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Empirical Study of Lane Changing in Urban Streets under Varying Traffic Conditions

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Abstract

This paper investigated the variations in accepted gaps and lane change durations with respect to different traffic flow rates on urban street. Data for accepted gaps and lane change durations were collected during the peak, off peak, and mid-day hours on normal working days to cover flow rates ranging from free flow to congested conditions. Descriptive statistics and best fit distributions were obtained for the collected data. Hypothesis testing using Mann-Whitney U Test proved that the mean size of accepted gaps was statistically different between free flow and congested conditions. The best fit distributions showed that a considerable number of drivers accepted smaller gaps during congested traffic conditions than in free flow conditions. However, lane change durations did not show any statistical difference between different flow rates. The findings from this study have direct implications on the gap acceptance and lane changing parameters used in microscopic traffic simulation, particularly during model calibration.

Keywords: Microscopic Traffic Simulation; Repetitions; Initialization Time; MOE; LOS; Saturation.

1. Introduction

Congestion is a major source of discontent and frustration for urban and suburban dwellers (Raney et al., 2000). It leads to increased fuel consumption and vehicular emissions. Excessive delays in moving goods and people affect the local economy. The Urban Mobility Report 2009 by the Texas Transportation Institute indicates that about 439 urban areas in America are experiencing problems due to congestion, and it is getting worse in regions of all sizes (Schrank and Lomax, 2009). The report states that as per 2007 data, congestion caused urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel, leading to a total congestion cost of $87 billion per year.

Based on the premise that congestion contributes to impatience and frustration among drivers, it is anticipated that driver behavior varies during the transition from free flow to congested traffic conditions. Understanding the changes in driver behavior under congested conditions may help to better predict and model these parameters in traffic simulation models. Among the many operational parameters related to driver behavior, this study investigated

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the changes in size of accepted gaps and lane change duration with increase in congestion. The main objectives of this paper are, (i) to identify the changes in size of accepted gaps and lane change durations between free flow, saturated flow, and other traffic conditions with statistical significance and (ii) to obtain and compare the range and best fit distributions for accepted gaps and lane change durations under different traffic flow rates.

2. Literature review

Lane changing refers to drivers changing roadway lanes without interfering with vehicles in the destination lane. It is classified as either mandatory or discretionary. When a lane change is required due to, for example, a lane drop, the operation is called a mandatory lane change. A lane change that is intended to improve the perceived driving conditions, it is called a discretionary lane change (Goswami and Bham, 2007). Gap acceptance in this study refers to the minimum size of gap (seconds) in traffic flow that drivers are willing to accept while changing lanes. Over the years, the characteristics and modeling of these two driver behavior parameters have attracted enormous attention from researchers (Goswami and Bham, 2007; Ahmed, 1999; Lee, 2006; Toledo and Zohar, 2007; Ramanujam et al., 2008; Coifman et al., 2006; Hidas, 2002; Thiemann et al., 2008; Tijerina et al., 1997; and Lee et al., 2003). Gap acceptance and lane changing depend on driver parameters like aggressiveness, urgency, and impatience (Lee, 2006). It is known that drivers behave differently under diverse traffic, geometric, and environmental conditions. Similarly, the same driver can behave differently under varying traffic and control conditions (Lee, 2006). The interactions between drivers involved in a lane change maneuver require complex behavioral decision-making processes (Hidas, 2002). Thus, it is expected that an increased level of congestion can have considerable impact on the lane changing process. It is claimed that transportation impedance (i.e., congestion) as a frustrating condition elicits negative effects in driver behavior such as aggressive lane switching (Stern et al., 1999). Another study on a related driver behavior parameter (headway) observed that at all traffic flow levels there were vehicles traveling at unsafe headways, but more drivers seemed to adopt unsafe headways as the flow level increased (Mahlawat and Zhang, 2008). Though the relationship between driver behavior and congestion has been studied for quite some time, the changes in driver behavior parameters such as gap acceptance and lane changes for different levels of congestion have not been proven with statistical significance. Also, many of the previous studies were restricted to freeway traffic conditions.

Gap acceptance and lane changing parameters have direct implications on the lane change models which form an integral and important part of microscopic traffic simulation. Studies on accurate modeling of gap acceptance (Goswami and Bham, 2007; Ahmed, 1999; and Lee, 2006) and lane changes (Toledo and Zohar, 2007; Ramanujam et al., 2008; Hidas, 2002; and Jones et al., 2004) have evoked keen interest among the research community. In a lane change model, generally each driver in the model is assigned lane changing characteristics, which may include maximum deceleration rates they will accept in order to make a lane change, average time/distance over which they will perform a lane change, minimum acceptable gap in an adjacent traffic stream, distance at which they begin positioning for lane changes ("look ahead" distance), and desire and thresholds for making discretionary lane changes (Jones et al., 2004). According to an earlier study, the mean value of leading gap for mandatory lane changes in a freeway segment ranged between 1.47 to 1.82 seconds and that of a trailing gap ranged between 1.58 to 1.82 seconds (Goswami and Bham, 2007). Another study found that the median lead critical gaps in a freeway ranged from 1.5 to 49.2 meters (Lee, 2006). A study conducted for modeling gap acceptance at freeway merges observed that the lead spacing in I-80 ranged between 0.13 to 102.9 meters and the lag spacing ranged between 0.5 and 172.9 meters (Ahmed, 1999). With respect to lane changes, most of the microscopic traffic simulation software models treat lane changes as instantaneous event (Toledo and Zohar, 2007). However, in reality lane changes have durations in the range of 1.0 to 13.3 seconds (Toledo and Zohar, 2007; Thiemann et al., 2008; Tijerina et al., 1997; and Lee et al., 2003) and follow a specific distribution. It is also shown that lane change maneuvers affect delays (Coifman et al., 2006), and the duration of lane changes for passenger cars differ significantly from that of heavy vehicles (Toledo and Zohar, 2007). Hence accurate modeling of lane changing process is necessary to achieve better results from microscopic traffic simulation.

Most of the existing research has been done on lane changes on freeways rather than urban streets. The reason could be that traffic operations on urban streets are more complex than on freeways due to the presence of traffic signals and the lack of sufficient access management on urban streets. This study is an attempt to enhance traffic operations by improving the understanding of lane changing and gap acceptance parameters on urban streets under different levels of traffic flow and to propose recommendations for better modeling of these parameters in microscopic traffic simulation.

3. Data description

The UTCA Intelligent Transportation Systems/Traffic Management Center (ITS/TMC) lab was used extensively for collecting the required data for this study. The lab receives live feed of real-time traffic by closed circuit television (CCTV) cameras placed along the study road (McFarland Boulevard), a six-lane, two-way arterial in Tuscaloosa, AL. One of the cameras was adjusted to view the intersection of McFarland Boulevard and 37th Street, including about 210 meters of southbound approach to the signal. As lane changing and gap acceptance took place, data were collected as per the method and timing plans described in the methodology section below. A sketch of the study approach and the intersection is given in Figure 1, and a snapshot of the camera view is given in Figure 2.

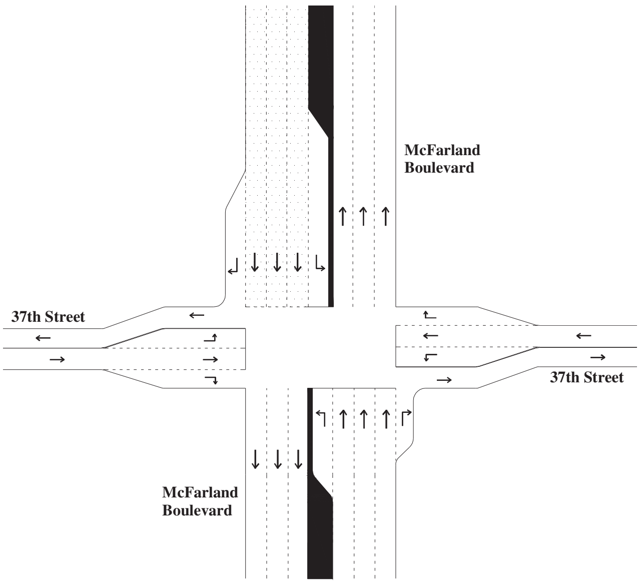

Figure 1. Study Approach and Intersection

Figure 2 – Snapshot of the South Bound Approach in the Study Road

4. Methodology

Real time traffic flow on the study approach was recorded from the ITS/TMC lab. The data collection protocol captured data from the AM peak (7 AM to 9 AM), midday (11 AM to 1 PM), and the PM peak (4 PM to 6 PM) on normal working days. The time periods chosen to collect data were sufficient enough to cover both under-saturated and saturated traffic conditions. Data were collected in time intervals corresponding to the green phase for the southbound traffic shown in Figure 2. The number of lane changes and gap acceptances per cycle of green time were noted. For each lane change and gap acceptance, the duration of the change maneuver (in seconds) and the size of the accepted gap (in seconds) were collected.

Initially, a sample of gap acceptance and lane change duration data was collected for both passenger cars and heavy vehicles. From the sample, it was observed that the sizes of accepted gaps and lane change durations were abnormal for heavy vehicles. An earlier study (Toledo and Zohar, 2007) also reported that the lane change durations of heavy vehicles were significantly different from that of passenger cars. Hence, heavy vehicles were removed subsequently from the data collection process. The gap acceptance and lane change duration data in this study correspond only to passenger cars.

4.1 Data collection procedure

In this study, gap acceptance refers to accepting a gap during a lane change maneuver. Hence, the parameters gap acceptance and lane changing duration are related to each other. Figure 3(a) shows all the lane change maneuvers possible within a three lane road, and Figure 3(b) shows the process of vehicle accepting gap while changing lanes. In this study, gap refers to the time gap available to the subject vehicle in the target lane, and accepted gaps are those gaps accepted by the subject vehicle.

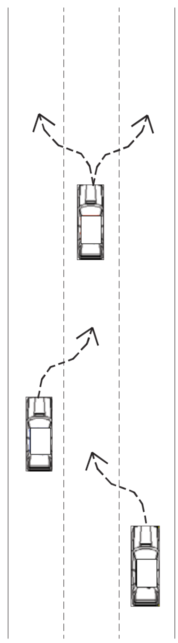

Figure 3(a) Possible Lane Changes on a Three Lane Road

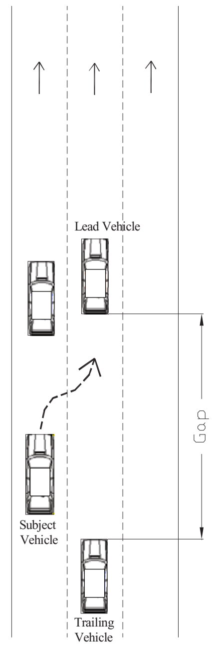

Figure 3(b) Gap Acceptance while Changing Lanes

The accepted gaps were collected as follows:

- The time (T_1) and location of the leading vehicle in the target lane were noted at the instant the subject vehicle first began changing its alignment in the present lane.
- The time (T2) was noted when the following vehicle crossed the same spot as that noted in the first step.
- The difference between times T_1 and T_2 gives the accepted gap size (in seconds).
- The other parameter, duration of the lane change maneuver was calculated as the time taken by the subject vehicle to completely change from one lane to another.

Past studies have indicated that a leading gap (between the leader and subject vehicle) or a trailing gap (between the subject vehicle and the following vehicle) of 60 meters or more will result in vehicles not interacting with each other (Goswami and Bham, 2007). In this study, gaps are defined as the time between the leading and trailing vehicles (see Figure 3(b)). So a gap size of 120 meters was taken as the limit for vehicles to be in interaction. Based on travel time measurements conducted for another study on the same road, the speed of vehicles on the approach under consideration was chosen as 55 km/hr. Hence, about 8 seconds is needed to clear the gap size of 120 meters. Thus, gap sizes equal to or more than 8 seconds were not counted in the data collection process. Since the study approach was close to the signalized intersection and there were frequent queue build ups, sufficient care was taken to collect data only when there was continuous flow of vehicles and not during stop and go movement.

The approach under consideration had three through lanes. With the absence of any lane drops or other similar situations, lane changes at the studied location were mainly for positioning the vehicles for turns to enter an upcoming freeway (I-20), to enter adjacent driveways (gas stations, malls, etc.), or for improved driving comfort. Thus, these lane changes in general can be considered discretionary in nature. Lane changes and gap acceptances occurring only within the three through lanes were collected for the study.

4.2 Creation of flow rate bins and categorizing data

The flow rate of each cycle of green time was obtained by dividing the volume of traffic clearing the intersection during green with the green time (in minutes). The flow rate is expressed as the number of vehicles per minute of green time. Hence, each cycle has a flow rate associated with it. The lane changes and gap acceptances occurring in a particular cycle correspond to the flow rate of that cycle. For analysis purposes, four different flow rate bins were created to cover the range of traffic flow: (i) 10 – 30 vehicles per minute of green, (ii) 30 – 50 vehicles per minute of green, (iii) 50 – 70 vehicles per minute of green, and (iv) 70 – 90 vehicles per minute of green.

These flow rate bins can be loosely correlated to different levels of congestion or levels of service to observe the effect of congestion on accepted gaps and lane change durations. For example a flow rate of 10-30 vehicles per minute can be considered as free flow state (LOS A and B) and a flow rate of 70 – 90 vehicles per minute can be considered as saturated state (LOS E and F). The flow rates in between these two extremes can come under LOS C and D. Each lane change and accepted gap was recorded in the appropriate bin. To ensure a valid statistical analysis of the grouped data, the minimum sample requirement of each bin was calculated as shown below.

4.3 Sample requirements

The minimum sample size was calculated using the standard procedure given in reference (Currin, 2001). A confidence level of 90%, a sample standard deviation(s) of 1 for 6 samples, and a permitted error of the estimate of 0.25 were assumed. The number of required samples was calculated as 44. This number was taken as the number of lane changing or gap acceptance maneuvers required for statistical validity.

The number of samples available in each bin is shown in Table 1. It should be noted that for each lane change the duration of lane change was measured, but an accepted gap was measured only if both the lead and following vehicle were present in the target lane. Thus, in Table 1 there are fewer samples of accepted gaps when compared to the number of lane changes.

Table 1. Available Number of Samples

Flow Rate bins	Number of Samples Available	
	Accepted Gaps	Lane Changes
10 – 30 veh/min of green	61	135
30 – 50 veh/min of green	164	288
50 – 70 veh/min of green	136	218
70 – 90 veh/min of green	65	103

5. Analysis of data

5.1 Descriptive statistics for accepted gaps

The accepted gaps corresponding to each flow rate bin were analyzed to obtain basic statistics such as mean, median, standard deviation, range, and skewness. Table 2 shows the basic statistics obtained for the collected data.

Table 2. Basic Statistics of Accepted Gaps for Different Flow Rates

Flow Rate	Mean (s)	Standard Deviation (s)	Median (s)	Range (s)	Skewness
10 to 30 veh/min	4.42	1.59	4.34	1.78 to 7.75	0.144
30 to 50 veh/min	4.44	1.72	4.36	1.60 to 7.62	0.175
50 to 70 veh/min	4.28	1.62	4.11	1.60 to 7.71	0.306
70 to 90 veh/min	4.04	1.61	3.74	1.60 to 7.80	0.634

From the table it can be observed that the mean and median values of accepted gaps show a declining trend with increase in traffic flow. For all the flow rates considered, the size of accepted gaps ranged between 1.6 and 7.8 seconds, and the standard deviation was roughly 1.6 seconds. The increase in positive values of skewness with increase in flow rates indicate that the distributions of accepted gaps under higher traffic flow conditions are more skewed towards the right. To statistically confirm the difference between the mean values for different flow rates, hypothesis testing using a Mann-Whitney U Test was performed as described in the following paragraph.

5.2 Hypothesis test for difference between two means

Since all the samples of accepted gaps for different flow rates did not follow a normal distribution, the Mann-Whitney U Test, which is a distribution-free test, was performed. Also, the assumptions required for this test (populations must be continuous and their probability density functions must have the same shape and spread) are somewhat less restrictive than the assumptions needed for the Student's t-Test in which the populations to be tested need to be normally distributed (Navidi, 2007). The null and alternate hypothesis was defined as follows:

H_0: There is no difference between the mean values of accepted gaps obtained for different flow rates.

H_A: There is difference between the mean values of accepted gaps obtained for different flow rates.

The hypothesis test was performed at a 90% confidence interval. The results including the Z-Statistic and the P-Value of the Mann-Whitney U Test are given in Table 3.

Table 3. Hypothesis Test for Accepted Gaps (Mean)

Flow Rate Bins	Z-Statistic	P-Value	Hypothesis (H_0/H_1)
10-30 & 30-50 veh/m	-0.03	0.488	Do not Reject H_0
10-30 & 50-70 veh/m	0.60	0.274	Do not Reject H_0
10-30 & 70-90 veh/m	1.41	0.079	Reject H_0
30-50 & 50-70veh/m	-0.70	0.242	Do not Reject H_0
30-50 & 70-90 veh/m	-1.56	0.059	Reject H_0
50-70 & 70-90 veh/m	-1.03	0.152	Do not Reject H_0

The results of the hypothesis test indicate that the mean value of the accepted gap for the highest flow rate (70 to 90 veh/m) is indeed smaller than that obtained for flow rates of 10 to 30 and 30 to 50 vehicles per minute.

5.3 Best fitted distributions for accepted gaps under different flow rates

The samples collected for accepted gaps for different flow rates were used to find the corresponding fitting distribution. To overlay the fitted distributions of accepted gaps of four different flow rates, the shape, scale and location parameters obtained from a statistical package were used to recreate the distributions. The best fitted distributions are shown in Figure 4 and their parameters and squares errors are given in Table 4. The Kolmogorov-Smirnov (K-S) statistic and corresponding values to check the goodness of fit are also given in Table 4.

Table 4. Parameters, Square Errors, and Goodness of Fit Estimates of Best Fitted Distributions for Accepted Gaps

Flow Rate (veh/min)	Best Fitted Distribution	Parameters		Square Error	Goodness of Fit	
		Scale	Shape		K-S Statistic	P-Value
10 to 30	Weibull	2.19	3.67	0.0206	0.102	> 0.15
30 to 50	Weibull	2.14	3.89	0.0093	0.072	> 0.15
50 to 70	Gamma	0.899	3.65	0.0107	0.0862	> 0.15
70 to 90	Gamma	0.862	3.53	0.0096	0.0687	> 0.15

The P-Values of K-S Test and low values of square errors of the fitted distributions confirm that the samples of accepted gaps under different flow rates have been fitted with the best distributions.

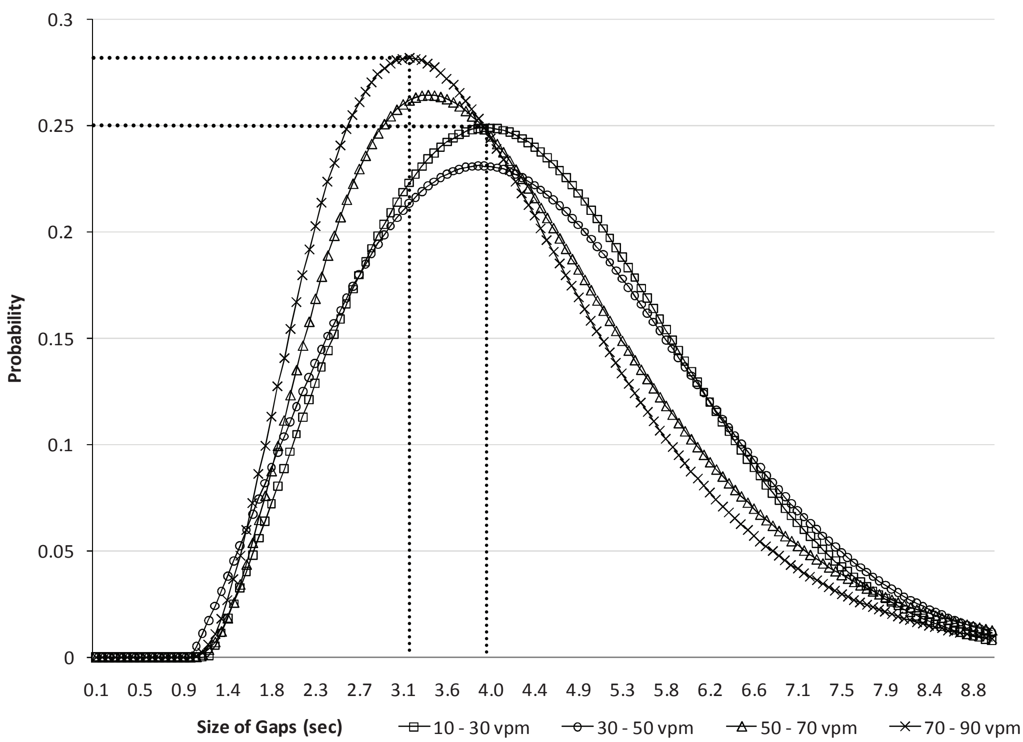

Figure 4: Best Fitted Distributions for Gap Acceptance under Different Flow Rates

From Figure 4, it can be observed that as the flow rate increases the accepted gap size corresponding to the highest expected outcome decreased. For instance, consider the highest and lowest flow rates. For 10 – 30 vehicles/minute, the accepted gap size corresponding to the highest probability (24%) is 4.00 seconds. For the 70 – 90 vehicles/minute, the accepted gap corresponding to the highest probability (27%) is 3.20 seconds. Similarly the accepted gap size corresponding to the highest probability of the other two flow rates falls in between the two extremes. It can also be observed that the distributions are increasingly skewed to the right with increasing flow rate further confirming that an increased flow rate resulted in considerable proportion of drivers accepting smaller gaps.

5.4 Findings

From the analysis of accepted gaps, it can be observed that the mean value of the accepted gaps during the highest flow rate (70 – 90 vehicles per minute of green time) was lower than that obtained for other flow rates. The hypothesis tests confirmed that the mean of accepted gaps during 70 – 90 flow rate was indeed less than that corresponding to 10 – 30 and 30 – 50 flow rates. This finding suggests that on an average, drivers accepted smaller gaps when traffic flow was heavy. The steady decline in the median value of accepted gaps with increasing flow rates (4.34, 4.36, 4.11, and 3.74 seconds for 10-30, 30-50, 50-70, and 70-90 vehicles/minute flow rates respectively) supports the earlier statement. The shape and skewness of the best fitted distributions showed that a considerable proportion of drivers accepted smaller gaps when the traffic flow was heavy. The reason could be that the size of available gaps itself will be small during congested conditions, and drivers accept them. Also, drivers usually travel at lower speed during congested traffic conditions and hence might find it still safe to accept smaller gaps to change lanes.

An attempt was made to compare the results of this study with related studies done earlier. In one of the studies (Goswami and Bham, 2007) conducted for mandatory lane changes in a freeway, the mean value of accepted leading gap ranged between 1.47 to 1.82 seconds and that of a trailing gap ranged between 1.58 to 1.82 seconds. Hence the combined range of accepted leading and trailing gaps was 3.05 to 3.64 seconds. This range is smaller than what was obtained in this study (4.04 to 4.42 seconds). However, in the previous study, the data were collected only for mandatory lane changes. Also, freeways are operationally different than urban streets. Similarly, results from some other studies could not be compared with this study due to the nature of the results in those studies and because all the studies identified used only freeway data.

5.5 Descriptive statistics for lane change durations

The mean, median, standard deviation, range, and skewness were obtained for lane change durations of each flow rate bin. The results obtained are given in Table 5.

Table 5. Basic Statistics of Lane Change Durations under Different Flow Rates

Flow Rate	Mean (s)	Standard Deviation (s)	Median (s)	Range (s)	Skewness
10 to 30 veh/min	4.21	0.83	4.20	2.33 to 5.97	0.086
30 to 50 veh/min	4.24	0.85	4.22	2.30 to 5.94	-0.008
50 to 70 veh/min	4.21	0.86	4.20	2.32 to 6.10	0.027
70 to 90 veh/min	4.19	0.81	4.20	2.60 to 6.00	0.016

From the table, it can be observed that the mean and median values of lane change durations across different flow rates did not show any marked difference. For all the flow rates considered, the lane change durations ranged between 2.3 and 6.1 seconds, and the standard deviation was roughly 0.85 seconds, which is much lower than that obtained for accepted gaps (around 1.6 seconds). This finding indicates that there is not much variation in the duration of lane changes under varying flow rates when compared with the variation of the accepted gaps. The skenwness values are closer to zero, indicating that the probability distributions of lane change durations will be symmetrical in shape. To statistically confirm the difference between the mean values of lane change durations obtained under different flow rates, an hypothesis test was performed as described in the following section.

5.6 Hypothesis test for difference between two means/medians

The procedure for conducting the hypothesis testing was the same as that done for the accepted gaps. A Mann-Whitney U Test with a confidence level of 90% was performed to check whether the mean values of lane change durations were different for different flow rates. Hence, the null and alternate hypothesis were defined as follows,

H_0: There is no difference between the mean of lane change durations obtained for different flow rates.
H_A: There is difference between the mean of lane change durations obtained for different flow rates.
The results of the hypothesis test including the Z-Statistic and the P-Value are given in Table 6.

Table 6. Hypothesis Test for Lane Change Duration (Mean)

Flow Rate Bins	Z-Statistic	P-Value	Hypothesis (H_0/H_1)
10-30 & 30-50 veh/m	-0.47	0.32	Do not Reject H_0
10-30 & 50-70 veh/m	-0.05	0.48	Do not Reject H_0
10-30 & 70-90 veh/m	-0.01	0.50	Do not Reject H_0
30-50 & 50-70veh/m	-0.47	0.32	Do not Reject H_0
30-50 & 70-90 veh/m	-0.45	0.33	Do not Reject H_0
50-70 & 70-90 veh/m	0.00	>0.5	Do not Reject H_0

The table shows that null hypotheses were rejected for all combinations of comparisons of mean lane change durations of different flow rates. This suggests that irrespective of the flow rate, the mean values of lane change duration are statistically not different for the urban street studied. In other words, drivers on an average require the same amount of time to complete a lane change maneuver for any level of traffic flow.

5.7 Best fitted dstributions for lane change durations under different flow rates

The procedure adopted to create the best fitted distributions for lane change durations for different flow rates is the same as that adopted for accepted gaps. The parameters of the fitted distributions, square errors, and the goodness of fit estimates are given in Table 7. The best fitted distributions are shown in Figure 5. The low values of square errors and higher P-Values indicate that these distributions are the best fit.

Table 7. Parameters, Square Errors, Goodness of Fit Estimates of Fitted Distributions for Lane Change Durations

Flow Rate (veh/min)	Best Fitted Distribution	Parameters		Square Error	K-S Statistic	P-Value
		Scale	Shape			
10 to 30	Weibull	2.48	2.94	0.0069	0.0528	> 0.15
30 to 50	Weibull	2.51	2.92	0.0038	0.0396	> 0.15
50 to 70	Weibull	2.48	2.80	0.0046	0.0382	> 0.15
70 to 90	Normal	4.19	0.80	0.0062	0.0681	> 0.15

Figure 5 shows that there is not much variation between the distributions of lane change durations for different flow rates and that they are symmetrical in shape. For all the distributions, a lane change duration of 4.2 seconds had the highest expected outcome.

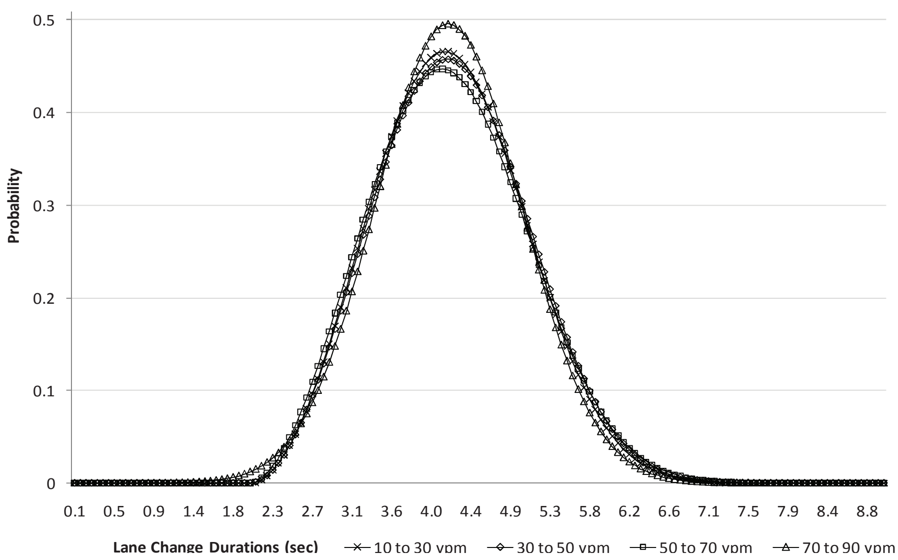

Figure 5: Best Fitted Distributions for Lane Change Durations under Different Flow Rates

5.8 Findings

From the analysis of lane change durations, it was observed that there was not much variation in the mean values of lane change durations for different flow rates. The standard deviations of lane change durations ranged between 0.81 and 0.86 seconds. These values are much less than those obtained for accepted gaps (1.59 to 1.72 seconds), indicating that the variation of lane change duration values is less than that of accepted gaps. The median values of the lane change durations show that irrespective of the flow rate, about 50% of the drivers required around 4.20 seconds to complete the lane change maneuver. The shape and skewness of the best fitted distributions did not show any marked difference among them. By combining the above observations with that obtained for accepted gaps, it can be understood that during heavy traffic flow conditions a considerable proportion of drivers accept smaller gaps but take the same time on an average to complete a lane change maneuver under any level of traffic flow.

The results obtained in this study were compared with similar studies done in the past. Only one study (Tijerina et al., 1997) considered city streets (and that study also separately studied highways). Table 8 shows the basic statistics obtained from some of the earlier studies identified on lane change durations.

Table 8. Basic Statistics of Lane Change Durations Obtained from Previous Studies

Study	Mean (s)	Standard Deviation (s)	Range
Tijerina et al. (1997)	5.00*	-	3.5 to 6.5*
Tijerina et al. (1997)	5.80+	-	3.5 to 8.5+
Lee et al. (2006)	6.28	2.00	-
Thiemann et al. (2008)	4.01	2.31	-
Toledo et al. (2007)	4.60	2.30	1.0 to 13.3
Current Study	4.21	0.84	2.3 to 6.1

*Note: * - from data collected in city streets; + - from data collected in highways.*

From the table, it can be observed that the mean duration of lane change obtained in this study is in the lower end of the values reported in earlier studies. Three studies reported higher values of mean duration of lane changes, and all these studies considered freeway data. It may be noted that in freeways the travel speed is usually higher than urban streets. At higher speeds it can be expected that drivers take extra precaution and time for preparation to change lanes and for lane change maneuver itself. This can be the reason for lane change durations being higher in freeways than in urban streets as reported in Table 8. However, the low mean value of lane change duration obtained in one of the earlier studies (Thiemann et al., 2008) could not be explained. The only study that considered city street had a higher value of mean duration of lane changes than the current study. The reason could be that the study was conducted in 1997, hence, the technological advancement in automobiles between then and now should be taken into account. It should also be noted that the data in Table 8 are geographically different, and drivers from two different regions behave differently (Tsimhoni et al., 2008; Dorn, 2005; Noyce et al.).

5.9 Rate of lane changes

The rate of lane changes was obtained by dividing the number of lane changes for each flow rate bin with the average flow rate. The rate of lane changes was obtained to determine its trend with increasing flow rates. The rates of lane changes obtained for different flow rate bins are given in Table 9, and they are plotted on Figure 6.

Table 9. Rate of Lane Changes

Flow Rate Bins	No of Lane Changes	Rate of Lane Changes
10-30 veh/m	144	7.2
30-50 veh/m	302	7.6
50-70 veh/m	223	3.7
70-90veh/m	103	1.3

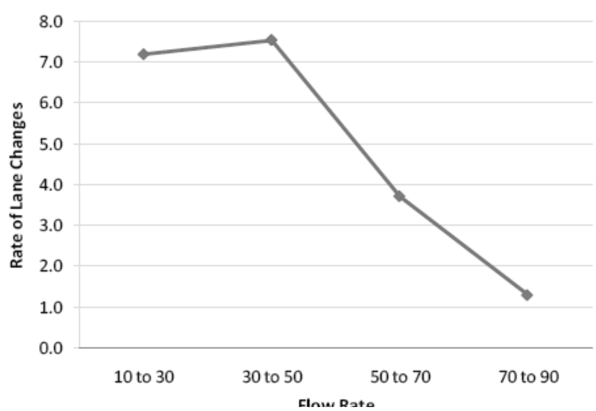

Figure 6: Trend of Rate of Lane Changes

The table and figure show that the rate of lane changes decreases with increase in traffic flow. This is reasonable because even though the number of gaps may be higher during higher traffic flow, a considerable proportion of these gaps will be smaller, and those that can be accepted will be fewer when compared to normal flow conditions. Thus, during higher levels of traffic flow or saturated flows, considerable proportion of drivers accepts smaller gaps.

6. Conclusions

There is a keen interest in changes in driver behavior parameters such as lane changing and gap acceptance under varying traffic flow conditions. This study explored the changes in gap acceptance and lane changing parameters on an urban arterial under different levels of traffic flow. The mean values of accepted gaps ranged from 4.42 to 4.04 seconds for flow rates of 10 to 30 and 70 to 90 vehicles per minute, and standard deviations were ranged from 1.59 to 1.72 seconds. A hypothesis test using Mann-Whitney U Test indicated that the extreme values (4.42 and 4.04) are indeed different. The shape and skewness of the best fitted distributions showed that a considerable proportion of drivers accepted smaller gaps when the traffic flow was heavy.

The mean values of lane change durations ranged from 4.19 to 4.24 seconds for average flow rates of 20 to 80 vehicles/minute. The hypothesis tests indicated that the extreme values (4.19 and 4.24) are not different. The standard deviations of lane change durations ranged between 0.81, and 0.86 seconds. These values were much lower than those obtained for accepted gaps (1.59 to 1.72 seconds), indicating that the variation of lane change duration values was lower than the variation of accepted gaps. The shape and skewness of the best fitted distributions for lane change durations for different flow rates did not show any marked difference among them. Also, the rate of lane changes was found to be the lowest for the highest traffic flow. The reason behind this finding could be that there are fewer gaps of acceptable length in congested traffic than in a normal flow condition.

These findings from accepted gaps and lane change durations indicate that during heavy traffic flow conditions a considerable proportion of drivers accept smaller gaps but take the same time on an average to complete the lane change maneuver irrespective of the level of traffic flow. The findings of this study have direct implications upon the gap acceptance and lane changing parameters used in microscopic traffic simulation, particularly during model calibration. The default values of lane changing and gap acceptance parameters used in some of the common traffic simulation tools are indeed different from those obtained in this study. For instance, CORSIM has a default lane change duration value of 3 seconds (CORSIM 6.0 User's Guide, 2005), while the results obtained in this study show that the mean value of lane change duration varied from 4.04 to 4.42 seconds depending on the traffic flow rate and that they follow specific distribution. The authors suggest that the distributions of accepted gaps and lane change durations obtained in this study be used in lane change models in microscopic traffic simulation models.

7. Future research

To further extend the current research, the sample size of data collection could be increased to reduce data-related variation. Future studies could focus on the interaction between drivers in a lane changing situation, i.e. forced and/or cooperative behavior and its relationship with gap acceptance parameters. Also, lane change maneuvers could be separated into mandatory and discretionary lane changes, as the behavioral and physical characteristics of these classes are likely to be quite different. Future efforts could also focus on how to measure the two types of lane changes. A study on the differences between the size of accepted gaps and duration of lane changing when driver conducted right and left lane changes could be explored. The impact of geometric characteristics, safety implications, and lane changing of heavy vehicles could also be studied. Instead of flow rates, driver behavior parameters could be compared with more representative parameters such as delay, speed or LOS of the arterial approach under consideration. Also, how driver behavior parameters, as currently used in microscopic traffic simulation models, relate to the field data obtained in this research could be studied. Both logical and statistical relationships can be examined.

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