management of speed, and opportunities for community enhancement features. In some cases, roundabouts can eliminate or delay the need for an expensive widening of an intersection approach that would be necessary for signalization (Rodegerdts et al., 2010; Brilon, 2016).

The growing potential use of roundabouts with all their benefits may be greatly diminished because they may not accommodate oversize/overweight (OSOW) vehicles. The design vehicle for a roundabout, as in any design, should be the largest vehicle that can reasonably be anticipated for normal use. However, OSOWs are vehicles that use the roadway by special permit and travel on a random basis. To use these OSOW vehicles as a design vehicle for roundabouts would be costly and inefficient, and more importantly, could negate the benefits of roundabouts which rely on being designed to operate at slower speeds from adequate deflection. Large roundabouts with little deflection and wide lanes would encourage higher speeds which would likely reduce the safety benefits. Further, OSOW vehicle's physical characteristics may exceed the dimensions for standard design vehicles recommended in "A Policy on Geometric Design of Highways and Streets" (AASHTO, 2011). Therefore, the central issue is how to accommodate OSOW vehicles where appropriate without sacrificing the integrity, i.e. safety and operational efficiency, of the roundabout. Typical OSOW vehicles are routed around roadway restrictions such as certain bridges and narrow roadways. However, with the popularity of roundabouts and the benefits they provide, such routing could become more difficult and could potentially lead to reduced or prohibited roundabout use if OSOW vehicles cannot be accommodated.

Generally, a raised section of the pavement called truck apron is constructed around the center island of a roundabout which acts as an extra lane for large vehicles (design vehicle) while circulating the roundabout. Generally, for single lane roundabouts, a traversable truck apron (raised section of pavement) is provided around the perimeter of the center island to accommodate the additional width needed for tracking the rear wheels of large vehicles (Rodegerdts et al., 2010). However, large vehicle accommodation at multilane roundabouts is considered in such a way that either they use more than one lane for entering, circulating, and exiting or to stay within their lane. According to a study conducted by MnDOT and WisDOT (2012), roundabouts at intersections with lower truck (design vehicle) volume allow trucks to encroach into adjacent lanes and when the truck volume is high, roundabouts are designed with wider outer and/or center island truck aprons so that trucks stay in their lanes. Gingrich and Waddell (2008) conducted a truck apron field study at the Interstate-17/Happy Valley Road intersection in Phoenix in July 2007 and found that the 77% of semis and large single-unit trucks did not use the truck apron during the peak hour. Among the trucks that did use the apron, most (67%) used it because a car was in the adjacent lane. It was also observed that when a car and truck were side by side, the smaller vehicle usually accelerated ahead of the truck or applied brakes to get behind the truck (Gingrich and Waddell, 2008). Truck aprons are designed in such a way that they are traversable by trucks, but discourage passenger vehicles by raising the apron 2 to 4 in. above the circulatory roadway surface. Truck apron width is determined by using templates or conducting vehicle turning path simulations of larger vehicles expected at the roundabout with a computer-aided design (CAD)-based software (Rodegerdts et al., 2010). Godavarthy and Russell (2015b) have conducted vehicle clearance analysis to determine the vertical requirements of low clearance trucks at roundabouts and concluded that 4 in. and 3 in. truck apron heights were not suitable for low clearance vehicles as terrain conflicts were observed. Instead, a 2.5 in. or a 2 in. truck apron height can be potentially considered; however, only after checking for any vehicle-terrain conflicts using a 3-dimensional CAD-based software analysis (Godavarthy and Russell, 2015b).

Park and Pierce (2013) studied the motor carrier perspective of efforts to accommodate large trucks at roundabouts and summarized that trucking agencies feel there is a need for larger roundabout circumferences, more education to drivers of passenger vehicles on how to interact with large trucks at roundabouts, and a need for re-evaluation of roundabout design to better accommodating large trucks. Petru and Zeman (2013) have studied the problems with transport of abnormal loads (OSOW vehicles) at roundabouts in Czech and Slovak republic and concluded that roundabout features such as elevated center island, curbs, and elevated splitter islands can be damaged if they were not properly designed. Further, intersection elements such as lamp posts and traffic signs can make the passage of abnormal loads impossible at roundabouts (Petru and Zeman, 2013). Petru and Zeman (2013) suggests counter flow travel idea (vehicle traveling in opposite direction at the roundabout without circulating the center island) and traversable center island for abnormal loads to have minimal obstructions for their passage. Russell et al. (2013a, 2013b) conducted several surveys with U.S. state departments of transportation and the trucking industry to understand the problems OSOW vehicles face at roundabouts and solicit possible techniques to accommodate OSOW vehicles. Based on input received from designers throughout United States and from the trucking industry, the different design elements that can be incorporated into roundabout design to accommodate OSOW vehicles include: widened entries and exits, unobstructed center islands with large truck aprons, outer truck aprons, bypass lanes, mountable curbs, no vertical obstructions on the splitter island, easily mountable curbs, and with signs, light poles, etc. outside of the turning path and/or designed to be easily removed (Russell et al., 2013a, 2013b). Flores et al. (2015) have conducted field tests with a wind blade transporter OSOW vehicle and compared its swept path to that of the swept path generated by AutoTURN software and concluded that AutoTURN software vehicle simulation can reasonably model the vehicle's turning characteristics and serve as a cost effective option for designers.

Based on various possible treatments that can be adapted in roundabout design to accommodate large truck and OSOW vehicles, this study sets forth several strategies to accommodate specific OSOW vehicles at standard roundabout settings and calibrates their effectiveness.

2. Study objective

The current study objective is to determine various strategies to effectively accommodate the OSOW vehicles at roundabouts and also to make sure roundabout safety for regular road users is not diminished. These objectives can be achieved by:

(1) Conducting vehicle simulations of the design vehicle, and select OSOW vehicles at six major kinds of roundabout intersections and study the space requirements at each.
(2) Suggest various treatments to better accommodate OSOW vehicles and design various alternative OSOW vehicle accommodation strategies at roundabouts.

2.1. OSOW vehicles used for the study

Accommodation of OSOW vehicles at the roundabout was checked by considering the swept path analysis for six OSOW vehicles, called "check vehicles." The "check vehicles" used were developed for use in Wisconsin. The AutoTURN vehicle files for six OSOW check vehicles were used from Wisconsin Department of Transportation (WisDOT) vehicle library. The six check vehicles (shown in Fig. 1) obtained from the WisDOT vehicle library are:

1. 55 m wind blade (Vehicle length = 63.20 m, wheelbase = 5.86 m, trailer length = 57.15 m),
2. 80 foot mobile home (Vehicle length = 34.29 m, wheelbase = 6.63 m, trailer length = 24.38 m),
3. 165 foot beam (Vehicle length = 60.60 m, wheelbase = 4.67 m, trailer length = 14.63 m),
4. Wind tower section (Vehicle length = 34.29 m, wheelbase = 5.94 m, trailer length = 23.77 m),
5. Wind tower upper mid-section (Vehicle length = 45.35 m, wheelbase = 6.25 m, trailer length = 10.12 m),
6. WisDOT WB-67 long (Vehicle length = 31.39 m, wheelbase = 5.94 m, trailer length = 25.30 m).

Among the six OSOW check vehicles used in this study, the 55 m wind blade, the wind tower section, and the 165 foot beam were vehicles with rear steering capability.

2.2. Software used for the study

TORUS software was used to generate six standard roundabout designs (3 types of single-lane roundabouts and 3 types of double-lane roundabouts), designed according to the Federal Highway Administration (FHWA) latest roundabout guide (Rodegerdts et al., 2010). Later, AutoTURN software was used on the six TORUS designed roundabouts to conduct swept path analysis of six OSOW check vehicles and analyze the space requirements at the six standard roundabouts. The authors used

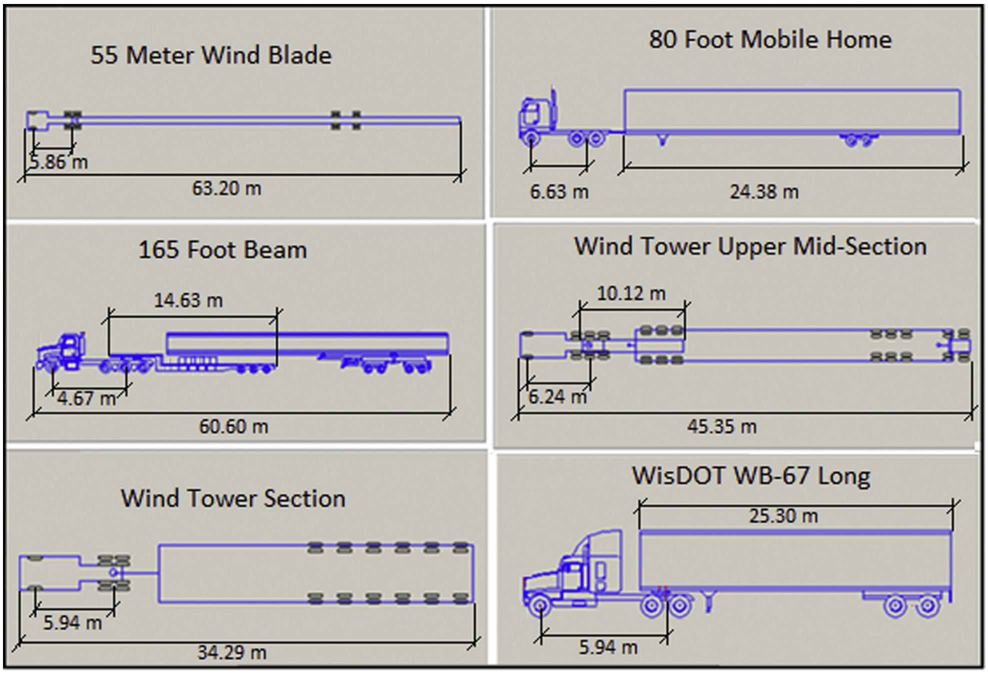

Fig. 1. Six OSOW check vehicles.

these software packages because they were suitable to demonstrate their accuracy to perform the tasks required in this study and the authors are not advocating exclusive use of AutoTURN or TORUS software.

3. Study methodology

This study considered the most common roundabout intersections on rural roads that can expect OSOW vehicle movements. Roundabout configurations such as single-lane roundabout and a double-lane roundabout were considered for this study. For each configuration, roundabout types such as a typical symmetric three-leg roundabout, a three-leg roundabout at a T intersection, and a typical four-leg roundabout were designed. According to the latest roundabout guide, AASHTO designation WB-67 is considered the most common design vehicle for rural intersections (Rodegerdts et al., 2010). Therefore, WB-67 was used as a design vehicle to generate the selected roundabout designs and truck apron design using TORUS software. The designs generated were then used to conduct swept path analysis (using AutoTURN software) of the six OSOW check vehicles for right turn, through, and left turn movements from all approaches. Based on the tire tracks for all possible OSOW check vehicles from all approaches, and using various accommodation strategies, an outer truck apron and a custom center island truck apron were analyzed to suggest best accommodation strategies at different roundabout settings where OSOW vehicles are expected.

3.1. Single lane roundabouts

For the single-lane roundabout configuration, a typical symmetric three-leg roundabout, a three-leg roundabout at a T intersection, and a typical four-leg roundabout were considered. According to NCHRP Report 672 (Rodegerdts et al.,

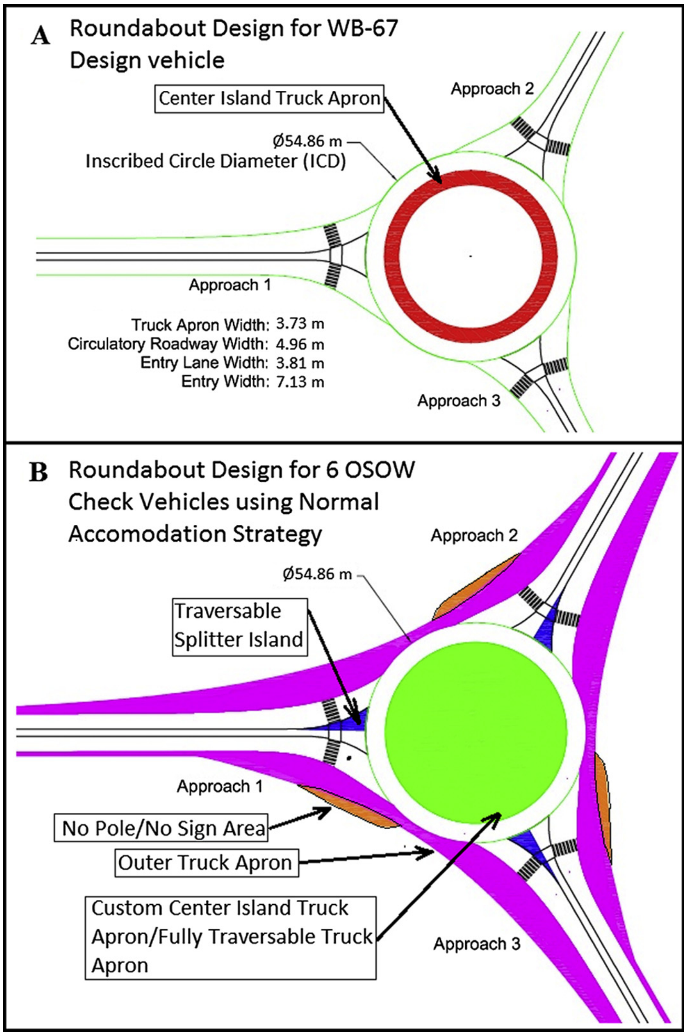

Fig. 2. Single lane typical symmetric 3-leg roundabout designs.

2010), the inscribed circle diameter (ICD) (distance across the circle that is inscribed by the outer curbs in a roundabout (shown in Part A of Fig. 2)) range for single lane roundabout with WB-67 as design vehicle is 39.62–54.86 m. As this study deals with OSOW vehicles which are larger than WB-67, the upper limit, 54.86 m. ICD was used for all the three single-lane roundabouts. Therefore all three types of single-lane roundabouts considered for the study were designed using 54.86 m. as ICD and WB-67 as the design vehicle in the TORUS software. At these three designed roundabouts, right turn, through, and left turn movement simulations of all six OSOW check vehicles from all possible approaches were made and the space requirements for accommodating all movements of these six OSOW check vehicles at each of the three roundabouts were studied. Each simulation was conducted in such a way that the front wheels travel through a roundabout like a normal vehicle and the rear tire impressions were studied if they passed beyond the roundabout design or onto the center island beyond the provided truck apron. If the rear tires of OSOW check vehicle were found to use the space beyond the roundabout design, an outer truck (external) apron was suggested in such areas. The truck apron can be a center island truck apron or an outer truck apron, based on the space requirements. The area of total truck apron (center island truck apron and outer truck apron) was calculated after simulating all possible maneuvers of the six OSOW check vehicles for all three single-lane roundabouts considered for analysis. Apart from outer truck apron and custom center island truck apron, simulation of six OSOW check vehicles also resulted in a no pole/no sign area which provides vehicle body clearance, but doesn't need a traversable truck apron. This area should not have any poles or signs that cannot be removed. Part A of Fig. 2 shows a typical symmetric three-leg roundabout designed using TORUS software with ICD 54.86 m. and design vehicle WB-67. Part B of Fig. 2 shows the modified design of the roundabout with suggested center island truck apron, outer truck apron, traversable portion of splitter islands, and no sign/no pole area to accommodate all possible vehicle maneuvers of the six OSOW check vehicles from all three approaches. It can be understood from part B of Fig. 2 that there is a need to construct a large outer truck apron (4141 m^2), and a fully traversable center island (2554 m^2) to accommodate all possible movements of the six OSOW check vehicles. By comparison, for the typical symmetric three-leg roundabout for design vehicle WB-67 (part A of Fig. 2), the center island truck apron is 483 m^2. Therefore, it would be unnecessary to construct 750% more truck apron (2554 m^2 + 1587 m^2) at this roundabout to accommodate OSOW vehicles which use the roundabouts on a very random basis. Therefore, this study focuses on ways to better accommodate the six OSOW check vehicles by reducing the need to construct a large area of truck apron.

These OSOW vehicle movements can also be effectively accommodated by certain unique treatments such as: (Note that traffic control would be required for some movements, but OSOW vehicles are escorted so this should be no problem)

(1) Making the splitter islands "truck tire friendly" and fully traversable such that the OSOW vehicle movements can be made more effective by riding over the splitter island if needed. This means that the traversable splitter islands should not be installed with poles or signs which cannot be removed. However, if a sign is warranted, removable signs need to be considered for installation.
(2) When needed, use lanes in both directions of traffic and the splitter island as approach lane for the OSOW vehicle.
(3) Allowing the left turn maneuvers of OSOW vehicle movements in such a way that the OSOW vehicles enter from the furthest right lane/side of the approach and travel in the opposite direction of normal traffic flow without circulating the center island such that the need for a large outer truck apron and center island truck apron is decreased.
(4) Allowing the right turn maneuvers so that the vehicle/vehicles enter from the opposite direction of traffic (or furthest left lane in an approach) at the approach and exit into any lane such that a minimum truck apron is required.

Using the above techniques, the OSOW vehicles was proposed to be accommodated in two ways

(1) Opposite Direction Travel (ODT) (sometimes called "counterflow"). In this technique, the width of the center island truck apron initially is kept the same as the roundabout design to accommodate a WB-67 design vehicle. Later, based on the six OSOW check vehicle simulations, an outer truck apron and more center island truck apron are added to the design. An OSOW check vehicle was allowed to enter from any lane of the approach (same direction of traffic or opposite direction of traffic) and exit into any lane of the exit. Further, while in the circulatory roadway, the circulatory roadway width for the front tires was considered as the sum of the designed circulatory roadway width and basic truck apron width designed for a WB-67 and the OSOW vehicle simulation was performed in such a way that minimum outer truck apron is required. A left turn for an OSOW vehicle was made in such a way that it may enter from any lane (same direction of traffic or opposite direction of traffic) of the entering approach, travel in the opposite direction of normal traffic flow without circulating the center island and exit into any lane of the exiting approach in such a way that it uses the basic, provided center island truck apron width and minimum outer truck apron. The splitter islands are assumed to be traversable. Based on all possible simulations of the six OSOW check vehicles, no pole/no sign area, additional width of center island truck apron, and/or outer truck apron is designed.
(2) Fully Traversable Center Island (FTCI). In this technique, the center island is made fully traversable and the right turn, through movement, and left turn maneuvers of six OSOW check vehicles were simulated so that the OSOW vehicles can completely use the fully traversable center island to minimize the need for an outer truck apron. The OSOW vehicles were also allowed to enter from any lane (same direction traffic or opposite direction traffic) and exit into any lane (same direction traffic or opposite direction traffic) to decrease the use of an outer truck apron area. The splitter islands are assumed traversable.

Fig. 3 shows a typical symmetric three-leg roundabout designed to accommodate six OSOW check vehicles using ODT accommodation strategy. Part A of Fig. 4 shows an OSOW check vehicle, 55 m wind blade left turn movement from approach 3 to approach 1 at a typical symmetric three-leg single lane roundabout using FTCI accommodation strategy and part B of Fig. 4 shows the final design for accommodating all six OSOW check vehicles using FTCI strategy. All possible simulations of six OSOW check vehicles were performed at the three single-lane roundabout configurations using ODT, and FTCI accommodation strategies and the total truck apron width was measured and summarized in Table 1. It can be observed from the Table 1 that the need for larger center island truck aprons and total outer truck aprons was reduced by implementing ODT and FTCI strategies for accommodating OSOW vehicles at all three of the single-lane roundabout configurations considered. Though there is minor difference in the truck apron area needed among ODT and FTCI accommodation strategies, ODT accommodation strategy has the largest reduction in truck apron area for typical symmetric three-leg roundabout and three-leg roundabout at T-intersection configurations when compared to normal accommodation strategies. However, at suitable locations, the FTCI accommodation strategy may be preferred because it does not need any area beyond the roundabout for constructing an outer truck apron and because the design and construction is simpler without this outer truck apron. For a typical four-leg roundabout configuration, the FTCI accommodation strategy requires a smaller truck apron compared to the ODT strategy.

3.2. Double lane roundabouts

For double-lane roundabout configurations, a typical symmetric three-leg roundabout, a three-leg roundabout at a T intersection, and a typical four-leg roundabout were considered. According to NCHRP Report 672 (Rodegerdts et al., 2010), the ICD range for double lane roundabout with WB-67 as design vehicle is 50.29 to 67.07 m. The upper limit of 67.06 m. ICD was used for designing all the three types of double-lane roundabouts. At these three types of double-lane roundabouts, right turn, through, and left turn movement simulations of all the six OSOW check vehicles from all possible approaches were conducted using normal, ODT, FTCI accommodations. The truck apron requirements were studied and summarized in Table 1. Numerous final designs of single-lane and double-lane roundabouts with normal, ODT, and FTCI accommodation strategies were illustrated by the authors in various other research reports (Russell et al., 2013b; Godavarthy, 2012). It can be understood from Table 1 that for the three double-lane roundabout types, ODT accommodation strategy resulted in the smallest truck apron area required to accommodate all six of the OSOW check vehicles. While these results were useful in understanding the effective accommodation strategy, future research is needed in this subject area to validate the truck apron requirements of OSOW vehicles and their accommodation strategies using field tests.

3.3. Straight-through passage for four-leg roundabout

Four-leg roundabouts are very common on rural intersections and most of the time, OSOW vehicles might enter from only one or two opposite approaches and travel straight through. For this specific case, providing a straight passage through the center island might be a best option. Straight-through passage through the center island of roundabouts to accommodate

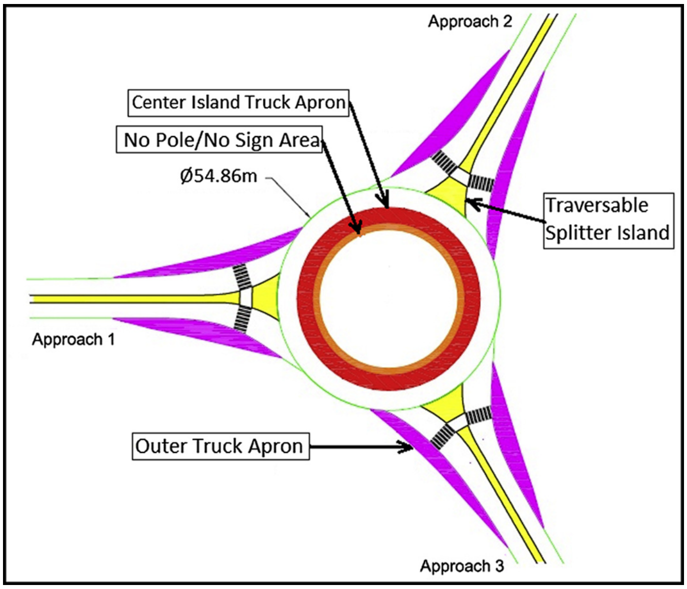

Fig. 3. Single lane typical symmetric 3-leg roundabout design generated using ODT accommodation strategy.

OSOW vehicles is successfully used in the Netherlands and Germany (Russell et al., 2013a; Gazzarri et al., 2014). Therefore for this study, through movements simulations of all six OSOW check vehicles were conducted from each side of the two opposite approaches for single-lane roundabouts and double-lane roundabouts using normal accommodation strategies to determine the space requirements for truck apron. Part A of Fig. 5 illustrates the single-lane roundabout designed with a custom center island truck apron and an outer truck apron to accommodate the through movements of six OSOW check vehicles entering from approach 2 and approach 4 in a normal way. Later, a straight-through passage was designed into the single- and double-lane roundabouts and through movement simulation of six OSOW check vehicles were conducted using the straight-through passage to study the space requirements. Part B of Fig. 5 shows the modified design of a single-lane roundabout to accommodate the six OSOW check vehicles with a straight-through passage. Observe from part B of Fig. 5 that, with a straight through passage, there was no need to provide any extra truck apron area except for making the splitter islands tire friendly for OSOW vehicle entering and exiting approaches so that they could enter the straight-through passage from any lane in the approach. The straight through passage is not aligned with the direction of the vehicle travel and is designed at an angle to minimize the need for external truck apron, and also for the OSOW vehicle to exit in its appropriate lane without any obstruction to the on-coming traffic.

The total truck apron area needed to accommodate straight-through movements of all six OSOW check vehicles from approach 2 and approach 4 using normal accommodation strategy is calculated as 1303 m^2 and 1144 m^2 for single-lane and double-lane roundabouts whereas the total truck apron area needed for straight-through passage is 437 m^2 (66% reduction) and 433 m^2 (62% reduction). Using a roadway width of 7.62 m. through the single-lane roundabout and double-lane roundabout as a straight-through passage, an additional road area of 274 m^2 and 371 m^2 respectively would need to be constructed, making the total paved area (truck apron area and straight-through passage area) 45% and 30% less at the single- and double-lane roundabouts when compared to the normal accommodation strategy. If a straight-through passage is constructed through the center island, gates need to be installed so normal traffic does not have access to the passage (Russell et al., 2013b).

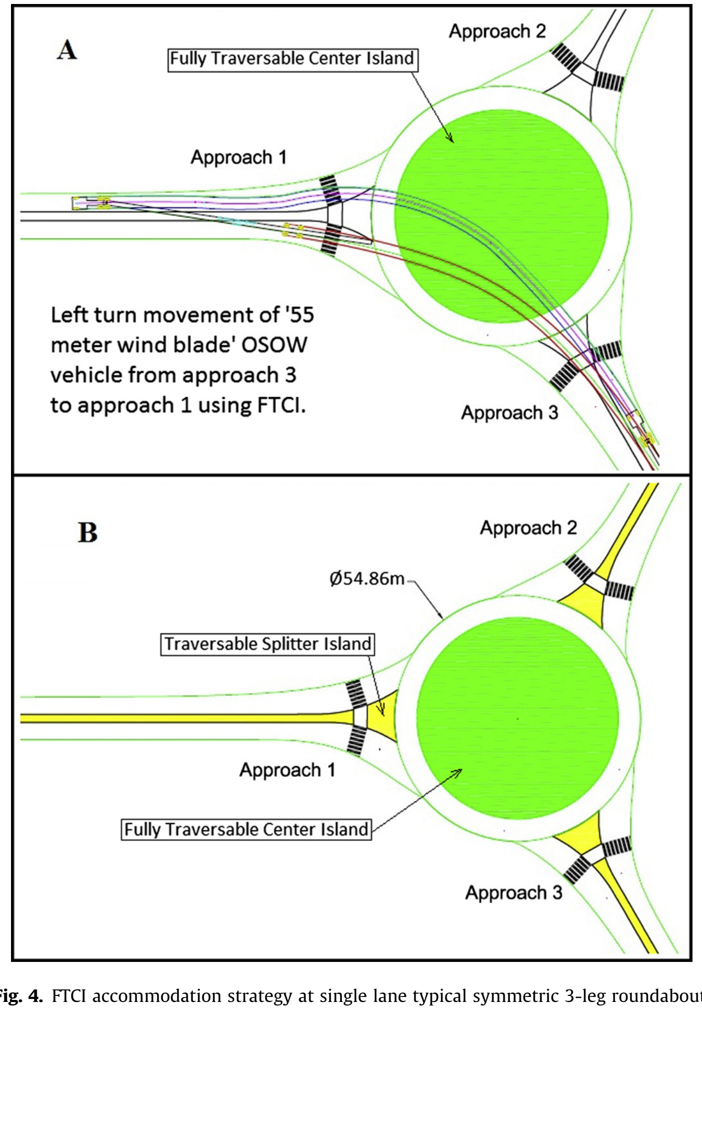

Fig. 4. FTCI accommodation strategy at single lane typical symmetric 3-leg roundabout.

Table 1
Center Island truck apron area, outer truck apron area, and total truck apron area for roundabouts designed for accommodating six OSOW check vehicles.

Roundabout type	OSOW accommodation method	ICD (m)	Center island truck apron area, (C) (m^2)	Total outer truck apron area, (O) (m^2)	Total Truck Apron, ($T = C + O$) (m^2) [% truck apron area reduced compared to normal accommodation]
Single Lane Typical Symmetric 3-Leg	Normal	54.86	1587	2554	4141
	ODT	54.86	483	711	1194 [71%]
	FTCI	54.86	1587	0	1587 [62%]
Single lane 3-leg at T intersection	Normal	54.86	1587	3002	4589
	ODT	54.86	1041	1660	2702 [41%]
	FTCI	54.86	1587	1248	2835 [38%]
Single lane typical 4-leg	Normal	54.86	1587	5582	7170
	ODT	54.86	919	3517	4437 [38%]
	FTCI	54.86	1587	2496	4083 [43%]
Double lane typical symmetric 3-leg	Normal	67.06	1555	1059	2614
	ODT	67.06	485	0	485 [81%]
	FTCI	67.06	1890	0	1890 [27%]
Double lane 3-leg at T intersection	Normal	67.06	1504	1992	3496
	ODT	67.06	751	858	1608 [54%]
	FTCI	67.06	1890	0	1890 [46%]
Double lane typical 4-leg	Normal	67.06	1801	3888	5688
	ODT	67.06	853	886	1739 [69%]
	FTCI	67.06	1890	0	1890 [67%]

ICD: Inscribed Circle Diameter, ODT: Opposite Direction Travel, FTCI: Fully Traversable Central Island

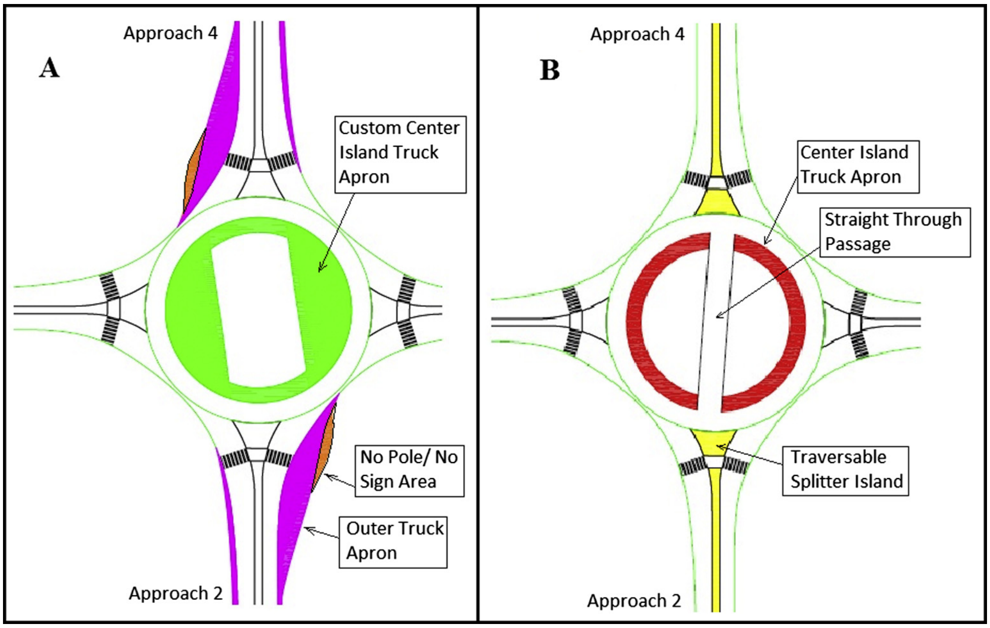

Fig. 5. Single-lane typical symmetric four-leg roundabout designs for OSOW vehicles straight-through movement.

4. Conclusions and recommendations

Roundabout use in United States is growing because of their safety and operational benefits over signalized and stop-controlled intersections. Their potential use and benefits may be greatly diminished if their design geometrics do not accommodate oversize/overweight (OSOW) vehicles. This study evaluated the effectiveness of various accommodations for OSOW check vehicles at typical roundabouts and in three alternative roundabout strategies: opposite direction travel (ODT), fully traversable center island (FTCI), and straight passage through the center island.

ODT and FTCI methods of accommodating the six OSOW check vehicles always resulted in reduced total truck apron area when compared to typical designs for accommodating the six OSOW check vehicles. However, these two accommodation strategies assumes a need for unique treatments such as making the splitter island traversable and truck tire friendly, installing removable signs when a sign is warranted in splitter island or in truck apron area, constructing poles away from the no-pole area, allowing OSOW vehicles to use any lane (same direction traffic and opposite traffic) or splitter island in an approach to enter, allowing OSOW vehicles to use any lane or splitter island on the exit, and when necessary, and allowing left-turn maneuvers to be made in the opposite direction of traffic without circulating the center island. As all OSOW vehicles are escorted in the United States, so traffic control should not be a problem for various vehicle maneuvers. Though FTCI strategy did not yield a greater reduction of truck apron area for most of the cases when compared to ODT strategy, this strategy is relatively easy to design and implement because there is no need for an outer truck apron for most of the roundabout types. Further, if the OSOW vehicle frequency is not high, the basic truck apron and the center island can be constructed with compacted soil (or other inexpensive paving method) sufficient for use by infrequent OSOW vehicles, thereby decreasing the cost of construction. One possible drawback of FTCI strategy that has to be noted is that there is no possibility for center island landscaping for aesthetic reasons and/or driver recognition of the roundabout upon approach.

In the real world, all six OSOW vehicles may not enter from all approaches and exit into all other approaches; OSOW vehicles maneuvers may be limited to certain approaches. However, the accommodation strategies demonstrated in this study would accommodate anticipated OSOW vehicles and a design should be chosen after the designer conducts a swept path analysis for expected OSOW vehicle movements. Further, the study has considered the upper limit of inscribed circle diameter (ICD) for designing single-lane and double-lane roundabout configurations. However, in real world situations there might be space constraints at an intersection (or some other reason) for designing a roundabout with ICD less than the upper limit. In these cases more truck apron area may be required than presented in this study and sometimes OSOW vehicle maneuvers may be impossible due to space constraints.

Providing a straight-through passage through the center island for four-leg roundabout (both single lane and double lane) was shown to be an effective strategy for reducing the need for truck apron area when compared to the typical designs for accommodating the six OSOW check vehicles. This is being used successfully in Netherlands and Germany. If a straight-through passage is used, gates must be installed to prevent normal traffic from using it.

Selecting the correct OSOW vehicles accommodation strategy for any kind of roundabout configuration is dependent on various factors such as OSOW vehicle movement patterns, OSOW vehicle frequency, space availability for building outer/center island truck aprons, possibility of installing removable signs, possibility of building traversable splitter islands, possibility of installing straight-through passages, etc. The results of this study will help decision makers, engineers, designers and planners select optimum OSOW vehicles accommodation strategies at any roundabout configuration.

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