Simulation Evaluation on the Rollover Propensity of Multi-trailer Trucks at Roundabouts

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Abstract

The main intent of this study is to provide a simulation analysis of rollover dynamics of multi-trailer commercial vehicles in roundabouts. The results are compared with conventional tractor-semitrailer with a single 53-ft trailer for roundabouts that are of typical configuration to those in the U.S. cities. The multi-trailer commercial vehicles that are considered in this study are the A-double trucks commonly operated in the U.S. roads with the trailer length of 28 ft, 33 ft, and 40 ft. The multi-body dynamic models for analyzing the rollover characteristics of the trucks in roundabouts are established in TruckSim®. The models are intended to be used to assess the maximum rollover indexes of each trailer combination subjected to various circulating speeds for two types of roundabouts, 140-ft single-lane and 180-ft double-lane. The simulation results suggest that the 40-ft double has rollover speed thresholds 2-9 mph lower (more vulnerable to rolling over) as compared with the conventional 53-ft semi-trailer-truck. The lower roll stability for the 40-ft A-train configuration is attributed to its pintle-hitch coupling that allows for a certain amount of roll degree of freedom between the front and rear trailers. In addition, the worse tracking performance of the 40-ft double due to its longer wheelbase contributes to the heavier use of truck apron, greatly increasing the chance of rollover. The results also indicate that the 28-ft and 33-ft double-trailer trucks possess better maneuverability (less off-tracking) and can tolerate the rollover speed 1-3 mph higher than that of the 53-ft single-trailer truck. Furthermore, it is found that increasing the trailer from 28 ft to 33 ft results in the truck slightly less prone to rollover crashes, because of their longer wheelbase providing a slight amount of additional roll stability.

Keywords: roundabout, rollover dynamics, commercial vehicles, dynamic modeling, rollover index, rollover propensity, multi-trailer trucks

1. Introduction

During the past decades, roundabouts have become increasingly popular across the U. S. [1]. As of 2013, there have been approximately 3,200 roundabouts in the U. S. [2]. A further rise in the number is consistently reported with an estimation of about 200 new ones constructed every year [3]. As compared with the traditional signalized and stop-controlled intersection, a roundabout provides operational benefits such as increased traffic capacity, improved traffic flow control, and better safety performance [4]. A study conducted by Rodegerdts [5] indicates that roundabouts result in 12 seconds less delay than a signalized intersection. Despite the benefits of roundabouts to traffic flow, there are maneuvering limitations for long vehicles, such as single- and multi-trailer commercial trucks [6]. Specifically, geometric characteristics of roadway in roundabouts pose challenges to the roll stability of commercial vehicles that could trigger rollover, which has been observed at roundabouts in places such as the United States, Australia, and the United Kingdom [7-9].

Crash statistics indicate that rollovers account for 81% of truck crashes in roundabouts [10]. Two rollover cases in roundabouts in the U.S. are shown in Figure 1. Avoiding rollovers has become a central issue in driving roundabouts and in a limited number of studies evaluating the driving dynamics of commercial trucks on city roads [11]. This paper is aimed at providing a comprehensive evaluation of the dynamics of multi-trailer commercial trucks in roundabouts. This study includes trucks with A-double trailers of 28-ft, 33-ft, and 40-ft length. For each configuration, the rollover index is evaluated for two types of roundabouts, a single-lane 140-ft and a double-lane 180-ft. The rollover index for each double trailer truck is compared with the conventional tractor with a 53-ft semitrailer.

Figure 1. Rollover crashes for trucks at roundabouts in the U. S. [12, 13]

The rest of the paper is organized as follows. Section 2 gives some background knowledge on roundabouts and A-double trucks, and an overview of previous works associated with the lateral dynamics of commercial trucks in roundabouts. Section 3 introduces the development of multi-body dynamic models for the selected truck configurations in TruckSim®. Section 4 provides a description of the roundabout models established in TruckSim®. In Section 5, the maximum rollover index (RI) of the trucks is evaluated subject to various speeds in single- and double-lane roundabouts. At last, a discussion of conclusions closes the paper.

2. Background and Literature Review

A roundabout is a circular intersection in which the traffic travels counterclockwise around the central island, with the entering vehicle yielding to the traffic in the roundabout [14]. Figure 2 illustrates the basic geometric elements of a single-lane roundabout. This typically consists of entering roadways, entry curve, circulatory roadway, a central island, exit roadways, and a truck apron. The roundabout geometry results in successive tight reverse steering necessary for negotiating the roadway, which could increase the likelihood of rollover, particularly for high-center-of-gravity (CG) vehicles such as commercial trucks [15 - 17]. For example, a through or left-turn requires a compounded steering that is similar to a double lane change maneuver. Such maneuvers could lead to large lateral accelerations at vehicle body. It is well known that the commercial vehicle possesses a considerably higher center of gravity (CG) than the passenger car, which makes them less tolerant of large lateral accelerations [18]. Additionally, the circulatory roadway in a roundabout typically has a cross-slope for drainage that could results in more lateral load transfer in large trucks, further exacerbating the rollover risk.

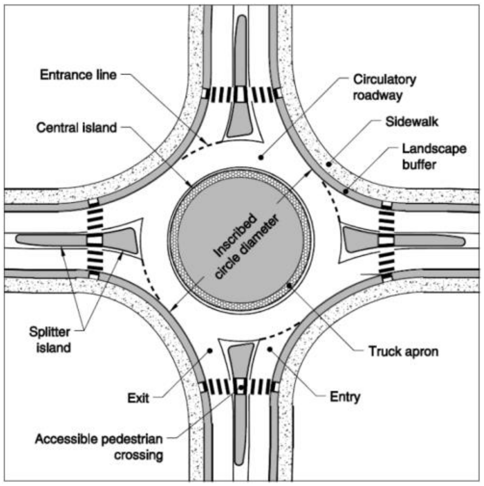


Figure 2. Basic geometric elements of a single-lane roundabout [19]

Currently, there exist various combinations of multiple trailers on tractor trucks. This study focuses on the A-double trailer truck (referred to as "A-train or A-double") that is the most prevalent multi-trailer combination in North America [20]. The A-double consists of two semi-trailers linked together by a converter A-dolly, as shown in Figure 3. The dolly is coupled with the rear trailer by a fifth wheel while hooked up to a pintle hitch on the rear of the front trailer. Compared with the conventional 53-ft single-trailer truck, the A-train provides some operational advantages, such as more flexible cargo handling and logistics, as well as easier maneuvering at tight turns. In addition, the A-train configuration is easier to installation than other multi-trailer configurations, such as the B-train. Despite the above benefits, there is a concern of rollover for the A-train when negotiating tight turns such as in roundabouts. In this regard, the A-train trucks dynamic stability need to be investigated, especially when traveling through the roundabouts.

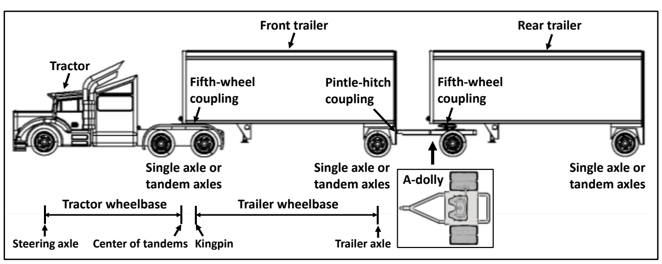


Figure 3. A-train double configuration

There are very few studies pertaining to the roll stability of commercial trucks in the context of existing roundabouts. Tarko et al. [21] evaluated the rollover propensity of single-trailer trucks in the daytime and nighttime conditions, using an advanced 3-D model of rollover established with the input of data from a remote recording video. They found that the rollover propensity at night is lower than during the day, since the drivers were observed driving more cautiously during the night. Hou and Ahmadian [9] conducted a simulation study on the effect of truck configurations on roll stability in roundabouts. Their results indicate that the 53-ft single-trailer and 40-ft double-trailer trucks have less roll stability than the single-unit truck in roundabouts. In this paper, we extend the previous study by providing a comprehensive simulation evaluation of the rollover characteristics for the A-doubles in roundabouts. In particular, the maximum rollover indexes of 28-ft, 33-ft, 40-ft A-doubles are evaluated under various circulating speeds and compared with those of the conventional 53-ft single-trailer truck for the single- and double-lane roundabouts. The simulation analysis is based on truck multi-body dynamic models established in TruckSim®, as will be introduced in the next section.

3. Truck Dynamic Model Development

TruckSim® is a commercial software package that has been well recognized for providing accurate and realistic predictions of vehicle dynamic behavior. The software also provides a road design package to emulate the effect of complex road geometry on vehicle dynamics, such as those in roundabouts. Therefore, TruckSim® is selected in this study for predicting rollover dynamics of the tractor-multi-trailer in roundabouts. The truck models for the 28-ft, 33-ft, 40-ft A-doubles, and the conventional 53-ft semitrailer established in TruckSim® are shown in Figure 4.

Figure 4. Truck models in TruckSim®

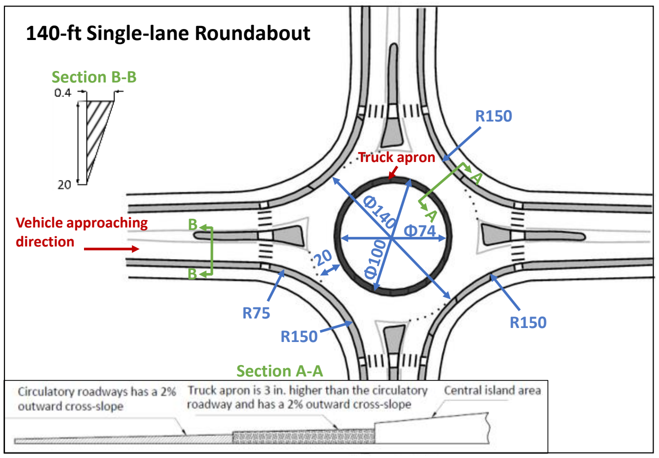
Dimensional parameters of the truck models are defined according to measurements on the real trucks. The weight and inertial properties of the 28-ft and 33-ft trailers are estimated by SolidWorks® simulation (creating CAD models), as shown in Figure 4. The CAD models include all the structural details and material property (density) is assigned to each component included in the model. The dimensional inertial (CG) properties for the 40-ft and 53-ft trailers are determined based on prior research [9, 22, 23]. If the parameters cannot be measured or simulated, they are selected from manufacturer manuals, other technical literature [24, 25], or TruckSim® default values. Tables A1 and A2 (Appendix A) show the comprehensive parameters used for the tractor, dolly, and trailers simulations. The bodies of the tractor and trailer are assumed to be rigid in the simulation, since the effect of the flexibility of the tractor and trailer frames on rollover is negligible for this study.

Figure 5. CAD models developed in SolidWorks® for inertial (CG) property determination of 28-ft and 33-ft trailers

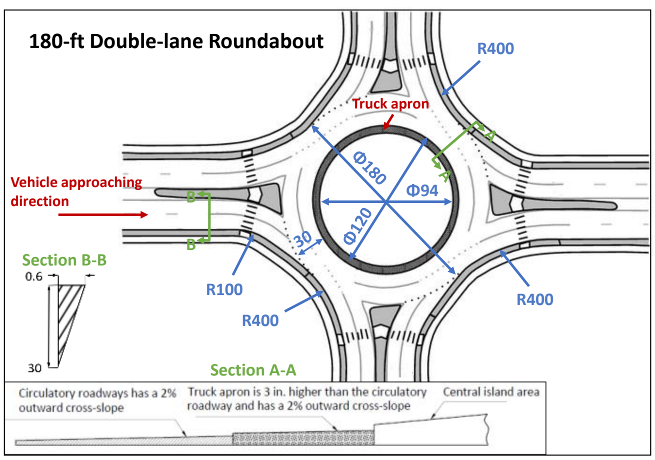
In this study, the trucks are loaded close to the maximum gross weight limit (80,000 lb) enforced by the interstate system in the U.S., except the 40-ft double [26]. The 40-ft double-trailer truck is often operated with an overload permit (140,000 lb), therefore the gross weight for this configuration is set to a separate value [27]. In addition, for a comparison study between the 28-ft and 33-ft doubles, they are assigned to carry the same trailer load, resulting in the 28-ft double with the total weight slightly lower than 80,000 lb. For all truck configurations, the loads are assumed to be fixed to the trailer floor, having uniform density and rectangular shape, as well as occupying 80% of the trailer.

4. Roundabout Model Development

The roundabout configurations considered in the current work are single-lane and double-lane with inscribed circle diameters (ICDs) of 140 ft and 180 ft, respectively. Models of the two types of roundabouts are developed in TruckSim®, taking into account the geometric factors that affect the truck dynamics, as shown in Figures 5a and 5b. The truck apron is set 3-in higher than the circulatory roadway, 13-ft wide, and have a constant 2% outward cross-slope. A common 2% cross-slope to the passenger side on the circulatory roadways (for drainage) is also considered in the roundabout models.



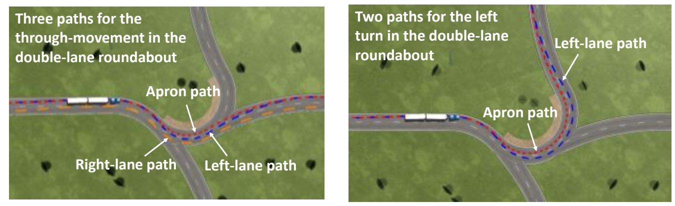
(a)



(b)

Figure 6. Horizontal geometry of (a) 140-ft single-lane and (b) 180-ft double-lane roundabout models

Right-turn, through-movement, and left-turn maneuvers, which are commonly performed by trucks in the single- and double-roundabouts, are separately modeled in TruckSim®. Specifically, three paths through the double-lane roundabout are considered, including right-lane path (entering from right lane and staying in that lane), left-lane path (entering from left lane and steering around the roundabout by using both lanes), and apron path (through the roundabout by using the apron), as depicted in Figure 7a. Additionally, two paths for the left turn in a double-lane configuration are determined: left-lane path and apron path, as shown in Figure 7b. In the simulation, the vehicle speed is held constant when entering and circulating the roundabouts. The road surface is assumed to be dry asphalt with the friction coefficient of 0.85.



(a) (b)

Figure 7. Paths considered for (a) through-movement and (b) left turn in the double-lane roundabout (ICD=180ft) in TruckSim®

5. Simulation Evaluation of Rollover Propensity

Figure 8 shows the preliminary simulation result regarding paths of the tractor steering axle center and rear trailer axle center for the left turn in the single-lane roundabout (ICD=140 ft) at 14 mph. The results indicate that there is a tendency for the rear trailer to follow inside the path of the steering axle (inboard off-tracking) for all truck configurations maneuvering the roundabouts. Among the truck configurations, the 40-ft double exhibits the largest inboard off-tracking (the worst maneuverability), followed by the 53-ft single. The 28-ft and 33-ft A-doubles have less off-tracking than the 53-ft single-trailer combination due to their two more yaw articulation points enhancing the flexibility. To accommodate the large off-tracking of the trucks, the apron needs to be used, which could affect the roll dynamics, as will be discussed later.

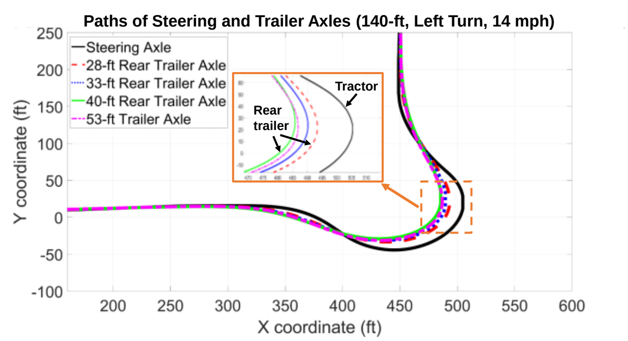


Figure 8. Paths of the tractor steering axle center and rear trailer axle center for the left turn in the single-lane roundabout (ICD=140 ft) at 14 mph

To quantitatively evaluate the potential likelihood of rollover events, a metric known as rollover index (RI) is introduced, which are derived from side-to-side tire normal forces as:

$$RI = \frac{F_{z_R} - F_{z_L}}{F_{z_R} + F_{z_L}} \quad (1)$$

where F_{z_L} and F_{z_R} denote the total tire vertical loads on the driver and passenger sides, respectively. When tires on either side lift off the ground or rest on the road surface with negligible load, the RI equals to 1. The maximum rollover index is defined as:

$$RI_{max} = max\left(\frac{|F_{z_R} - F_{z_L}|}{F_{z_R} + F_{z_L}}\right) \quad (2)$$

For the A-double configuration, the rear trailer has less roll stability than the front trailer due to the pintle-hitch coupling (between the front and rear trailers) offering a larger amount of roll and yaw degrees of freedom than the fifth wheel coupling (between the tractor and front trailer) [18]. Therefore, the RI for the rear trailer is applied to represent the rollover likelihood of the truck for this study. Figure 9, as an example, shows the time trace of the rollover index when performing the left-turn in the 140-ft roundabout at 14 mph. An offset of rollover index observed during the straight road driving is attributed to the 2% outward cross-slop on the roadway. For the 53-ft single and 40-ft double, bouncing up onto the truck apron and traveling over it result in the peak of rollover index, causing a high likelihood of rollover occurrence. In addition, abruptly large fluctuation of the rollover index is observed in a quite short period of time after the truck back down (leave off the apron), since the tires are losing contact with both apron and ground at that moment. Such fluctuation is not contributing to the truck rollover, thereby not counted in the roll dynamics evaluation.

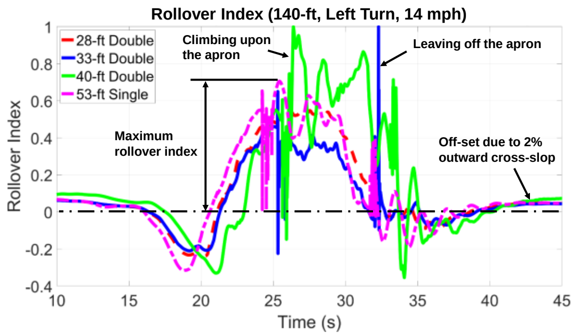


Figure 9. Time trace of rollover index for the left turn in the single-lane roundabout (ICD=140 ft) at 14 mph

5.1 Summary Results of Maximum RI for 140-ft Single-lane Roundabout

To thoroughly learn the truck rollover propensity in roundabouts, the four truck models are assigned to perform the maneuvers in the single- and double-lane roundabouts with 1-mph incremental speed until tires lift off the ground. The maximum RI of 0.8 is considered as an upper limit beyond which the truck becomes involved in an unsafe situation subject to a high likelihood of rollover. Figure 10 provides a summary of the maximum RI of the truck configurations for the right turn in the single-lane roundabout (ICD= 140 ft) at different speeds. According to Figure 10, the maximum RI increases with increasing speed, and the 40-ft double, with a nearly 3-mph lower rollover speed threshold (at RI=0.8), is more susceptible to rollover crashes than the conventional 53-ft single-trailer truck. In addition, the 28-ft and 33-ft doubles can tolerate a 2-mph higher rollover speed better than the 53-ft single. No discernible difference is found between the 28-ft and 33-ft doubles for this maneuver.

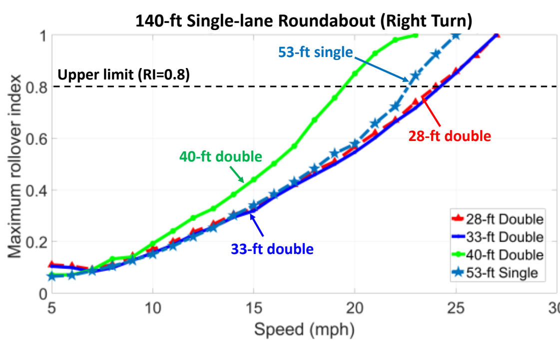


Figure 10. Simulation results of truck maximum RI for the right turn in the single-lane roundabout (ICD=140 ft)

Figures 11 and 12 summarize the results of maximum RI for the through-movement and left turn in the single-lane roundabout, respectively. Compared to the other configurations, the 40-ft double has the largest RI in the speed range, while exhibiting a rollover threshold of 9 mph, far lower than those of other trucks. This amounts to that the 40-ft double experiences high risk of rollover when traveling in the roundabout even at low speeds. It is mainly because the rear trailer and dolly wheels experiencing large off-tracking have to ride up on the apron, imposing more lateral load transfer that works together with the centrifugal force to further increase trailer body roll and thus leading to high rollover risk. In addition, for the 40-ft A-double, there is a lack of anti-roll moment transferred from the front trailer to the rear trailer, owing to the pintle-hitch coupling allowing for a large free relative roll motion between them.

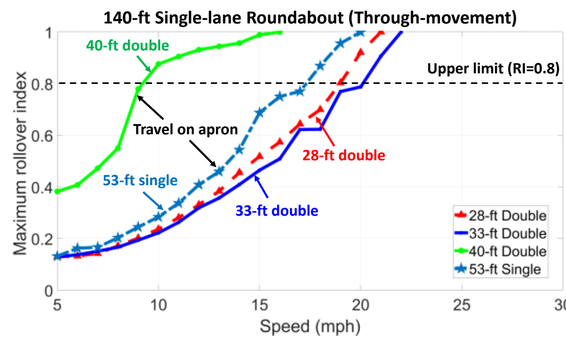


Figure 11. Simulation results of truck maximum RI for the through-movement in the single-lane roundabout (ICD=140 ft)

As indicated in Figures 11 and 12, the 28-ft and 33-ft doubles display favorable roll stability with obvious lower maximum RI (less likelihood of rollover) than the 53-ft single for the speeds that are considered. The reason is that the double-trailer arrangements provide additional flexibility with better off-tracking performance, therefore less affected by the destabilizing influence of the apron. More interestingly, increasing the trailer length from 28 ft to 33 ft slightly diminishes the peak RI, due to the longer wheelbase rendering a slight amount of additional roll stability. However, increasing the length of the trailer from 33 ft to 40 ft results in the truck exhibiting a heavy use of apron significantly promoting the likelihood of rollover.

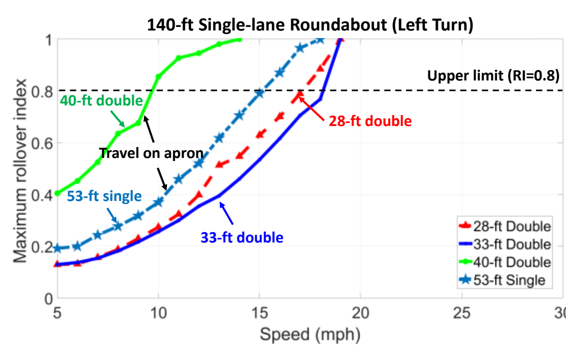


Figure 12. Simulation results of truck maximum RI for the left turn in the single-lane roundabout (ICD=140 ft)

Comparing the results of the three maneuvers for the single-lane roundabout in Figures 10-12, the trucks negotiating the left turn exhibit larger maximum RI at the corresponding speeds as compared to those for the right-turn and through-movement. In other words, the trucks would experience a higher risk of rollover when circulating the central island in the left-turn movement. In contrast, the trucks in the right turn have the lowest risk of rollover because they perform a relatively larger-radius turn and do not need to use the truck apron. These also confirm the research results by Yunbo and Ahmadian [9] and Waddell et al. [14].

5.2 Summary Results of Maximum RI for 180-ft Double-lane Roundabout

Figure 13 compares the maximum RI among the truck configurations for the right-turn in the double-lane roundabout (ICD=180 ft) at the corresponding speeds. Similar to the results in Figure 10, the 40-ft double, with a nearly 4-mph lower rollover speed threshold (RI=0.8), is more prone to roll over as compared to the 53-ft single-trailer truck. The 53-ft single exhibits aprroximately1-mph lower rollover speed worse than the 28-ft and 33-ft doubles.

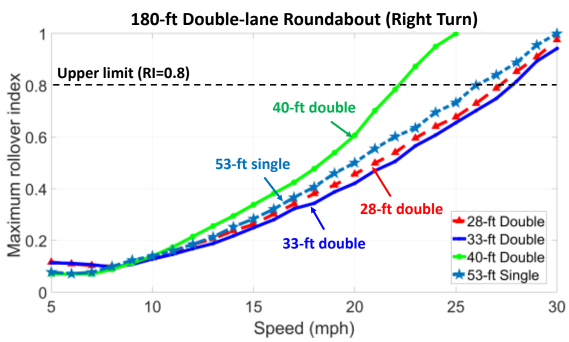


Figure 13. Simulation results of truck maximum RI for the right turn in the double-lane roundabout (ICD=180 ft)

Figures 14-16 provide the comparison of the trucks' maximum RI for the three various paths when performing through-movement in the double-lane roundabout. Among the truck configurations, the 40-ft double is apparently the most likely to turn over (with the largest value of maximum RI) for the speeds and paths, especially when traveling along the apron path and the left-lane path (due to encountering the truck apron). As the speed increases over 11 mph for the apron path, the truck stops using the apron, since the increased speed results in more tire sliding and outward trailer sway (less off-tracking). Consequently, the maximum RI for the 40-ft double drops by 50% at the speed of 12 mph, as shown in Figure 15. Furthermore, the 28-ft and 33-ft doubles exhibit 1-mph and 2-mph lower rollover thresholds as compared to that of the 53-ft single-trailer truck, respectively. This finding also intensifies the certainty that the extra length of the 33-ft trailer gives slightly better roll stability (less chance of rollover) as compared to the 28-ft trailer. Notably, when traveling in the apron path at the speed below 15 mph in Figure 16, a higher maximum RI is observed for the 33-ft double than the 28-ft double, mainly caused by the destabilizing influence of the apron curb.

By comparing the results in Figures 14 -16, the trucks using the right-lane path experience less likelihood of rollover than those adopting left-lane and apron paths when traveling through the double-lane roundabout. The right-lane path, where the trucks enter from the right lane and then keep in that lane, provides a shorter lateral transition, contributing to less lateral acceleration at the vehicle body (less load transfer). This implies that for the through-movement in a double-lane roundabout, entering from the right lane and staying in that lane make trucks less likely to roll over than maneuvering from and using the left lane. If the driver has to enter from the left lane, straddling on both lanes to avoid the use of apron (left-lane path) is more favorable than staying in the left lane (apron path) to accomplish the through-movement, as indicated in Figures 15 and 16.

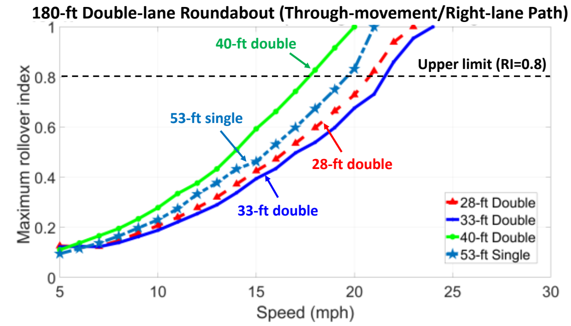


Figure 14. Simulation results of truck maximum RI for the through-movement (right-lane path) in the double-lane roundabout (ICD=180 ft)

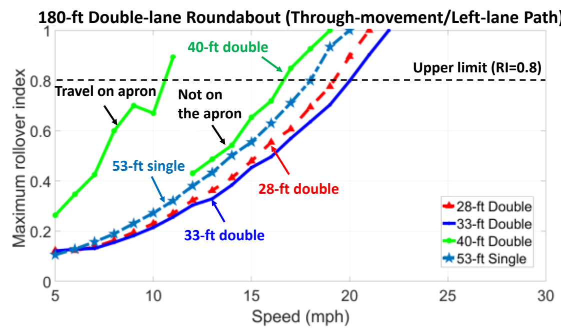


Figure 15. Simulation results of truck maximum RI for the through-movement (left-lane path) in the double-lane roundabout (ICD=180 ft)

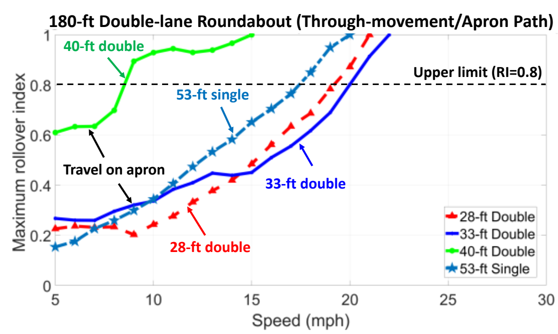


Figure 16. Simulation results of truck maximum RI for the through-movement (apron path) in the double-lane roundabout (ICD=180 ft)

The summary results of the trucks' maximum RI for the two paths considered in the left turn are shown in Figures 17 and 18, respectively. There observe larger values of maximum RI for the 40-ft doubles than the other truck configurations, which are consistent with the results discussed previously. The difference becomes more pronounced as the speed increases. As compared to the apron path (in Figure 18), the left-lane path (in Figure 17) results in the trucks experiencing lower maximum RI (less chance of rollover), especially for the truck with poor off-tracking performance such as 40-ft double and 53-ft single.

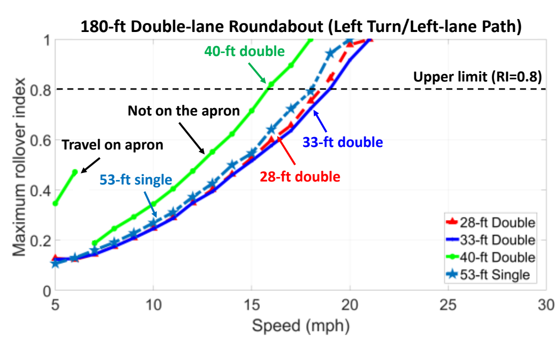


Figure 17. Simulation results of truck maximum RI for the left turn (left-lane path) in the double-lane roundabout (ICD=180 ft)

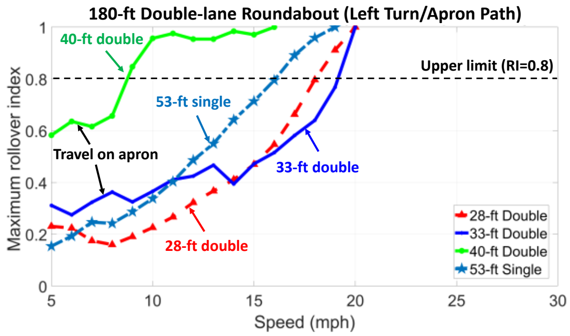


Figure 18. Simulation results of truck maximum RI for the left turn (apron path) in the double-lane roundabout (ICD=180 ft)

6. Conclusions

A comprehensive simulation analysis of rollover propensity of multi-trailer commercial trucks in roundabouts has been performed in this paper. The truck models for the 28-ft double, 33-ft double, 40-ft double, and 53-ft single are developed in TruckSim®. The models are used to perform an extensive simulation to analyze the maximum RI among these trucks for two types of roundabouts, 140-ft single-lane and 180-ft double-lane roundabouts. The simulation results indicate that the 40-ft double-trailer truck, with 2-9 mph lower rollover speed thresholds (as shown in Table 1), are more susceptible to roll over than the conventional 53-ft single-trailer truck in the roundabouts. It is mainly because the pintle-hitch coupling in the A-double configuration provides a certain amount of roll degree of freedom between the front and rear trailers, diminishing the roll stability. Additionally, the 40-ft A-double makes heavier use of the truck apron to accommodate its larger off-tracking, which considerably increases the likelihood of rollover. The results also show that the 28-ft and 33-ft doubles exhibit better maneuverability (less off-tracking) and can tolerate 1-3 mph higher rollover speeds than the 53-ft single when traveling through the roundabouts, as shown in Table 1. As compared to the 28-ft double, the longer wheelbase of the 33-ft double renders a slight amount of additional roll stability, slightly lowering the chance of rollover crashes in roundabouts.

Table 1. Summary of the truck rollover speed thresholds (RI=0.8) in the roundabouts

Roundabout maneuvers		53-ft single	28-ft double	33-ft double	40-ft double
140-ft single-lane	Right turn	23 mph	25 mph	25 mph	20 mph
	Through-movement	17 mph	19 mph	20 mph	9 mph
	Left turn	15 mph	17 mph	18 mph	10 mph
180-ft double-lane	Right turn	26mph	27mph	28mph	22 mph
	Through-movement (right-lane path)	20 mph	21mph	22mph	18 mph
	Through-movement (left-lane path)	18 mph	19 mph	20 mph	11 mph
	Through-movement (apron path)	17 mph	19 mph	20 mph	8 mph
	Left turn (left-lane path)	18 mph	19 mph	19 mph	16 mph
	Left turn (apron lane path)	16 mph	18 mph	19 mph	9 mph

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Appendix A

Table A1. Parameters for the tractor and dolly dynamics simulation

Vehicle	Parameter	Value
Tractor	Tractor body weight (sprung weight)	14559.0 lb
	Tractor roll inertia	168436.0 lb·ft^2
	Tractor pitch inertia	539261.0 lb· ft^2
	Tractor yaw inertia	488202.0 lb· ft^2
	Tractor wheelbase	253.0 in
	Tractor front track	80 in
	Tractor rear track	73.5 in
	Longitudinal distance from tractor CG to steer axle	103.4 in
	Tractor CG height to the ground	39.8 in
	Front suspension stiffness	12197.0 lb/ft
	Front suspension damping coefficient	1199.0 lb·s/ft
	Front suspension lateral span (springs)	32.5 in
	Front suspension lateral span (dampers)	43.3 in
	Rear suspension damping coefficient	1980.0 lb·s/ft
	Rear suspension lateral span (springs)	30.0 in
	Rear suspension lateral span (dampers)	42.0 in
	Steering ratio	22.0
	Fifth-wheel height to the ground	43.3 in
	Fifth-wheel roll freedom	±1 deg
	Fifth-wheel pitch freedom	-15 ~ 11 deg
	Fifth-wheel yaw freedom	±180 deg
	Steering axle and wheels weight (unsprung weight)	1256.6 lb
	Drive axle and wheels weight (unsprung weight)	1730.6 lb
A-dolly	Dolly weight (sprung weight)	1329.0 lb
	Dolly roll inertia	28476.0 lb· ft^2
	Dolly pitch inertia	35596.0 lb· ft^2
	Dolly yaw inertia	41647.0 lb· ft^2
	Dolly CG height to ground	35.4 in
	CG to hitch longitudinal distance	70.9 in
	Dolly axle and wheels weight (unsprung weight)	1411.0 lb
	Dolly suspension lateral span (springs)	34.0 in
	Dolly suspension lateral span (dampers)	31.0 in
	Pintle hitch roll freedom	±16 deg
	Pintle hitch yaw freedom	±70 deg
	Pintle hitch pitch freedom	±90 deg
	Dolly fifth-wheel height to ground	43.3 in

Table A2. Parameters for the semi-trailer dynamics simulation

Trailer parameters	53-ft single	28-ft double	33-ft double	40-ft double
Gross weight (total)	80.0 kips	77.9 kips	80.0 kips	140.0 kips
Trailer tare weight	17.0 kips	10.5 kips	11.5 kips	14.8 kips
Unloaded trailer sprung weight	14.2 kips	9.0 kips	10.1 kips	12.0 kips
Trailer CG height to the ground	75.2 in	75.2 in	75.2 in	75.2 in
Payload CG height to the ground	93.5 in	93.5 in	93.5 in	93.5 in
Trailer CG long. distance to the kingpin	282.0 in	138.0 in	168.0 in	204.0 in
Roll moment of inertia	559416.0 lb·ft^2	209519.0 lb·ft^2	304497.0 lb·ft^2	471418.0 lb·ft^2
Pitch moment of inertia	4501595.0 lb·ft^2	1020132.0 lb·ft^2	1905968.0 lb·ft^2	3793479.0 lb·ft^2
Yaw moment of inertia	4388541.0 lb·ft^2	978121.0 lb·ft^2	1842725.0 lb·ft^2	3698209.0 lb·ft^2
Distance from kingpin to the axle	522.0 in	276.0 in	324.0 in	384.0 in
Estimated cargo load (each trailer)	43.7	17.5	17.5	44.2
Estimated load volume	80.0 %	80.0 %	80.0 %	80.0 %