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Roundabout or Traffic Signal: A Selection Dilemma

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Abstract

At-grade intersections are one of the vital elements in any road network. Traffic control for at-grade intersections plays a significant role in the level of delay experienced by the vehicles on the road network. Traffic signals and roundabout control are the most common types of at-grade intersection control. Many transportation planners around the world debate the selection between these two types of control for a new at-grade intersection. The aim of this research is to provide some guidelines for selecting one of the two types of control for some at-grade intersections. The research utilized the well-known software packages of Synchro and Sidra to evaluate the performance of traffic signals and roundabouts, respectively. The experimental work considered a four leg at-grade intersection that was operated under different traffic congestion levels and different traffic distribution percentages. The research results indicated that roundabouts are recommended for small traffic volumes while traffic signals are proven to be more suitable for high traffic volumes.

Keywords: Traffic signals, roundabouts, intersection delays, planning applications

1. INTRODUCTION

Traffic congestion is one of the major problems in many cities around the world. Local agencies try to often propose some solutions to reduce traffic delays at intersections. Some of the proposed solutions include changing roundabout intersections to signalized intersections. Nonetheless, many professionals believe that the solution to this daily problem is much more complicated than just replacing roundabout intersections with signalized ones. This is a concern to both urban planners and traffic engineers on the spot, as the public expect urban planners to open new areas carefully to avoid future congestion and traffic engineers to propose solutions to existing intersections.

Usually, urban planners cannot recommend the use of a roundabout or a traffic signal or replacing one of them at any intersection without consulting traffic engineers. Traffic engineers usually use computer software programs to analyze whether the intersection should be implemented with a signalized intersection or a roundabout intersection. Then, based on a comparison on the average delay in each case, a decision can be made.

Even though there are plenty of commercial traffic design software programs available, choosing between a roundabout or a signalized intersection is not a straightforward decision. The reasons behind that are: firstly, the software programs are not always affordable or available. Secondly, urban planners are usually not familiar with the software programs. Therefore, the urban planners need traffic engineers to run the software analysis. Running the software analysis is time consuming, while finding and hiring a traffic engineer might be cost-intensive. Therefore, this study is aimed at providing some guidelines on the suitability of constructing a roundabout or a traffic signal based on the level of traffic congestion.

In general, the objective of this study is to develop a selection procedure that can assist urban planners in selecting the type of intersection control (i.e. roundabout or traffic signal) without conducting a detailed analysis of the considered intersection.

2. RESEARCH BACKGROUND

The delay and level of service on at-grade intersections have been considered by many researchers in the past. The use of roundabouts has been increasing over the past decade. A study estimated the number of roundabouts in the US and Canada to be more than two thousand in 2010 [1]. Delays at roundabouts have been considered in several researches since the 1960's and 1970's [2-5]. Most roundabout evaluation studies adopted SIDRA software for the estimation of delay and level-of-service characteristics [6, 7]. The use of a roundabout has been recommended as it has been proven to improve safety and provide better traffic performance for high traffic volumes, than all-way-stop controlled intersections or traffic signals [8]. One such research study had compared the roundabout performance under different control types (i.e. yield control, two-way stop, all-way stop, or traffic signal on the roundabout). The analyses concluded that roundabouts are recommended for high through or left turning traffic volumes [9]. However, this recommendation was based on two scenarios of traffic distribution only; equal split of traffic on the four approaches or a minor street with a very small traffic volume. Therefore, the generalization of the results cannot be simply justified.

In recent studies, the use of signals on roundabouts has been considered as a special case of traffic signals to determine the optimum lane marking and signal timing. Using the problem solving formulation, these studies aimed at maximizing the capacity, minimizing the delay and the cycle length, as well as much needed requirements to match real-life operation of roundabouts. The application of the proposed formulation to a case study indicated that the proposed model can improve the roundabout performance and provide some guidelines for their use in real-life applications [10]. Different evaluation techniques for applying traffic signals to roundabouts have been discussed in several papers [11-16].

3. EXPERIMENTAL DESIGN

In this study, we analyzed a 4-leg intersection with the 4 approaches labeled as A, B, C, and D, as shown in Figure 1. Each approach had 2 lanes. The intersection was evaluated for both roundabout and traffic signal control for the following conditions.

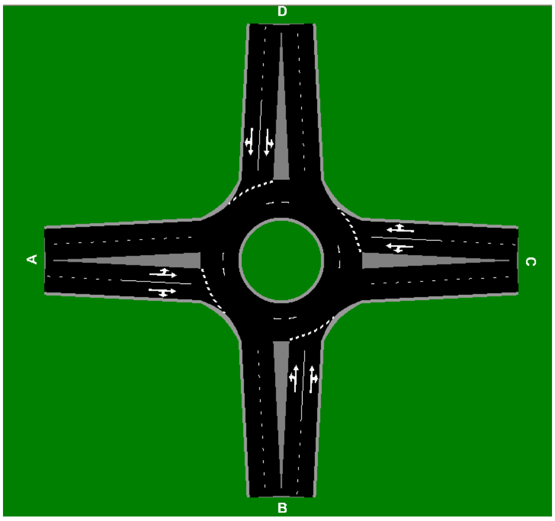

Figure 1. Considered Intersection

- The total traffic volume on the intersection was varied from low traffic congestion to very high traffic congestion. The total traffic volume for the intersection on approaches A, B, C and D were 2500, 3000, 3500, 4000, 4500, and 5000 veh/hr. These values represent the total traffic volume on the four approaches.

- For the purposes of the study, the traffic distribution on the approaches was considered for the three cases:

  I. Equal distribution of traffic volume on all approaches (25% on each approach)

II. Dominant traffic flow was purposely set to flow on one street (both directions). The dominant traffic was considered to be on approaches B and D. The percentage of traffic using these two directions were 60%, 70% or 80%. The distribution of the dominant flow over the two approaches started with a 50/50 split and then the percentage of traffic on one of the approaches (B) increased by an additional 10% or 20%. Table 1 summarizes the considered cases for this scenario. The traffic volume on approaches A and C was equal.

Table 1. Traffic Distribution for Case II

60 % of traffic flow assigned to approaches B&D	a. 30% on B and 30% on D
	b. 40% on B and 20% on D
	c. 50% on B and 10% on D
70 % of traffic flow assigned to approaches B&D	d. 35% on B and 35% on D
	e. 45% on B and 25% on D
	f. 55% on B and 15% on D
80 % of traffic flow assigned to approaches B&D	g. 40% on B and 40% on D
	h. 50% on B and 30% on D
	i. 60% on B and 20% on D

III. The dominant traffic flow was in two perpendicular directions i.e. on approaches A and B. The traffic distribution on approaches A and B was similar to case II, as shown in Table 2. The traffic on the other two approaches had an equal split.

Table 2. Traffic Distribution for Case III

60 % of traffic flow assigned to approaches A&B	a. 30% on A and 30% on B
	b. 40% on A and 20% on B
	c. 50% on A and 10% on B
70 % of traffic flow assigned to approaches A&B	d. 35% on A and 35% on B
	e. 45% on A and 25% on B
	f. 55% on A and 15% on B
80 % of traffic flow assigned to approaches B&D	g. 40% on A and 40% on B
	h. 50% on A and 30% on B
	i. 60% on A and 20% on B

- The traffic movements on all approaches were assumed either to go straight or left. The right turning vehicles were assumed to not use the intersection. Accordingly, the turning percentages on each approach were assumed to have the following scenarios:

1. The percentage of vehicles turning left on approach A would increase from 0 to 50% (increment of 10%) of the volume assigned to left turn movement on approach A. On approach B, vehicles turning left would decrease from 50% to 0% (decrement of 10%). Approaches C and D would have a constant left turning percentage of 25%.

2. The percentage of vehicles turning left on approach C would increase from 0 to 50% of the volume assigned for the left turn movement on approach C. On approach B, vehicles turning left would decrease from 50% to 0%. Left turn percentage on approaches A and D would be fixed at 25%.

3. The percentage of vehicles turning left on approach D would increase from 0 to 50%. On approach B, vehicles turning left would decrease from 50% to 0%. A constant left turning percentage of 25% would be fixed on approaches A and C.

The analyses included the evaluation on the delay per vehicle and level of service (LOS) for each traffic volume. Each case was individually analyzed for the traffic distribution and scenarios.

Three Cases (I,II, and III) were illustrated for the experimental design and different cases were considered. For Cases II and II, there were 9 possible traffic distribution percentages (i.e. a, b, c … etc.), as shown in Tables 1 and 2. Then, there were three cases of turning percentages (1, 2, and 3). Accordingly, a case having a reference code of Case III.b.3, means that the dominant traffic was according to Case III (dominant traffic on two perpendicular approaches). The distribution to the approaches was b, which indicated 70% on the dominant approaches with 45% on A, 25% on B, while approaches C and D had 15% of the total traffic on each. Finally, the left turning percentages followed Scenario 3, which showed an increase in the left turn percentage on approach D from 0 to 50%, decrease in the left turn percentage on approach B from 50% to 0%, and the left turn movement on approaches A and C were fixed at 25%. Figure 2 provides a schematic representation of the experimental design.

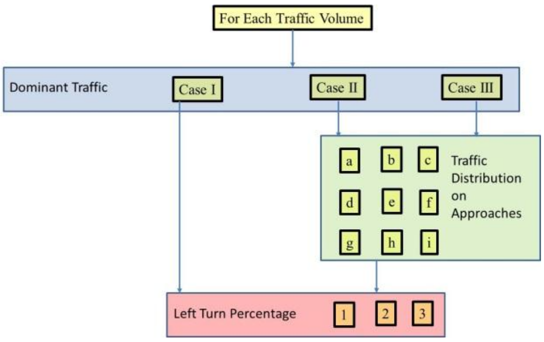

Figure 2. Experimental Design

The comparison between traffic signal and roundabout performances was made based on the delay per vehicle.

4. RESULTS AND ANALYSIS

As discussed in the previous section, the number of evaluation cases was very large. A sample of the evaluation results is presented in this section. The sample had been selected to represent the general trend of all cases. The following tables and charts illustrate the results for Case I.2 (equal split of traffic on all approaches) and Scenario 2 for left turn percentages (increase in the left turn percentage on approach C and reduction in the left turn percentage on approach B). Table 3 summarizes the results for roundabout evaluation, while Table 4 shows the results of a traffic signal evaluation. Figure 3 provides a combined representation of the results for roundabout and traffic signal evaluation for Case I.2.

Table 3. Summary Results for Case I.2 (Roundabout)

RA	Case I.2											
	2500		3000		3500		4000		4500		5000	
LT %C	D	L	D	L	D	L	D	L	D	L	D	L
0%	12	B	13	B	29	C	73	E	120	F	183	F
10%	9	A	13	B	24	C	66	E	119	F	177	F
20%	9	A	13	B	23	C	62	E	111	F	165	F
30%	9	A	13	B	23	C	64	E	111	F	165	F
40%	9	A	13	B	24	C	66	E	126	F	180	F
50%	10	B	13	B	29	C	68	E	128	F	196	F

D: Delay L: Level of Service

Table 4. Summary Results for Case I.2 (Traffic Signal)

Signal	Case I.2											
	2500		3000		3500		4000		4500		5000	
LT % C	D	L	D	L	D	L	D	L	D	L	D	L
0%	42	D	51	D	76	E	110	F	153	F	196	F
10%	39	D	42	D	59	E	85	F	116	F	153	F
20%	34	C	37	D	47	D	67	E	87	F	115	F
30%	34	C	37	D	47	D	67	E	87	F	115	F
40%	39	D	42	D	59	E	85	F	116	F	153	F
50%	42	D	51	D	76	F	110	F	153	F	196	F

D: Delay L: Level of Service

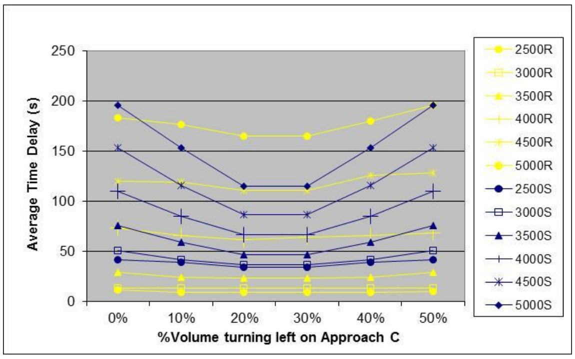

Figure 3. Summary Results for Case I.2

The sample analysis for Case II is presented with the summary of two cases. The first case is Case II.a.2, which represents dominant traffic on approaches B and D with a percentage of 30% on each approach and the left turn percentage of approach C increased from 0 to 50%. Tables 5 and 6 present the summary for the roundabout and traffic signal evaluations, respectively. Figure 4 shows the combined summary of the roundabout and traffic signal evaluation.

Table 5. Summary Results for Case II.a.2 (Roundabout)

RA	Case II.a.2											
	2500		3000		3500		4000		4500		5000	
%LT C	D	L	D	L	D	L	D	L	D	L	D	L
0%	11	B	18	B	57	E	133	F	192	F	263	F
10%	10	B	16	B	42	D	109	F	171	F	246	F
20%	10	A	15	B	32	C	95	F	161	F	238	F
30%	10	A	14	B	20	C	88	F	155	F	214	F
40%	10	A	14	B	28	C	92	F	144	F	202	F
50%	9	A	14	B	30	C	86	F	146	F	254	F

D: Delay L: Level of Service

Table 6. Summary Results for Case II.a.2 (Traffic Signal)

Signal	Case II.a.2											
	2500		3000		3500		4000		4500		5000	
%LT C	D	L	D	L	D	L	D	L	D	L	D	L
0%	35	D	40	D	66	E	104	F	152	F	213	F
10%	33	C	35	D	48	D	80	F	120	F	179	F
20%	31	C	35	D	46	D	64	E	96	F	143	F
30%	34	C	36	D	48	D	65	E	95	F	134	F
40%	32	C	39	D	53	D	75	E	103	F	134	F
50%	37	D	44	D	63	E	91	F	125	F	162	F

D: Delay L: Level of Service

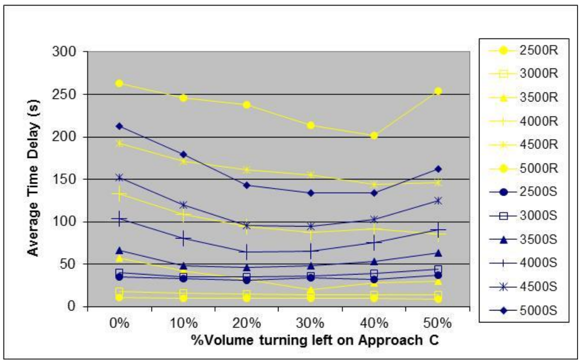

Figure 4. Summary Results for Case II.a.2

The second case is Case II.i.3, which represents a dominant traffic of 80% at approaches B and D, distributed as 60% at B and 20% at D, and the left turn percentage at D increased from 0 to 50%. The results of this case are presented in Tables 7 and 8 and Figure 5.

Table 7. Summary Results for Case II.i.3 (Roundabout)

RA	Case II.i.3											
	2500		3000		3500		4000		4500		5000	
%LT D	D	L	D	L	D	L	D	L	D	L	D	L
0%	11	B	22	C	62	E	117	F	179	F	250	F
10%	10	B	17	B	50	D	109	F	177	F	251	F
20%	10	B	17	B	58	E	122	F	196	F	280	E
30%	11	B	8	A	71	E	142	F	225	F	300	F
40%	11	B	9	A	87	F	166	F	258	F	368	F
50%	12	B	9	A	105	F	192	F	296	F	421	F

D: Delay L: Level of Service

Table 8. Summary Results for Case II.i.3 (Traffic Signal)

Signal	Case II.i.3											
	2500		3000		3500		4000		4500		5000	
%LT D	D	L	D	L	D	L	D	L	D	L	D	L
0%	49	D	56	D	82	F	116	F	111	F	145	F
10%	33	C	46	D	53	D	72	E	67	E	90	F
20%	32	C	38	D	45	D	60	E	54	D	71	E
30%	33	C	39	D	48	D	64	E	68	E	100	F
40%	37	D	54	D	64	E	101	F	106	F	153	F
50%	54	D	61	D	99	F	150	F	153	F	210	F

D: Delay L: Level of Service

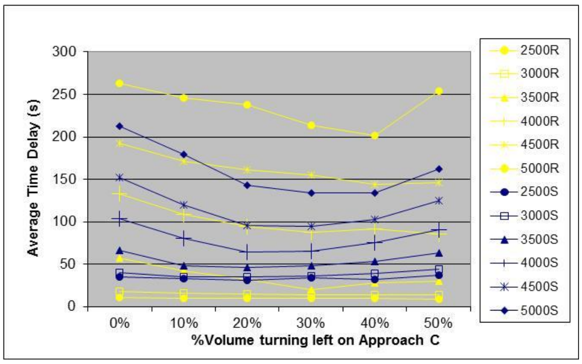

Figure 5. Summary Results for Case II.i.3

For Case III, which represents dominant traffic at approaches B and D, it was represented by 2 cases, namely Case III.a.3 and Case III.i.1.

Tables 9 and 10 and Figure 6 illustrate the results for Case III.a.3, while Tables 11 and 12 and Figure 7 represent the results for Case III.i.1.

Table 9. Summary Results for Case III.a.3 (Roundabout)

RA	Case III.a.3											
	2500		3000		3500		4000		4500		5000	
%LT D	D	L	D	L	D	L	D	L	D	L	D	L
0%	11	B	15	B	34	C	96	F	155	F	214	F
10%	11	B	11	B	39	D	100	F	158	F	217	F
20%	11	B	15	B	45	D	117	F	168	F	226	F
30%	11	B	16	B	54	D	141	F	178	F	242	F
40%	11	B	18	B	67	E	171	F	205	F	262	F
50%	11	B	22	C	83	F	210	F	245	F	295	F

D: Delay L: Level of Service

Table 10. Summary Results for Case III.a.3 (Traffic Signal)

Signal	Case III.a.3											
	2500		3000		3500		4000		4500		5000	
%LT D	D	L	D	L	D	L	D	L	D	L	D	L
0%	38	D	52	D	78	E	111	F	152	F	202	F
10%	33	C	43	D	61	E	87	F	118	F	157	F
20%	31	C	38	D	51	D	72	E	108	F	140	F
30%	30	C	38	D	52	D	74	E	106	F	145	F
40%	32	C	44	D	64	E	96	F	130	F	174	F
50%	36	D	52	D	81	F	119	F	164	F	218	F

D: Delay L: Level of Service

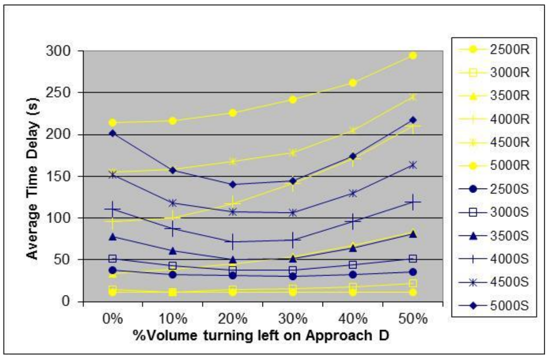

Figure 6. Summary Results for Case III.a.3

Table 11. Summary Results for Case III.i.1 (Roundabout)

RA	Case III.i.1											
	2500		3000		3500		4000		4500		5000	
%LT A	D	L	D	L	D	L	D	L	D	L	D	L
0%	10	B	59	E	180	F	242	F	315	F	386	F
10%	10	B	60	E	178	F	242	F	315	F	386	F
20%	11	B	60	E	178	F	243	F	316	F	387	F
30%	11	B	60	E	178	F	244	F	316	F	388	F
40%	11	B	61	E	179	F	245	F	317	F	389	F
50%	12	B	63	E	182	F	249	F	320	F	392	F

D: Delay L: Level of Service

Table 12. Summary Results for Case III.i.1 (Traffic Signal)

Signal	Case III.i.1											
	2500		3000		3500		4000		4500		5000	
%LT A	D	L	D	L	D	L	D	L	D	L	D	L
0%	55	E	65	E	107	F	158	F	156	F	265	F
10%	36	D	53	D	65	E	101	F	102	F	187	F
20%	36	D	41	D	52	D	66	E	66	E	142	F
30%	30	C	49	D	49	D	80	F	82	F	154	F
40%	38	D	81	F	80	F	134	F	141	F	224	F
50%	59	E	133	F	136	F	212	F	232	F	347	F

D: Delay L: Level of Service

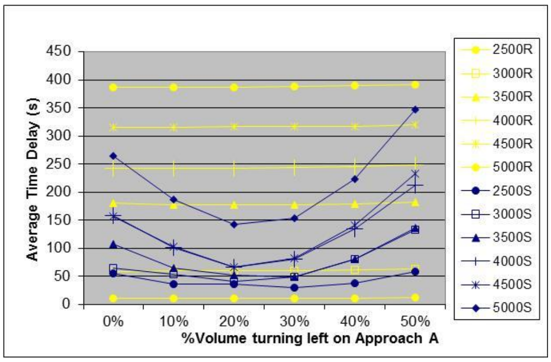

Figure 7. Summary Results for Case III.c.3.1

5. DISCUSSION OF RESULTS

Considering the results for Case I (equal traffic volume on all approaches), it can be concluded that the roundabout performance was better than the traffic signal performance under all traffic conditions.

In the cases where there was a predominant traffic in two opposite directions (i.e. One road with both directions, Case II, it appears that the roundabout showed lower delays and better level of service when the total traffic volume on the intersection was 3000 veh/hr or less. However, for traffic volumes around 3500 veh/hr, the roundabout presented a better performance in cases where the left turn percentage was less than 20%. The traffic signal showed better performance for high traffic volumes (total traffic volume of 4000 veh/hr or more on the intersection).

Finally, for the cases where there was high traffic volume on two perpendicular approaches, Case III, the results almost matched those of Case II, except for total traffic volume of 3500 veh/hr, where the roundabout showed better performance for left turn percentage of 30% or less. For low traffic volumes (3000 veh/hr or less), the roundabout performed better while for high traffic volumes (4000 veh/hr or more), the traffic signal illustrated better performance.

6. RECOMMENDATIONS

As general recommendations, the following criteria can be used as guide for selecting the type of intersection control are:

1. For low traffic volume on the intersection (3000 veh/hr or less), a roundabout is recommended, regardless of the traffic distribution on the approaches.
2. If the traffic volume on the intersection is distributed uniformly (i.e. Equal traffic volume on all approaches), then a roundabout is recommended regardless of the traffic volumes and the turning percentages. This is in agreement with some previous studies [9][17]
3. For high traffic volume (4000 veh/hr), a traffic signal is recommended for all traffic distributions and turning percentages. The conclusion in this case contradicts with some previously reported results [9]. The main reason for the difference is the fact that the previous work did not consider unbalanced traffic on the approaches.

4. In case of moderate traffic volume (between 3000 veh/hr to 4000 veh/hr), special attention should be paid to the left turn percentage before deciding on the type of control for such intersection.

It is recommended to consider the following points for future research:

1. Consider having different layout of the intersection (i.e. More than two lanes per approach).
2. Utilize micro simulation models to confirm the results obtained from this study.
3. Consider the case for signalized roundabouts as a third option for the intersection control.

7. ACKNOWLEDGEMENT

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