DRAFT

Paper No. 07-1511

Title: Approximated Headway Distributions of Free-Flowing Traffic on Ohio Freeways for Work Zone Traffic Simulations

Helmut T. Zwahlen, Erdinc Oner and Kiran R Suravaram
Ohio Research Institute for Transportation and the Environment
Department of Civil Engineering
114 Stocker Engineering and Technology Center
Ohio University
Athens, OH 45701-2979
Phone (740) 597-1790 or (740) 593-2476
Fax (740) 593-0625
Email zwahlen@ohio.edu, eo189602@ohio.edu, ks146905@ohio.edu

Prepared for Presentation
at the 86th Annual Meeting of Transportation Research Board,
January 21-25, 2007,
National Academy of Sciences
Washington, D.C.

November 14th, 2006

Number of words: 4285
Number of tables: 2
Number of figures: 10
Total number of words counting tables and figures as 250 words each: 7385

ABSTRACT

Headway or interarrival time (IAT) data of successive vehicles in free-flowing traffic ahead of work zones at six different Ohio freeways (two with two lanes in one direction, three with three lanes, and one with four lanes) for three days were measured and analyzed. Approximated cumulative IAT distributions were generated as a function of the traffic volume for each lane and relationships between traffic volumes and approximate cumulative IAT distributions were established allowing a direct conversion from hourly traffic counts to corresponding cumulative IAT distributions. Based upon the validation of these cumulative IAT distributions using IAT data collected in an independent study, this conversion method produces fairly accurate cumulative IAT distributions for selected hourly traffic volumes.
A set of cumulative IAT distribution spreadsheets may be downloaded at http://webce.ent.ohiou.edu/orite/cumulativeIATdistributions.html. It was also found that the same approximated cumulative IAT distribution can be used to model and simulate the free-flowing traffic at other freeway locations in Ohio. It is not known whether or not these universal approximated IAT distributions would apply for freeways in other states.

INTRODUCTION

Two methods or approaches exist to determine the effects of factors such as lane closures in work zones or other traffic bottlenecks. One method is based on using simple deterministic queuing models which are usually based on hourly traffic counts, a standard traffic measure. Basic variables of uninterrupted traffic flow, including volume or flow rate, speed, density, and concentration are discussed in *(1)*. For example the Quick Zone traffic simulation software is based on a simple deterministic queuing model and uses hourly traffic counts to estimate traffic delays and queues in work zones *(2)*. Any such deterministic queuing model has, however, limited accuracy due to the assumption of a constant interarrival time (IAT). Deterministic models do not properly account for the stochastic nature of the variables or the transient nature of the traffic (steep increases to peaks and/or steep decreases to valleys in arrival rates). Deterministic and stochastic queuing models are discussed in *(3, 4)*. Based on the literature review performed, it was found that no simple method to convert the hourly traffic volumes to IAT distributions was developed so far but lot of research was done on the distributions that can be used to describe the IAT distributions for traffic on freeways.
If higher prediction accuracy for queue build-up and delay times under congested traffic conditions is required, a stochastic queuing simulation model is needed. This requires probabilistic IAT and service time distributions. Service times in such a stochastic traffic queuing simulation model refer to the elapsed times a vehicle spends driving through restricted road sections after leaving the bottleneck or taper area. To obtain probabilistic cumulative IAT distributions for a given traffic volume requires more time and effort. According to the Traffic Engineering Handbook *(1, p. 84)* 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.

According to May.D *(5)* the headway distribution varies a lot based on the traffic flow rate. A classification scheme is proposed for time headway distributions consisting of a random state for low traffic flow levels, an intermediate distribution state for moderate traffic flow levels and a constant distribution state for high traffic flow levels. The Negative exponential, the Normal distribution and the Pearson Type-III distribution are the mathematical models that can be used to model the time headways for the flow states mentioned above respectively. It would, therefore, be of advantage to find a way to convert hourly traffic counts into corresponding cumulative IAT distributions for cases where the random traffic based Poisson assumption *(1)* does not hold, or where other mathematical IAT distributions *(6, 7, 8)* require field measurements or do not fit the real world data closely. These could then be combined with probabilistic service time distributions in stochastic queuing models to obtain a higher predictive accuracy for congestion measures such as the aforementioned expected queue lengths and delay times at work zones. In *(9, 10)* traffic data were collected and fitted using statistical distributions available for headways, however the data used for fitting were limited to specific roads and one statistical headway distribution is not capable of estimating headways on all types of freeways. In this study headways were observed for long periods of time at locations with different road characteristics and a least squares method was used to produce a better fit of headway data collected from Ohio freeways with similar characteristics.

Ali S. AlGhamdi *(11)* did an analysis of the time headways on urban roads in Riyadh, Saudi Arabia. He established boundaries for three states of flow based on the distributions that fit the flow on the roadways. The headway data for low, medium and high flow states were analyzed for thirteen freeway and seven arterial sites. Enough data was collected at each site to

be sufficient for distribution fitting. Then the chi-square statistical testing technique was used to obtain the best fit among the distributions attempted. The distribution was selected on the basis of increments of 100 or 200 vph so that any change in data behavior with respect to the fitted distributions can be detected. The flow range of the vehicles observed was divided into three classifications of low (<400 vph), medium (400-1200 vph) and high (>1200 vph) flows. The distributions that were fitted to the flow ranges mentioned above were negative exponenential, shifted exponential gamma and erlang distributions respectively. The author concluded that the modeling of headways for high traffic flows is still vague and the research done so far focused on the low traffic conditions where the independence between successive vehicles is satisfied. The author stated that the time headway distributions proposed are good for the data analyzed in Riyadh but may not necessarily reflect traffic conditions elsewhere.

OBJECTIVE

The first objective of this research is to measure the IAT's of free-flowing traffic on freeways at different locations in Ohio and determine the IAT or headway distributions for different hourly traffic volumes for selected traffic lanes and develop Microsoft Excel *(12)* spreadsheets which will produce approximate cumulative IAT distributions for any traffic volume per hour per lane within the range of the observed traffic volumes. The actual interarrival time distributions are needed to run digital simulations to examine the effects of the bottlenecks in work zones and to model multilane traffic in driving simulators.

The second objective of this research is to investigate whether or not the IAT or headway distributions for different freeways in Ohio for selected hourly traffic volumes are similar (portability). If the IAT's or headway distributions of similarly configured freeways are sufficiently similar for the same traffic volumes in the corresponding lanes, then universal approximate IAT or headway distributions can be used in probabilistic queuing simulations in conjunction with hourly traffic counts.

DATA COLLECTION

Microwave radar trailers were used in data collection efforts in 2004 at six different construction work zone sites on Ohio freeways *(13).* One trailer was placed before the beginning of the construction work zone on freeways, which provided the data for free-flowing traffic conditions. The six sites selected for data collection were; I-76 Westbound near Akron (2 lanes in one direction, average speed=65 miles per hour (mph) (104 kilometers per hour (kph))), I-270 Westbound in Columbus (2 lanes, average speed=60 mph (97 kph)), I-270 Eastbound in Columbus (3 lanes, average speed=60 mph (97 kph)), I-90 Eastbound in Cleveland (3 lanes, average speed =50 mph (80 kph)), I90 Westbound in Cleveland (4-lanes, average speed=60 mph (97 kph)), and I-75 Southbound in Dayton (3 lanes, average speed=60 mph (97 kph)).

The key parameter collected by the microwave radar trailers was a timestamp for the vehicle arrivals. The microwave radar trailer recorded arrival time of vehicles for each lane in 2.5 millisecond increments. Lane of traffic for each vehicle, a moving average of speed based on the last 16 vehicles in miles per hour, and a vehicle class (three classes: class 0 is 0-20 ft (0-6.1 m), class 1 is 21-40 ft (6.1-12.2 m), and class 2 is anything at least 41 ft (12.2 m) long) were also recorded by the microwave radar trailers.

In addition to the microwave radar trailers, the Ohio Research Institute for Transportation and the Environment (ORITE) researchers validated the trailer measurements by separately measuring traffic for approximately an hour at each site, for all lanes in the same direction. The traffic was videotaped with a time-stamped video camera synchronized to the same laptop the radar units were synchronized with to determine IAT's. The vehicle speeds were measured with a Kustom Signals TR-6 radar unit and recorded by hand, along with a notation of the type of vehicle (passenger vehicle, bus or large truck) to correlate the trailer data with the video record. The ORITE recorded independent data were documented in a Microsoft Excel spreadsheet with the time a vehicle passed the trailer to the nearest second, vehicle type, and speed.

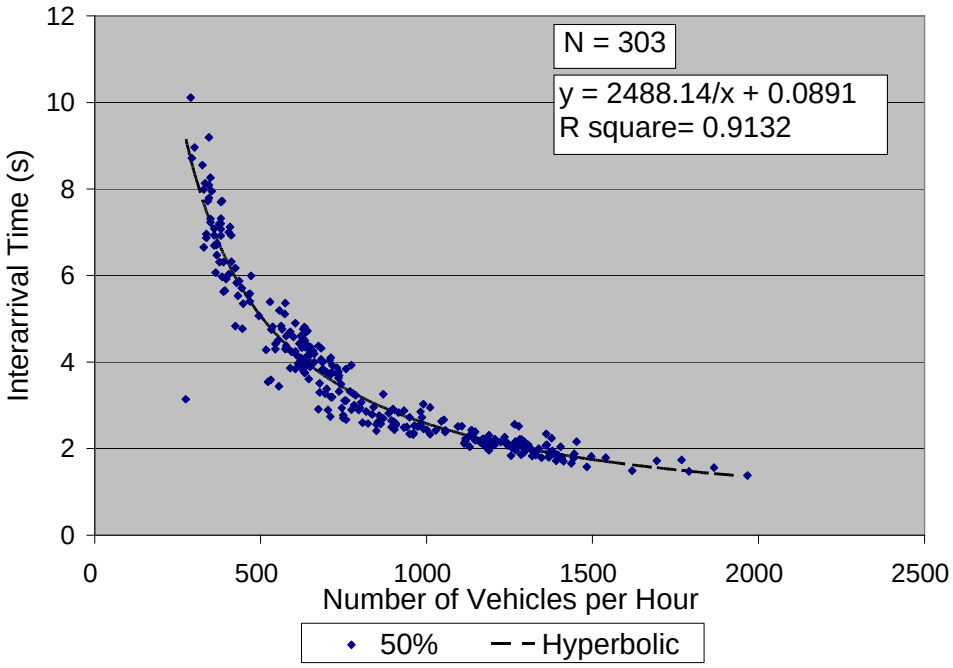
METHOD

A total of 3 days of data (about 72 hours) were collected in the field with the microwave radar trailers at each site. As mentioned earlier the key parameter used in this research was the timestamp for each vehicle arrival. The downloaded text file from the trailer was imported into Microsoft Excel, and the ORITE data were entered into a separate worksheet in the same Excel file. ORITE vehicle arrival data records were matched against the radar trailer data, and misses (a vehicle observed on the video but not detected by the trailer) and phantoms (vehicles reported by the trailer but not seen in the video) were identified. The net error was tabulated. This is the number of phantoms minus the number of misses; thus a negative value represents an undercount by the trailer system (more misses than phantoms). For purposes of establishing overall traffic counts, a phantom and a miss will cancel each other out and the net error is the figure of interest. Using the net error correction factors for the microwave radar trailer, adjusted vehicle counts were generated.

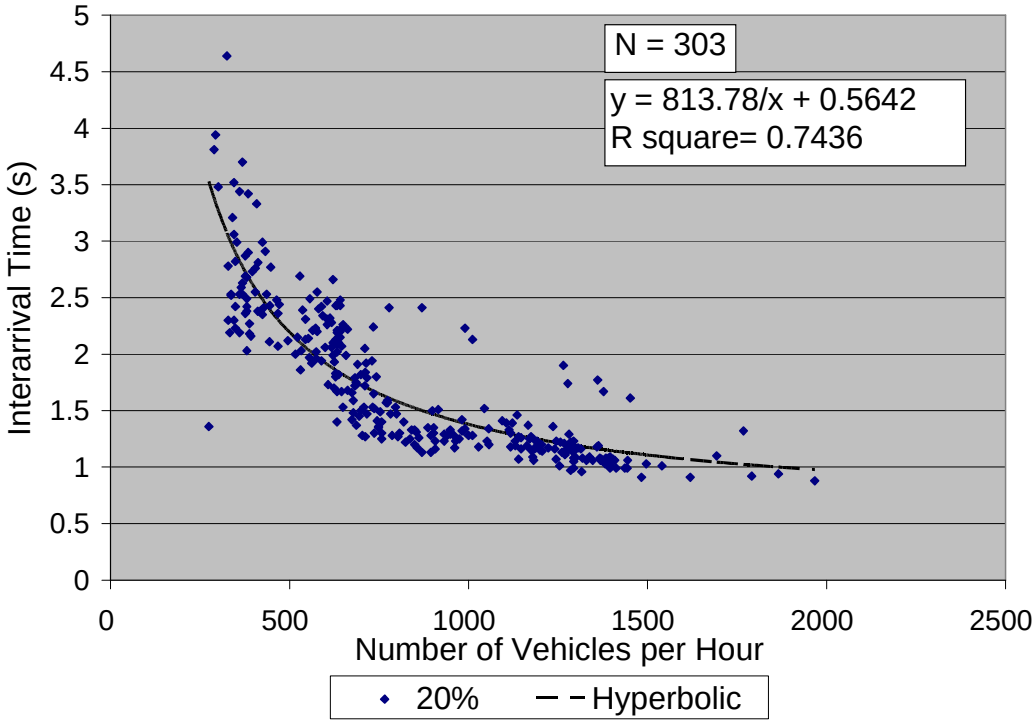
The three days of data for each site were separated according to the lane of travel and then split into 15-minute time intervals. The vehicle counts for each 15-minute time period were multiplied by 4 to obtain hourly vehicle counts. A correction factor obtained from phantoms and misses analysis was used to multiply the hourly vehicle counts to obtain the adjusted hourly traffic counts. This number indicated the best estimate of the actual number of vehicles per hour per lane (vphpl).

Matlab *(14)* scripts were employed for computing cumulative percentages for each 15-minute time interval data sets. Bins were set up from 0.01 to the maximum observed IAT in the time interval in increments of 0.01 seconds. An IAT time of 0.1 seconds was arbitrarily assigned for the minimum cumulative value of 0%. After calculating the cumulative percentage values, IAT's were extracted for the following 16 percentiles: 1%, 2%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99%, and 100% (taken as the maximum IAT recorded). The sixteen points selected are judged to be adequate to represent an estimate of the true cumulative IAT distribution for the simulation purposes mentioned in the objectives. While the selected percentile values appear to be adequate for work zone bottleneck simulations they may not be accurate and detailed enough for capacity estimation based on short headways and safety analyses which may require a larger number of percentile values. For each site, date, and lane the following data was tabulated: 15 minute time period, adjusted vehicles per hour per lane (vphpl), IAT's from the extracted cumulative percentiles. Cumulative percentages were used in determining the IAT distributions instead of histograms since cumulative percentages are better suited for statistical tests such as the Kolmogorov-Smirnov Goodness of Fit Test *(17)*.

After having adjusted hourly traffic counts, each data set was combined according to the type of freeway on which the data were collected. 15-minute data sets were combined for 2-lane freeways (I-76 Westbound and I-270 Westbound) according to the travel lane (Right Lane (Lane 1) and Lane 2), for 3-lane freeways (I-270 Eastbound, I-90 Eastbound, and I-75 Southbound) according to the travel lane (Right Lane (Lane 1), Lane 2, and Lane 3), for 4-lane freeways (I-90 Westbound) according to the travel lane (Right Lane (Lane 1), Lane 2, Lane 3, and Lane 4). The combined data sets formed the universal data sets of observed IAT's. For all universal data sets at each percentile, IAT versus flow rate (vphpl) graphs were plotted using Microsoft Excel. The number of data points (N) plotted for each percentile to generate hyperbolic fit distributions were as follows: 2-Lane Freeway-Lane 1, N=823; 2-Lane Freeway-Lane 2, N=654; 3-Lane Freeway-Lane 1, N=967; 3-Lane Freeway-Lane 2, N=1197; 3-Lane Freeway-Lane 3, N=928; 4-Lane Freeway- Lane 1, N=249; 4-Lane Freeway-Lane 2, N=275; 4-Lane Freeway-Lane 3, N=276; 4-Lane Freeway-Lane 4, N=213. On each graph, the data were fitted using a hyperbolic fit of the form: $y = (a/x) + b$. The hyperbolic fit to describe the relationship between the IAT value and the hourly traffic volume for a given percentile value is the correct fit considering that in the case of constant IAT's the relationship between the IAT and the hourly traffic volume is exactly hyperbolic with $b = 0$. Based on this one would expect the quality of the hyperbolic fit expressed by the R-square value to be highest around the 50 percentile value and because of the increased variability at the tails of the IAT distribution the R-square values would be lower as demonstrated in Table 1. Figure 1a and Figure 1b illustrate the hyperbolic relationship between IAT and hourly traffic volume for the 50 percentile (median) and 20 percentile values for all the sites for the driving lane. The least squares fitting method was used to estimate the coefficients a and b. R-square (R^2) values were also estimated along with the coefficients, which provided a measure of quality of fit. Table 1 shows the hyperbolic formulae and the corresponding R^2 values used to determine the cumulative IAT's for selected percentiles for lane 2 of 2-lane freeways. It should be noted that the effect of geometrics on the vehicle headways is not analyzed because all the sites where data was collected were straight tangent road sections with no lane restrictions. As expected, based on the literature of the analysis of extreme value data *(15)* the R-square (R^2) values for the smallest and the largest percentiles are relatively low for the sample size when compared to the (R^2) values around the median.



a



b

FIGURE 1 Hyperbolic relationship between IAT and hourly traffic volume for all the sites for driving lane for a) 50% value b) 20% value.

TABLE 1 Hyperbolic Formulae and R^2 Values used in Excel Sheet for Determining Cumulative IAT's for Selected Percentiles for 2-Lane Freeways - Lane 2

Cumulative Percentage	Model	R^2
0%	0.1*	
1%	y = 13.69/x + 0.4546	0.0110
2%	y = 20.30/x + 0.5226	0.0473
5%	y = 66.46/x + 0.5776	0.2289
10%	y = 144.59/x + 0.6084	0.3671
20%	y = 360.90/x + 0.5567	0.4646
30%	y = 659.95/x + 0.4986	0.5100
40%	y = 1090.44/x + 0.4175	0.5922
50%	y = 1748.85/x + 0.2373	0.6699
60%	y = 2732.76/x - 0.0678	0.7924
70%	y = 3981.30/x - 0.0906	0.8497
80%	y = 5812.98/x + 0.0053	0.9019
90%	y = 8856.03/x + 0.5695	0.9133
95%	y = 11508.31/x + 2.1736	0.8670
98%	y = 14087.42/x + 5.7302	0.7990
99%	y = 16656.71/x + 5.2332	0.7352
100%	y = 17268.75/x + 16.1636	0.4615

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

After determining the hyperbolic fit distributions for each of the 15-minute interval universal data sets, a table for extracting cumulative IAT values at different hourly traffic counts (vphpl) was prepared. These values were obtained for a range of vphpl values from the observed minimum to the maximum in increments of 50.

The average IAT's computed using the cumulative IAT distribution tables from the universal data sets were compared with the corresponding hourly traffic volumes' (vphpl) average IAT's for fine tuning of the distributions. The average IAT for a given hourly traffic volume (vphpl) can be calculated by dividing the number of seconds in an hour (3600) by hourly traffic volume (vphpl). The average IAT of fit is computed as a weighted average of the IAT's at the different cumulative percentiles. The formula to calculate the average IAT's of fit distributions is given below:

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

where p_i = *cumulative percentage value from the hyperbolic fit table*
y_i = *corresponding IAT for* p_i

Since the IAT's at different percentiles are calculated from the hyperbolic fit distributions, the average IAT obtained from the fitted distributions may differ somewhat from the average IAT determined from the hourly traffic volumes (vphpl) by a factor. Hence, an adjustment factor is needed to correct the cumulative IAT's at different percentiles. Adjustment factors were computed by dividing the average IAT from the hourly traffic volumes (vphpl) by

the weighted average IAT from the fitted distributions. Then the IAT's at different percentiles were multiplied by the correction factor for fine tuning and the adjusted IAT's at different percentiles were tabulated along with the observed hourly traffic volumes from the minimum to maximum in increments of 50 vphpl.

The next step was to obtain the IAT distribution for any given hourly traffic volume (vphpl) in the observed range of traffic volumes. To obtain the IAT distribution at any intermediate volume in the interval between two hourly traffic volumes (vphpl) in the table, the IAT's at these points were linearly interpolated as given below:

1) Let c be the desired hourly traffic volume (vphpl) for which the IAT distribution needs to be determined. Identify hourly traffic volumes (vphpl) a and b, such that c is in the interval (a, b) and IAT distributions for a and b are known.
2) Let x be the cumulative IAT at hourly traffic volume (vphpl) a and y be the cumulative IAT at hourly traffic volume (vphpl) b. The IAT at c can be calculated as:
   $x + [(c - a) / (b - a)]*(y-x)$.

Universal Cumulative IAT Distribution spreadsheets were prepared to compute the scaled IAT distribution for any user-specified hourly traffic volume (vphpl) in the observed range of traffic volume, for each lane of 2, 3, or 4 lane freeways based on the above interpolation scheme.

RESULTS AND DISCUSSION

A total of nine Universal Cumulative IAT Distribution spreadsheets to compute the cumulative IAT distributions for any user-specified hourly traffic volume (vphpl) in the observed range of traffic volumes were generated. The range of the hourly traffic volumes observed in a lane is indicated at the end of each freeway mentioned below. The generated 9 Universal Cumulative IAT Distributions and their applicable volume ranges are as follows:

- 2-Lane Freeway-Right Lane (Lane 1), 200-1600 vphpl;
- 2-Lane Freeway-Lane 2, 150-1450 vphpl;
- 3-Lane Freeway- Right Lane (Lane 1), 200-1800 vphpl;
- 3-Lane Freeway-Lane 2, 200-1550 vphpl;
- 3-Lane Freeway-Lane 3, 150-1650 vphpl;
- 4-Lane Freeway- Right Lane (Lane 1), 100-1150 vphpl;
- 4-Lane Freeway-Lane 2, 150-1400 vphpl;
- 4-Lane Freeway-Lane 3, 100-1400 vphpl;
- 4-Lane Freeway-Lane 4, 100-1300 vphpl.

In TABLE 2, a Universal IAT Distribution spreadsheet for a 2-Lane freeway for lane 2 is given as an example for how to determine the IAT distribution for a given hourly traffic volume. In the spreadsheet the user enters only the observed number of vehicles per hour per lane in the corresponding interval into the shaded cell on the left and the IAT's for the corresponding cumulative probabilities are generated according to the linear interpolation formula and displayed in the cells to the right of the shaded cell.

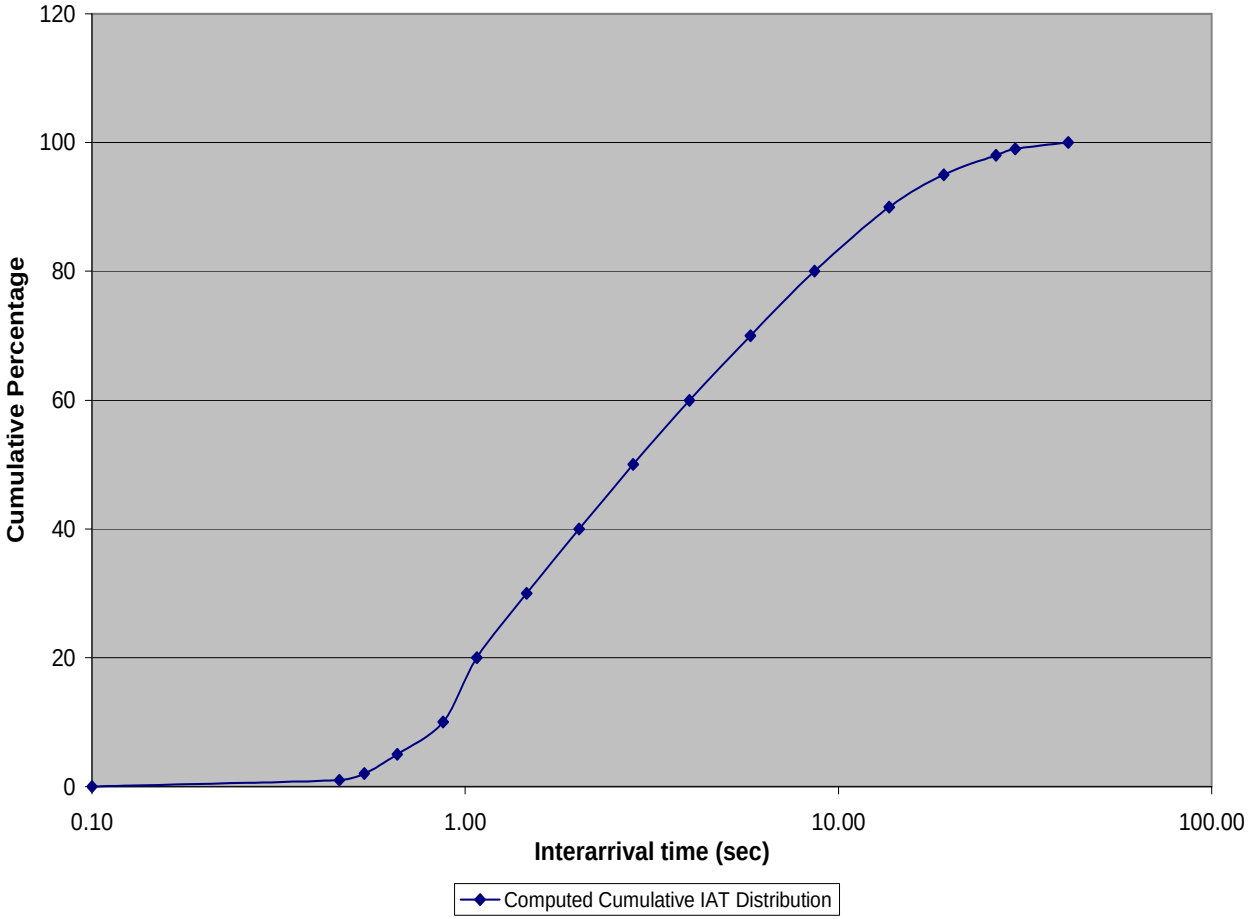
TABLE 2 Approximated and adjusted Cumulative IAT Distribution Spreadsheet for 2-Lane Freeways – Lane 2 for Traffic Volume of 150-1450 vphl

Interval for the Hourly traffic volume	Number of vehicles per hour	Cumulative Percentage																
		0%	1%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	99%	100%
150-200	175	0.10	0.57	0.69	1.03	1.62	2.82	4.60	7.17	11.03	16.77	24.44	35.83	48.37	73.27	93.00	108.30	123.86
201-250	225	0.10	0.54	0.64	0.91	1.38	2.25	3.58	5.49	8.35	12.60	18.36	26.95	41.64	55.61	71.27	82.66	96.90
251-300	275	0.10	0.52	0.62	0.85	1.25	1.93	3.00	4.53	6.82	10.20	14.87	21.85	33.87	45.50	58.87	68.01	81.61
301-350	325	0.10	0.51	0.60	0.80	1.15	1.71	2.59	3.86	5.75	8.54	12.46	18.33	28.50	38.50	50.27	57.86	70.99
351-400	375	0.10	0.50	0.59	0.77	1.08	1.54	2.29	3.38	4.97	7.33	10.69	15.75	24.56	33.37	43.96	50.42	63.17
401-450	425	0.10	0.49	0.57	0.74	1.03	1.42	2.06	3.00	4.38	6.40	9.34	13.77	21.55	29.45	39.13	44.72	57.17
451-500	475	0.10	0.48	0.56	0.72	0.98	1.31	1.88	2.71	3.91	5.67	8.27	12.22	19.17	26.35	35.31	40.22	52.41
501-550	525	0.10	0.48	0.56	0.70	0.95	1.23	1.74	2.47	3.53	5.08	7.41	10.96	17.25	23.84	32.21	36.56	48.53
551-600	575	0.10	0.47	0.55	0.68	0.91	1.16	1.61	2.27	3.21	4.60	6.70	9.92	15.67	21.76	29.65	33.55	45.31
601-650	625	0.10	0.46	0.54	0.67	0.89	1.10	1.51	2.10	2.95	4.19	6.11	9.05	14.34	20.02	27.50	31.01	42.60
651-700	675	0.10	0.46	0.53	0.65	0.86	1.05	1.42	1.96	2.73	3.84	5.60	8.31	13.20	18.54	25.66	28.85	40.27
701-750	725	0.10	0.45	0.53	0.64	0.84	1.01	1.35	1.84	2.53	3.54	5.17	7.67	12.23	17.26	24.07	26.98	38.25
751-800	775	0.10	0.45	0.52	0.63	0.82	0.97	1.28	1.73	2.36	3.28	4.79	7.12	11.38	16.15	22.68	25.35	36.47
801-850	825	0.10	0.44	0.51	0.62	0.81	0.94	1.22	1.64	2.22	3.05	4.46	6.64	10.64	15.17	21.46	23.92	34.91
851-900	875	0.10	0.44	0.51	0.61	0.79	0.90	1.17	1.55	2.09	2.85	4.16	6.21	9.98	14.31	20.38	22.65	33.51
901-950	925	0.10	0.43	0.50	0.60	0.77	0.88	1.12	1.48	1.97	2.67	3.90	5.82	9.39	13.53	19.41	21.52	32.25
951-1000	975	0.10	0.43	0.50	0.59	0.76	0.85	1.08	1.41	1.86	2.51	3.67	5.48	8.87	12.84	18.54	20.50	31.12
1001-1050	1025	0.10	0.43	0.49	0.59	0.75	0.83	1.04	1.35	1.77	2.37	3.46	5.17	8.39	12.21	17.75	19.58	30.09
1051-1100	1075	0.10	0.42	0.49	0.58	0.74	0.82	1.03	1.34	1.76	2.35	3.43	5.13	8.33	12.12	17.61	19.43	29.85
1101-1150	1125	0.10	0.42	0.49	0.57	0.73	0.79	0.97	1.24	1.61	2.12	3.09	4.64	7.57	11.13	16.38	17.98	28.27
1151-1200	1175	0.10	0.42	0.48	0.56	0.72	0.77	0.94	1.20	1.54	2.01	2.94	4.41	7.22	10.66	15.78	17.28	27.48
1201-1250	1225	0.10	0.41	0.48	0.56	0.71	0.75	0.92	1.16	1.47	1.91	2.79	4.20	6.89	10.22	15.22	16.64	26.74
1251-1300	1275	0.10	0.41	0.47	0.55	0.70	0.74	0.89	1.12	1.41	1.82	2.66	4.00	6.59	9.82	14.71	16.04	26.05
1301-1350	1325	0.10	0.40	0.47	0.55	0.69	0.72	0.87	1.08	1.35	1.74	2.54	3.82	6.31	9.45	14.24	15.49	25.41
1351-1400	1375	0.10	0.40	0.46	0.54	0.68	0.71	0.85	1.05	1.30	1.66	2.42	3.66	6.05	9.11	13.80	14.98	24.81
1401-1450	1425	0.10	0.40	0.46	0.54	0.67	0.69	0.82	1.01	1.26	1.59	2.32	3.50	5.82	8.79	13.39	14.51	24.25

As an example, suppose the user desires to obtain the cumulative IAT distribution for 653 vehicles per hour per lane for Lane 2 of a 2-lane freeway. First, it needs to be determined if the user-specified vphpl is in the observed range (between 150-1450). If the user-specified vphpl is in the range then it is entered into the corresponding cell according to the traffic volume ranges specified in increments of 50 vphpl in the spreadsheet. For 653 vphpl, the corresponding cell is in the 651-700 vphpl range of the traffic volumes. We obtain the cumulative IAT distribution values as shown in FIGURE 2a for the traffic volume of 653 vphpl. For illustration purposes FIGURE 2b shows the generated cumulative IAT distribution.

vphpl = 653	
Cumulative Percentage	**Inter arrival time**
%	**(seconds)**
0	0.10
1	0.46
2	0.54
5	0.66
10	0.87
20	1.07
30	1.46
40	2.02
50	2.82
60	3.99
70	5.81
80	8.62
90	13.68
95	19.17
98	26.43
99	29.76
100	41.25

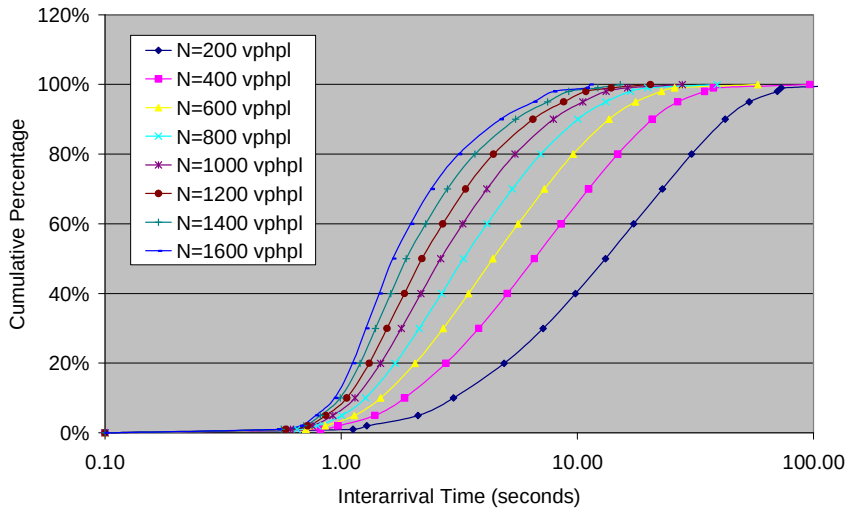
a



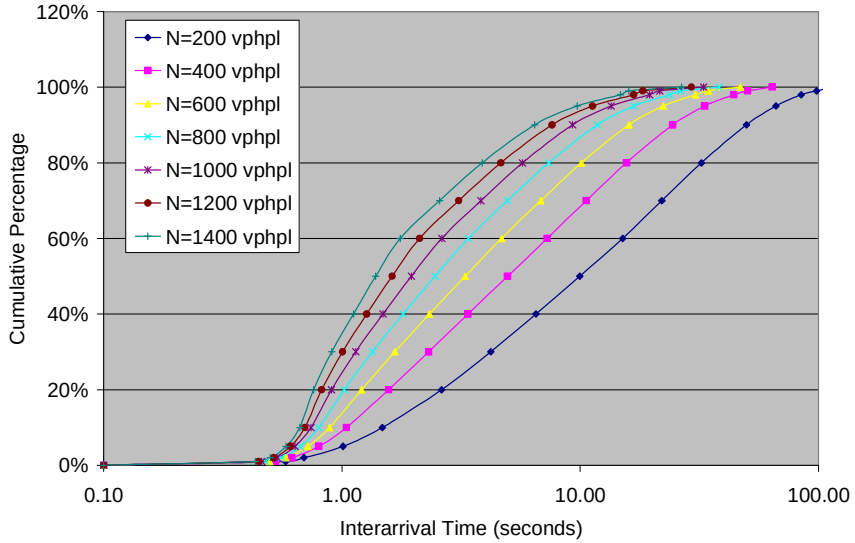
b

FIGURE 2 Approximated Cumulative IAT Distribution for N=653 vphpl for 2-Lane Freeway Lane 2 Traffic a) IAT's at given cumulative percentages b)Plot of the IAT's vs. cumulative percentage.

In FIGURE 3, FIGURE 4, FIGURE 5, and FIGURE 6 the graphs for the generated universal cumulative IAT distributions for different freeway configurations for different lanes are given for selected traffic volumes within the observed ranges of traffic. The IAT scales in the graphs are given using a logarithmic scale along the abscissa to highlight the difference between lower IAT's at higher traffic volumes.

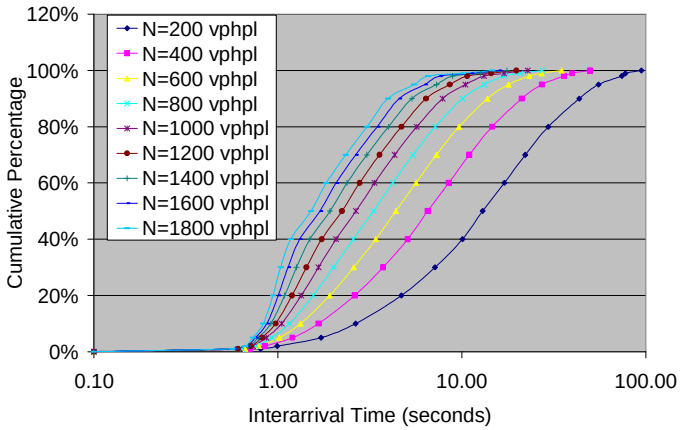


a

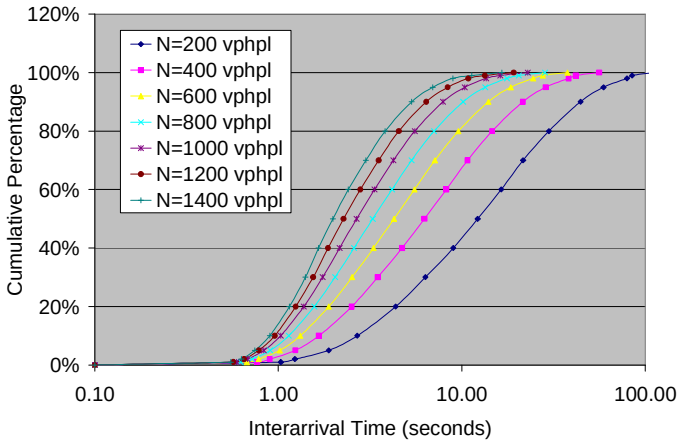


b

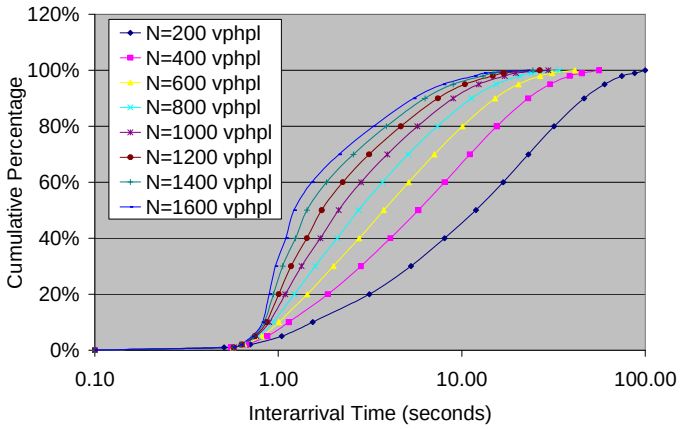
FIGURE 3 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for 2-Lane Freeways for a) Right Lane (Lane 1) (Cumulative IAT Distribution Range= 200-1600 vphpl) and b) Lane 2 (Cumulative IAT Distribution Range= 150-1450 vphpl).



a

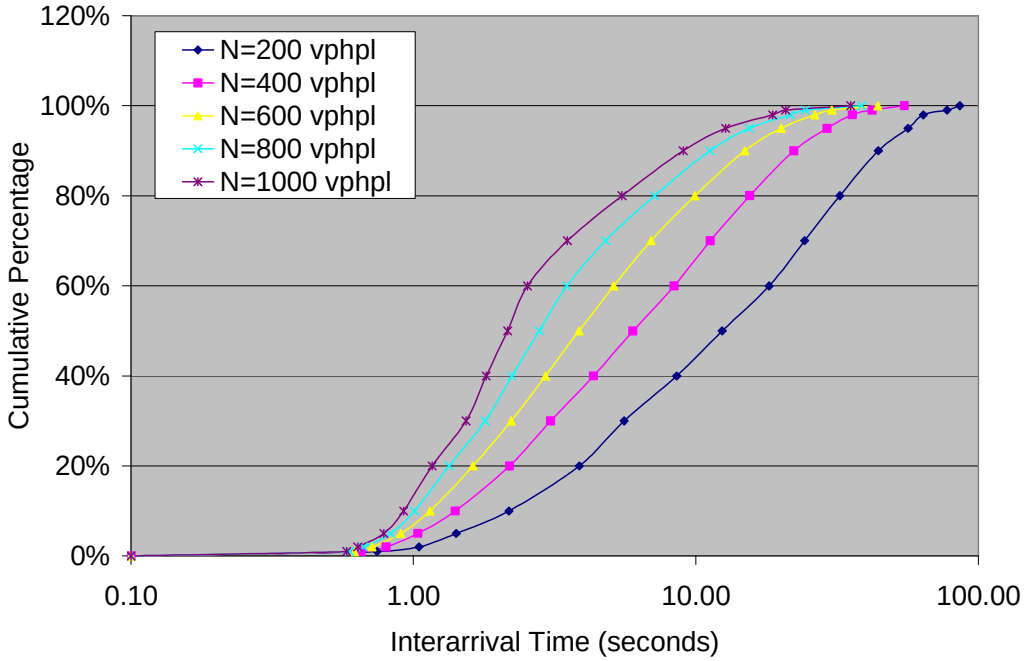


b

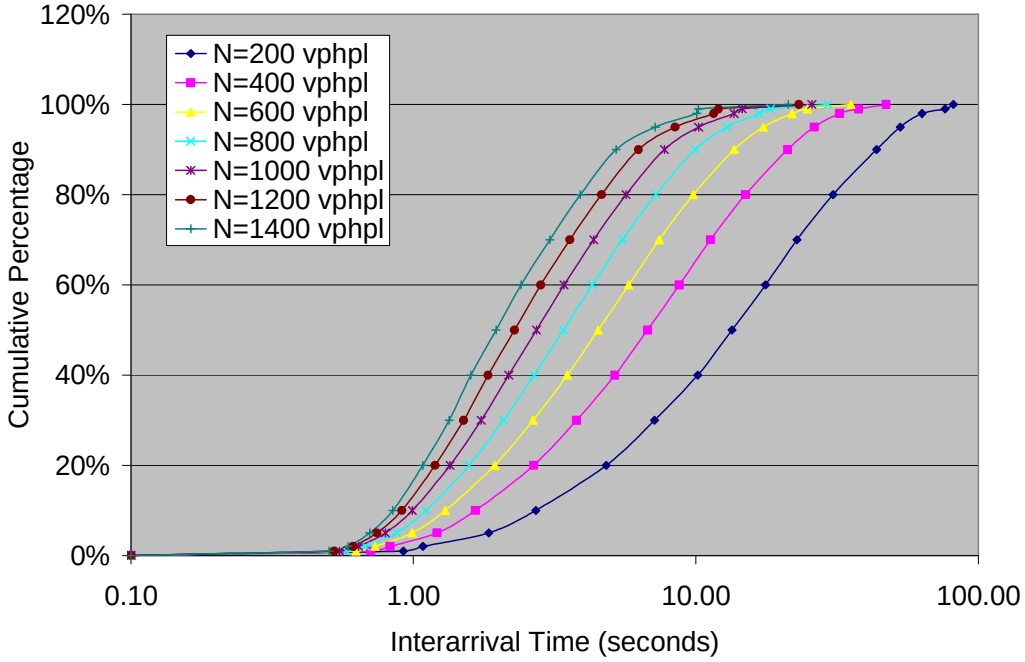


c

FIGURE 4 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for 3-Lane Freeways for a) Right Lane (Lane 1) (Cumulative IAT Distribution Range= 200-1800 vphpl), b) Lane 2 (Cumulative IAT Distribution Range= 200-1550 vphpl), and c) Lane 3 (Cumulative IAT Distribution Range= 150-1650 vphpl).

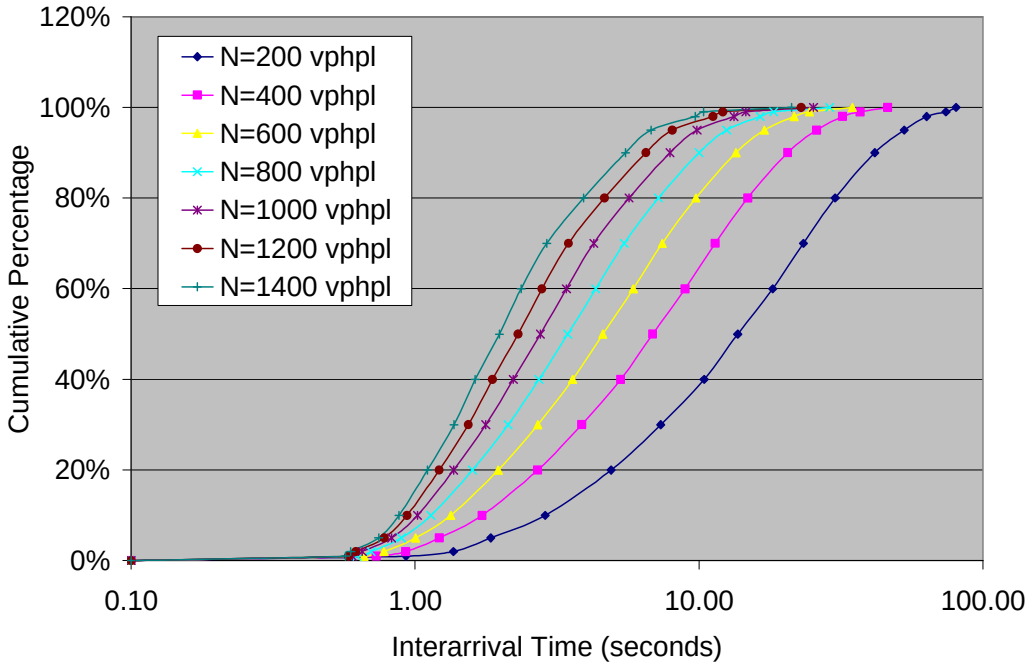


a

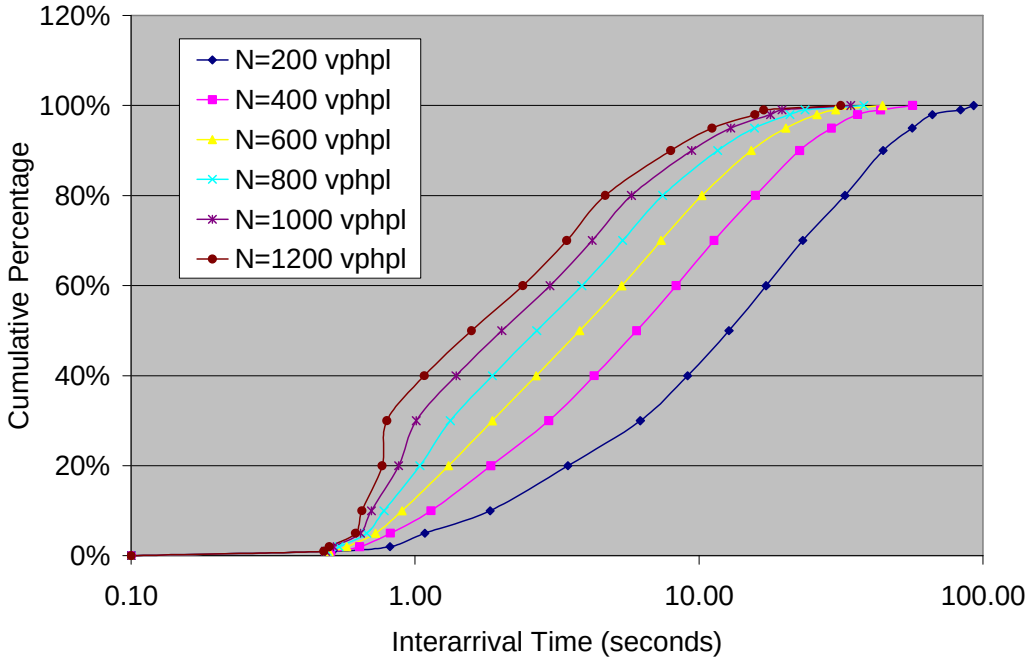


b

FIGURE 5 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for 4-Lane Freeways for a) Right Lane (Lane 1) (Cumulative IAT Distribution Range= 100-1150 vphpl) b) Lane 2 (Cumulative IAT Distribution Range= 150-1400 vphpl).



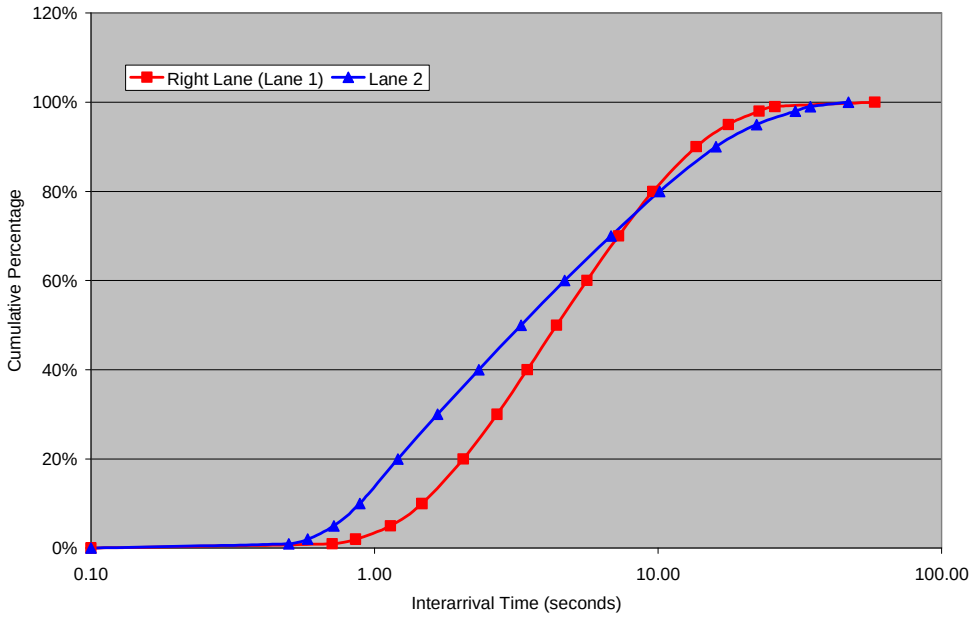
a



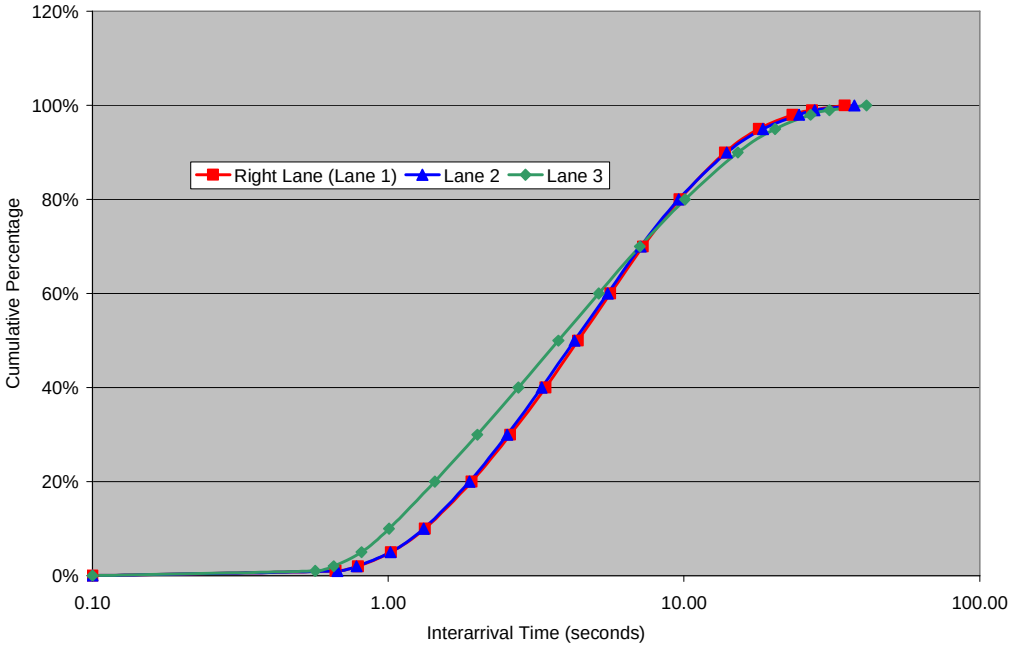
b

FIGURE 6 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for 4-Lane Freeways for a) Lane 3 (Cumulative IAT Distribution Range= 100-1400 vphpl) b) Lane 4 (Cumulative IAT Distribution Range= 100-1300 vphpl).

In Figure 7 and Figure 8 cumulative IAT distributions generated with the universal distributions for freeways with different number of lanes are compared according to the lane of travel for a selected hourly traffic volume of 600 vphpl and for all sites for an hourly traffic volume of around 470 vph in Figure 8b.

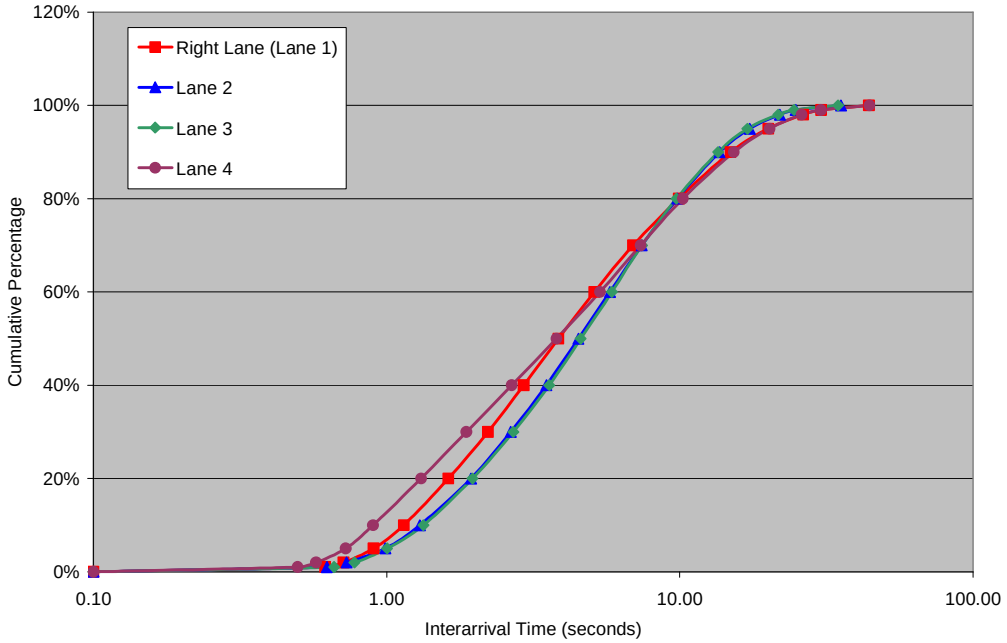


a

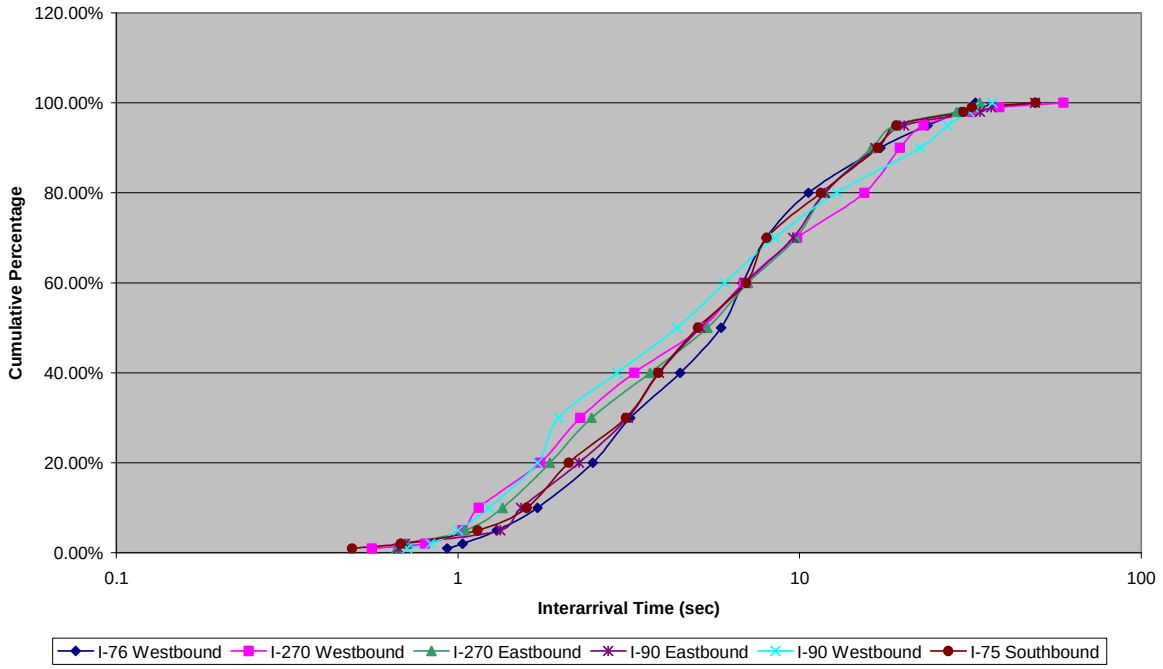


b

FIGURE 7 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for a) 2-Lane Freeways for Right Lane (Lane 1) and Lane 2 (N=600 vphpl) b) 3-Lane Freeways for Right Lane (Lane 1), Lane 2, and Lane 3 (N=600 vphpl).



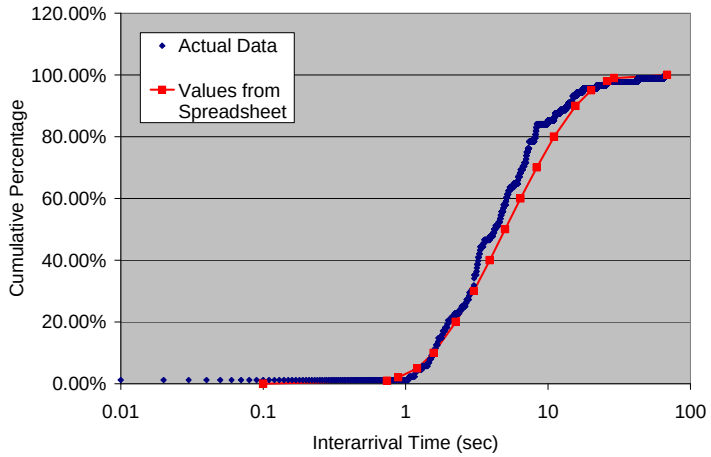
a



b

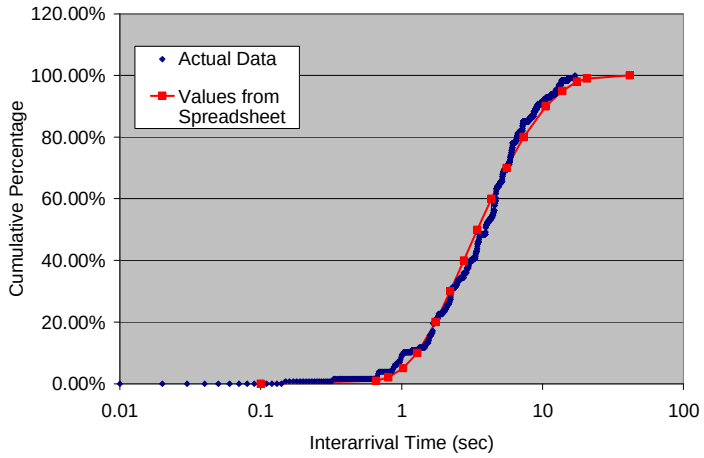
FIGURE 8 Comparison of Universal Approximated Cumulative Interarrival Time Distributions for a)4-Lane Freeways for Right Lane (Lane 1), Lane 2, Lane 3, and Lane 4 (N=600 vphpl) b) Comparison of Approximated Cumulative IAT's for Daytime for Driving Lanes for I-76 Westbound (N=476 vph), I-270 Westbound (N=466 vph), I-270 Eastbound (N=479 vph), I-90 Eastbound (N=483 vph), I-90 Westbound (N=474 vph), and I-75 Southbound (N=472 vph).

The validation results in FIGURE 9 and FIGURE 10 show fairly good fits for traffic volumes near the minimum, the middle, and the maximum range of the observed traffic volumes. The independent actual IAT data used for the validation were recorded at another site by Schnell, et al. *(16)* at I-70 Westbound near SR-256 in 2000. The independent data available were for a 2-Lane freeway for the Right Lane (Lane 1) and Lane 2. The universal IAT distributions were compared with the actual independent data using the Kolmogorov-Smirnov Goodness of Fit Test *(17)*. For both lanes all validation data sets are fitted rather well by the universal IAT distributions.



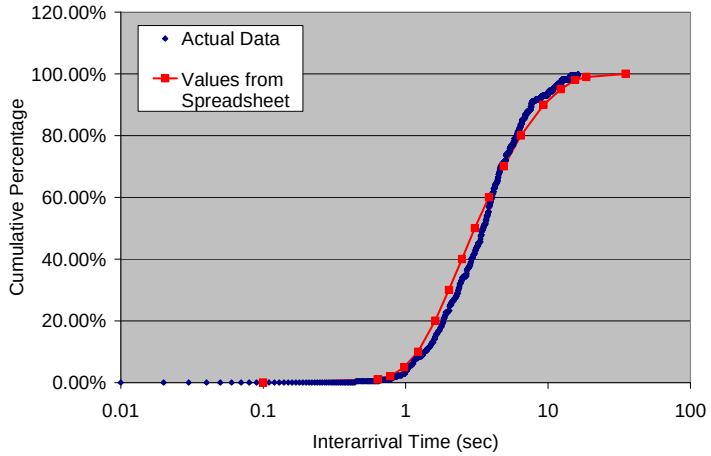
a
Actual Data
N=88
Average= 6.64 sec
Standard Deviation= 8.8 sec
Number of Vehicles= 528 vphpl

Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.10
D Critical=0.20 (Level of Significance=0.05)
Do not Reject



b
Actual Data
N=128
Average= 4.61 sec
Standard Deviation= 3.4 sec
Number of Vehicles= 768 vphpl

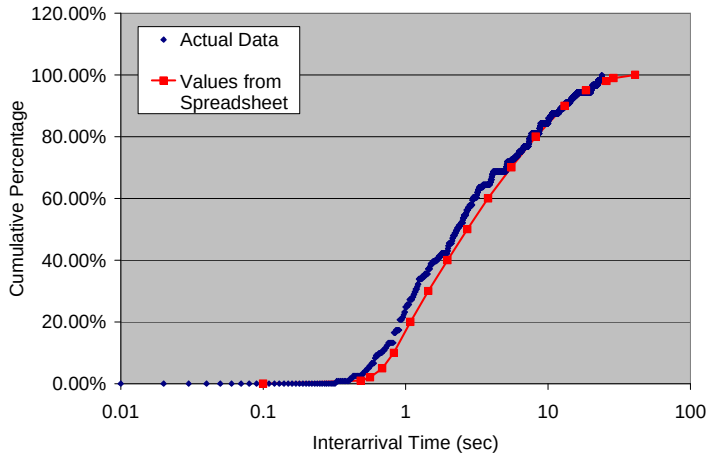
Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.06
D Critical=0.17 (Level of Significance=0.05)
Do not Reject



c
Actual Data
N=215
Average= 4.19 sec
Standard Deviation= 2.92 sec
Number of Vehicles= 860 vphpl

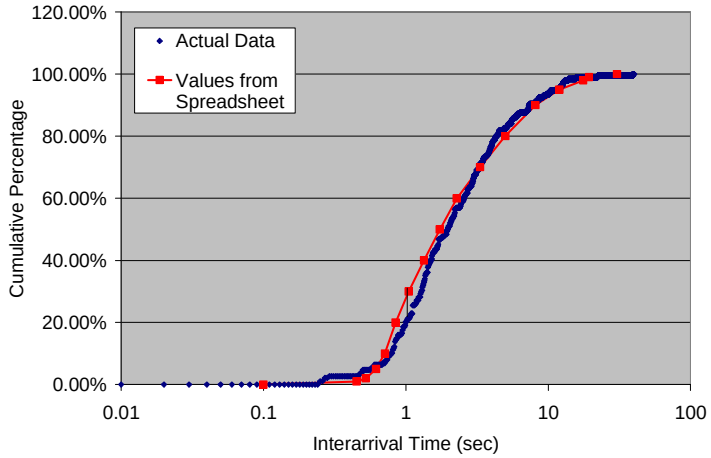
Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.07
D Critical=0.13 (Level of Significance=0.05)
Do not Reject

FIGURE 9 Comparison of Actual Interarrival Time Data for Urban (I-70 WB/SR-256) Right Lane (Lane 1) and Calculated Interarrival Time Data using Right Lane (Lane 1) Universal Approximated Cumulative Interarrival Time Distribution for 2-Lane Freeways for a) N=528 vphpl, b) N=768 vphpl, and c) N=860 vphpl.



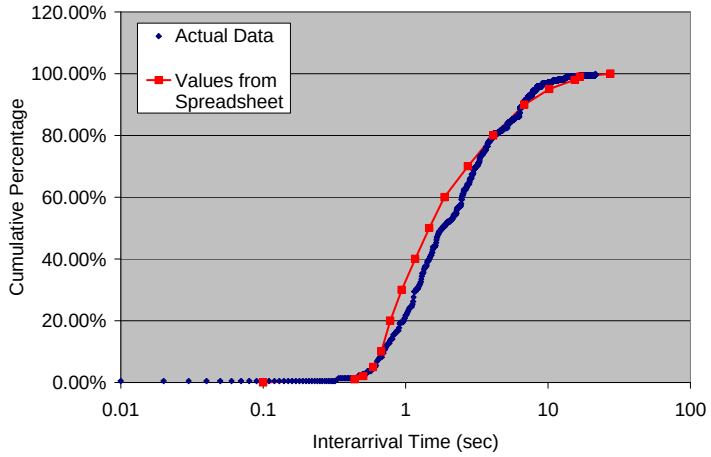
a
Actual Data
N=121
Average= 4.74 sec
Standard Deviation= 5.66 sec
Number of Vehicles= 726 vphpl

Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.07
D Critical=0.17 (Level of Significance=0.05)
Do not Reject



b
Actual Data
N=188
Average= 3.32 sec
Standard Deviation= 4.21 sec
Number of Vehicles= 1128 vphpl

Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.09
D Critical=0.14 (Level of Significance=0.05)
Do not Reject



c
Actual Data
N=221
Average= 2.93 sec
Standard Deviation= 2.93 sec
Number of Vehicles= 1326 vphpl

Kolmogorov-Smirnov Goodness of Fit Test
D Observed (by visual inspection)=0.11
D Critical=0.13 (Level of Significance=0.05)
Do not Reject

FIGURE 10 Comparison of Actual Interarrival Time Data for Urban (I-70 WB/SR-256) Lane 2 and Calculated Interarrival Time Data using Lane 2 Universal Approximated Cumulative Interarrival Time Distribution for 2-Lane Freeways for a) N=726 vphpl, b) N=1128 vphpl, and c) N=1326 vphpl.

In this research the approximated cumulative IAT or headway distributions for similar hourly traffic volumes for the same lane for different freeways in Ohio had similar configurations meaning that vehicle arrivals have the same pattern for similar types of freeways in Ohio. These were also compared to investigate portability of IAT distributions between different freeways with the same configuration. Two 2-lane freeways and three 3-lane freeways were compared with each other. Traffic data were available only for one 4-lane freeway, so no portability analysis could be performed for 4-lane freeways. Nearly equal hourly traffic volumes were selected near the minimum, center, and the maximum of the observed ranges of traffic volumes.

CONCLUSIONS

We have developed an easy to use and nearly automatic method to convert hourly traffic volumes into corresponding approximate cumulative IAT distributions for 2, 3, and 4 lane freeways in Ohio which can be used as input for running discrete digital simulation models to analyze the effects of the bottlenecks in a work zone. It should be noted that the approximated IAT distributions developed are useful in traffic simulations, driving simulators and they may not be accurate and detailed enough to be used for capacity estimation and safety analyses. One might ask whether or not the conversion method developed in this study is important and useful? Most existing mathematical models for headways, such as the ones based on the Poisson or Erlang distributions, do not model IAT distributions observed on freeways very closely. More complex mathematical headway models such as a Pearson Type III *(5)* model could be used to generate probabilistic IAT's, however such two-parameter models require knowledge of the average IAT and the standard deviation of the IAT's which must be calculated using actual field data which requires a substantial data collection effort. The conversion approach presented here, using a least squares fit approach to hyperbolic equations to get the best relationship between the cumulative IAT's and the hourly traffic volumes has been implemented in an easy-to-use Excel spreadsheet which works quite well and appears to provide reasonably accurate cumulative IAT distributions which can then be used in stochastic queuing model simulations to investigate traffic bottlenecks in work zones with lane closures. The approximated cumulative IAT Distribution spreadsheets for freeways with different number of lanes may be downloaded at http://webce.ent.ohiou.edu/orite/CumulativeIATDistributions.html. The study also investigated the portability of the approximated cumulative IAT distributions for a given traffic volume, traffic lane, and freeway configuration for different freeway locations in Ohio. The comparison included 2-lane and 3-lane freeways and found that the approximated cumulative IAT or headway distributions are nearly the same for a given lane and for a similar hourly traffic volume.

Future research efforts could include expanding the range of hourly traffic volumes in the spreadsheet by studying freeway sites with lower and higher hourly traffic volumes and to investigate headway or IAT distributions in other geographic areas of the United States where driver behavior might differ from what is observed in Ohio. Research is also needed to possibly refine and validate the use of the approximated cumulative IAT distributions and the developed conversion method for other purposes such as capacity estimations and safety analyses.

ACKNOWLEDGEMENTS

This research was sponsored by the Ohio Department of Transportation and the Federal Highway Administration. We'd like to thank our technical liaisons David Holstein, administrator of the ODOT Office of Traffic Engineering, Mack Braxton, and Ken Linger of the ODOT Office of Traffic Engineering for their technical and logistical support. We also thank Monique Evans, administrator and her staff, ODOT Office of Research and Development, for their administrative support.

REFERENCES

1. Kyte, Michael and Stan Teply, Traffic and Flow Characteristics, *Traffic Engineering Handbook*, James L. Pline, Editor, Institute of Transportation Engineers, 5th edition, 1999.
2. *QuickZone Delay Estimation Program Version 1.01 User Guide*, prepared by Mitretek Systems for Federal Highway Administration, February 2002. See also http://www.tfhrc.gov/its/quickzon.htm, accessed July, 2005.
3. Gross, Donald and Harris, Carl M., *Fundamentals of Queuing Theory*, Second Edition, John Wiley & Sons, New York, 1985.
4. Naylor, Thomas H. et al., *Computer Simulation Techniques*, John Wiley & Sons, New York, 1966.
5. May, A. D. *Traffic Flow Fundamentals*, Prentice Hall, Englewood Cliffs, NJ, 1990.
6. Gerlough, Daniel L. and Matthew J. Huber, *Traffic Flow Theory, A monograph*, Special Report 165, Transportation Research Board, National Research Council, Washington, D.C., 1975, p. 17-31.
7. Munjal, P.K. and Y.S. Hsu, *Characteristics of Freeway Traffic and of Freeway Lane-Changing Behavior*, Highway Research Record, Number 453: Traffic: Capacity, Delay, and Quality of Service, Highway Research Board, National Research Council, Washington, D.C., 1973, p. 10-27.
8. Drew, Donald R., *Traffic Flow Theory and Control*, McGraw-Hill Series in Transportation, 1968, p. 147-172.
9. Chowdhury, D., A. Pasupathy, and S. Sinha, Distributions of time- and distance-headways in the Nagel-Schreckenberg model of vehicular traffic: effects of hindrance. *The European Physical Journal B 5*, 1998, pp.781-786.
10. Luttinen, R.T., Statistical Properties of Vehicle Time Headways. In *Transportation Research Record: Journal of the Transportation Research Board*, No.1365, TRB, National Research Council, Washington, D.C., 1992, pp. 92-98.
11. Al-Ghamdi, Ali S., Analysis of Time Headways on Urban Roads: Case Study from Riyadh. *Journal of Transportation Engineering*, July-August 2001, pp. 289-294.
12. *Statistics Tool; Microsoft Office* by Microsoft, Inc available at http://office.microsoft.com/en-us/default.aspx, accessed on July, 2005
13. Zwahlen, Helmut T. et al., Evaluation of Microwave Radar Trailers for Nonintrusive Traffic Measurements. Paper no.05-1472. Presented at the 84th Annual Meeting of the Transportation Research Board, Washington, DC, 2005.
14. *MATLAB Statistical Software* by MathWorks, Inc, available at http://www.mathworks.com/index.html?ref=logo, accessed on July, 2005.
15. Mary Gibbons Natrella. *Experimental Statistics*. National Bureau of Standards Handbook 91, United States Department of Commerce, Issued August 1st, 1963 chapter 19, pp.19-1 to 19-4.
16. Schnell T., J. Mohror, F. Aktan. Evaluation Of Traffic Flow Analysis Tools Applied To Work Zones Based On Flow Data Collected In The Field. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1811*, TRB, National Research Council, Washington, DC, 2002.
17. Siegel, Sidney, *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill Book Company, Inc., 1956.