Experimental Analysis of a Direct Access Driveway at a Roundabout: Performance with One or More Slip Lanes

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Abstract

This paper studies the performance of single-lane roundabouts with a direct driveway access road, one lane driveway right-out movements only, to allow facility (land parcel) driveway volumes to access directly at a roundabout. VISSIM micro- simulation assessment considers experimental origin-destination (O-D) balanced flow scenarios with three different driveway volumes (low, moderate, high, and compared to no driveway) and with and without slip lane scenarios (no slip lane, one slip lane, and two slip lanes). Simulated right-turning traffic volumes range from 50 to 500 vehicles per hour. Experiment results indicate that average delay of a roundabout is sensitive to changing driveway's volumes. As expected, results indicate a direct access driveway increases the roundabout vehicle average traffic delay. At high driveway's volumes level, the total average roundabout delay was increased by 50% at a moderate vehicle traffic level and by 71% at a high vehicle traffic level, before oversaturation. The total average driveway traffic delay also was increased by 8% at a moderate traffic level and by 12% at a high traffic level. Finally, this study also suggests that having more than one slip lane, at different roundabout approaches, reliefs total roundabout average delay, provides an efficient direct roadway driveway access, and enhances access management.

Key words: Roundabout, Driveway, Average delay, VISSIM, Slip lanes.

INTRODUCTION

Access Management enhances vehicular access points to land parcels adjacent to roadways including a direct access to roundabouts. KDOT (2014) restricts accesses directly at a roundabout, but allows accesses near a roundabout that meet certain conditions. The KDOT Access Management Policy provides guidance on access management at roundabouts, including access spacing criteria.

Malik et al. (2011) studied the driveways with direct access, in commercial areas, and found that the driveways can create operational as well as safety concerns for both mainline and driveway traffic. They focused on the left turns in and out of developments by using microscopic simulation models. They recommended ranges for driveway left turns, as results, in terms of delay for the mainline and driveway traffic, and queues for the mainline traffic.

Roundabouts can be used as an alternate intersection design to facilitate major traffic turning movements and to enhance operational and safety performance. A slip lane, a separate lane that facilitates right-turning traffic flow, reduces approach delay by allowing right-turning movements to bypass the roundabout, thereby reducing vehicle conflicts. Though roundabouts are an increasingly common form of intersection control in the U.S., research has yet to quantify slip lane contributions to Access Management operational and safety improvements when slip lanes are installed.

NCHRP Reports 572 (2007) and 672 (2010) define two types of slip lane: a nonyield slip lane, merging with the roundabout exit leg and forming a new acceleration (free-flow) lane adjacent to exiting traffic; and a yield slip lane, terminating at a sharp angle with the roundabout exit approach so that right-turning traffic is yielding.

Al-Ghandour et al. (2011) experimentally studied roundabout with a and without slip lane performance by simulating both balanced (total traffic flow into and out of each roundabout approach is the same) and more realistic unbalanced flow scenarios (traffic flow into and out of different roundabout approaches is different) for a range of volume levels, likewise using a microscopic simulation package (VISSIM) (PTV2007). They found that a roundabout with a free-flow or with a yield slip lane exit types significantly reduce total roundabout average traffic delay, compared to no slip lane.

So far, the research has rarely developed "direct driveway access" at roundabouts based on vehicle delay. Therefore, it would be useful to explore an experimental procedure that considers some driveway traffic volumes patterns. This paper explores overall roundabout and driveways' operational performance in a simulated environment by quantifying average delay with and without slip lanes options.

APPROACH

In this study, single-lane roundabout-based experimental simulation was used to determine the average delay of roundabout and driveway with different driveway's volumes and with slip lanes configurations. Roundabout entry and exit flow volumes for each approach are assumed the same (symmetric), although the dominant right-turning traffic percentages are same (75%), Al- Ghandour et al. (2011). Six experimental scenarios with equal traffic percentage turning volume distributions were assumed for balanced scenarios (traffic flow into and out of each roundabout approach is the same) and with different slip lanes configurations (Figure 1). The base scenario, a single-lane roundabout with no slip lane, is shown in S1. In S2, similar as S1, with direct access driveway at a roundabout circle and is placed at the northbound entry approach; in S3, similar to S1, is a single-lane roundabout with a slip lane placed at the northbound entry approach, in S4, similar to S2 and S3, is a single-lane roundabout with a slip lane and a driveway is placed at the northbound entry approach; in S5, is a single-lane roundabout with two slip lanes are placed at the northbound and the southbound entry approaches; finally, in S6, similar to S5 with two slip lanes and with a driveway, (Figure 1).

The scenarios (S1 to S6) were initialized, analyzed, and then controlled through several iterations. Several variables were tested across the traffic percentage distribution scenarios: 1) right-turning traffic volume as the dominant turn (from 50 vehicles per hour to 500 vehicles per hour, in increments of 50—representing low, moderate, and high volumes), 2) traffic percentage distribution flow patterns (75%), and 3) three different driveway volumes vehicles per hour (DRW50: low: 50 vehicles per hour, DRW100: moderate: 100 vehicles per hour, and DRW300: high: 300 vehicles per hour).

These six traffic volumes distribution scenarios were coded into VISSIM to evaluate the performance of roundabout. The total minimum number of VISSIM runs was 20 (1 hour each) based on statistical equation to be met with a 95% confidence interval and acceptable error. In total, 60 scenarios were modeled: 1 traffic O-D (75%) x 10 traffic volumes (50 to 500 vehicles per hour) x 6 scenarios (S1-S6). For each simulation scenario, 20 VISSIM runs, executed using different random number seeds, resulted in a total of 1,200 simulations. The driveway were modeled, as VISSIM allows, for the

driveway, the vehicle type and vehicle model were both selected as cars (no trucks or buses). The driveway geometry was constructed using links modeled as (one lane driveway right-out movements only - 12 feet.) Drivers on the driveway must yield the right-of-way to roundabout circle or slip lane traffic crossing (priority rule).

Average roundabout delay (in seconds) for all vehicles entering the roundabout and average of delay for the driveway (vehicles in seconds) is used in this study as the Measure of Effectiveness (MOE) of the roundabout and the driveway.

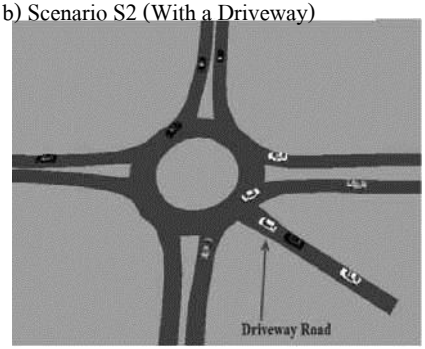
ANALYSIS AND RESULTS

A sample of total approach (V_a) volume flows for scenarios S1-S6 is summarized in Table 1. At high traffic volumes (V_{rt} = 500 vehicles per hour), northbound approach volume (V_a) is 677 vehicles per hour. Scenario (S2), which has driveway, sustains more vehicles circulating than the other scenarios S3 to S6.

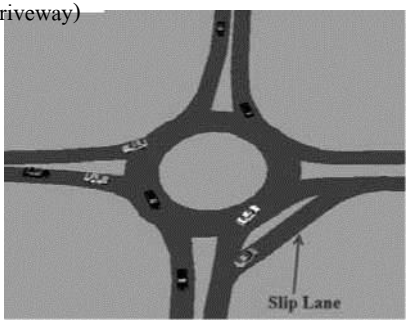
a) Scenario SI (No Driveway)

- A =

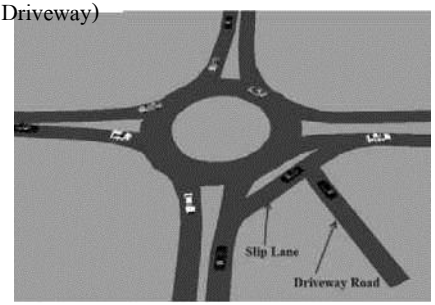
b) Scenario S2 (With a Driveway)



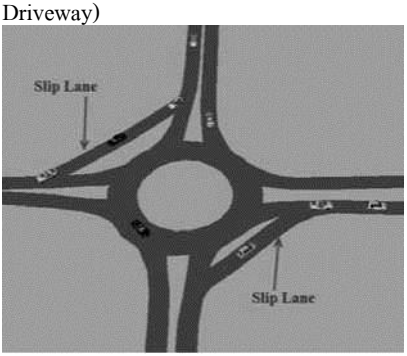
a) Scenario S3 (Slip Lane and No Driveway)



b) Scenario S4 (Slip Lane and a Driveway)



c) Scenario S5 (Two Slip Lanes No Driveway)



d) Scenario S6 (Two Slip Lanes and a Driveway)

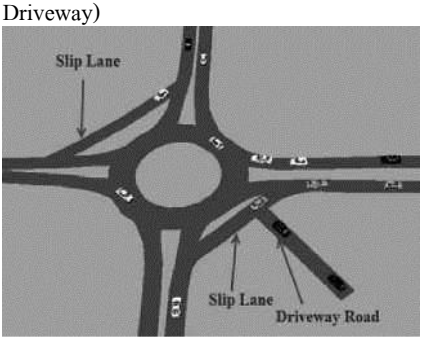


Figure 1. VISSIM Snapshots with a Driveway and Slip Lanes Scenarios (S1-S6).

Table 1. Sample of Total Approach Volumes, Vehicles per Hour.

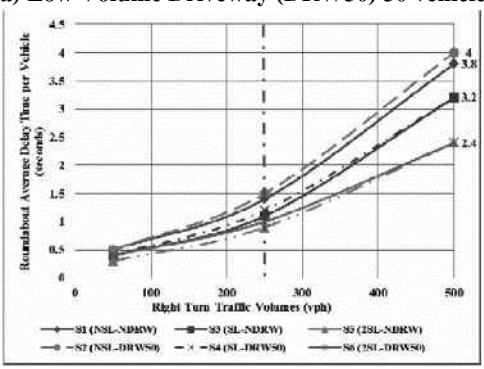
V_{rt}: Right Turn Volume at Northbound (NB) Approach (V ehicle/hour)	$V(_a)$:Volumes (Vehicle/hour)	S1-S6 (75%)
$V_{rt} = 50$ (Low)	Va	166
$V_{rt} = 250$ (Moderate)	Va	333
$V_{rt} = 500$ (High)	Va	677

V_a : Approach volumes. V_{rt}: A dominant right turns volumes, vehicles per hour.

Average Roundabout Delay with a Driveway Access

VISSIM results with driveway volumes for balanced scenarios were analyzed. Results showing average vehicle delay in seconds for all vehicles in the roundabout with three driveway volumes levels range from 50 to 300 vehicles per hour. Figures 2a to 2c show the roundabout average delay time per vehicle with driveway.

a) Low Volume Driveway (DRW50) 50 vehicles per hour



For example, for low driveway volumes DRW50 (50 vehicles per hour), roundabout average vehicle delay (in seconds) delay decreases from 3.8 seconds per vehicle (Scenario S1 - no slip lane no driveway) to 3.2 seconds per vehicle (Scenario

b) Moderate Volume Driveway (DRW100) 100 vehicles per hour

c) High Volume Driveway (DRW300) 300 vehicles per hour

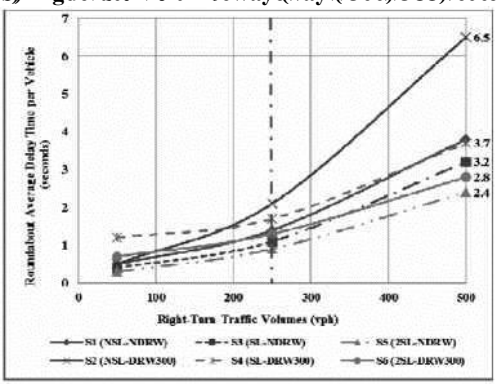


Figure 2. Sample of Outputs from VISSIM: Comparison between R Average Delay, Scenarios S1-S6.

S3 - no slip lane and no driveway) at right-turn volumes V_{rt}= 500 vehicles per hour, a (-15.79 %) change, (Figure 2a).

At moderate driveway volumes, volumes DRW100 (100 vehicles per hour), Scenario S2 (no slip lane and driveway) shows the highest delay for the roundabout with driveway (4.3 seconds per vehicle) compared to S6 (two slip lanes and driveway) (2.4 seconds per vehicle, a (-44.19 %) change Figure 2b).

Finally, results shows at highest driveway volumes, volumes DRW300 (300 vehicles per hour), Scenario S2 (no slip lane and driveway) shows the highest delay for the roundabout with driveway (6.5 seconds per vehicle) compared to S4 (one slip lane and driveway) (3.7 seconds per vehicle, a (-43.08 %) change (Figure 2c) and compared to S6 (two slip lanes and driveway) (2.8 seconds per vehicle, a (56.92 %) change (Figure 2c).

Figure 3 shows the “delay-induced” value which is defined as the difference between roundabout average delay with a driveway and slip lane, at specific driveway traffic volume level. Figure 3 shows the delay-induced is more significant when a roundabout include driveway and two slip lanes S6 (-1.6) compared to S2 (no slip lane and driveway), at any driveway volumes levels. When a roundabout traffic becomes oversaturated, a theoretical capacity thresholds values (limits) for right-turning volumes (V_{rt}) are estimated to be within a range of 200 to 300 vehicles per hour for various balanced traffic distribution volumes (vertical dashed line on Figure 2).

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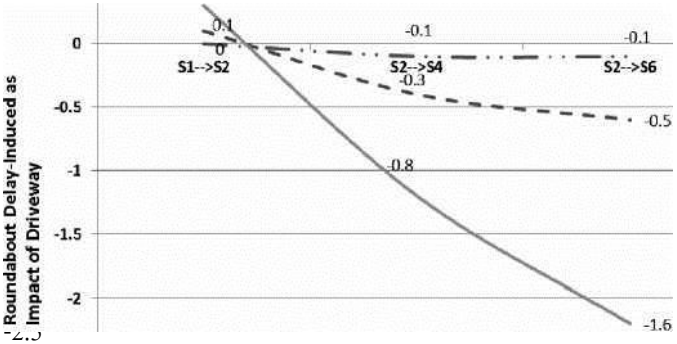


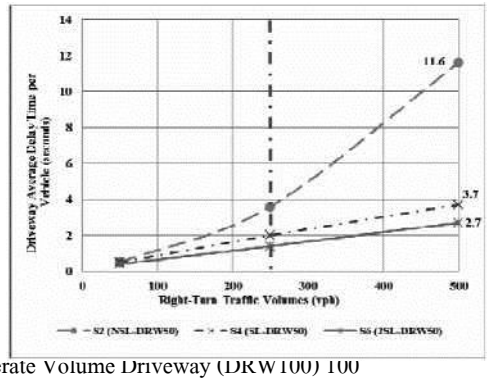
-2.5

study field data for S2 (no slip lane with a driveway) off Hillsborough Street and W. Morgan Street, Raleigh, NC, as shown in Figure 5. The driveway volumes were collected (18 vehicles per hour AM peak time and 36 vehicles per hour PM peak time) and matched the low volumes levels (DRW 50: 50 vehicles per hour).

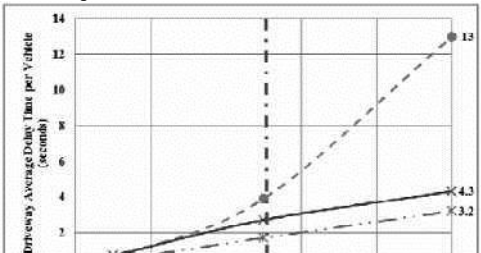
Finally, a statistical validation also was tested from VISSIM results for the six experiments, based on the standard error for the percentage change of the driveway's average delay, Table 2, using a driveway is 0.15. The 95% confidence interval is ±1.96 standard errors from the average delay percentage of reduction. Therefore, the VISSIM 95% confidence interval for implementing a driveway type is estimated between 37.33 and 17.87 with high driveway's volumes for S2 Scenario (no slip lane and driveway) and is estimated between 11.01 and 4.79 with high driveway's volumes for S4 Scenario (one slip lane).

a)

Low Volume Driveway (DRW50) 50 vehicles per hour



b) Moderate Volume Driveway (DRW100) 100 vehicles per hour



c) High Volume Driveway (DRW300) 300 vehicles per hour

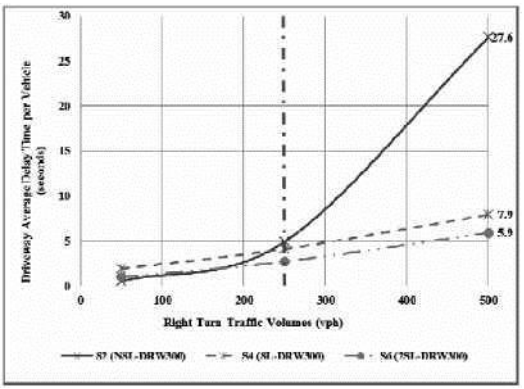


Figure 4. Sample of Outputs from VISSIM: Comparison between Driveway Average Delay, Scenarios S1-S6.

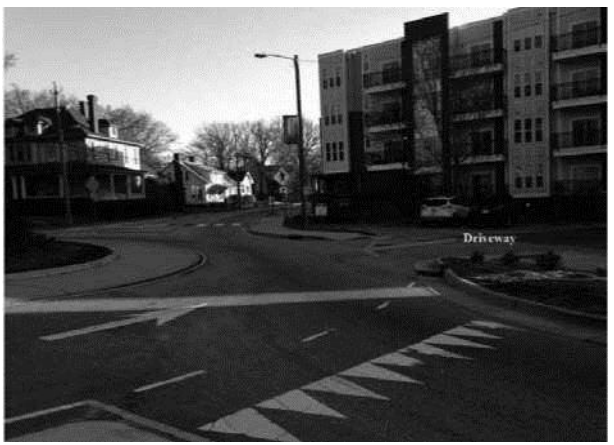


Figure 5. A Case Study: Roundabout with No Slip Lane and a Driveway off Hillsborough Street and W. Morgan Street, Raleigh, NC - Scenario S2 (with a Driveway).

Table 2. Sample of VISSIM Driveway Average Delay-Balanced Scenarios (S2 and S4)

Scenarios	Vrt: Right Turn Volume at Northbound Approach (Vehicle/hour)	Average Driveway Delay (seconds) (Standard Deviation(s) Errors for 20 Runs)		
		Driveway (DRW50)	Driveway (DRW100)	Driveway (DRW300)
S2	50 (Low)	0.5 (1.3)	0.5 (1.3)	0.5 (1.3)
	250 (Mod)	2.6	3.0	4.9
	500 (High)	11.6	13	27.6
S4	50 (Low)	0.5 (1.7)	0.7 (1.89)	1.9 (3.8)
	250 (Mod)	2.0	2.7	4.1
	500 (High)	2.7	4.3	7.9

V_{rt}: A dominant right turns volumes, vehicles per hour. S2: Scenario S2 (with a driveway). S4:
Scenario S4 (slip lane and a driveway). DRW50: Low driveway's volumes (50 vehicles/hour).
DRW100: Moderate driveway's volumes (100 vehicles/hour).
DRW300: High driveway's volumes
(300 vehicles/hour).

CONCLUSIONS

The driveway traffic with a direct access at a roundabout may cause longer waiting time for right out traffic movements, crossing the circulating roundabout traffic and cause more vehicle conflicts. As expected, results indicate a direct access driveway increases the roundabout vehicle average delay. At high driveway's volumes level, the total average roundabout traffic delay was increased by 50% at a moderate vehicle traffic level and by 71% at a high vehicle traffic level, before oversaturation. The total average driveway traffic delay also was increased by 8% at a moderate traffic level and by 12% at a high traffic level, before oversaturation.

A hypothesis, having more than one slip lane, at different roundabout approaches, help to reduce total roundabout average traffic delay and provides efficient roadway driveway access. Finally this study suggests that incorporating slip lanes are significant sensitive per driveway which impact on the driveway access and operation for a roundabout.

RECOMMENDATION

Future research should include investigating the performance of access point driveways with full movement (right-in and right-out) access near a roundabout, including the capacity of the access point, left-tum storage needs, including access spacing criteria and sight-distance. Also futures studying the impact of pedestrian's crosswalks are crossing access point driveways.

Additional analysis should be conducted for other variables such as roundabout geometric (spacing distance from the end of the splitter island leaving the roundabout). More field collected data for different driveways (public and private) traffic volumes that affect roundabout operational performance. Finally, future analysis should be conducted to consider more variations in percentages of trucks in and out from the driveways.

ACKNOWLEDGEMENTS

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