CRITICAL GAPS AT UNSIGNALIZED INTERSECTIONS – A COMPARISON OF THE U.S. VERSUS INDIAN DRIVERS

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Abstract -A critical gap can be defined as the minimum time gap in the major stream that the minor street driver would accept to enter or cross the major stream path. A critical gap is a significant parameter which affects the delay and capacity of unsignalized intersections. Different drivers display different critical gaps under different scenarios. Different drivers or even the same driver may have different critical gaps at different situations, as the critical gap of a driver is affected by several factors such as age, gender, driver aggressiveness, type of vehicle, location, vehicle condition, weather, time of day, etc. This paper presents a statistical comparison of critical gaps between drivers at two different locations (India and the U.S). Using video recordings at both locations, a sample size of 30 observations was obtained at each location. Critical gap is the median value of those gaps, i.e. the gap size accepted by as many drivers as rejected. Using these gap data, an F-test for two-population variance and hypothesis tests were performed for comparing the critical gaps. The results of these tests strongly suggest that the critical gap of drivers in the U.S. are 2 seconds greater than the critical gap of drivers in India at 5% level of significance.

Key Words - gap acceptance; critical gaps; unsignalized intersections; driver behavior.

I. INTRODUCTION

Critical gap is primarily used for determination of capacity of individual movements made by vehicles at unsignalized intersections. In general, in any major to minor street intersection, the vehicles in the major street always have the right of way (ROW), whereas the vehicles in the minor street should wait until thedistance (or time) between two successive major stream vehicles is long enough to enter the intersection/conflict area.

Critical gap can be defined as "the minimum time gap in the major stream that the minor street driver accepts to enter the conflict intersection" [1].

The primary purpose of this study was to compare the critical gaps between the drivers in India and the U.S. The selection of these two countries was because the traffic conditions and driving behavior are seemingly very different. In the U.S., the speed limits are designated for each and every roadway type accordingly; drivers generally follow lane markings; and proper placements of Stop and Yield signs can be observed at required intersections (both unsignalized and signalized). However, in India, drivers do not follow lane markings; speed limits are not designated for roadways; and Yield and Stop signs are not present to regulate rights of way at intersections (both signalized and unsignalized).

Moreover, the traffic mixes in both countries are also very different. In India, vehicles of various types, sizes and operating conditions can be observed. Bicycles, two wheelers and three wheelers (auto-rickshaw) constitute the highest percentages in the traffic mix (within the city limits). However, in the U.S., most of the traffic mix contains passenger cars and pick-up trucks (within the city limits).

In general, the prime factors affecting the critical gap of any driver are 1. Driver aggressiveness (aggressive drivers tend to accept shorter gaps); 2. Age of the driver (younger drivers tend to accept shorter gaps); 3. Gender of the driver (male subjects tends to accept shorter gaps); 4. Roadway conditions, such as pavement conditions (dry or wet) and type of road (major or minor arterials, collectors, etc.); 5. Weather conditions (dry and clear weather promotes accepting shorter gaps); 6. Time of day (good visibility improves chances of accepting shorter gaps); 7. Type of vehicle (a vehicle with small size and mass enhances the chances of accepting shorter gaps); 8. Type of Maneuver (right turn maneuvers require shorter time gaps than those of through and left turn maneuvers), etc.

The study sites for the critical gap comparison of drivers were in the following two cities: the City of

Vijayawada located in the State of Andhra Pradesh in the southern part of India and the City of Arlington located in the State of Texas in the south central part of the U.S. The evening peak hour is same for both cities (about 5-6 PM). A video recording was made at an unsignalized intersection in each city during the evening peak hour of 5:00 PM to 6:00 PM. Northbound through maneuvers from the minor streets were taken into consideration. The video recording was performed on days with dry and clear weather conditions.

Given this information for making a comparison between the critical gaps of drivers from two cities that are located in different countries, the following factors must be taken into consideration. First, both cities possess similar kind of weather conditions with slight variations in temperatures. Second, similar pavement conditions can be observed; however, drivers in India drive on the left-hand side, whereas, drivers in the U.S. drive on the right-hand side. Since, the video was made during the peak hour; time of day was taken into consideration. The video recording in each city captured subjects (drivers) of all age groups, genders and driving behaviors.

After video-recording all the required maneuvers, accepted gaps of all the northbound through maneuvers of minor street drivers were estimated by replaying the video and using a stopwatch to measure the gap durations. This procedure was repeated until 30 samples of accepted gaps at each location were obtained. The reason behind choosing 30 samples is that "the t-distribution becomes a close fit for the Normal distribution when the number of samples/sample size reaches 30 (Kufs, 2011). Using these values, an F-test for two population variances is performed to check the equality of variances for two sets of accepted gap data. Then a statistical t-test is performed to compare critical gaps between two sets of accepted gap data. From the results of the statistical t-test, it is determined whether or not there is a significant difference between critical gaps of drivers in India and the U.S.

Keeping this in mind, the project has considered the drivers in India and the U.S. as the subjects of interest, with an assumption that the car drivers in India are likely to be more aggressive than car drivers in the U.S. In other words, drivers in India are likely to accept shorter critical gaps than drivers in the U.S.

II. BACKGROUND

Gap acceptance is used in modeling and analysis of instances where a vehicle is to cross the path of a priority stream of vehicles, such as at unsignalized intersections or freeway merge ramps. Gap acceptance is mostly related to the perception and judging skills of the respective drivers and how risk averse they are. For this reason, the gap acceptance has a wide range of values depending on the driver behavior. For the same reason, the drivers at two different regions are likely not to exhibit similar gap acceptance behavior (TUPPER, 2011, p. 10).

Even though there are several methods available to observe drivers' gap acceptance behavior, the two best methods for collecting data on gap acceptance behavior are through direct field observations and by video-recording. Even though the required sample size is small, video-recording is preferred over direct field measurements, as it would improve the accuracy in calculating the gap accepted and determining the maneuver for which the gap is utilized. The other reason for choosing the video-recording option is due to the minimal labor requirement-with one person being able to do both the data collection and the data reduction.

As stated above, the critical gap can be defined as "the minimum time gap in the major stream that the minor street driver accepts to enter the conflict intersection" (Brilon, July 1997). Raff's method (1940) of determining the critical gap from the gap acceptance data is shown below:

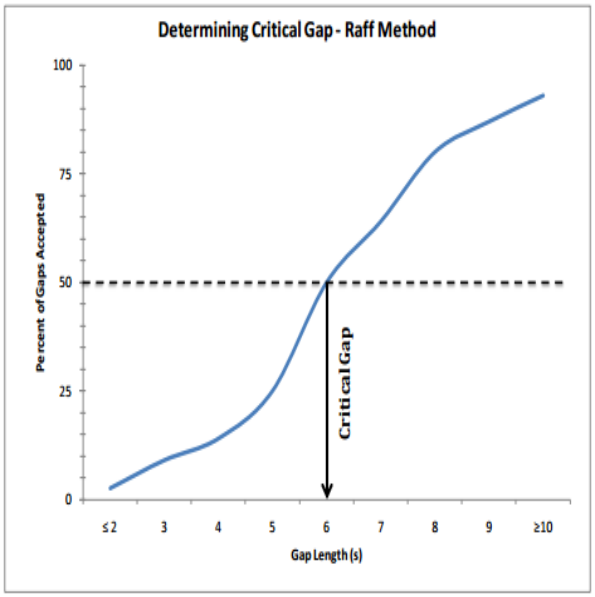

FIGURE 1. RAFF'S METHOD FOR DETERMINING CRITICAL GAP

From the above figure, it can be observed that the critical gap can be estimated to be the 50-percentile value of the gaps accepted by all the drivers. The same procedure is followed in this study to determine the critical gap in both study regions.

III. DATA COLLECTION METHODOLOGY

Data collection approach in the U.S.:

- Location of study: The intersection of the UTA BLVD (Major Street) and S. West Street (Minor Street).
- Time of study: 5:00 PM to 6:00 PM.
- Dates of study: 19th (Friday), 23rd (Tuesday) and 26th (Friday) of September 2014.
- Weather during study: Clear and dry.
- Pavement condition: Dry with few cracks.
- Equipment used: Video camera and stopwatch.
- Number of samples: 30 northbound through maneuvers.

A schematic view of this intersection is shown in Figure 2, in which blocks A, B, and C represent the northbound vehicles on Minor Street. Similarly, blocks 1, 2, and 3 represent the eastbound and westbound vehicles on Major Street. Since the minor street traffic is stop-controlled in both directions, each and every vehicle on the minor street must come to a complete stop before entering the intersection. The stopwatch is started when a vehicle from the minor street (S. West St.) starts rolling to make a northbound through movement and the stopwatch is stopped when the vehicle from either direction on the major street (UTA Blvd.) enters the intersection. For example, if vehicle A on the minor street starts the northbound through movement at time t_0 and vehicle 1 on the major street enters the intersection at time t_1, then ($t_1 - t_0$) is the gap accepted by the driver A to make the northbound through maneuver.

Data collection approach in India:

- Location of study: The intersection of Siddhartha College Road (Major Street) and Jammi Chettu Road (Minor Street).
- Time of study: 5:00 PM to 6:00 PM.
- Dates of study: 22nd (Thursday) and 23rd (Friday) of January 2015.
- Weather during study: Clear and dry.
- Pavement condition: Dry with very few cracks.
- Equipment used: Video camera and stopwatch.
- Number of samples: 30 northbound through maneuvers

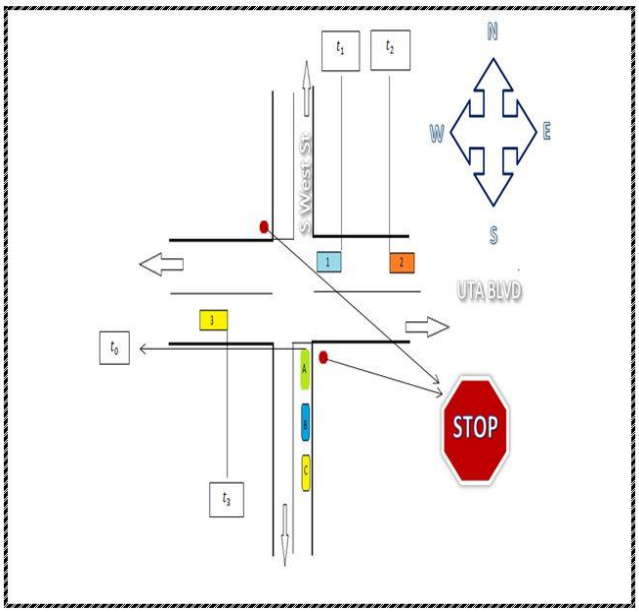

FIGURE 2. MAJOR AND MINOR STREET INTERSECTION IN THE U.S. (ARLINGTON, TX).

FIGURE 3. AN AERIAL VIEW OF THE UTA BLVD AND S. WEST ST INTERSECTION, ARLINGTON, TX.

A schematic view of this intersection is displayed in Figure 4, in which blocks A and B represent the northbound vehicles on the minor street. Similarly, blocks 1, 2, and 3 represent the eastbound and westbound vehicles on the major street. The same procedure as in the U.S. followed in India to determine the accepted gaps. The only difference is that in India the minor street traffic is not stop-controlled. So the minor street vehicles may not come to a complete stop before entering the street. Due to this difference, the stopwatch is started when a vehicle from the minor street (Jammi Chettu Rd.) enters the intersection to make a northbound through movement and the stopwatch is stopped when the vehicle from either direction of the major street (Siddhartha College Rd.) enters the intersection. As mentioned before, if vehicle A on the minor street starts the northbound through movement at time t_0 and vehicle 1 on the major street enters the intersection at time t_1, then $(t_1 - t_0)$is the gap accepted by the vehicle on the minor street to make the northbound through maneuver.

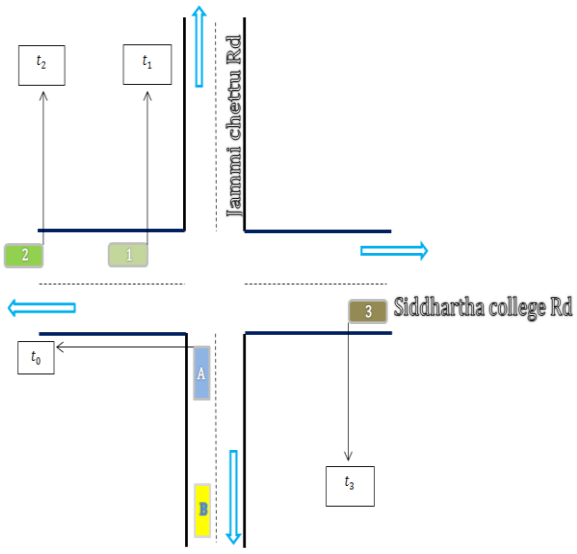

FIGURE 4. MAJOR AND MINOR STREET INTERSECTION IN INDIA (VIJAYAWADA).

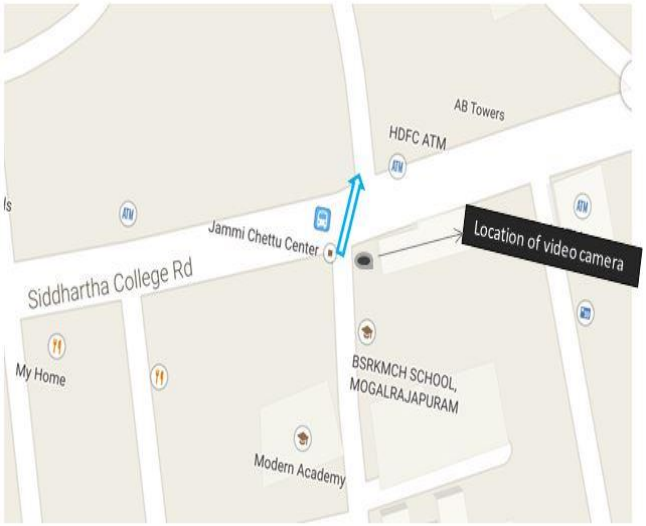

FIGURE 5.AN AERIAL VIEW OF THE SIDDHARTHA COLLEGE RD. AND JAMMI CHETTU RD. INTERSECTION IN VIJAYAWADA.

IV. DATA ANALYSIS AND RESULTS

Available methods:

Given this data, initially an F-test for the two population variances was conducted to check if the variances of the accepted gaps of drivers in India and the U.S. are significantly different. Then according to the result of this test, we have two methods to test if the critical gaps of drivers in India and the U.S. are significantly different.

- ❖ Method 1 (The Pooled T-test):
  - ➢ If S^2 (USA) = S^2 (India), then the pooled T-test should be used (Kanji, 1999, p. 31).
- ❖ Method 2 (Behrens-Fisher T-test):

- If S^2 (USA) ≠ S^2 (India), then the Behrens-Fisher T-test is recommended (Kanji, 1999, p. 33).

The means and standard deviations of accepted gaps for both drivers in India and the U.S. are calculated using the following formulae:

$$\text{Mean:} \quad \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \quad (1)$$

$$\text{Standard deviation:} \quad S = \sqrt{\frac{(x_i - \bar{x})^2}{(n-1)}} \quad (2)$$

The individual gap acceptance observations and the respective means and standard deviations are provided in Tables 1 (India) and 2 (U.S.).

TABLE 1. THE DATA ON GAPS ACCEPTED BY DRIVERS IN INDIA AND THEIR MEAN AND STANDARD DEVIATION

Obs. No	Movement	Gap accepted (Yi) (Sec)	(Yi-ȳ1) (sec)	(Yi-ȳ1)² (Sec²)
1	NBTH	6.261	0.079	0.006
2	NBTH	4.200	2.140	4.580
3	NBTH	6.804	-0.464	0.215
4	NBTH	7.714	-1.374	1.888
5	NBTH	4.935	1.405	1.974
6	NBTH	4.500	1.840	3.386
7	NBTH	5.591	0.749	0.561
8	NBTH	8.452	-2.112	4.461
9	NBTH	10.410	-4.070	16.565
10	NBTH	5.548	0.792	0.627
11	NBTH	10.940	-4.600	21.160
12	NBTH	7.480	-1.140	1.300
13	NBTH	6.556	-0.216	0.047
14	NBTH	4.660	1.680	2.822
15	NBTH	10.852	-4.512	20.358
16	NBTH	6.451	-0.111	0.012
17	NBTH	5.554	0.786	0.618
18	NBTH	4.312	2.028	4.113
19	NBTH	6.688	-0.348	0.121
20	NBTH	4.879	1.461	2.135
21	NBTH	4.354	1.986	3.944
22	NBTH	4.285	2.055	4.223
23	NBTH	6.805	-0.465	0.216
24	NBTH	2.237	4.103	16.835
25	NBTH	7.219	-0.879	0.773
26	NBTH	4.783	1.557	2.424
27	NBTH	4.010	2.330	5.429
28	NBTH	5.996	0.344	0.118
29	NBTH	10.454	-4.114	16.925
30	NBTH	7.270	-0.930	0.865
Total		**190.200**		**138.700**
Mean(ȳ1)		**6.340**	**Variance**	**4.623**
			Standard Deviation	**2.150**

TABLE 2. THE DATA ON GAPS ACCEPTED BY DRIVERS IN THE U.S. AND THEIR MEAN AND STANDARD DEVIATION

Obs. No	Movement	Gap accepted(Yi) (Sec)	(Yi-ȳ1) (sec)	(Yi-ȳ1)² (Sec²)
1	NBTH	5.530	-3.300	10.890
2	NBTH	6.090	-2.740	7.510
3	NBTH	13.250	4.420	19.540
4	NBTH	12.030	3.200	10.240
5	NBTH	12.290	3.460	11.970
6	NBTH	11.260	2.430	5.900
7	NBTH	7.630	-1.200	1.440
8	NBTH	3.880	-4.950	24.500
9	NBTH	12.660	3.830	14.670
10	NBTH	8.060	-0.770	0.590
11	NBTH	11.750	2.920	8.530
12	NBTH	5.060	-3.770	14.210
13	NBTH	7.940	-0.890	0.790
14	NBTH	4.400	-4.430	19.620
15	NBTH	13.280	4.450	19.800
16	NBTH	12.690	3.860	14.900
17	NBTH	7.600	-1.230	1.510
18	NBTH	8.290	-0.540	0.290
19	NBTH	7.900	-0.930	0.860
20	NBTH	7.160	-1.670	2.790
21	NBTH	14.280	5.450	29.700
22	NBTH	13.660	4.830	23.330
23	NBTH	7.530	-1.300	1.690
24	NBTH	8.660	-0.170	0.030
25	NBTH	9.600	0.770	0.590
26	NBTH	7.930	-0.900	0.810
27	NBTH	5.220	-3.610	13.030
28	NBTH	8.250	-0.580	0.340
29	NBTH	7.060	-1.770	3.130
30	NBTH	4.030	-4.800	23.040

Total		**264.970**		**286.240**
Mean (ȳ1)		**8.832**	**Variance**	**9.541**
			Standard Deviation	**3.089**

the gap acceptance variances of drivers in India and the U.S. are significantly different (Kanji, 1999, p. 11).

Based on this result, in comparing the mean gap acceptance values, we must conduct the Behrens-Fisher T-test as opposed to the two-sample T-test. The former test assumes that the variances are not equal, which is the case in this study.

Note: If Ho can be rejected at 5% level of significance ($\propto= 0.05$) , it will be rejected at higher levels of significance (i.e.,$\propto= 0.10, \propto= 0.15$).

The F-Test for Equal Variance:

To perform an F-significance test for two population variances to check the equality of variances, a hypothesis must be set and variance ratio (F^*) must be calculated.

- Hypothesis:
  - Ho: difference in variances is not significant.
  - Ha: difference in variances is significant.

$$F^* = \frac{Greater\ estimate\ of\ gap\ variance}{Lesser\ estimate\ of\ gap\ Variance}$$

$$F^* = \frac{Variance\ of\ accepted\ gaps\ in\ the\ U.S.}{Variance\ of\ accepted\ gaps\ in\ India}$$

$$F^* = \frac{S^2 usa}{S^2 India} \qquad (3)$$

$$= \frac{3.089^2}{2.150^2}$$

F^* =2.063

At 5% level of significance:

Since,
$F_{table} = F(1-\propto, n_1 - 1, n_2 - 1) = F(1 - 0.05, 30 - 1, 30 -$
= 1.8543 <F^*, we reject the Ho. So, we conclude that

TABLE 3. THE OBSERVED AND CUMULATIVE FREQUENCIES OF THE ACCEPTED GAPS IN THE U.S.

Gaps	Observed Frequency	Cumulative Frequency
<4	1	1
<5	2	3
<6	3	6
<7	1	7
<8*	**8**	**15***
<9	4	19
<10	1	20
<11	0	20
<12	2	22
<13	4	26
<14	3	29
<15	1	30

***critical gap for drivers in the U.S. (50- percentile value) = 8 sec**

TABLE 4. THE OBSERVED AND CUMULATIVE FREQUENCIES OF THE ACCEPTED GAPS IN INDIA

Gaps	Observed Frequency	Cumulative Frequency
<4	1	1

<5	10	11
<6**	**4**	**15****
<7	6	21
<8	4	25
<9	1	26
<10	0	26
<11	4	30
<12	0	30
<13	0	30
<14	0	30
<15	0	30

****critical gap for drivers in India (50- percentile value) =6 sec**

The Behrens-Fisher T-test:

In performing this test, initially critical gaps $\bar{c}_{India}$ *and* $\bar{c}_{USA}$ have to be calculated. From Tables 3 and 4, it can be observed that the critical gap for drivers in the U.S. is about 8 seconds while the critical gap for drivers in India is about 6 seconds.

Hypothesis:

Ho: $\bar{c}_{India} = \bar{c}_{USA}$ (critical gap of drivers in India and the U.S. are equal)

Ha: $\bar{c}_{India} < \bar{c}_{USA}$ (critical gap of drivers in India is less than that of drivers in the U.S.)

Formulae and calculation for Behrens-Fisher T-test (Kanji, 1999, p. 33):

$$t^* = \frac{\bar{c}_{India} - \bar{c}_{USA}}{\sqrt{\frac{S^2{}_{India}}{n_1} + \frac{S^2{}_{USA}}{n_2}}} \qquad (4)$$

$$= \frac{6 - 8}{\sqrt{\frac{3.089^2}{30} + \frac{2.15^2}{30}}}$$

$= -2.910$

Degrees of freedom

$$v = \left[\frac{\left(\left(\frac{s^2{}_{USA}}{n_1}\right) + \left(\frac{s^2{}_{India}}{n_2}\right)\right)^2}{\frac{\left(\frac{s^2{}_{USA}}{n_1}\right)^2}{n_1 + 1} + \frac{\left(\frac{s^2{}_{India}}{n_2}\right)^2}{n_2 + 1}}\right] - 2 \qquad (5)$$

$$= \left[\frac{\left(\left(\frac{3.089^2}{30}\right) + \left(\frac{2.150^2}{30}\right)\right)^2}{\frac{\left(\frac{3.089^2}{30}\right)^2}{30 + 1} + \frac{\left(\frac{2.150^2}{30}\right)^2}{30 + 1}}\right] - 2$$

$= 53.32$

≈ 53

$$t_{table} = t(1 - \propto, n - 2) \qquad (6)$$

$= t\,(0.95, 53)$

$= 1.674.$

Since, $|t^*| = 2.910 > t_{table} = 1.674$,null hypothesis is rejected; therefore it can be concluded that the critical gap of drivers in India is statistically less than that of the U.S. It should again be noted that if Ho can be rejected at 5% level of significance ($\propto = 0.05$) ; it will also be rejected at higher levels of significance (i.e. $\propto = 0.10, \propto = 0.15$).

V. CONCLUSION AND DISCUSSION

- two-second difference in critical gaps between the drivers in India and the U.S. can be observed from the data collected and analyzed.
- he F-test for the two population variances conducted at 5% level of significance shows that the variances of gaps accepted by drivers in India and the U.S. differ significantly.
- rom the Behrens-Fisher T-test conducted at 5% level of significance, it can be concluded that the critical gap of drivers in India is in fact statistically shorter than that of the critical gap of drivers in the U.S., as the null hypothesis is rejected.

- hese results strongly support our initial assumption that the drivers in India are more aggressive from a gap acceptance perspective when compared to that of drivers in the U.S.
- his aggressive nature is observed in India possibly due to the overall shorter gaps between major street vehicles in India compared to that of the U.S.
- ven though the gaps accepted by drivers in India and the U.S. turned out to be significantly different as excepted in the beginning, a larger sample size for the gaps accepted and more study sites in both regions would have made the results even more accurate.
- oth the study areas of interest are slightly congested and do not exhibit excessive delays. So, conducting the same study at intersections with higher delays and congestion levels should exhibit different gap acceptance behavior of drivers. Thereby, the significant difference between the accepted gaps might increase/decrease accordingly.
- he traffic mix and driving conditions in India are similar to those of the neighboring countries like Pakistan, Bangladesh, Nepal and Sri Lanka. So, a similar kind of aggressive driving behavior is likely to be the case in those countries as well. It would be interesting to expand this study to include some of those countries as well.

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