Comparing Roundabout and Metered Roundabout Performance under Different Traffic Conditions

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***Abstract*— At-grade intersections are one of the most critical components of urban transportation networks. They are major impedance, which create a significant interruption to traffic flow. Traffic control is required to regulate the flow of at-grade intersections to achieve the greatest efficiency and reduce traffic delay for road network users. Several models and studies are performed to determine the control type while designing new at- grade intersections. This research focuses on comparing the performance of an intersection under two types of control, roundabouts and metered roundabouts. The experimental design evaluated a four-leg at-grade roundabout with several traffic congestion levels and different traffic distribution scenarios on the approaches. The research results show that metered roundabouts increase delay at high traffic volumes and does not improve the operation of roundabouts. In addition, the metered roundabouts may increase the delay at an intersection when the traffic on the approaches does not show a major approach or when there is a major approach with a significantly high left-turn percentage.**

***Index Terms*—roundabout, metered roundabout, traffic performance, delay, level of service**

I. Introduction

Traffic congestion exists across the world even though transportation and urban planners perform studies to achieve well-designed road networks. The intersection design is a major element that affects the transportation network performance. If a design fails to operate effectively, transportation authorities will still have to consider improvement plans for the failing intersection. This will scatter their focus to carry on with urban plans and may negatively affect developers and clients' plans as well. Hence, cooperation between traffic engineers and urban planners is required in early planning and design stages to insure that at-grade intersections' design will have efficient operation and minimum average delays for traffic [1].

While it is common to have a roundabout control at intersections with low traffic volumes and a signalized control for intersection with higher traffic volumes, several at-grade intersections still fail at peak periods. One of the most common solution for congested intersections is replacing roundabouts with signalized junctions. However, that is not the case always since traffic volumes vary from time to another, and signals might not be justified during low traffic volumes periods. Therefore, some solutions try to aggregate roundabouts and signals specifications. Such solutions should be able to discharge traffic with an acceptable level of service and minimize traffic delay. An example of these solutions is the metered roundabout, where it combines the operation of traffic signals and roundabouts.

The objective of this study is to compare the operation of roundabouts and metered roundabouts as at-grade intersection control types and to recommend a suitable control for intersections based on their traffic conditions.

II. Literature Review

A. Roundabout and Signalized Roundabouts Operation

Roundabout control is a junction control when a circulated island is placed in the middle of the junction. Vehicles flow in a counterclockwise traffic pattern, and yield at roundabout entry approaches. Conflict points are mainly merge/diverge areas, and lane changing areas. The most common parameters to evaluate roundabout performance are: vehicles' velocities distribution, gap distribution, and lane change distance distribution. It has been concluded that the inner lane's circulating vehicles have greater velocities than outer circulating lanes, the velocity of entering vehicles are the smallest, the gaps at weaving segments are greater than the ones for non-weaving segments, and lane change distance increases when vehicles try to approach the inner lanes more than the outer lanes [2]. In fact, microsimulation through several software packages could be used to evaluate the junctions' level of service (LOS). Average control delay is the main parameter of determining the roundabout's level of service (LOS). Also, the roundabout's geometry contributes significantly to its LOS evaluation [3]. Roundabout capacities are analyzed based on a gap-acceptance model developed by Akcelik, which is applied in the well-known software Sidra Intersection to estimate delay and LOS for roundabouts [4]. Several research studies compared roundabout and signalized roundabout capacities and showed that signalized ones are more effective [5]-[7].

B. Metered Roundabout Operation

In fact, the traffic flow at junctions varies depending on the area, and from approach to another in the same

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roundabout. Roundabouts have several congestion distributions among its approaches. The issue of unbalanced traffic flow on roundabout approaches is highly addressed at its performance evaluation and operational control [8], [9]. The idea of combining both systems: roundabouts and signalized roundabouts, is most effective in having a metered roundabout. A metered roundabout operates as a partially signalized roundabout to allow a controlling approach movement by stopping a metered approach for a minimum red time. The roundabout operates normally once traffic is dissipated [10], [11]. Advanced studies regarding installation of advanced detectors using numerical methods to estimate queue length and compare it with software estimation showed similar results [12]. Several studies concluded that applying metering for unbalanced traffic flows at roundabouts resulted in increasing circulating gaps, decreasing follow up headway, increasing the capacity, which resulted in reducing the overall average control delay for the roundabout [7], [10], [11].

In this research, the effect of traffic distribution among the roundabout approaches and the turning percentages on each approach on the performance of roundabout and metered roundabout is investigated.

III. Experimental Design

This study is evaluating a four-leg roundabout. The considered roundabout will be analyzed for roundabout and metered roundabout operations using Sidra Intersection software.

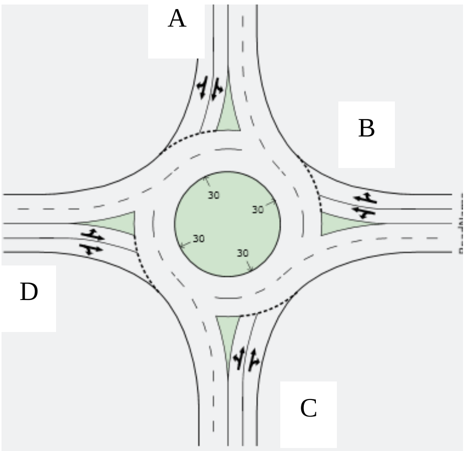

Figure 1. Intersection approaches

The experimental design considers three different cases for the traffic distribution among the roundabout approaches:

- Case I: traffic volume will be assigned into two opposing dominant approaches (A and C).
- Case II: traffic volume will be assigned in to two perpendicular approaches (A and B) and the major traffic will be assigned to approach A.
- Case III: Similar to case II, but the major traffic is assigned to approach B.

Each case (from I to III) considers different ratios of traffic on the two dominant directions (conditions a, b, c, and d) and different ratios of distributing the traffic to the two dominant directions (conditions 1, 2, 3, and 4).

Traffic distribution in Cases I, II and III is shown in Tables I, II and III respectively.

These three cases are applied to the two control conditions (roundabout and metered roundabout and for a total traffic volume on all approaches of 3500 and 4000 veh/hr. In addition, the left turn percentages will be 20% on all approaches, but it will have the values of 20%, 40%, or 60% on the approach with the highest traffic flow. It should be noted that Tables I, II, and III show the percentage of traffic on the dominant directions and the rest of the traffic is distributed equally on the non-dominant directions (approaches B and D for Case1 and approached C and D for Cases II and III).

TABLE I. Case I Traffic Distribution

a.80% of traffic assigned on Approaches A and C	1)80% of traffic assigned on A and 20% on C
b.70% of traffic assigned on Approaches A and C	2)70% of traffic assigned on A and 30% on C
c.60% of traffic assigned on Approaches A and C	3)60% of traffic assigned on A and 40% on C
d.50% of traffic assigned on Approaches A and C	4)50% of traffic assigned on A and 50% on C

TABLE II. Case II Traffic Distribution

a.80% of traffic assigned on Approaches A and B	1)80% of traffic assigned on A and 20% on B
b.70% of traffic assigned on Approaches A and B	2)70% of traffic assigned on A and 30% on B
c.60% of traffic assigned on Approaches A and B	3)60% of traffic assigned on A and 40% on B
d. 50% of traffic assigned on Approaches A and B	4)50% of traffic assigned on A and 50% on B

TABLE III. Case III Traffic Distribution

a.80% of traffic assigned on Approaches A and B	1)80% of traffic assigned on B and 20% on A
b.70% of traffic assigned on Approaches A and B	2)70% of traffic assigned on B and 30% on A
c.60% of traffic assigned on Approaches A and B	3)60% of traffic assigned on B and 40% on A
d. 50% of traffic assigned on Approaches A and B	4)50% of traffic assigned on B and 50% on A

The roundabout and metered roundabout intersections were evaluated to determine the average control delay and level of service (LOS). The Cases are labeled based on the notation shown in Tables I, II, and III. For example, Case III.b.1 represents a case where there is 70% of the total traffic on approaches A and B. The traffic on approach B is 80% of the total on A and B (i.e. it is 56% of the total traffic on the roundabout). The rest of the traffic is divided equally between the other two approaches.

IV. Analysis and Results

As discussed earlier, plenty of scenarios were considered for each case. However, the analysis and result in this section presents an output of a sample from each case, which reflects the general trend of the results. This section presents multiple aggregated results for three cases in tables and their associated graphs. Table IV shows the results of roundabout and metered roundabout evaluation for Case I.a.1, which represents 80% of total traffic to be on opposing approaches A and C and 80% of dominant traffic on approach A (i.e. 64% of the total traffic). Figure 2 illustrates the delays for roundabout and metered roundabout evaluation for Case I.a.1.

TABLE IV. SUMMARY RESULTS FOR CASE I.A.1

Case I.a.1								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Del.	LS	Del.
20	E	61	F	179	D	48	F	158
40	E	66	F	185	D	53	F	163
60	F	125	F	243	E	74	F	396

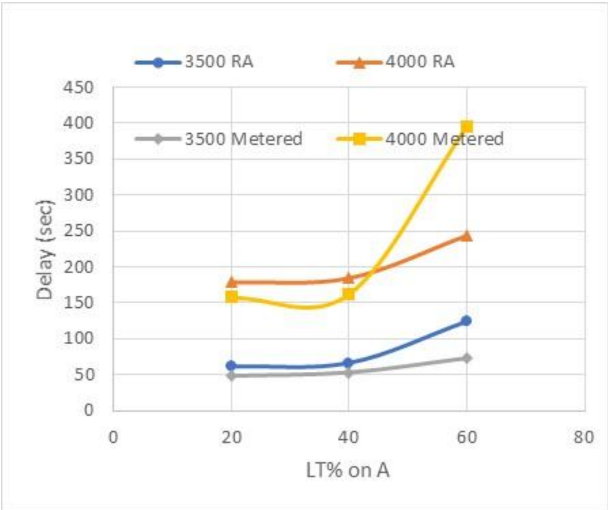

Figure 2. Summary Results for Case I.a.1

In Case I.a.1, the metered roundabout slightly reduced the roundabout delay when traffic volume is 3500 veh/hr. This is because the traffic on the controlling approach (A) is much higher than the flows on all other approaches and the roundabout metering will help in providing higher priority for this approach. However, when the traffic volume is higher (4000 veh/hr) and the left-turn percentage is greater (60%), the controlling approach traffic is causing significant delays to other approaches because more vehicles are circulating in the roundabout for a longer time to turn left. On the other hand, the yield operation of roundabout would allow other approaches to enter between available gaps of approach A traffic flow.

Table V shows the results of roundabout and metered roundabout evaluation for Case I.d.4 (equal traffic distribution on all approaches. The left-turn percentage on all approaches is 20%, while on approach A it is 20%, 40%, or 60%. Fig. 3 shows the delays for roundabout and metered roundabout evaluation for Case I.d.4.

TABLE V. SUMMARY RESULTS FOR CASE I.D.4

Case I.d.4								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Delay	LS	Del.
20	B	13	B	16	F	247	F	479
40	B	15	D	46	F	342	F	483
60	C	21	F	100	F	283	F	495

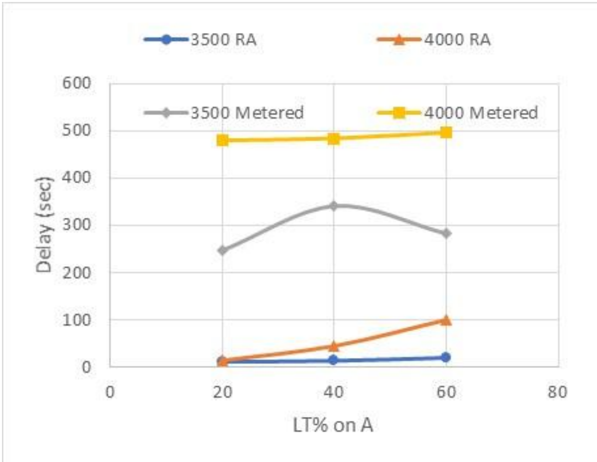

Figure 3. Summary Results for Case I.d.4

Case I.d.4 is a general case, which have equal splits of traffic volume on the approaches. The metered roundabout evaluation implementation has increase delay significantly especially for high traffic volumes. The roundabout operates with an acceptable level of service unless the traffic volume and left-turn percentage is increasing significantly, which will result in more delay time for vehicles to find a gap in the roundabout flow and more time spent to turn left respectively.

Table VI shows the results of roundabout and metered roundabout evaluation for Case II.a.1 (80% traffic distribution on Approaches A and B. The traffic on approach A is 80% of traffic on the dominant approaches with left-turn percentage of 20%, 40%, or 60%. Fig. 4 shows the delays for roundabout and metered roundabout evaluation for Case II.a.1.

TABLE VI. SUMMARY RESULTS FOR CASE II.A.1

Case II.a.1								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Delay	LS	Del.
20	F	122	F	266	C	22	F	165
40	F	126	F	272	E	61	F	176
60	F	148	F	295	E	77	F	176

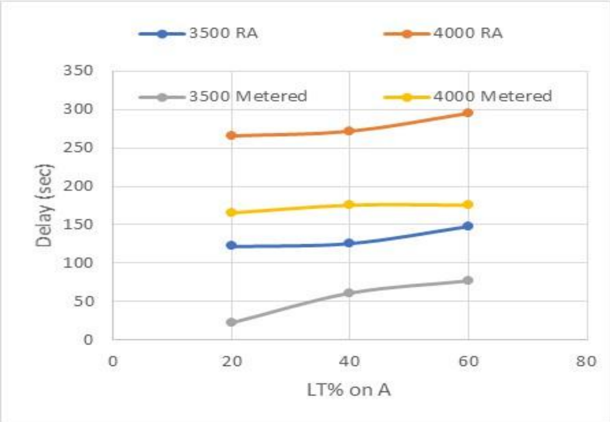

Figure 4. Summary results for Case II.a.1

Table VII shows the results of roundabout and metered roundabout evaluation for Case II.c.3 (60% traffic distribution on Approaches A and B. The traffic volume on approach A is 60% of traffic on A and B, with left-turn percentage of 20%, 40%, or 60%. Figure 5 shows the delays for roundabout and metered roundabout evaluation for Case II.c.3.

TABLE VII. SUMMARY RESULTS FOR CASE II.C.3 – ROUNDABOUT

Case II.c.3								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Delay	LS	Del.
20	B	16	E	73	C	23	F	80
40	B	18	E	78	C	25	F	83
60	C	27	F	96	D	38	F	108

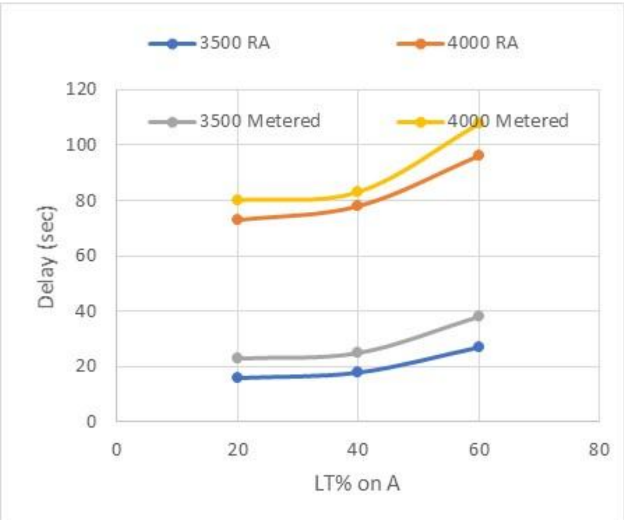

Figure 5. Summary results for case II.c.3

In Case II.a.1, the roundabout performs at LOS "F" for all scenarios. The metered roundabout shows a better performance than the roundabout due to having low volume on the adjacent approach (B), which is a suitable scenario for metered roundabout operation. It should be noted that the traffic volume on approach A in this case represents 64%, the volume on approach B is only 16%, and the volume on approaches C and D is 10% of the total volume on the junction. When the traffic distribution on major approaches becomes closer to balance (60/40%) as in Case II.c.3, the delays significantly decrease for both operations, but the roundabout operation performs better. In Case II when two perpendicular approaches have high traffic volumes, the metered roundabout shows much worse performance.

Table VIII shows the results of roundabout and metered roundabout evaluation for Case III.b.3 (70% of the total traffic on Approaches A and B. A total of 60% of traffic on the dominant approaches is on approach B with left-turn percentage of 20%, 40% or 60%. Fig. 6 shows the delays for roundabout and metered roundabout evaluation for Case III.b.3.

TABLE VIII. SUMMARY RESULTS FOR CASE III.B.3

Case III.b.3								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Del.	LS	Del.
20	D	43	F	183	C	28	F	81
40	D	46	F	186	C	31	F	84
60	E	79	F	225	D	41	F	118

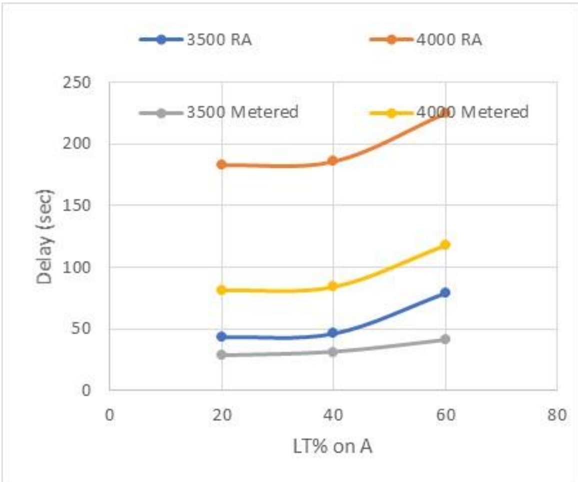

Figure 6. Summary results for case III.b.3

Table IX shows the results of roundabout and metered roundabout evaluation for Case III.b.4 (70% of the total traffic on Approaches A and B with 50% of that traffic on approach B. The Left-turn percentage on B is 20%, 40%, or 60%. Fig. IX shows the delays for roundabout and metered roundabout evaluation for Case III.b.4.

TABLE IX. SUMMARY RESULTS FOR CASE III.B.4

Case III.b.4								
	Roundabout				Metered Roundabout			
LT% A	3500		4000		3500		4000	
	LS	Del.	LS	Del.	LS	Del.	LS	Del.
20	D	47	F	185	D	49	F	139
40	D	50	F	188	D	51	F	141
60	E	77	F	234	E	69	F	162

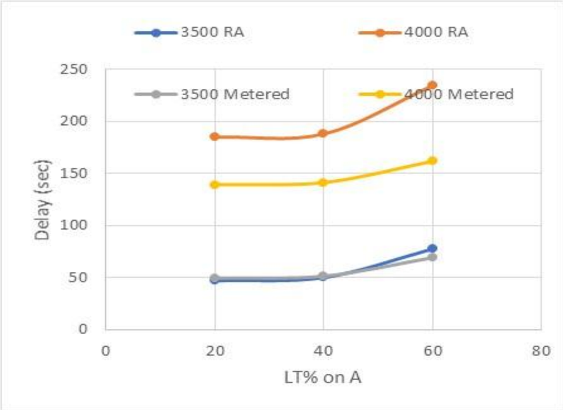

Figure 7. Summary results for Case III.b.4

In Case III.b.3, the total traffic on approach B is 42%, on approach A, is 28%, and on approaches C and D is 15%, of the total traffic on the intersection. The metered roundabout decreases the delay of roundabout operation due to providing a higher priority for the major approach (B). The level of service is however only acceptable for lower traffic volumes. However, in Case III.b.4, when the traffic volume is split between the two major approaches A and B equally, the metered roundabout shows almost the same performance as roundabout operation at the lower traffic volume. When traffic volume on the intersection increases to 4000 veh/hr, the metered roundabout illustrates a much better performance than the roundabout operation.

V. Conclusions

Since the traffic congestion impact on roundabouts varies, the level of service varies from roundabout to metered roundabout operation. When the major traffic is distributed on opposing approaches (Case I), the metered roundabout performs with slightly less delay than normal roundabout at 3500 veh/hr traffic with 20% and 40% left-turn percentage on major approach. However, when the total traffic volume is higher (4000 veh/hr) and left-turn percentage becomes 60%, the delay for metered roundabout operation exceeds the delay for the roundabout operation. For Cases II, the dominant traffic is on two perpendicular approaches, with the highest traffic volume is on an approach (approach A) and the approach with the second highest traffic volume (approach B) is the preceding approach. The metered roundabout performs better than the roundabout when the flow on A is much higher than the other approaches (Case II.a.1). However, when approach A has a comparable volume to the flow on approach B (Case II.c.3), the roundabout shows a better performance. For Case III, the dominant traffic is on two perpendicular approaches with the highest traffic is on approach B and the other dominant approach is the following approach (Approach A). For the lower traffic volume (3500 veh/hr) the metered roundabout shows a slightly better performance than the roundabout operation. The improvement is much higher at higher traffic volume (4000 veh/hr). The delay decreases significantly when the traffic volume increases to 4000 veh/hr and approach B has higher traffic volume. Finally, Metered roundabout operation is recommended when there is only one major approach with relatively lower traffic volume on the other approaches. For equal split of the traffic on the four approached, the roundabout operation is much better than metered roundabout operation.

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