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Effect of Traffic Calming Lane Reduction on Critical Gap Sizes At Stop-Sign Controlled Crossings

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Abstract: The effect of restriping on the gaps accepted at a two-way stop-sign controlled intersection were investigated through a before/after restriping study. The major street at the study site was re-striped as a traffic calming strategy. Before re-striping the major Street was a two-way two-lane road without any bicycle lanes. After re-striping it became a two-way one-lane road with a two-way left-turn lane in the middle and one bicycle lane on each side. The results indicated that the critical gap sizes increased for both the left-turns and right-turns after re-striping compared to the before case. These increases were found to be statistically significant. The findingsshow that the traffic calming measures implemented appear to result in more caution being undertaken by drivers, as represented by higher critical gaps after the re-striping project.

I. PROBLEM DEFINITION

Road safety is a trending major issue. Unsignalized intersections are one of the roadway elements which can cause crash if driver is not cautious while accepting long enough a gap to make a maneuver safely. Therefore critical gap is an important aspect to study.Critical gap is also used to analyze the capacity of an unsignalized intersection.

Critical gap is "the minimum time interval in the major street traffic stream that allows intersection entry for one minor street vehicle"[1].Critical gap is the gap size that is accepted by as many drivers as rejected. It is the gap size which 50% of drivers reject and 50% of drivers accept to make a maneuver at a particular intersection[2].

Critical gap varies depending on various factors such as vehicle type, driver age, gender, location, maneuver,weather,time of day, presence of vehicles queued behind the turning vehicle and intersection geometry. Same individual can exhibit different critical gaps in different situations. In this paper effect of re-stripingthe UTA Blvd on critical gap for left-turn and right-turn maneuvers is studied.The UTA Blvd was restriped in 2015 for traffic calming purposes from four lanes to two lanes with a middles turn lane and a bicycle lane on each side. The effect of restriping on the gaps accepted at a two-way stop-sign controlled intersection on UTA Blvd were investigated through a before/after restriping study.

Effect of re-striping is considered because critical gap may vary with variation in the geometry. For this purpose data is collected at two time periods, before re-striping and after re-striping. The geometry of road has changed and is represented in figures below. Figure 1 represents the geometries of the Major and Minor Streets before re-striping and figure 2 represents geometries after re-striping.

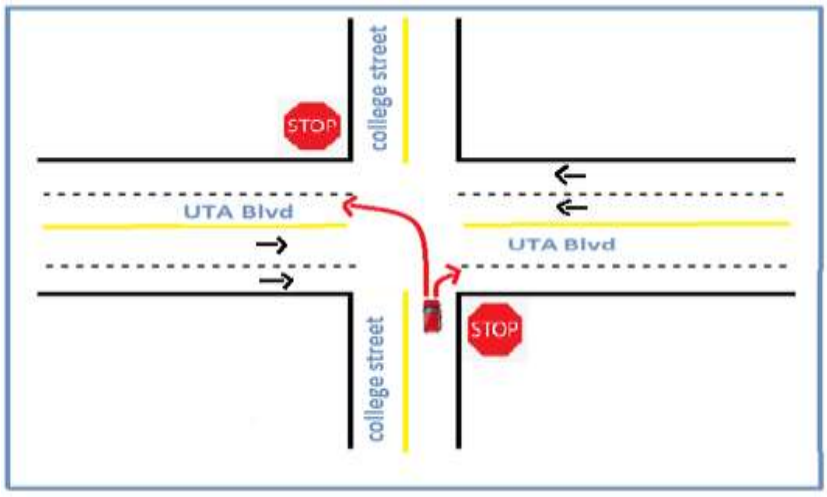

Figure 1: Lane geometry of UTA Blvd and College Street before re-striping

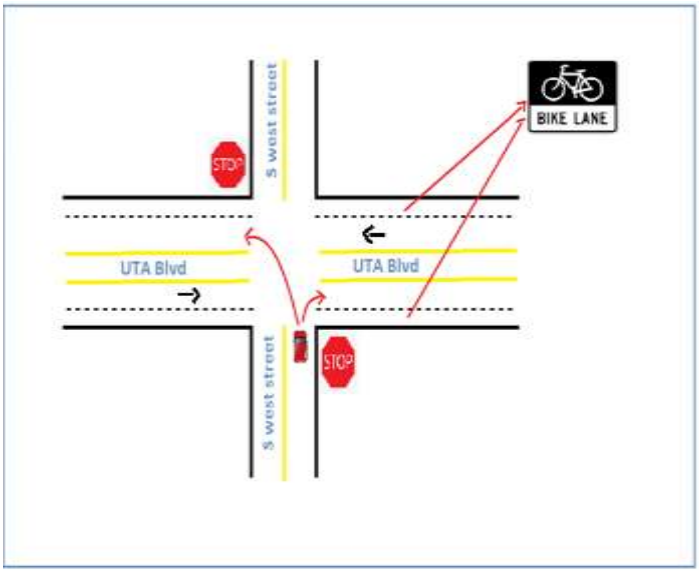

Figure 2: Lane geometry of UTA Blvd and S. West Street after re-striping

Before re-striping the major Street was a two-way two-lane road without any bicycle lanes. After re-striping it became a two-way one-lane road with two-way left-turn lane in the middle and one bicycle lane in each direction. The minor Street before re-striping was a two-way one-lane but after re-striping the northbound was converted into a one-way road. Therefore an adjacent intersection with similar minor road geometry as the old geometry was used for data collection after re-striping. The locations of both intersections are shown in figure 3.

Location 1 is the intersection of UTA Blvd and College Street. This intersection data was collected for the beforere-striping scenario. Location 2 is the intersection of UTA Blvd and S.West Street. This intersection data is collected for the after re-striping scenario. As critical gap also varies with the type of maneuver; only left-turn and right-turn maneuvers are considered in this paper.

Figure 3: Location 1 (before scenario) and location 2 (after scenario) for the study.

Critical gaps may vary with the type of maneuver and road geometry. For example the left-turn critical gap might be higher than the right-turn critical gap at a location.Critical gap might also depend on the number of lanes being crossed.Before re-striping, the UTA Blvd wasa two-lane road per direction but after re-striping it becamea one-lane road per direction with a two-way left-turn lane in the middle and one bicycle lane in each direction. General expectation would be that critical gap increases with an increase in number of lanes. But as bicycle lane is also included; which may result in an increase in the critical gap due to an increased concern of safety of cyclists. Critical gap for left-turn and right-turn before re-striping are in this study compared to those

for left-turn and right-turn after re-striping to test if the critical gap after re-striping is significantly higher than the critical gap before re-striping.

II. DATA COLLECTION

Vehicle maneuvers were recorded at the intersection of the UTA Blvd and S.West Street using video camera from 5PM to 6PM (peak period) which is similar to the time for which data was collected before re-striping. Number of observations: Left-turn maneuvers: 40,Right-turn maneuvers: 20
Timeof day: 5-6PM
Equipment used: Video camera and stop watch

While recording, the focus was placed onVehicles making left-turn and right-turn from S.West Street (minor street). After recording video for one hour, the video was played back and a stop watch was used to measure the gap sizes accepted by each vehicle.The minor street approaches are stop-controlled. Therefore, each minor street vehicle must stop and check for safe gap to make aleft-turn or right turn.Gap for left-turn is the time between when the vehicle starts its maneuverfrom complete stop to when the vehicle from the major Street enters the conflict area.For left-turns traffic from both eastbound and westbound are considered whereas for right-turns only eastbound traffic is considered. This is because for left-turnswestbound and eastbound traffic enter the conflict area whereas for right-turnsonly eastbound enters the conflict area [3].

Left-turn Data
Start point: Time when vehicle from the minorstreet starts making theleft-turn to enter into themajor street.
End point: Time when a major street vehicle from the eastbound or westbound enters the intersection, whichever happens first.

Right-turn Data
Start point: Time when vehicle from the minor street starts making theright-turnto enter into themajor street. **End point:** Time when a major street vehicle from the eastbound enters the intersection. This process is repeated until the desired sample sizes are obtained for both theleft-turnand right-turnmaneuvers. There are some vehicles with high critical gaps (greater than 14secs).These are neglected because this might be due to no vehicle arriving in the major street due to an upstream traffic signal. The before/after data for both right-turns and left-turns are summarized in tables 1 and 2,respectively.

III. DATA ANALYSIS AND RESULTS

The F-testis performed to test if the variances of critical gaps before re-striping and after re-stripingcan be considered statistically the same.Critical gaps before and after re-striping can be compared only after theF-test is performed. This is because if variances are statistically the same, then a pooled T-test can be performed. If variances differ significantly then the Behrens-Fisher T-test has to be performed. Table 1 represents gaps observed from field for left-turnsbefore and after re-striping.Table 2 represents gaps observed from field for right-turnsbefore and after re-striping. Using data in tables 1 and 2 the mean, standard deviation, and variances can be calculated.

Table 1 Gaps for left-turn before re-striping and after re-striping

Left –turn				
S.no	Gap (sec)		$(xi-\bar{x})^2$ (sec^2)	
	before re-striping	after re-striping	before re-striping	after re-striping
1	4.98	6.77	4.43	1.19
2	7.12	4.91	0.00	8.70
3	7.45	5.58	0.13	5.20
4	6.60	7.86	0.24	0.00
5	6.00	5.68	1.18	4.75
6	6.72	4.05	0.13	14.50
7	7.15	10.01	0.00	4.62
8	4.90	9.23	4.78	1.88
9	7.16	6.96	0.01	0.81
10	6.22	6.80	0.75	1.12
11	5.75	10.80	1.78	8.65
12	7.44	7.80	0.13	0.00

13	9.84	8.09	7.59	0.05
14	5.10	8.93	3.94	1.15
15	10.01	6.38	8.55	2.19
16	5.13	5.81	3.82	4.20
17	5.78	9.18	1.70	1.74
18	8.75	6.65	2.77	1.46
19	9.13	5.42	4.18	5.95
20	6.50	4.85	0.34	9.06
21	8.06	10.18	0.95	5.38
22	7.69	8.12	0.37	0.07
23	9.22	9.04	4.56	1.39
24	9.78	9.15	7.26	1.67
25	6.19	10.41	0.80	6.50
26	6.34	8.42	0.56	0.31
27	3.32	8.29	14.18	0.19
28	9.16	6.79	4.30	1.14
29	6.53	9.62	0.31	3.10
30	4.47	10.84	6.84	8.88
31	9.59	8.66	6.27	0.64
32	7.72	7.07	0.40	0.62
33	7.12	8.34	0.00	0.23
34	5.37	9.05	2.94	1.42
35	6.89	8.63	0.04	0.59
36	5.65	10.19	2.06	5.43
37	7.53	8.10	0.20	0.06
38	8.50	7.08	2.00	0.61
39	8.99	6.65	3.63	1.46
40	7.57	7.99	0.23	0.02

Table 2 Gaps for right-turnbefore re-striping and after re-striping

Right –turn				
S.no	Gap (sec)		$(xi-\bar{x})^2$ (sec^2)	
	before re-striping	after re-striping	before re-striping	after re-striping
1	3.46	8.82	14.20	1.71
2	8.60	8.74	1.88	1.51
3	4.90	7.29	5.42	0.05
4	5.75	4.21	2.18	10.89
5	6.47	4.30	0.57	10.31
6	4.80	5.27	5.90	5.02
7	4.18	9.65	9.29	4.58
8	13.13	6.40	34.83	1.23
9	9.50	11.16	5.16	13.32
10	4.47	6.52	7.61	0.98
11	8.47	9.58	1.54	4.28
12	6.05	4.15	1.39	11.29
13	12.13	6.01	24.03	2.25
14	5.43	11.22	3.23	13.76
15	6.28	9.51	0.90	4.00
16	10.32	6.30	9.56	1.47
17	3.54	9.41	13.60	3.61
18	10.02	8.63	7.80	1.25
19	10.22	8.92	8.95	1.99
20	6.84	4.12	0.15	11.50

To perform theF-test,the mean and variance of both samples are required. The estimatedmean, standard deviation and variance are summarized in table 3. These values are calculated for left and right-turnbefore and after re-striping.

Table 3 The mean, Standard deviation and variance for left and right-turnbefore and after re-striping

Mean			
Left-turn		Right-turn	
before re-striping	after re-striping	before re-striping	after re-striping
7.09	7.86	7.23	7.51
Standard Deviation			
Left-turn		Right-turn	
before re-striping	after re-striping	before re-striping	after re-striping
1.64	1.73	2.89	2.35
Variance			
Left -turn		Right-turn	
before re-striping	after re-striping	before re-striping	after re-striping
2.69	3.00	8.35	5.52

Test for variances of gaps forleft-turnsbefore re-striping and after re-striping are conducted as follows:
Hypothesis
H_0 = Variances of gap forleft-turn after re-striping and before re-striping are statistically equal.
H_1 =Variances of gap for left-turn after re-striping and before re-striping are not statistically equal.

$$F^*=\frac{\text{Greater estimate of gap variance}}{\text{Smaller estimate of gap variance}}$$
$$=\frac{\text{Variance after re}-\text{stripng for left}-\text{turns}}{Variance\ \ before\ re-striping\ \ for\ left-turns}$$
$$=\frac{3.00}{2.69}=1.1$$
$$F^*=1.1$$

The level of significance considered in this test is 5%.
F_{Table} =F (1-$\propto, n_1-1, n_2-1$)
=F (1-0.05, 40-1, 40-1)
=F (0.95, 39, 39)
=1.70>F^*

Therefore we fail to reject H_0 at the 5% level of significance.It can therefore be concluded that the variances of left-turnsbefore re-striping and after re-striping are not significantly different.
Test for variances of gaps for right-turnsbefore re-striping and after re-striping are similarly conducted, as follows:

Hypothesis
H_0 = Variances of right-turnsafter re-striping and before re-striping are statistically equal.
H_1 =Variances of right-turnsafter re-striping and before re-striping are not statistically equal.

$$F^*=\frac{\text{Greater estimate of gap variance}}{\text{Smaller estimate of gap variance}}$$
$$=\frac{\text{Variance before re}-\text{stripng for right}-\text{turn}}{Variance\ \ after\ re-striping\ \ for\ right\ turn}$$
$$=\frac{8.35}{5.52}=1.51$$
$$F^*=1.51$$

As before, a level of significance of 5% is used. Accordingly,
F_{Table} =F(1-$\propto, n_1-1, n_2-1$)
=F(1-0.05,20-1,20-1)
=F(0.95,19,19)
=2.17>F^*

Therefore we fail to reject H_0. It can therefore be concluded that the variances of right-turnbefore re-striping and after re-striping are not significantly different.

Since variances do not differ significantly for both left-turnsand right-turns, thePooled T-test can be used in both the cases. Observed and cumulative frequencies for left-turnsbefore re-striping, left-turnsafter re-striping, right-turnsbefore re-striping and right-turnsafter re-striping are shown in tables 4,5,6,and 7, respectively.

Table 4 Observed and cumulative frequency of gaps for left-turnsbefore re-striping

	Left-turn before re-striping	
Gaps	Observed frequency	Cumulative frequency
<4	1	1
<5	3	4
<6	6	10
<7	9	19
<8*	10	29
<9	4	33
<10	6	39
<11	1	40
<12	0	40
<13	0	40
<14	0	40

Table 5 Observed and cumulative frequency of gaps for left-turnsafter re-striping

	Left-turn after re-striping	
Gaps	Observed frequency	Cumulative frequency
<4	0	0
<5	3	3
<6	4	7
<7	7	14
<8	5	19
<9*	9	28
<10	6	34
<11	6	40
<12	0	40
<13	0	40
<14	0	40

Table 6 Observed and cumulative frequency of gaps for right-turnsbefore re-striping

	Right-turnbefore re-striping	
Gaps	Observed frequency	Cumulative frequency
<4	2	2
<5	4	6
<6	2	8
<7*	4	12
<8	0	12
<9	2	14
<10	1	15
<11	3	18
<12	0	18
<13	1	19
<14	1	20

Table 7 Observed and cumulative frequency of gaps for right-turnsafter re-striping

	Right turn after re-striping	
Gaps	Observed frequency	Cumulative frequency
<4	0	0
<5	4	4
<6	1	5
<7	4	9
<8	1	10
<9*	4	14
<10	4	18
<11	0	18
<12	2	20
<13	0	20
<14	0	20

The critical gap for left-turns before re-striping is 8 secs and for left-turns after re-striping is 9 secs. The critical gap increased from 8 secs to 9 secs. Therefore, the test is conducted to test if the critical gap for left-turns after re-striping is significantly greater than the critical gap for left-turns before re-striping.

The critical gap for right-turnsbefore re-striping is 7secs and forright-turnsafter re-striping is 9secs. The critical gap increased from 7 secs to 9 secs. Therefore,another hypothesis test is conducted to test if the critical gap for right-turnsafter re-striping is significantly greater the critical gap for right-turnsbefore re-striping.

The critical gaps of left-turnsbefore re-striping are compared to the critical gaps of left-turnsafter re-striping, as follows:

Hypothesis:

H_0 = Critical gaps for left-turnsafter re-striping and before re-striping are statistically the same.

H_1 =Critical gapsfor left-turnsafter re-striping are significantlygreater than the critical gaps before re-striping.

Level of significance=5%

$$S_p^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1+n_2-2)} = \frac{(40-1)1.64^2 + (40-1)1.73^2}{(40+40-2)}$$

$$S_p^2 = 2.84$$

$$S_P = 1.69$$

$$t^* = \frac{\overline{C_1} - \bar{C}_2}{S_P\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} = \frac{8-9}{1.69\sqrt{\frac{1}{40}+\frac{1}{40}}}$$

$$t^* = -2.65$$

T table =t(1-α, $(n_1 + n_2 - 2)$)=t(0.95, 78) =1.66<$|t^*|$

Hence, we reject H_0 and conclude that the critical gaps after re-striping aresignificantly greaterthan the critical gaps before re-striping,at 5% level of significance.

Similarly, the critical gaps of right-turnsbefore re-striping arecompared to the critical gaps of right-turnsafter re-striping, as follows:

Hypothesis

H_0 = Critical gaps for right-turns after re-striping and before re-striping are statistically the same.

H_1 =Critical gaps for right-turnsafter re-striping are significantly greaterthan critical gaps before re-striping.

Level of significance=5%

$$S_p^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1+n_2-2)} = \frac{(20-1)2.89^2 + (20-1)2.35^2}{(20+20-2)}$$

$$S_p^2 = 6.94$$

$$S_P = 2.63$$

$$t^* = \frac{\overline{C_1} - \bar{C}_2}{S_P\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} = \frac{7-9}{2.63\sqrt{\frac{1}{20}+\frac{1}{20}}}$$

$$t^* = -2.40$$

From the table, t(1-α, $(n_1 + n_2 - 2)$)= t (0.95, 38) = 1.68 < $|t^*|$

Hence, weagain reject the null hypothesis (H_0) and concludethat the critical gaps for right-turnsafter re-striping are significantly greaterthan critical gaps before re-striping,at 5% level of significance.

IV. CONCLUSIONS AND DISCUSSION

Effect of re-striping the UTA Blvd on the critical gap for left-turn and right-turnmaneuvers at a two-way stop is studied. For this purpose,the data for after re-striping scenario are collected from field while the data for before re-striping scenarioare obtained from previous records [4]. For analysis purposes, a level of significance of 5% is used.Initially F-tests are conducted to check if variances differ significantly. For both cases, i.e. for left-turn and right-turnmaneuvers, variances did not vary significantly.As variances are not different significantly, aPooled T-test is performed. At 5% level of significance, Pooled T-test is performed to test if critical gaps are equal or critical gaps after re-striping are greater than critical gaps before re-striping.

Results are same for both left-turnsand right -turns. For theleft-turnscritical gaps after re-striping are significantly greater than critical gaps before re-striping. Similarly for right-turns,critical gapsafter re-striping

are significantly greater than critical gaps before re-striping. The general expectation before conducting the study was to obtain lower critical gaps as the number of lanes decreased from before re-striping to after re-striping. But there is an increase in critical gaps for both left–turns and right-turns.This might be due to the addition of bicycle lanes which may make drivers more concerned about safety of bicycles and therefore more cautious.The results underscore that the traffic calming measures implemented have indeed resultedin more caution being undertaken by drivers, as represented by higher critical gaps for right-turns and left-turns from a stop-controlled minor street into a major street after the re-striping of the major roadway.

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