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Approximated headway distributions for non-signalized and signalized freeway entrance ramps

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Abstract

Cumulative interarrival time (IAT) distributions for 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 established which can be used in digital computer traffic simulation models. 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 2500 vehicles/hour can be obtained at http://www.ohio.edu/orite/research/uitds.cfm.

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Keywords: freeway entrance ramp; cumulative interarrival time distribution; traffic modelling; signalized; non-signalized; headway

1. Introduction and Background

Time headway or the interarrival time (IAT) is one of the important flow characteristics which affect the safety, level of service, driver behavior and capacity of the transportation system (May, 1990). Time headway distributions are required to determine the opportunity for passing, merging and crossing lanes on a freeway.

Mathematical forms of headway distributions give more insight into the behavior of the traffic. The distributions can also be used as an input to a traffic simulation model. Traffic situations which are hard to observe in the real world can be investigated with the use of simulation models which use the mathematical headway distribution models. Further, digital computer simulation can be used to simulate the flow of traffic in work zone bottlenecks. Simulation of the bottlenecks for work zones on freeways involves the use of headway distributions where the behavior of the traffic through the mainline and at the entrance ramps is modeled. Semi-Poisson (Buckley, 1968, Wasielewski, 1979), log-normal (Mei, 1993, Tolle, 1971, Sadeghhosseini and Benekohal, 1993), negative

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exponential (Khasnabis and Heinbach, 1980, Sullivan and Troutback, 1994) headway distribution models for free flowing traffic on the freeways have been studied and established in the past and there is need for 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: 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. (Zwahlen et al., 2005) traffic data was collected at different freeway locations in Ohio and a procedure to convert hourly traffic volumes into cumulative IAT distributions was established for freeway mainline traffic (Zwahlen et al., 2007). The approximated headway distributions of free flowing traffic for each lane of the 2-lane, 3-lane, and 4-lane traffic are developed and given in (Zwahlen et al., 2007). Cumulative IAT distributions for entrance ramps are needed in addition to the approximated IAT distributions for the mainline traffic in the simulation of bottlenecks in work zones which contain a number of entrance ramps. The entrance ramp IAT distributions may be used as an input in complex work zone traffic simulation models, which would enhance the accuracy of the simulation models and provide more accurate queue and traffic delay information in work zones. 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 (Chu et al., 2004, Samarigdis et al., 2004, Taylor et al., 2004, Kwon et al. 2001, Bellemans et al., 2006).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 were published.

2. Objectives

The objectives of the study are to develop approximated cumulative IAT or headway distributions for non-signalized and signalized freeway entrance ramps and to determine whether the non-signalized and signalized freeway entrance ramp approximated cumulative IAT distributions are similar. In addition, the IAT distributions for traffic at non-signalized and signalized freeway entrance ramps are compared with the approximated cumulative IAT distributions for each lane of the 2-lane, 3-lane, and 4-lane freeways in (Zwahlen et al., 2007) and similarity between freeway mainline IAT distributions and freeway entrance ramp IAT distributions are established.

3. Research Methodology

The method used for developing the IAT distributions for traffic on freeway entrance ramps was adapted from Zwahlen et al. (Zwahlen et al., 2007). The IAT distributions for four non-signalized and two signalized freeway entrance ramps with different configurations were developed using the procedure outlined in (Zwahlen et al., 2007).

The data for the 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 (Zwahlen et al., 2005). 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.

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 2shows 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 was 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 IATs or the headways which was the difference between two successive vehicle arrival time stamps. The numbers of IATs used in data analysis and in IAT distribution development for all the sites investigated in this study are given in Table 1.

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 (Number of vehicles observed – 1)
Non-Signalized I71 S to I270 W	6/23/2006-6/26/2006	8 - 836	12954
Non-Signalized I71 to I270 W	8/28/2004-8/31/2004	44 -1616	39224
Non-Signalized SR2 to I90 E Lane 1 (Right Lane)	9/13/2004-9/16/2004	4 - 692	15443
Non-Signalized SR2 to I90 E Lane 2	9/13/2004-9/16/2004	24 -1320	35130
Non-Signalized MLK to I90 E	9/15/2004-9/18/2004	23 - 1694	34974
Signalized 55th St to I90 E	9/13/2004-9/16/2004	4 - 1104	22623
Signalized US62 to I270 W	8/28/2004-8/31/2004	8 - 1079	22283

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 (Zwahlen et al., 2005) 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 (Zwahlen et al., 2007).

The Microsoft Excel Data analysis/Histogram tool was used to compute the cumulative percentages for all the 15-minute interval data. A minimum IAT value of 0.1 seconds was assigned to the 0% value and bins were set up from this value up to the maximum IAT value observed in a 15-minute interval. IATs for sixteen percentile values: 1%, 2%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99%, and 100% were extracted after calculating the cumulative percentage for all the 15-minute interval data sets . An Excel sheet was set up with the 15 minute time period, adjusted hourly vehicle count and the IATs for the sixteen percentile values according to the site, date and lane of travel. Cumulative percentages were used because cumulative percentage values can be easily used with the Kolmogorov-Smirnov (KS) two sample goodness of fit test (Siegel, 1956).

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 (Zwahlen et al., 2007). The coefficients "a" and "b" were calculated using the least squares fitting method. Hyperbolic fits were used because the average IAT for an hourly traffic volume is inversely proportional to the hourly traffic volume. After determining the hyperbolic fit relationship for all the 16 percentile values, cumulative IATs for 16 percentile values based on observed traffic volumes in increments of 50 were generated using the hyperbolic fits. The average IAT of the fit for the distribution for each traffic volume was calculated using the formula given in Equation 1 (Zwahlen et al., 2007) to compare it with the average IAT obtained for a given traffic volume. The average IAT of the fit is given by:

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

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. An adjustment factor was calculated for each traffic volume by dividing the average IAT for a given traffic volume by the average IAT from the cumulative IAT distribution (Zwahlen et al., 2007). All the cumulative IATs computed using the hyperbolic fits for a given traffic volume were then multiplied by the respective adjustment factor in order to obtain the corrected cumulative IAT values. Then all the adjusted cumulative IATs were tabulated for the observed traffic volumes in increments of 50 vehicles/hour.

4. Results and Discussions

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

4.1. Comparison of Cumulative IAT Distributions for the Non-Signalized and Signalized Freeway Entrance Ramps

Cumulative IAT 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 graph for 600 vehicles per hour is given in Figure 1. Figure 1 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.

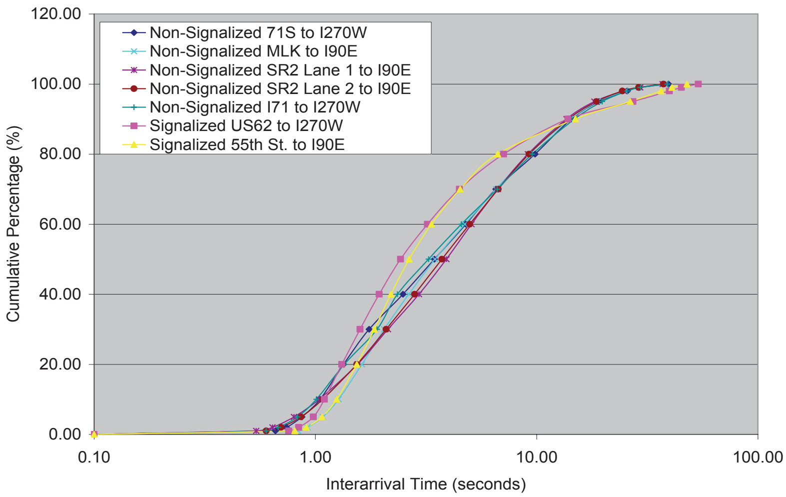


Figure 1 Cumulative IAT Distributions for All Freeway Entrance Ramps for 600 vehicles/hour

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 methods(Zwahlen et al., 2007). In addition, a universal cumulative IAT distribution for signalized entrance ramps was generated using the same procedure. As a result one (universal) cumulative IAT distribution for all non-signalized freeway entrance ramps and one (universal) cumulative IAT distribution for all signalized entrance ramps were developed.

Table 2 and Table 3 show the hyperbolic formulas and the corresponding R^2-values for the universal non-signalized and 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 smaller R^2-values show that there is more variability present for the smallest percentiles than near largest percentiles as expected. The low sample sizes for the smallest and the largest percentiles also resulted in smaller R^2-values.

Table 2 Hyperbolic Formulas 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

4.2. 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 2. The maximum differences 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 (Siegel, 1956). The maximum differences were compared with the critical value 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.

Table 3 Hyperbolic Formulas 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

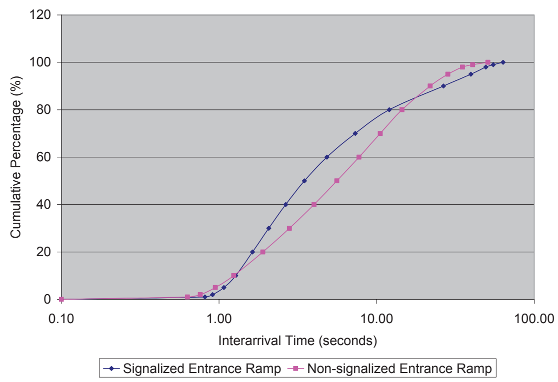
4.3. Comparison of Universal IAT Distributions for Non-Signalized and Signalized Freeway Entrance Ramps with Universal IAT Distributions for the Mainline

The universal IAT distributions for non-signalized and signalized freeway entrance ramps were also compared with the cumulative IAT distributions obtained for the freeways in (Zwahlen et al., 2007). 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 IATs 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.

The maximum absolute differences in percentages for each compared distribution for 300, 600, and 900 vehicles/hour are determined. 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 the lane 3 of 3-lane freeways.

The signalized freeway entrance ramp universal cumulative IAT distribution was also compared with the freeway mainline cumulative IAT distributions from (Zwahlen et al., 2007). The maximum absolute differences in percentages for each distribution 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 of 2-lane freeways and lane 4 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.



a) Universal IAT Distribution for Signalized Entrance Ramp

Average= 8.992

Standard Deviation= 12.232

Coefficient of Variation= 1.360

Universal IAT Distribution for Non-Signalized Entrance Ramp

Average= 8.986

Standard Deviation= 9.059

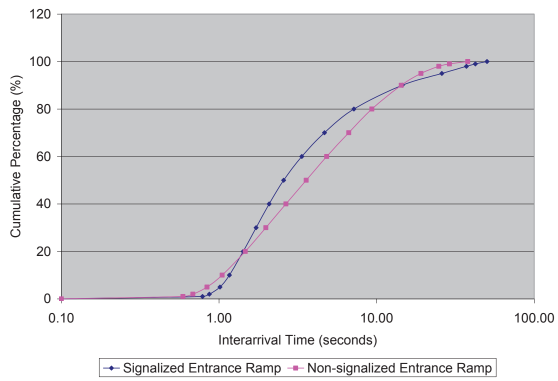
Coefficient of Variation= 1.008

KS Two Sample Goodness of Fit Test

D Observed (by visual inspection)= 0.16

D Critical= 0.096 (Level of Significance=0.05)

Reject



b) Universal IAT Distribution for Signalized Entrance Ramp

Average= 5.995

Standard Deviation= 8.413

Coefficient of Variation= 1.403

Universal IAT Distribution for Non-Signalized Entrance Ramp

Average= 5.992

Standard Deviation= 6.205

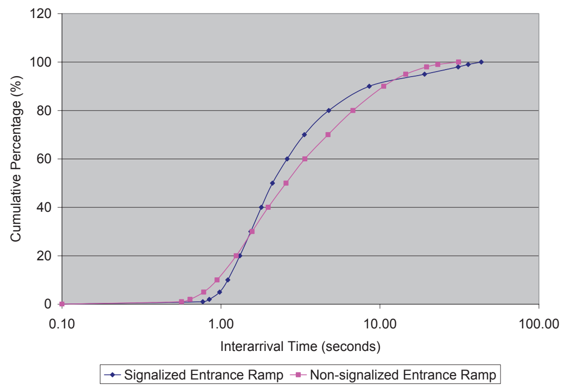
Coefficient of Variation= 1.036

KS Two Sample Goodness of Fit Test

D Observed (by visual inspection)= 0.12

D Critical= 0.078 (Level of Significance=0.05)

Reject



c) Universal IAT Distribution for Signalized Entrance Ramp

Average= 4.497

Standard Deviation= 6.618

Coefficient of Variation= 1.472

Universal IAT Distribution for Non-Signalized Entrance Ramp

Average= 4.495

Standard Deviation= 4.791

Coefficient of Variation= 1.066

KS Two Sample Goodness of Fit Test

D Observed (by visual inspection)= 0.09

D Critical= 0.068 (Level of Significance=0.05)

Reject

Figure 2 Comparison of Non-Signalized and Signalized Universal IAT Distributions for a) 400, b) 600, and c) 800 vehicles/hour

4.4. 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 the lane 3 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 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.

Figure 3 shows the IAT values (based on the field observations and extrapolation) for each percentile for very few to 2500 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 1100 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 2500 vehicles per hour in increments of 50. The universal cumulative IAT distributions were then adjusted and plotted as shown in Figure 2.

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 (Zwahlen et al., 2007). 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.

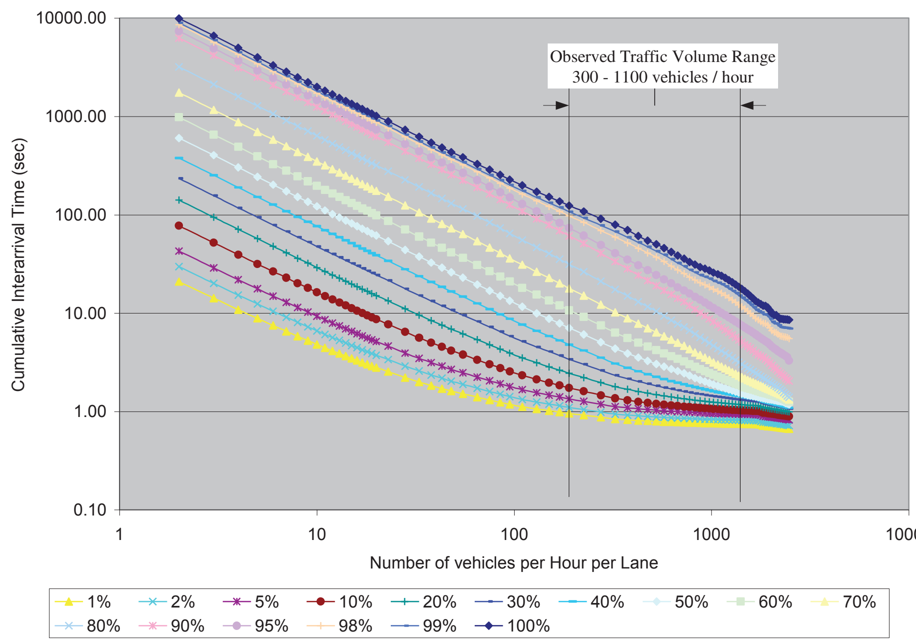


Figure 3 Extrapolated Cumulative IAT Distributions for Signalized Freeway Entrance Ramps Generated using the Hyperbolic Functions for 16 Percentile Values for a few Vehicles to 2500 Vehicles/Hour

5. Conclusions

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 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 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 (Zwahlen et al., 2007). 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 a very few vehicles to 2500 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 modeling effort and the data used in the analysis were collected on Ohio freeways, therefore the modeling is for conditions in Ohio. The IAT distributions may differ based on the road geometrics and different IAT distributions may be observed in other countries.

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