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CUMULATIVE INTERARRIVAL TIME DISTRIBUTIONS OF FREEWAY ENTRANCE RAMP TRAFFIC FOR TRAFFIC SIMULATIONS

ABSTRACT

Cumulative interarrival time (IAT) distributions for signalized and non-signalized freeway entrance ramps were developed to be used in digital computer traffic simulation models. The data from four different non-signalized entrance ramps (three ramps with a single lane, one ramp with two lanes) and two different signalized entrance ramps (both with a single lane) were used for developing the cumulative IAT distributions. The cumulative IAT distributions for the signalized and non-signalized entrance ramps were compared with each other and with the cumulative IAT distributions of the lanes for freeways. The comparative results showed that the cumulative IAT distributions for non-signalized entrance ramps are very close to the leftmost lane of a 3-lane freeway where the maximum absolute difference between the cumulative IAT distribution of the leftmost lane of a 3-lane freeway and the entrance ramps cumulative IAT distribution was 3%. The cumulative IAT distribution for the signalized entrance ramps was found to be different from the non-signalized entrance ramp cumulative IAT distribution. The approximated cumulative IAT distributions for signalized and non-signalized entrance ramp traffic for any hourly traffic volume from a few vehicles/hour up to 2,500 vehicles/hour can be obtained at http://www.ohio.edu/orite/research/uitds.cfm.

KEY WORDS

signalized, non-signalized, traffic modelling, headway, Kolmogorov-Smirnov test

1. INTRODUCTION

Interarrival time (IAT) or time headway is one of the important flow characteristics which affect the safety, level of service, driver behaviour and capacity of the transportation system [1]. According to the Traffic Engineering Handbook [2] the IAT or headway is defined as the time between successive vehicles as they pass a point on a lane, again using a common reference point on both vehicles. Time headway distributions are required to determine the opportunity for passing, merging and crossing lanes on a freeway.

Headway distributions in mathematical forms are very important part of the analysis of IAT or time headways and they can provide more insight into the behaviour of the traffic. The distributions can also be used as an input to a traffic simulation model. Traffic situations, which are hard to be observed in the real world, can be investigated with the use of simulation models. Further, digital computer simulation can be used to simulate the flow of traffic using mathematical headway distribution models. Traffic simulation models for freeways involve the use of headway distributions to mimic the behaviour of the traffic through the mainline and at the entrance ramps. Semi-Poisson [3, 4], lognormal [5, 6, 7], negative exponential [8, 9] headway distribution models for free flowing traffic on the freeways have been studied and established in the past and there is a need for the approximation of the headway distributions for the traffic on the entrance ramps. Vehicles entering the freeway mainline traffic from the entrance ramps can be divided into two classes: traffic entering from non-signalized freeway entrance ramps (entrance ramp traffic does not go through any intersection having a traffic signal before entering the freeway) and traffic entering from signalized freeway entrance ramps (entrance ramp traffic is controlled by a signal before the ramp).

In an earlier study by Zwahlen et al. [10] traffic data were collected at different freeway locations in Ohio, USA and a procedure to convert hourly traffic volumes into cumulative IAT distributions was established for freeway mainline traffic [11]. The approximated headway distributions of free flowing traffic for each lane of the 2-lane, 3-lane, and 4-lane traffic were developed [11]. Cumulative IAT distributions for entrance ramps are needed in addition to the approximated IAT distributions for the mainline traffic in the simulation of freeways which contain a number of entrance ramps. The entrance ramp IAT distributions may be used as an input in complex traffic simulation models, which would enhance the accuracy of the simulation models and provide more accurate queue and traffic delay information. Entrance ramp cumulative IAT distributions are also very important for the investigation and simulation of ramp metering strategies. Various ramp metering strategies based on mathematical headway distribution models were evaluated using traffic simulations [12, 13, 14, 15, 16].The probabilistic entrance ramp cumulative IAT distributions should generate more accurate results on the effects of ramp metered traffic on the mainline traffic flow and the possible traffic spill back into the local arterial roads. Based on an extensive literature review it appears that no simple method is available in the literature which deals with the cumulative IAT distributions of vehicles entering through non-signalized and signalized freeway entrance ramps.

2. OBJECTIVES

The objective of this study is to develop cumulative IAT distributions for freeway entrance ramps. The secondary objectives of this study can be listed as following: to determine the similarity between the cumulative IAT distributions of signalized and non-signalized freeway entrance ramps and to determine the similarity between the cumulative IAT distributions of signalized and non-signalized freeway entrance ramps and the cumulative IAT distributions for freeway mainline traffic.

3. METHODOLOGY

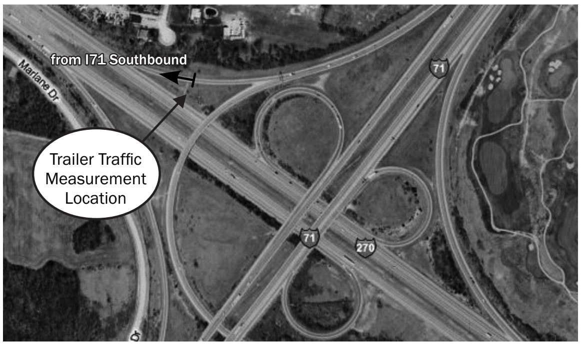
The method used for developing the interarrival time distributions for traffic on freeway entrance ramps was adapted from Zwahlen et al. [11]. The IAT distributions for four non-signalized and two signalized freeway entrance ramps with different configurations were developed using the procedure outlined in [11].

The data for six entrance ramp sites out of a total of nine sites were collected using microwave radar trailer units which were specially designed for data collection on freeways using non-intrusive methods [10].

The locations of the microwave radar trailers used in the data collection are given in *Figure 1* for non-signalized entrance ramps. The trailer location at the I71 and I270 interchange is the same for I71 Southbound to I270 Westbound non-signalized entrance ramp and I71 to I270 Westbound non-signalized entrance ramp. The traffic data at the interchange were collected at different dates in a way that in one situation only the I71 Southbound data were collected and in the other the combined I71 Southbound and I71 Northbound

a) Non-signalized entrance ramp from Martin Luther King Jr. Dr. (MLK) to I-90 Eastbound in Cleveland, OH

b) Non-signalized entrance ramp from SR2 to I-90 Eastbound in Cleveland, OH



c) Non-signalized entrance ramp from I71 Southbound to I-270 Westbound in Columbus, OH

Figure 1 - Location of Microwave Radar Trailers used in non-signalized entrance ramp traffic data collection (from [17])

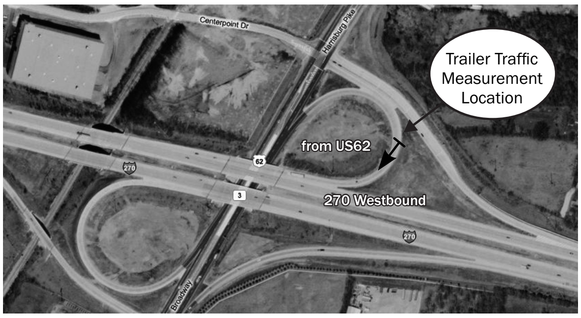
data were collected. The trailers used for data collection consisted of two microwave radar units which were mounted on two collapsible poles and used in side fire mode.

The microwave radar trailer locations used in the signalized entrance ramp traffic data collection are given in *Figure 2*. The signalized entrance ramp traffic data were collected at two locations. The signalized freeway entrance ramp data were collected at the US62 to I270 Westbound entrance ramp and the 55th Street to I90 Eastbound entrance ramp.

Table 1 gives a brief summary of the data used to develop the IAT distributions for the non-signalized and signalized freeway entrance ramps. *Table 1* shows the data collection dates, the observed traffic volumes at the data collection sites and the number of IATs or headways used for the data analysis and development of the IAT distributions.

Traffic volume data from the microwave radar trailers were recorded for each 15-minute interval for three consecutive days (72 hours) and tabulated. The time stamps recorded for the arrivals of vehicles (in 2.5-millisecond increments) were all converted into seconds to calculate the interarrival times (IATs) or the headways which was the difference between two successive vehicle arrival time stamps.

a) Signalized entrance ramp from E. 55th St. to I-90 Eastbound in Cleveland, OH



b) Signalized entrance ramp from US62 to I-270 Westbound in Columbus, OH

Figure 2 - Location of Microwave Radar Trailers used in signalized entrance ramp traffic data collection (from [17])

The traffic volume data collected using a video recorder for validation of the trailer measurements were entered into Excel and compared with the data collected from the trailer. As the trailers were not 100% accurate in measuring the traffic data [10] correction factors were calculated for each lane of each site so that the adjusted traffic volumes could be obtained. The 15-minute traffic volumes obtained in the previous step were multiplied by the correction factors to obtain the adjusted counts. Hourly traffic volumes for each 15-minute interval were then obtained by multiplying the adjusted 15-minute counts by four [11]. The same procedure as explained in [11] and [18] was used in developing the cumulative IAT distributions for freeway entrance ramps.

The cumulative percentages for all the 15-minute time interval data were computed using the Microsoft Excel Data analysis/Histogram tool. The IATs for sixteen percentile values (1%, 2%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99%, and 100%) were computed. A minimum IAT value of 0.1 seconds was assigned to the 0% value and the maximum IAT value observed in 15-minute time period was assigned to 100% value [11]. The procedure was used to compute the IATs of sixteen percentile values for each 15-minute time intervals according to the site, date, and lane of travel. The reason for the use of the cumulative percentage values was to be able to use the Kolmogorov-Smirnov (KS) two-sample goodness-of-fit test [19] easily.

A hyperbolic relationship of the form $y = (a/x) + b$ was used to generate the relationship between the IAT values and the observed traffic volumes for each percentile [11]. Least squares fitting method was used to determine the coefficients “a” and “b”. The average

Table 1 - Summary of the data used to develop freeway entrance ramp IAT distributions for all sites

Entrance ramp	Data collection dates	Observed traffic volumes (vehicles/hour)	Number of IATs observed
Non-signalized I71 S to I270 W	6/23/2006-6/26/2006	8 - 836	12,954
Non-signalized I71 to I270 W	8/28/2004-8/31/2004	44 -1,616	39,224
Non-signalized SR2 to I90 E Lane 1 (Right Lane)	9/13/2004-9/16/2004	4 - 692	15,443
Non-signalized SR2 to I90 E Lane 2	9/13/2004-9/16/2004	24 -1,320	35,130
Non-signalized MLK to I90 E	9/15/2004-9/18/2004	23 - 1,694	34,974
Signalized 55^{th} St to I90 E	9/13/2004-9/16/2004	4 - 1,104	22,623
Signalized US62 to I270 W	8/28/2004-8/31/2004	8 - 1,079	22,283

IAT for an hourly traffic volume is inversely proportional to the hourly traffic volume, therefore hyperbolic fits were used. The cumulative IATs for 16 percentile values based on the traffic volumes were calculated using the hyperbolic fit relationship. The minimum and the maximum traffic volumes observed in the field were used for cumulative IAT calculations. The cumulative IATs for 16 percentile values were also calculated for traffic volumes in increments of 50 between the minimum and the maximum traffic volumes observed. The average IAT for the hyperbolic fit was calculated using the formula given in [11]. The average IAT value was then compared with the average IAT obtained for a given traffic volume. The average IAT of the fit is given by:

$$AverageIAT = \sum_{i=1}^{16}\left[(p_i - p_{i-1}) * \left(\frac{y_i + y_{i-1}}{2}\right)\right]$$

where

p_i = cumulative percentage value from the hyperbolic fit table,

y_i = corresponding IAT for p_i.

The average IAT for a given traffic volume was computed by dividing the seconds in an hour by the traffic volume (3,600 seconds/traffic volume (vehicles/hour)). For each traffic volume; an adjustment factor was calculated by dividing the average IAT for a given traffic volume by the average IAT from the cumulative IAT distribution [11]. The adjustment factor was used to obtain the corrected cumulative IAT values. All of the cumulative IATs computed using the hyperbolic fits for a given traffic volume were multiplied by the respective adjustment factor. After that all of the adjusted cumulative IATs were tabulated for the observed traffic volumes in increments of 50 vehicles/hour.

4. RESULTS AND DISCUSSION OF RESULTS

The cumulative universal interarrival time distributions for non-signalized and signalized freeway entrance ramps were modelled using hyperbolic fits. This provided more insight into the nature of headways or interarrival times observed on the entrance ramps.

4.1 Analysis of data for the entrance ramps

The analysis done for I-71 to I-270 westbound non-signalized entrance ramp is described as an example. The data for this site was collected from 8/27/2004 to 9/1/2004 but three days of data from 8/29/2004 to 8/31/2004 were used for the analysis. A total of 39,224 headways were obtained with observed hourly traffic volumes ranging from 44 to 1,616 vehicles/hour with an average of 544 vehicles/hour. The correction factor obtained for this site using the validation procedure given in [10] was equal to 1.00; therefore, no adjustment was made to the 15-minute interval traffic counts. Cumulative interarrival times were extracted for all the 15-minute interval data sets based on the procedure described above. A total of 195 data sets out of 288 data sets were used to generate the cumulative interarrival times for traffic volumes ranging from 300-1,616 vehicles/hour. The fifteen minute interval data sets with traffic volumes of less than 300 vehicles/hour did not have cumulative IATs for all the 16 percentile values.

Hyperbolic fits were used to relate the hourly traffic volume with the IATs as described in the method above. Based on the hyperbolic fits obtained for the data, cumulative interarrival times for the sixteen percentile values for traffic volumes ranging from 300-1,600 vehicles/hour at increments of 50 vehicles/hour were calculated. The average IAT was calculated using the equation given above and the cumulative IATs were adjusted to obtain the corrected cumulative IAT values.

The same procedure was implemented for all of the entrance ramps listed in *Table 1*.

4.2 Comparison of cumulative IAT distributions for non-signalized and signalized freeway entrance ramps

Cumulative interarrival time distributions for the non-signalized and signalized freeway entrance ramps having different geometric configurations and hourly traffic volume ranges were established. The cumulative IAT distributions for each of the non-signalized and signalized freeway entrance ramps were compared with each other. The cumulative IAT graphs for 300, 400, and 600 vehicles per hour are given in *Figure 3*. The traffic volumes for the freeway entrance ramps were between 300 to 1,600 vehicles per hour; however, the minimum observed range for one of the freeway entrance ramps was between 300 to 700 vehicles per hour. Therefore, the traffic volumes selected for comparison were within 300 to 700 vehicles per hour. *Figure 3* shows that the cumulative IAT distributions for the four non-signalized freeway entrance ramps are similar for the data collection sites and the cumulative IAT distributions for the two signalized freeway entrance ramps are similar for the data collection sites. However, it can be observed that there is a difference between the cumulative IAT distributions for non-signalized and signalized freeway entrance ramps.

Since there is very little difference between the non-signalized cumulative IAT distributions for different locations, the IAT data for each of the 15-minute intervals were combined for all non-signalized entrance ramps and a universal cumulative IAT distribution for non-signalized freeway entrance ramps was generated using the procedure described in the methodology and in [11]. In addition, a universal cumulative IAT distribution for signalized entrance ramps was generated using the same procedure. As a result we have one (universal) cumulative IAT distribution for all non-signalized freeway entrance ramps and one (universal) cumulative IAT distribution for all signalized entrance ramps.

Table 2 shows the hyperbolic formulae and the corresponding coefficient of determination values (R^2-values), which shows the proportion of variability in a

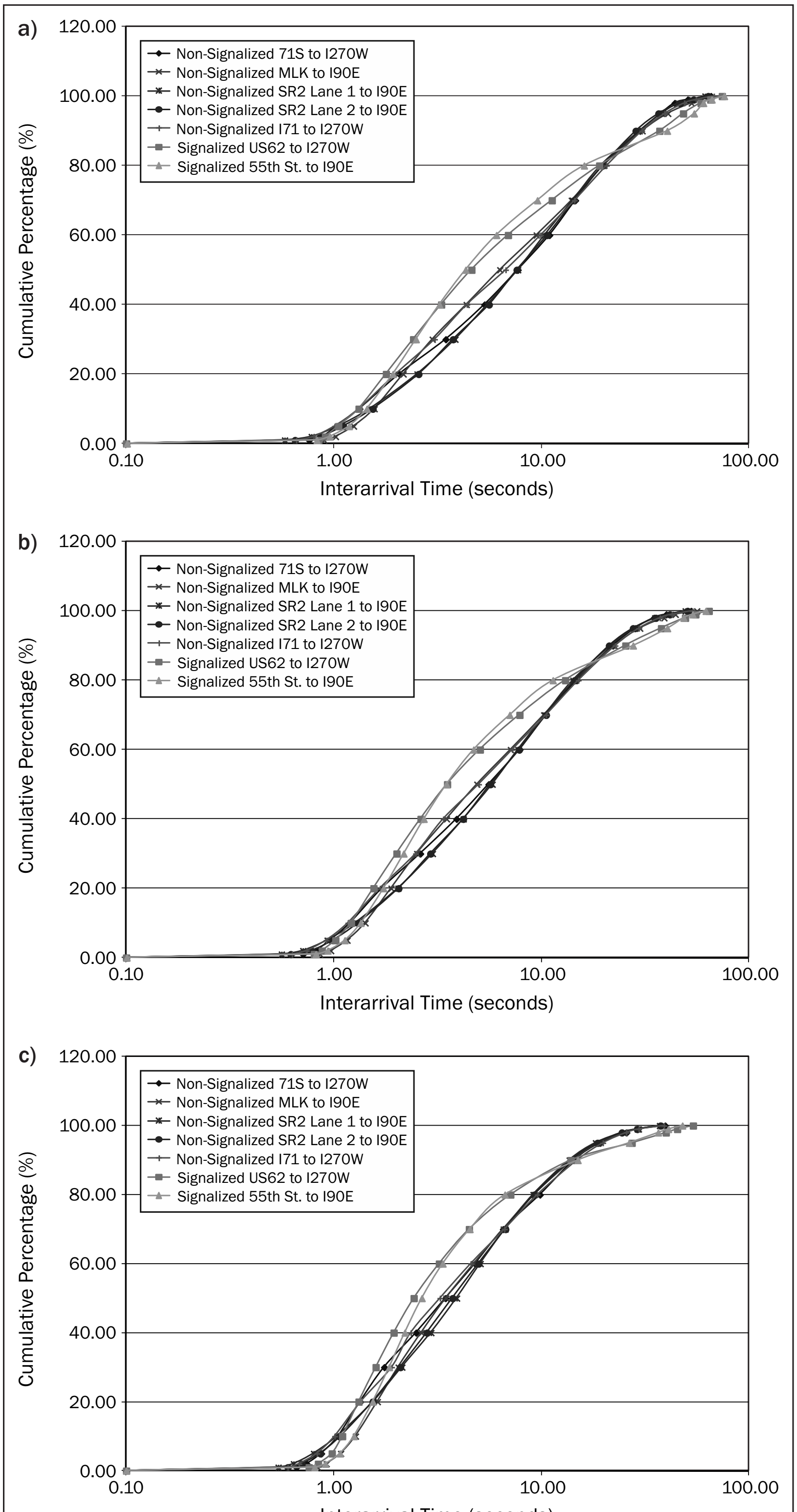


Figure 3 - Cumulative IAT distributions for all freeway entrance ramps for a) 300, b) 400, and c) 600 vehicles/hour

Table 2 - Hyperbolic formulae and R^2-values used in Excel sheet for determining the universal cumulative IATs for selected percentiles for non-signalized freeway entrance ramps

Percentage	Hyperbolic functions	R^2
0	0.1*	
1	y = 35.32/x + 0.5323	0.074
2	y = 77.57/x + 0.5544	0.287
5	y = 111.08/x + 0.6556	0.343
10	y = 205.01/x + 0.708	0.469
20	y = 475.93/x + 0.6777	0.587
30	y = 919.48/x + 0.453	0.726
40	y = 1536.21/x + 0.1032	0.805
50	y = 2304.85/x - 0.2618	0.879
60	y = 3337.46/x - 0.7322	0.928
70	y = 4458.63/x - 0.763	0.942
80	y = 5879.51/x - 0.4515	0.953
90	y = 8590.52/x + 0.0489	0.927
95	y = 10430.32/x + 1.7761	0.898
98	y = 11562.62/x + 5.5973	0.838
99	y = 13171.59/x + 7.1103	0.797
100	y = 14513.37/x + 13.7433	0.633

** IAT value for 0% was arbitrarily set to 0.1 seconds*

Table 3 - Hyperbolic formulae and R^2-values used in Excel sheet for determining the universal cumulative IATs for selected percentiles for signalized freeway entrance ramps

Percentage	Hyperbolic functions	R^2
0	0.1*	
1	y = 25.97/x + 0.7441	0.020
2	y = 40.74/x + 0.8021	0.057
5	y = 62.3/x + 0.9119	0.121
10	y = 123.62/x + 0.9605	0.249
20	y = 235.85/x + 1.0322	0.400
30	y = 401.3/x + 1.0542	0.541
40	y = 658.74/x + 0.9874	0.610
50	y = 1064.92/x + 0.7989	0.681
60	y = 1740.48/x + 0.4574	0.705
70	y = 3117.17/x - 0.519	0.776
80	y = 5711.92/x - 2.3279	0.836
90	y = 14200.05/x - 9.1048	0.867
95	y = 16076.23/x - 0.833	0.829
98	y = 14075.59/x + 13.7645	0.697
99	y = 14711.45/x + 17.8585	0.647
100	y = 15370.84/x + 24.6029	0.522

** IAT value for 0% was arbitrarily set to 0.1 seconds*

data set that is accounted for by the statistical model [20], for the universal non-signalized freeway entrance ramps. It should be noted that the R^2-values for the smallest and the largest percentiles are relatively low when compared to the R^2-values around the median.

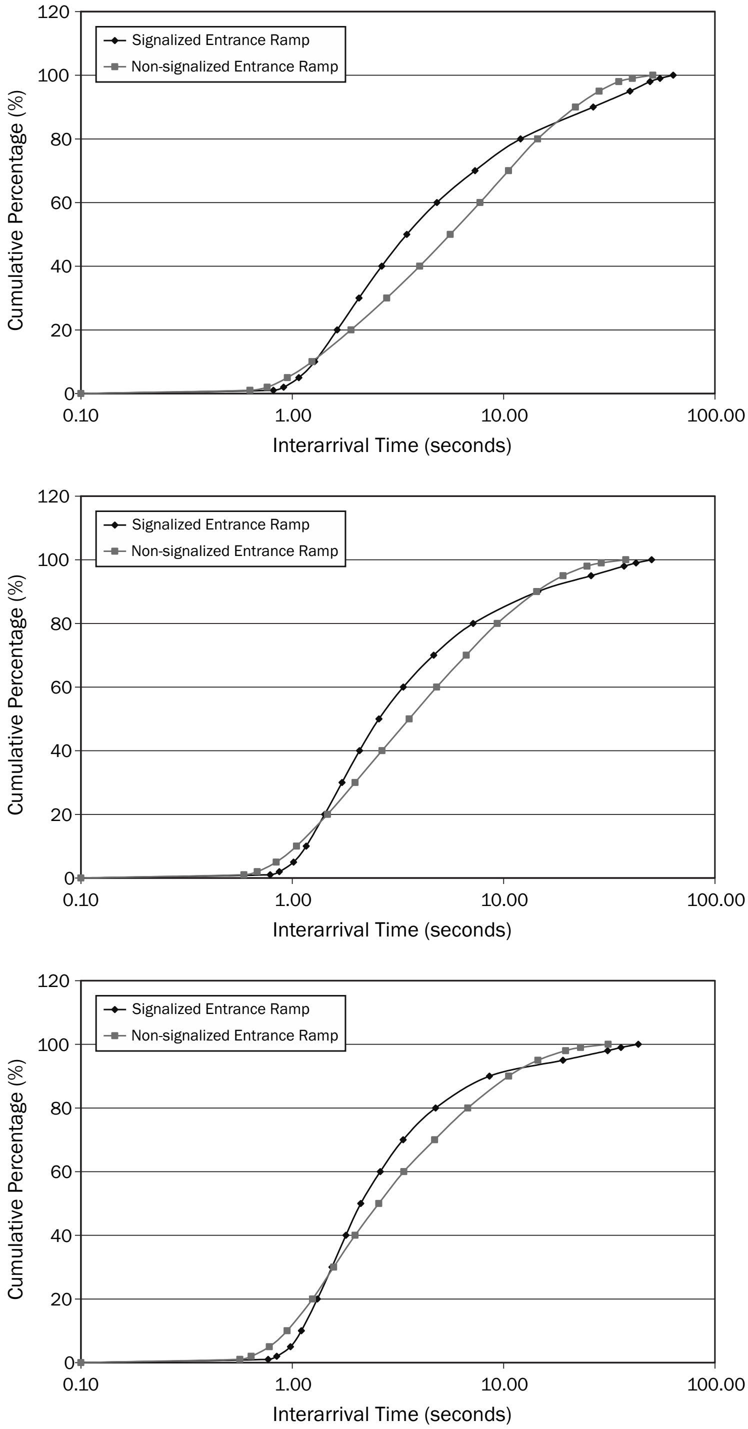
The hyperbolic formulae and the corresponding R^2-values for universal cumulative IAT distributions for signalized freeway entrance ramps are given in *Table 3*. The R^2-values for the smallest and the largest percentiles are relatively low when compared to the R^2-values around the median. The smaller R^2-values show that there is more variability present for the smallest and the largest percentiles because of the lower sample sizes.

4.3 Comparison of universal IAT distributions for non-signalized and signalized freeway entrance ramps

The developed universal cumulative IAT distributions had larger traffic volume ranges than the individual entrance ramp traffic volume ranges. Therefore, the cumulative IAT distributions for non-signalized and signalized entrance ramps were compared and plotted for 400, 600, and 800 vehicles per hour as given in *Figure 4*. The averages (μ), standard deviations (σ), and coefficients of variation ($c_v = \sigma/\mu$) of the distributions are also given in the figure. The maximum differences ($D_{observed}$) for the cumulative IAT distributions were then determined for each traffic volume by visual inspection. KS two-sample two tailed goodness-of-fit tests for large samples with a significance level of 0.05 were used to determine the similarity of the two universal freeway entrance ramp IAT distributions [19]. The maximum differences were compared with the critical value ($D_{critical}$) for the KS two-sample goodness-of-fit test for the low traffic volume sample, medium traffic volume sample, and high traffic volume sample for the universal cumulative IAT distributions for non-signalized and signalized freeway entrance ramps. In all three cases the observed maximum differences were greater than the critical maximum differences at level of significance of 0.05; therefore, the null hypothesis that the two distributions are the same was rejected. The maximum absolute differences were 0.16 for 400 vehicles/hour, 0.1 for 600 vehicles/hour, and 0.09 for 800 vehicles/hour, which were all greater than the critical maximum absolute differences calculated for the KS two-sample goodness-of-fit test.

4.4 Comparison of universal IAT distributions for non-signalized and signalized freeway entrance ramps with universal IAT distributions for the mainline

The universal IAT distributions for non-signalized and signalized freeway entrance ramps were also compared with the cumulative interarrival time distri-



a) Universal IAT Distribution for signalized entrance ramp

μ = 8.992
σ = 12.232
c_v = 1.360

Universal IAT Distribution for non-signalized entrance ramp

μ = 8.986
σ = 9.059
c_v = 1.008

KS Two-sample Goodness-of-Fit Test

$D_{observed}$ = 0.16
$D_{critical}$ = 0.096 (α = 0.05)
Reject

b) Universal IAT Distribution for signalized entrance ramp

μ = 5.995
σ = 8.413
c_v = 1.403

Universal IAT Distribution for non-signalized entrance ramp

μ = 5.992
σ = 6.205
c_v = 1.036

KS Two-sample Goodness-of-Fit Test

$D_{observed}$ = 0.12
$D_{critical}$ = 0.078 (α = 0.05)
Reject

c) Universal IAT Distribution for signalized entrance ramp

μ = 4.497
σ = 6.618
c_v = 1.472

Universal IAT Distribution for non-signalized entrance ramp

μ = 4.495
σ = 4.791
c_v = 1.066

KS Two-sample Goodness-of-Fit Test

$D_{observed}$ = 0.09
$D_{critical}$ = 0.068 (α = 0.05)
Reject

Figure 4 - Comparison of non-signalized and signalized universal IAT distributions for a) 400, b) 600, and c) 800 vehicles/hour

butions obtained for the freeways in [11]. The comparisons were done by plotting the cumulative IAT distributions and using the KS two-sample goodness-of-fit test.

The graphical comparisons were made by plotting the cumulative interarrival times for both the entrance ramps and the freeways for the same hourly traffic volumes. For each traffic volume, a total of nine cumulative IAT distribution plots were generated for all lanes of 2-lane, 3-lane and 4-lane freeways to compare with the entrance ramp cumulative IATs.

Table 4 shows the results of the comparisons which show the best approximation of the selected lane IATs of the freeways for the cumulative IATs of the non-signalized and signalized freeway entrance ramps and

Table 4 - Comparison of non-signalized freeway entrance ramp IAT distributions with the freeway mainline IAT Distributions for a) 300, b) 600, and c) 900 vehicles/hour

	Non-Signalized Entrance Ramp Universal IAT Distribution		
	D Observed – maximum absolute differences in percentages (by visual inspection)	D Critical (calculated by KS Two-sample Goodness-of-fit Test)	Null hypothesis (cumulative IAT distributions are the same)
a) 300 Vehicles/Hour			
2-lane Right Lane (Lane 1)	0.11	0.111	Do not reject
2-lane Lane 2 (Left Lane)	0.06	0.111	Do not reject
3-lane Right Lane (Lane 1)	0.07	0.111	Do not reject
3-lane Lane 2	0.06	0.111	Do not reject
3-lane Lane 3 (Leftmost Lane)	0.03	0.111	Do not reject
4-lane Right Lane (Lane 1)	0.03	0.111	Do not reject
4-lane Lane 2	0.08	0.111	Do not reject
4-lane Lane 3	0.07	0.111	Do not reject
4-lane Lane 4 (Leftmost Lane)	0.03	0.111	Do not reject
b) 600 Vehicles/Hour			
2-lane Right Lane (Lane 1)	0.11	0.079	Reject
2-lane Lane 2 (Left Lane)	0.07	0.079	Do not reject
3-lane Right Lane (Lane 1)	0.09	0.079	Reject
3-lane Lane 2	0.06	0.079	Do not reject
3-lane Lane 3 (Leftmost Lane)	0.02	0.079	Do not reject
4-lane Right Lane (Lane 1)	0.02	0.079	Do not reject
4-lane Lane 2	0.08	0.079	Reject
4-lane Lane 3	0.08	0.079	Reject
4-lane Lane 4 (Leftmost Lane)	0.04	0.079	Do not reject
c) 900 Vehicles/Hour			
2-lane Right Lane (Lane 1)	0.13	0.064	Reject
2-lane Lane 2 (Left Lane)	0.08	0.064	Reject
3-lane Right Lane (Lane 1)	0.11	0.064	Reject
3-lane Lane 2	0.12	0.064	Reject
3-lane Lane 3 (Leftmost Lane)	0.02	0.064	Do not reject
4-lane Right Lane (Lane 1)	0.03	0.064	Do not reject
4-lane Lane 2	0.1	0.064	Reject
4-lane Lane 3	0.11	0.064	Reject
4-lane Lane 4 (Leftmost Lane)	0.07	0.064	Reject

Figure 5 and *Figure 6* are given as an example to show the similarity and the dissimilarity of the universal IAT distributions.

Table 4 shows the maximum absolute differences in percentages for each compared distribution for 300, 600, and 900 vehicles/hour. The selected traffic volumes for comparison are close to the minimum and maximum of the observed traffic volumes and have smaller sample sizes. The smaller sample sizes have more variability; therefore, the similarity with fewer sample sizes would result in higher similarities for large samples. The maximum absolute differences were compared with the critical difference value calculated using the KS two-sample goodness-of-fit test (D-Critical). Smaller differences mean that the two distributions can be assumed to be the same. The results of the KS two-sample goodness-of-fit test showed that the universal cumulative IAT distributions for non-signalized freeway entrance ramps are closely the same as the cumulative IAT distribution for lane 3 (leftmost lane) of 3-lane freeways. *Figure 5* shows the comparison of non-signalized freeway entrance ramp cumulative IAT distribution with the cumulative IAT distribution for lane 3 (leftmost lane) of 3-lane˝freeways.

The signalized freeway entrance ramp universal cumulative IAT distribution was also compared with the freeway mainline cumulative IAT distributions from [11]. The maximum absolute differences in percent-

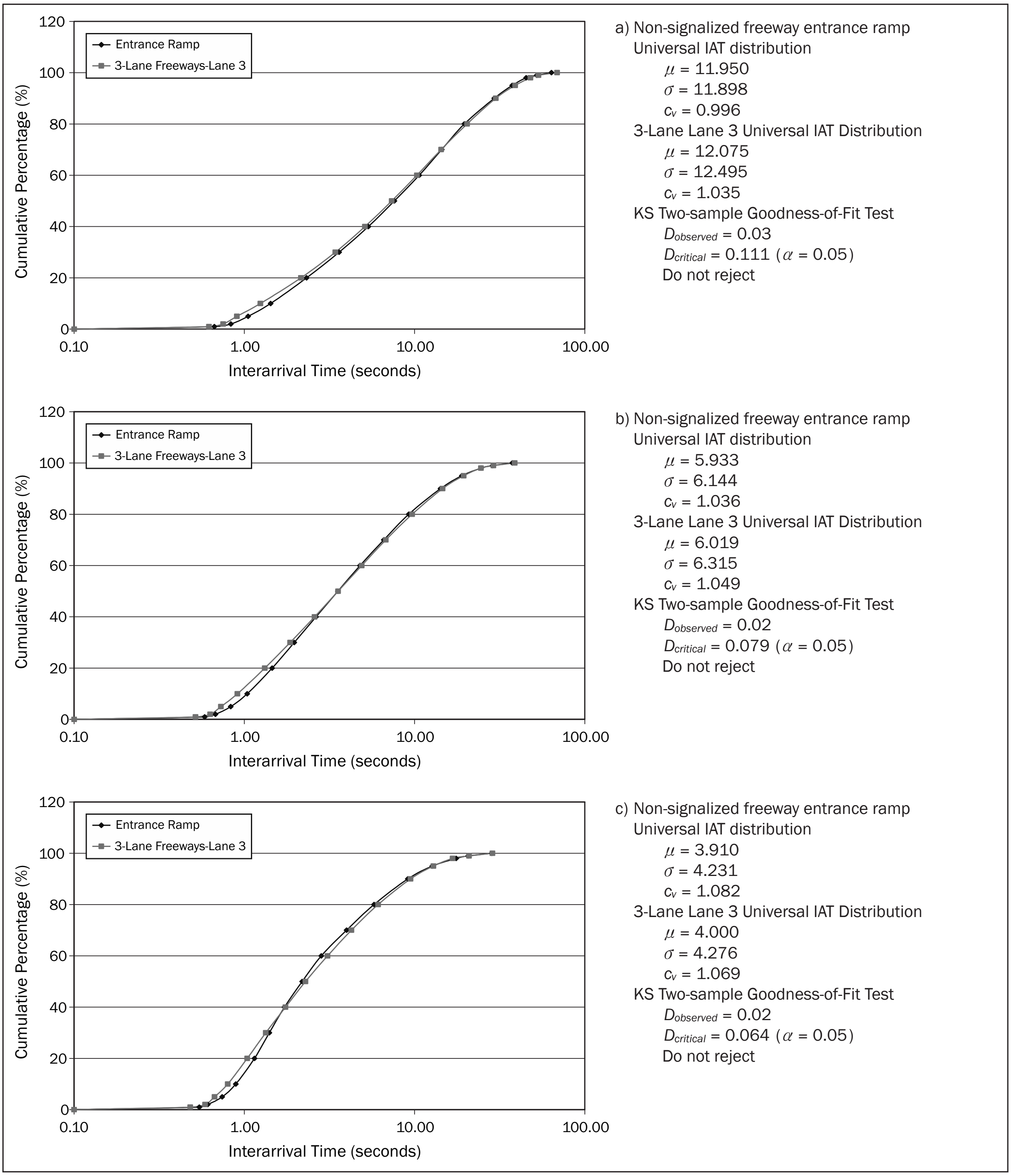
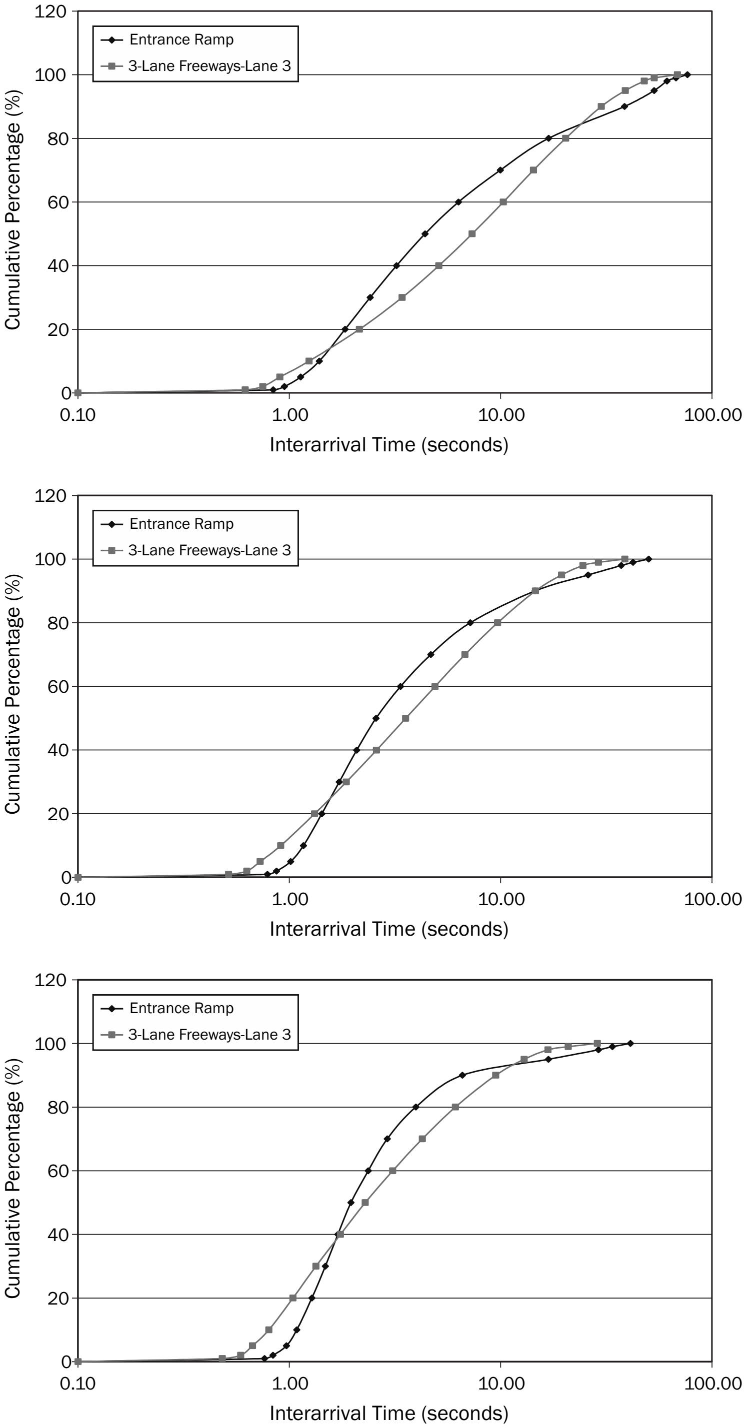


Figure 5 - Comparison of cumulative IAT distributions for universal non-signalized freeway entrance ramps with universal 3-lane freeway lane 3 (leftmost lane) a) 300, b) 600, and c) 900 vehicles/hour

ages for each distribution were compared for 300, 600, and 900 vehicles/hour. The maximum absolute differences were compared with the critical difference value calculated using the KS two-sample goodness-of-fit test (D-Critical). The maximum absolute differences were smaller than the critical value for lane 2 (left lane) of 2-lane freeways and lane 4 (leftmost lane) of 4-lane freeways only for 300 vehicles/hour. The results of the KS two-sample goodness-of-fit test showed that the universal cumulative IAT distributions for signalized freeway entrance ramps are not similar to the freeway mainline cumulative IAT distributions. *Figure 6* shows the comparison of signalized freeway entrance ramp cumulative IAT distribution with the cumulative IAT distribution for lane 3 (leftmost lane) of 3-lane freeways.



a) Non-signalized freeway entrance ramp
Universal IAT Distribution
μ = 11.989
σ = 16.180
c_v = 1.350
3-Lane Lane 3 Universal IAT Distribution
μ = 12.075
σ = 12.495
c_v = 1.035
KS Two-sample Goodness-of-Fit Test
$D_{observed}$ = 0.12
$D_{critical}$ = 0.111 (α = 0.05)
Reject

b) Non-signalized freeway entrance ramp
Universal IAT Distribution
μ = 5.995
σ = 8.413
c_v = 1.403
3-Lane Lane 3 Universal IAT Distribution
μ = 6.019
σ = 6.315
c_v = 1.049
KS Two-sample Goodness-of-Fit Test
$D_{observed}$ = 0.11
$D_{critical}$ = 0.079 (α = 0.05)
Reject

c) Non-signalized freeway entrance ramp
Universal IAT Distribution
μ = 3.997
σ = 6.052
c_v = 1.514
3-Lane Lane 3 Universal IAT Distribution
μ = 4.000
σ = 4.276
c_v = 1.069
KS Two-sample Goodness-of-Fit Test
$D_{observed}$ = 0.15
$D_{critical}$ = 0.064 (α = 0.05)
Reject

Figure 6 - Comparison of cumulative IAT distributions for universal signalized freeway entrance ramps with universal 3-lane freeway lane 3 (leftmost lane) a) 300, b) 600, and c) 900 vehicles/hour

4.5 Approximated universal cumulative IAT distribution for signalized freeway entrance ramps

The comparisons of the universal cumulative IAT distributions for non-signalized and signalized freeway entrance ramps showed that the cumulative IAT distributions are different. Further comparison of the freeway entrance ramp universal cumulative IAT distributions showed that the universal cumulative IAT distribution for non-signalized freeway entrance ramps is very similar to the cumulative IAT distribution of lane 3 (leftmost lane) of 3-lane freeways. The comparison of the universal cumulative IAT distribution for the signalized freeway entrance ramps with the freeway mainline cumulative IAT distributions showed that

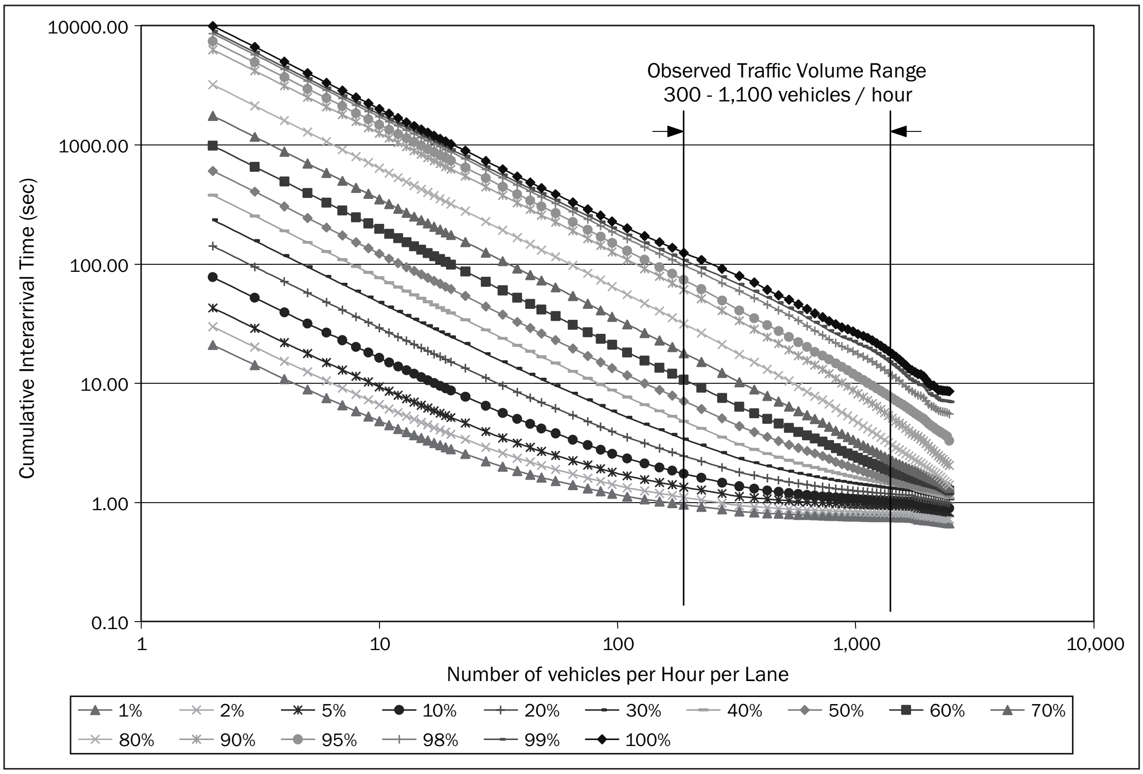


Figure 7 - Extrapolated cumulative IAT distributions for signalized freeway entrance ramps generated using the hyperbolic functions for 16 percentile values for a few vehicles to 2,500 vehicles/hour

they are different and the freeway mainline cumulative IAT distributions cannot be used to determine signalized freeway entrance ramp vehicle arrivals. A set of cumulative IAT distributions for signalized freeway entrance ramps was developed using the procedure in [11].

Figure 7 shows the IAT values (based on the field observations and extrapolation) for each percentile for very few to 2,500 vehicles per hour at signalized freeway entrance ramps. The data used for developing the cumulative IAT distribution for signalized freeway entrance ramps had a range of 300 to 1,100 vehicles per hour. The cumulative IAT distribution was further extrapolated to include the IAT values of lower and higher traffic volumes. The hyperbolic fit functions for each percentile were used to calculate the IATs for traffic volumes ranging from a few vehicles per hour to 2,500 vehicles per hour in increments of 50. The universal cumulative IAT distributions were then adjusted and plotted as shown in *Figure 7*.

The next step was to obtain the cumulative IAT distribution for any given traffic volume. Therefore, the IATs for each traffic volume increment were linearly interpolated using the procedure given in [11]. The approximated and adjusted universal IAT distribution spreadsheet for signalized freeway entrance ramps is available online at http://www.ohio.edu/orite/research/uitds.cfm.

5. CONCLUSION

The analysis of the non-signalized and signalized freeway entrance ramp IATs showed that the IATs or headways are different for the signalized freeway entrance ramps. As expected, the study showed that the IAT distributions for non-signalized freeway entrance ramps for the free flowing traffic entering from another freeway are very similar to the cumulative IAT distributions of the freeways for the same hourly traffic volumes. It is recommended that lane 3 (leftmost lane) of 3-lane freeways be used as a reasonable approximation for non-signalized freeway entrance ramps as it had the lowest maximum absolute difference when the non-signalized entrance ramp cumulative IATs were compared with the freeway mainline cumulative IATs. This approximation is judged to be accurate enough for the purpose of a stochastic computer simulation of bottlenecks in the work zones.

The study also showed that the cumulative IAT distributions for signalized freeway entrance ramps are different from the non-signalized freeway entrance ramp cumulative IAT distributions and the freeway mainline cumulative IAT distributions. Therefore, the freeway mainline cumulative IAT distributions should not be used to determine signalized freeway entrance ramp vehicle IATs or headways. A set of cumulative IAT distributions for signalized freeway entrance ramps was developed using the procedure in [11]. The developed cumulative IAT distributions can be used to determine the IATs or headways of vehicles at signalized freeway entrance ramps for traffic volumes from very few vehicles to 2,500 vehicles per hour, which can be obtained at http://www.ohio.edu/orite/research/uitds.cfm. It should be noted that the effect of geometrics (alignment, grade, etc.) was not taken into consideration for the modelling effort.

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ÖZET

TRAFIK SIMÜLASYONLARI IÇIN OTOYOL GIRIŞI RAMPA TRAFIĞININ KÜMÜLATIF TAŞIT TAKIP ARALIĞI SÜRE DAĞILIMLARI

Bu çalışmada trafik ışıklarının kullanıldığı ve kullanılmadığı otoyol giriş rampaları için kümülatif taşıt takip aralığı (TTA) süre dağılımları trafik simülasyon modellerinde kullanılmak üzere geliştirilmiştir. Dört farklı trafik ışığı kullanılmayan otoyol giriş rampasında (üç tek şeritli, bir iki şeritli rampa) ve iki farklı trafik ışığı kullanılan otoyol giriş rampasında (tek şeritli) toplanan veriler kümülatif TTA süre dağılımlarının geliştirilmesinde kullanılmıştır. Trafik ışığı kullanılan ve kullanılmayan rampalar için geliştirilen kümülatif TTA süre dağılımları birbirleri ile ve otoyol anahat şeritlerinin kümülatif TTA süre dağılımları ile karşılaştırılmıştır. Karşılaştırmalar sonucunda; trafik ışığı kullanılmayan otoyol giriş rampası kümülatif TTA süre dağılımlarının üç şeritli otoyolların en sol şeridi için geliştirilen kümülatif TTA süre dağılımları ile aralarındaki mutlak farkın %3 olduğu ve bu dağılımların benzer olduğu görülmüştür. Trafik ışığı kullanılan otoyol giriş rampası kümülatif TTA süre dağılımlarının, trafik ışığı kullanılmayan otoyol giriş rampası kümülatif TTA süre dağılımlarından farklı olduğu da tespit edilmiştir. Trafik ışığı kullanılan ve kullanılmayan otoyol giriş rampası kümülatif TTA süre dağılımları birkaç araç/saat trafik hacim değerlerinden 2500 araç/saat trafik hacim değerlerine kadar erişim link verilen internet sayfasından elde edilebilir (http://www.ohio.edu/orite/research/uitds.cfm).

ANAHTAR KELIMELER

otoyol giriş rampası, trafik ışığı kullanımı, trafik modelleme, Kolmogorov-Smirnov testi, otoyol taşıt takip aralığı

LITERATURE

[1] **May, A.D.**: *Traffic Flow Fundamentals*. Prentice Hall Inc., 1990, pp.11-51

[2] **Pline, J.L.**: *Traffic Engineering Handbook*. Institute of Transportation Engineers, 5th Edition, 1999, pp.84.

[3] **Buckley, D.J.**: *A Semi-Poisson Model of Traffic Flow*, Transportation Science, Volume 2, Number 2, 1968, pp. 107-133

[4] **Wasielewski, P.**: *Car Following Headways on Freeways Interpreted by Semi-Poisson Headway Distribution Model*, Transportation Science, Volume 13, Number 1, 1979, pp. 36-55

[5] **Mei, M.** and **Bullen, A.G.**: *Lognormal Distribution for High Traffic Flows*, Transportation Research Record, Number 1398, 1993, pp. 125-128

[6] **Tolle, J.E.**: *The Lognormal Headway Distribution Model*, Traffic Engineering and Control, Volume 13, Number 1, 1971, pp. 22-24

[7] **Sadeghhosseini, S.**, and **Benekohal R. F.**: *Headway Models for Low to High Volume Highway Traffic*, Proceedings of the Transportation Research Board Annual Meeting, National Research Council, Washington, D.C., 2002

[8] **Khasnabis, S.** and **Heimbach C.L.**: *Headway-Distribution Models for Two-Lane Rural Highways*, Transportation Research Record, Number 772, 1980, pp. 44-50

[9] **Sullivan, D.** and **Troutbeck, R.**: *The Use of Cowan's M3 Headway Distribution for Modeling Urban Traffic Flow*, Traffic Engineering and Control, Volume 35, Number 7, 1994, pp. 445-450.

[10] **Zwahlen, H.T.**, **Russ, A.**, **Oner, E.**, and **Parthasarathy, M.**: *Evaluation of Microwave Radar Trailers for Nonintrusive Traffic Measurements*. Transportation Research Record, Number 1917, 2005, pp.127-140

[11] **Zwahlen, H.T.**, **Oner, E.**, and **Suravaram, K.R.**: *Approximated Headway Distributions of Free-Flowing Traffic on Ohio Freeways for Work Zone Traffic Simulations*. Transportation Research Record, Number 1999, 2007, pp.131-140

[12] **Chu, L.**, **Liu, H.X.**, **Recker, W.**, and **Zhang, H.M.**: *Performance Evaluation of Adaptive Ramp-Metering Algorithms Using Microscopic Traffic Simulation Model*, Journal of Transportation Engineering, Vol. 130, No. 3, 2004, pp. 330-338

[13] **Smaragdis, E.**, **Papageorgiou, M.**, and **Kosmatopoulos, E.**: *A Flow-Maximizing Adaptive Local Ramp Metering Strategy*, Transportation Research. Part B, Methodological, Vol. 38B, No. 3, 2004, pp. 251-270

[14] **Taylor, J.C.**, **McKenna, P.G.**, **Young, P.C.**, **Chotai, A.**, and **MacKinnon, M.**: *Macroscopic Traffic Flow Modelling and Ramp Metering Control using Matlab/Simulink*, Environmental Modelling and Software, Vol. 19, No. 10, 2004, pp. 975-988

[15] **Kwon, E.**, **Nanduri, S.**, **Lau, R.**, and **Aswegan, J.**: *Comparative Analysis of Operational Algorithms for Coordinated Ramp Metering*, Transportation Research Record, Number 1748, 2001, pp. 144-152

[16] **Bellemans, T.**, **De Schutter, B.**, and **De Moor, B.**: *Model Predictive Control for Ramp Metering of Motorway Traffic: A Case Study*, Control Engineering Practice, Vol. 14, 2006, pp. 757-767

[17] *Microsoft Live Search Maps*, http://maps.live.com/. Accessed December 18, 2011

[18] **Suravaram, K.** *Modeling the Interarrival Times for Non-Signalized Freeway Entrance Ramps*, Master's Thesis, Ohio University, 2007.

[19] **Siegel, S.**: *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill Book Company, Inc., New York, 1956, p.131

[20] **Steel, R.G.D.** and **Torrie, J.H.**: *Principles and Procedures of Statistics*. McGraw-Hill, New York, 1960, pp. 187- 287