To simplify MOVES2010b coding used for a project level analysis, the four activity modes are assumed for a vehicle entering the roundabout, decelerating to the yield line, and accelerating out entering the circulating lane then accelerating leaving the roundabout. The average speed is assumed as 18 miles per hour for all roundabout links. MOVES2010b specifications were completed for an input database that included required spreadsheet inputs such as links, road type, link source types, and age distribution. MOVES2010b was executed and MySQL database output was extracted to estimate emissions.

ANALYSIS AND RESULTS

With assumption that approaching traffic stays the same, as slip lane (right-turning) traffic volume (V_{sl}) increases, the conflicting circulating volumes (V_c), decrease; average delay, fuel consumption, and emissions also decrease, in a non-linear, or exponential, relationship. For roundabouts (S1-S3), the highest roundabout average delay (Figure 2), fuel consumption (Figure 3), and emissions (Figures 4 and 5) observed in Scenario S1 (no slip lane), were a result of the combined highest approach volumes (V_a), highest total roundabout volumes, and highest conflicting circulating flow (V_c), and also an increased amount of idling (stops). The lowest roundabout average delay, fuel consumption, and emissions observed in Scenario S3 (free-flow slip lane), was a result of the combined lowest approach volumes (V_a), lowest total roundabout volumes, lowest conflicting circulating flow (V_c), and number of stops.

If Scenario S3 (free-flow slip lane) is compared with Scenario S4 (AWSC intersection) (Figures 2 to 5), Scenario S3 shows significant reduction of total average fuel consumption and pollutant emissions. Therefore, under different scenarios, slip lane performance is most effective under a higher right-turning traffic pattern distribution.

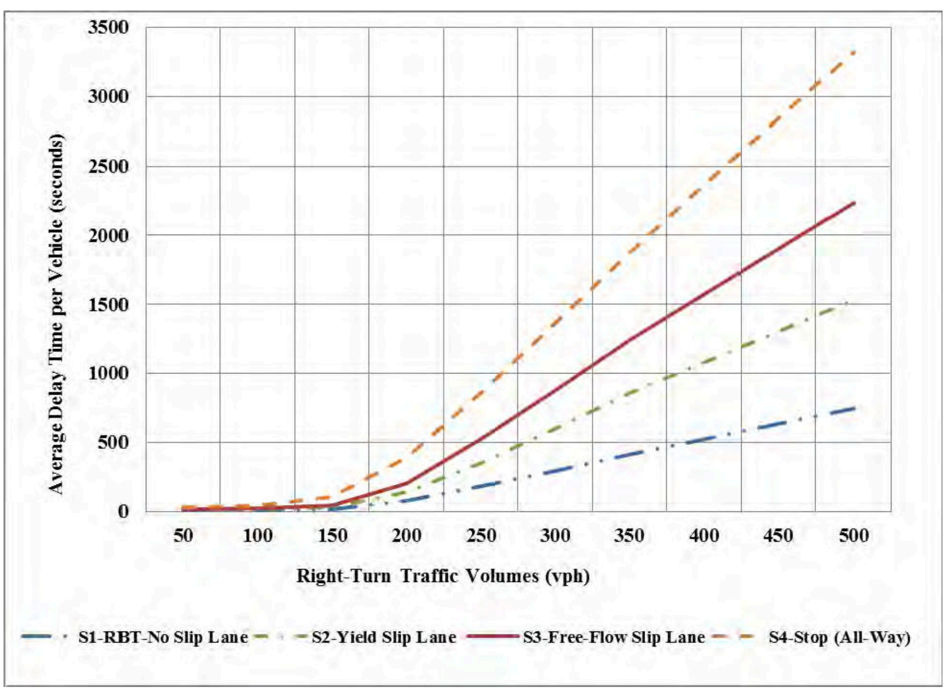

Figure 2. SIDRA: Roundabout (Intersection) Average Delay for Scenarios S1-S4.

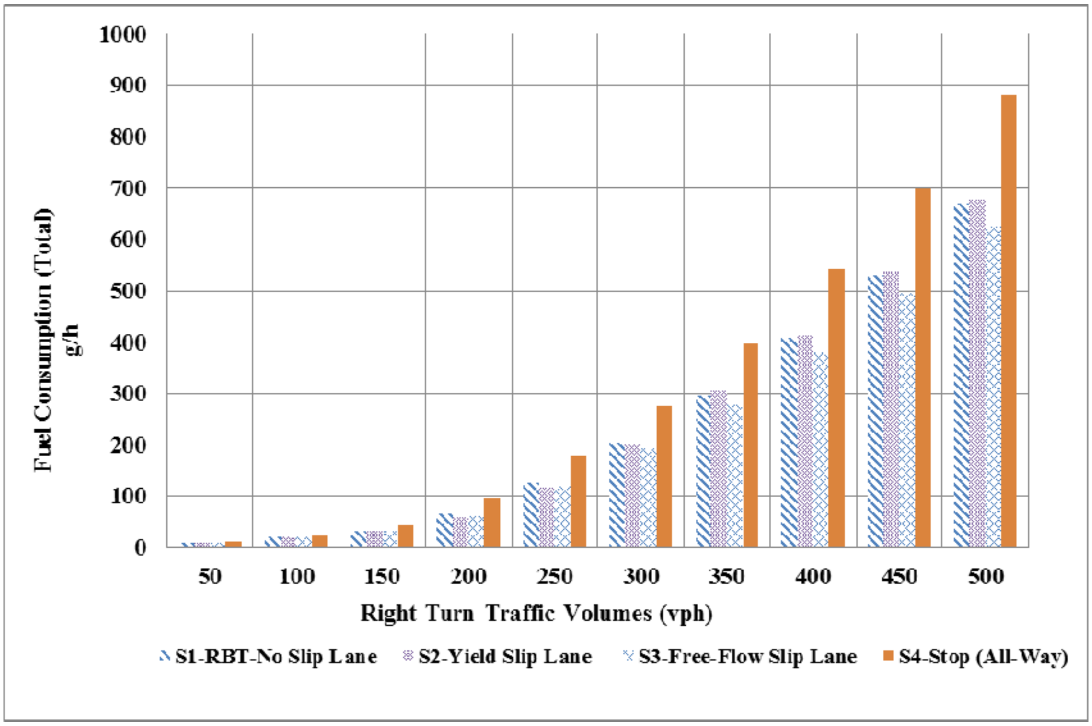

Figure 3. SIDRA: Roundabout (Intersection) Total Fuel Consumption for Scenarios S1-S4.

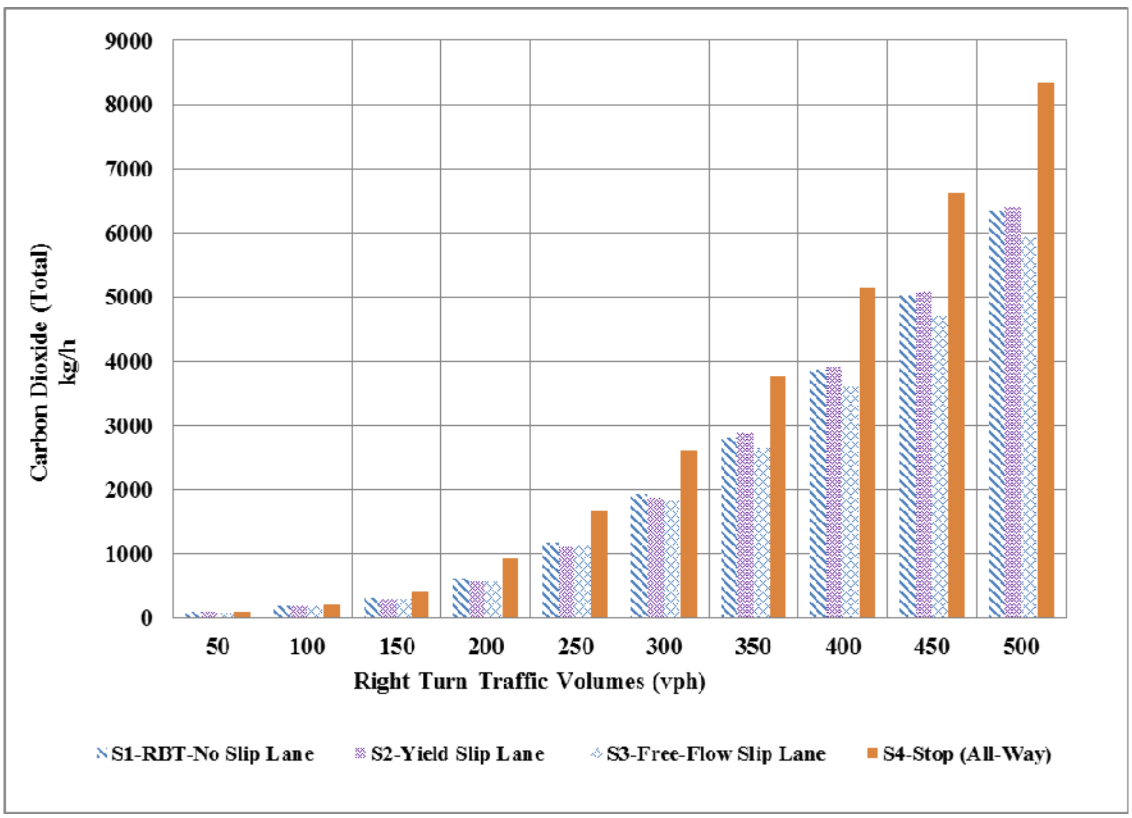

Figure 4. SIDRA: Roundabout (Intersection) Total Carbon Dioxide (CO_2) Emissions for Scenarios S1-S4.

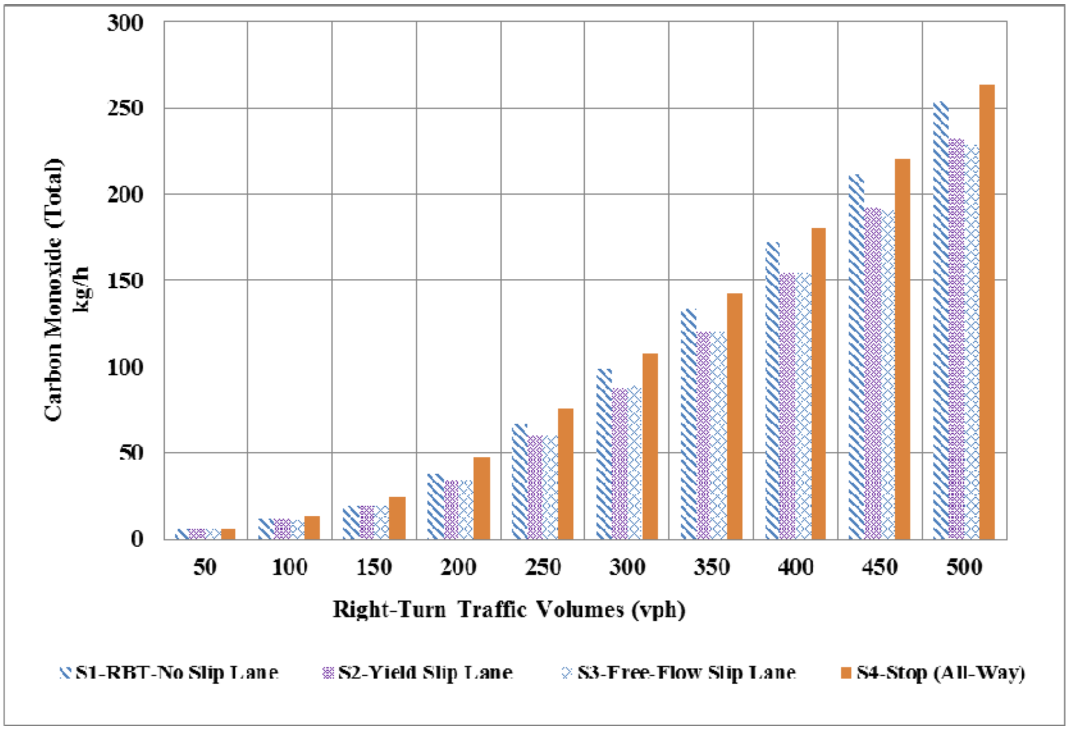

Figure 5. SIDRA: Roundabout (Intersection) Total Carbon Monoxide (CO) Emissions for Scenarios S1-S4.

As more traffic is diverted outside the roundabout on the slip lane (right-turn movement), more roundabout conflicting circulating volumes are reduced. The average delay in the roundabout is reduced, thereby reducing vehicle conflicts, delays, and stops, and reducing vehicle fuel consumption and pollutant emissions.

Number of stops correlates to both fuel consumption and emissions. For example, with traffic volumes V_{sl} = 50 vehicles per hour, a roundabout with a free-flow slip lane exit type has fewer total effective stops (349 vehicles/hour), and less fuel consumption and emissions, than an AWSC intersection (850 vehicles/hour).

Impact of Slip Lane on Total Fuel Consumption

A sample of the results from SIDRA is compared, based on total fuel consumption between highest values from Scenario S4 (AWSC intersection), as the before case, and lowest values from Scenario S3 (roundabout with a free-flow slip lane exit type), as the after case (Table 3). Total fuel consumption for all vehicles is shown in Table 3 in gallons per hour.

With high traffic volumes V_{sl} = 500 vehicles per hour, a roundabout with a free-flow slip lane exit type has less total fuel consumption for all vehicles (626.7 gal/hour) than an AWSC intersection (881.9 gal/hour)—a 29% reduction (calculated as -28.94 % = ((626.7-881.9)/881.9)). Thus, total fuel consumption via the use of a free-flow slip lane is shown to be less than in an all-way stop-controlled intersection.

Table 3. SIDRA Percent Change in Fuel Consumption – Scenarios (S3 and S4).

V_{sl}: Slip Lane Volume, Right-Turn Volume (Vehicle/hour) at Northbound (NB) Approach	Total Fuel Consumptions (gal/hour)		Percent Change
	S4 (Before)	S3 (After)	
V_{sl} = 50 (Low)	10.4	9.6	-7.96%
V_{sl} = 250 (Moderate)	176.3	118.3	-32.90%
V_{sl} = 500 (High)	881.9	626.7	-28.94%

V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour, for S3. Northbound right turn, vehicles per hour, for S4.

Impact of Slip Lane on Total Emissions

With high traffic volumes V_{sl} = 500 vehicles per hour (Table 4), a roundabout with a free-flow slip lane exit type has less total CO_2 emissions for all vehicles (5,935 kg/hour) than AWSC intersection (8,353 kg/hour)—a 29% reduction (Table 4). Similarly, with a free-flow slip lane, there is a 17% reduction of CO emissions, compared to an AWSC intersection. Thus, reduction of total CO_2 and CO emissions via the use of a free-flow slip lane is shown to be greater than in an AWSC intersection.

Table 4. SIDRA Percent Change in Emissions – Scenarios (S3 and S4).

V_{sl}: Slip Lane Volume, Right-Turn Volume (Vehicle/hour) at Northbound (NB) Approach	Total Carbon Dioxide (CO_2) (kg/hour)		Percent Change		Total Carbon Monoxide (CO) (kg/hour)		Percent Change
	S4 (Before)	S3(After)			S4 (Before)	S3 (After)	
V_{sl} = 50 (Low)	98.60	90.80	-7.91%		6.28	5.34	-14.9%
V_{sl} = 250 (Moderate)	1,669.40	1,120.00	-32.90%		75.96	59.53	-21.04%
V_{sl} = 500 (High)	8,352.70	5,935.10	-28.94%		263.41	229.13	-13.01%

V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour, for S3. Northbound right turn, vehicles per hour, for S4.

Validation of the SIDRA Result

For each scenario, the standard deviation and standard error were recorded for roundabout (intersection) fuel consumption that tested statistically significant, using the 95% confidence interval (alpha 0.05). Using the standard error, it was possible to calculate the 95% confidence interval for the roundabout (intersection) total fuel consumption reduction that might be achieved by implementing the free-flow slip lane exit type. The 95% confidence interval is ±1.96 standard errors from the total fuel consumption reduction percentage of reduction. Therefore, reduction of total fuel consumption from implementing a free-flow slip lane exit type, compared to an all-way stop-controlled intersection, is estimated between -34% and -19% (Table 3). Reduction of total fuel consumption from implementing a yield-sign slip lane exit type is estimated between -32% and -16%.

The SIDRA results for the S1 scenario were validated and compared to MOVES2010b outputs (Figure 6). At low and medium traffic levels, both SIDRA and MOVES 2010b results are very significantly similar. At higher traffic volume, MOVE2010b results were slightly lower for CO emissions.

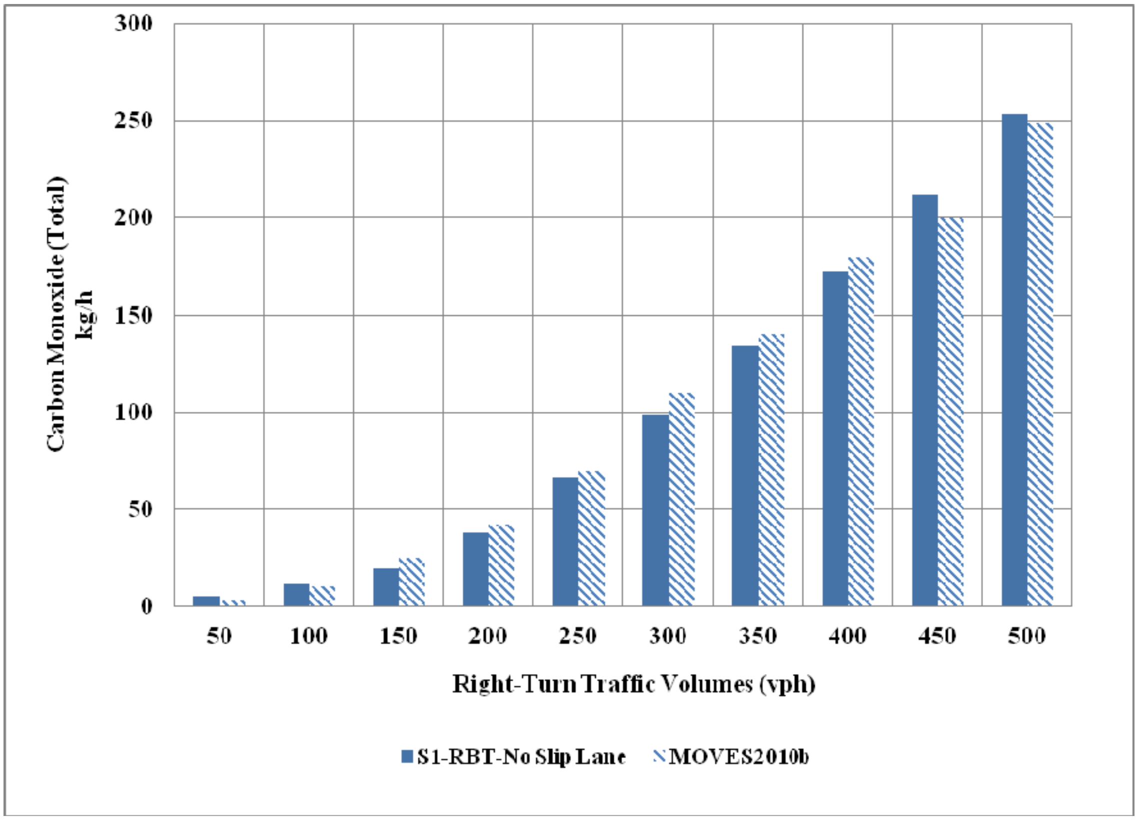

Figure 6. SIDRA and MOVES2010b Comparison: Total Carbon Monoxide (CO) Emissions for Scenario S1.

A free-flow slip lane exit type with moderate traffic volumes (250 vehicles per hour) shows significant reduction in roundabout average delay (operational improvement), from 182.3 sec/vehicle (no slip lane) to 171.3 sec/vehicle: a 6% reduction in S3, and from 333.1 sec/veh (AWSC): a 46% reduction (Figure 2). Similar results were noticed for CO_2 and CO emissions. A free-flow slip lane exit type shows significant reduction of CO_2 from an average total of 2,982 kg/h (AWSC): a 27% reduction. Finally, for CO emissions, a free-flow slip lane exit type shows significant reduction of CO from an average total of 108 kg/h (AWSC) to 91 kg/h: a 17% reduction.

CONCLUSIONS

SIDRA and MOVES2010b were used in this study to explore experimental traffic flows in a single-lane roundabout with a slip lane, compared to all-way stop-controlled (AWSC) intersections. Roundabouts with slip lanes were expected to reduce vehicle fuel consumption and emissions as a result of reduced delays and stops. Reasonable estimates were generated for overall CO_2 and CO emissions as well as fuel consumption.

As expected and statistically validated, results indicate that a roundabout with a free-flow slip lane exit type significantly reduces total roundabout (intersection) average fuel consumption and pollutant emissions values, compared to having no slip lane or AWSC intersection. With a free-flow slip lane exit type, overall average roundabout fuel consumption was reduced -26% (the estimated 95% confidence interval of reduction estimated between -19% and -34%) compared to an AWSC intersection. Results are similar for carbon emissions: the overall average CO_2 value was reduced from 2,982 kg/hour (AWSC intersection) to 2,099 kg/hour (roundabout with a free-flow slip lane). A roundabout with and without slip lane shows a more significant reduction (improvement) of fuel consumption and pollutant emissions values than an AWSC intersection. Hence, the most effective roundabout performance in reducing delay, fuel consumption, and pollutant emissions generally is obtained from a free-flow slip lane.

RECOMMENDATIONS

SIDRA and MOVES2010b can be used to analyze a slip lane's contribution to improving roundabout capacity and delay, and to diminishing fuel consumption and pollutant emissions. Additional analysis should be conducted for other variables: different unbalanced flow scenarios (traffic flow into and out of different roundabout approaches is different); heavy vehicles (trucks and buses), different speeds, and other traffic controls such as a two-way stop sign of a major-minor intersection. To validate results, field data collection is required, and future analysis should be compared with a micro-simulation such as VISSIM, which will be able to estimate emissions based on vehicle mode. Hydrocarbons (HC) and nitrogen oxides (NO_x) emissions can be included in future studies.

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A Decision Analysis Tool: Experimental Analysis of Roundabout Slip Lanes under Unbalanced Traffic Volumes

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ABSTRACT

This paper introduces a decision problem to evaluate when a single-lane roundabout incorporates a slip lane. Considers six origin-destination (O-D) traffic matrices that represent experimental of different unbalanced flow scenarios (traffic flow into and out of different roundabout approach is different) for a range of volume levels (low, moderate, and high). Performance of single-lane roundabouts with a slip lane is evaluated, based on the calculated roundabout average delay and the 95% queues results, using SIDRA under two control scenarios: yield and free-flow and results are compared to a roundabout with no slip lane. Slip lane right-turning traffic volumes range from 50 to 500 vehicles per hour. Results indicate that a free-flow slip lane exit type provides significant reductions in total roundabout average delay and the 95% queues and can be presented, and perhaps more efficient way, as the best alternative using a decision tree diagrams.

Key words: Roundabout, slip lane, decision tree, unbalanced flow, delay, the 95% queues, SIDRA.

INTRODUCTION

A slip lane, a separate lane that relieves right-turning traffic flow, reduces approach delay by allowing right-turning movements to bypass the roundabout, thereby reducing vehicle conflicts, delays, and stops, Al-Ghandour et al. (2011).

Operational performance of roundabouts, measured as roundabout capacity and delays explained by and NCHRP Reports 572 and 672 (NCHRP, 2007 and 2010). SIDRA software (Signalized and Unsignalized Design and Research Aid) is commonly used to analyze traffic operations at roundabouts (SIDRA 2007).

Using SIDRA for various traffic conditions, Sisiopiku and Heung-Un (2001) compared the performance of roundabouts with four-leg intersections under different scenarios such as yield control, two- and four-way stop control, and signal control. From SIDRA outputs, on the basis of average delay, they concluded that for intersections with one-lane approaches, the performance of roundabouts is similar to that of signalized intersections.

FDOT (1998), KSDOT (2003), NCDOT (2005), and other State DOT guides used SIDRA for roundabout analysis to determine capacity and performance, based on traditional gap acceptance and queuing theory.

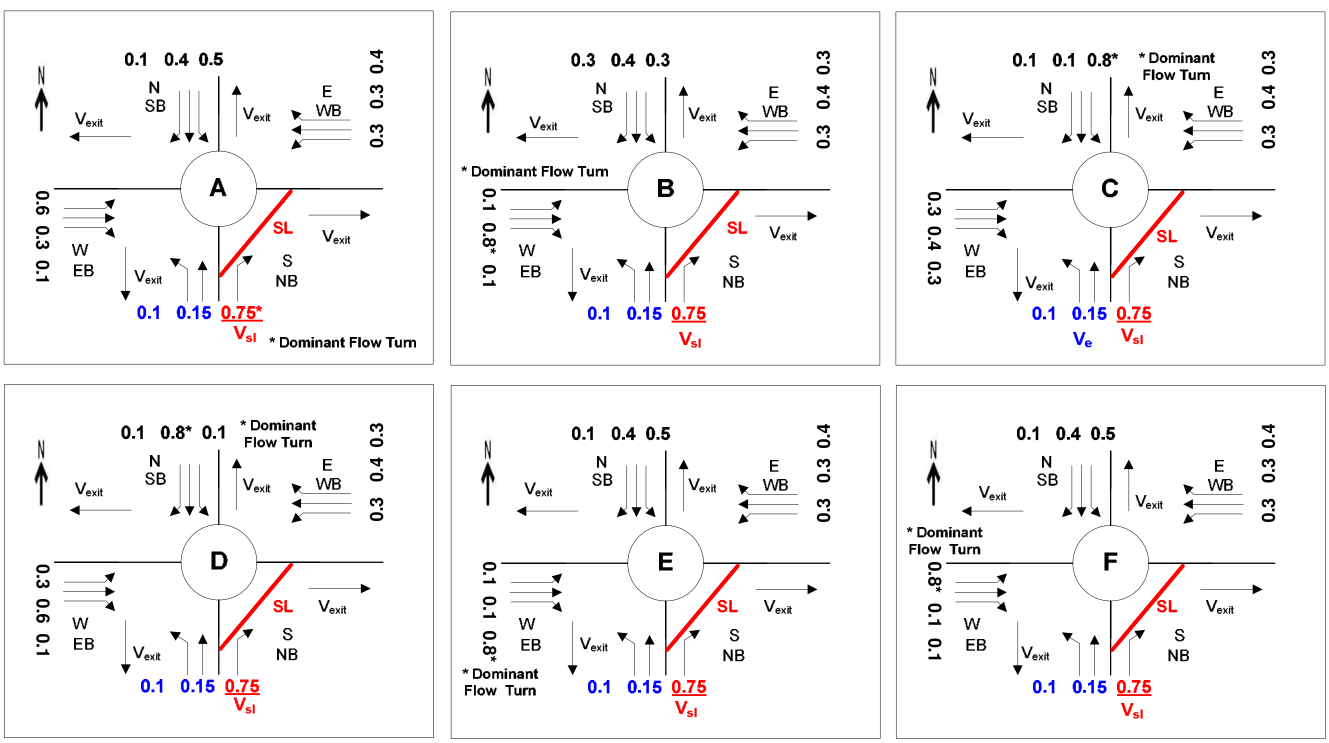
Neither decision tool related to operational performance nor safety evaluations were found in the literature for roundabouts where slip lanes were installed or not. The purpose of this paper is to introduce a decision problem to evaluate when a single-lane roundabout incorporates a slip lane based only on the operational performance of roundabout using SIDRA assessments.

APPROACH

In this study, for a single-lane roundabout, additional work done, Al-Ghandour et al. (2011), using six flow Models (A-F) represent unbalanced volumes (traffic flow into and out of the roundabout approach is different). For a practice example, the unbalanced O-D traffic flow may take place at freeway interchanges and T-intersection roundabouts scenarios.

The models were initialized, analyzed, and then controlled through several iterations. A slip lane was assumed to be placed at the northbound (NB) entry to the roundabout as shown in Figure 1. Several variables were tested across different traffic percentage distribution scenarios (models) as follows:

1. Slip lane exit type (free flow lane and yield sign) compared to having no slip lane (base case).
2. Slip lane right-turning traffic volume as the dominant turn (in increments of 50 vehicles per hour and ranging from 50 vehicles per hour to 500 vehicles per hour—representing low, moderate, and high volumes).
3. Approach entry volume.
4. Assume 75% right turns traffic percentage distribution flow patterns.



V_a : Approach volumes. V_{exit}: Exit approach volumes. V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour, for Models A-F.

Figure 1. Traffic Percentage Distribution Flow Pattern (Models A-F).

Table 1 shows a list of assumed slip lane right turns with dominant turn (75%) and approach entry and exit volumes for the unbalanced roundabout scenarios. For example, at slip lane (right-turn) traffic volume V_{sl}=500 vph (highlighted in yellow), Model E shows balanced entry volumes for every approach as 666 (vph) and with unbalanced exit approach volumes as 733 (vph). The heaviest volumes are shown at the (South–East) approach where right turns. These volumes were coded into SIDRA for different scenarios to evaluate the sensitivity of a slip lane.

Table 1. Sample of Total Approach Balanced Approach Entry and Unbalanced Exit Volumes.

V_{sl}: Slip Lane Volume, Right-Turn Volume (Vehicle/hour) at Northbound (NB) Approach	Volumes (Vehicle/hour)	Model E (75%)
V_{sl} = 50 (Low)	V_a	66
	V_{ext}	73
V_{sl} = 250 (Moderate)	V_a	333
	V_{ext}	366
V_{sl} = 500 (High)	V_a	666
	V_{ext}	733

V_a : Approach entry volumes. V_{ext}: Unbalanced exit volumes. V_{sl}: Slip lane volumes as dominant right turn, vehicles per hour.

ANALYSIS AND RESULTS

Sample of the SIDRA MOE (average roundabout delay) output values for the unbalanced Models (A to F) are shown in Figures 2 to 3. For example, in Figure 2, the unbalanced Model F, at high traffic volumes, 500 (vph), and shows a significant improvement in the roundabout average delay: from 137.35 sec/vehicle (no slip lane) to 97.06 sec/vehicle (slip lane with a free lane exit type), a (-29.33%) change. Within a yield slip lane exit type, the reduction of roundabout average delay is 28.64%. As expected, the results from SIDRA for the six models show that delay is significantly reduced in a single-lane roundabout with any type of slip lane, before oversaturation occurs. A free-flow slip lane exit type shows significant reduction (operational improvement) in roundabout average delay.

Samples from the SIDRA results (average delay and average of the 95% queue length) are shown in Figures 4 and 5 for all models using a free-flow slip lane exit type and having no slip lane as the base. Corresponding oversaturated conditions (volume/capacity>1.0) that are expected to occur as roundabout approach volumes and right-turning traffic volumes are increased are also shown. For example, Model C presenting the greatest delay, and Model E is the most least.