EXAMINATION OF PROBE VEHICLE'S TIME HEADWAY CHARACTERISTICS

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1. INTRODUCTION

The area of time headway distribution (THD) modeling is fundamental to many traffic flow-related studies such as capacity estimation, safety analysis, microscopic simulation, etc. Up to now, most of the existing THD models concern about the behavior of general vehicles on a single lane traffic stream or on multiple lanes traffic stream.

With the advent of Intelligent Transportation Systems (ITS), the systems that concern with probe vehicles have become popular and important. Such systems include Automatic Vehicle Identification (AVI), Global Positioning System (GPS), Beacon, etc. One of the advantages of these systems is that they can automatically detect and collect real-time traffic data with less or without employing observers, thereby provide valuable information such as arrival time at a reader station, point-to-point travel times, current location of probe vehicles, etc. These data have been applied to the Advanced Traffic Information System (ATIS) to provide travel time information to road users. Another application of the probe data is the incident detection and management, particularly using the time headway information of probes.

The existing time headway models, however, have not considered for only the sample vehicles (i.e. probe vehicles) of the whole traffic stream. This problem is raised since the time headway between probe vehicles is a byproduct of some ITS systems and also easily to obtain. It is expected that the study on probes' THD is an efficient way to gain good understanding of general vehicles' THD. In this context, the goal of this paper is to analyze the probes' THD.

This paper firstly discusses the notation used to represent the parameters of time headway distribution. Next, the real world data of probes obtained from AVI system is analyzed. Finally, the analysis is done based on the data generated from simulation technique. Some relationships between the parameters of probes' headway and the parameters of general vehicles' headway are also developed.

2. NOTATION

r	=	market penetration of probe vehicles;
V	=	volume of general vehicles on a lane, veh/hr/lane (vphpl);
Δ	=	shifted value of general vehicles' headway distribution on a lane;
Δ^p	=	shifted value of probe vehicles' headway distribution on a lane;
m	=	mean of general vehicles' headway on a lane;
m'	=	shifted mean of general vehicles' headway (i.e., $m-\Delta$) on a lane;
s	=	standard deviation of general vehicles' headway on a lane;
m^p	=	mean of probes' headway on a lane;
s^p	=	standard deviation of probes' headway on a lane.

3. INVESTIGATING PROBE'S HEADWAY: REAL WORLD PART (AVI DATA)

3.1 Data Collection and Experimental Study Design

The test bed freeway is US-290, which is a radial urban freeway in Houston, Texas. It is a part of the Houston traffic monitoring system which currently includes approximately 365 km of freeway and 113 km of high occupancy vehicle (HOV) lane installed with AVI system. AVI station number 41 was used as the observation point. Station number 41 is for a HOV lane which is located at the median lane.

The time headway data of probes for 10 weekdays, 14-18 and 21-25 April in 1997, were used in this study. The study time period was defined as lasting from 6:00 AM to 6:00 PM. Only the Eastbound headway data were employed in this study. Due to the nature of AVI system, the information of non-probe vehicles was not available. The volume of the AVI vehicles was 42-168 veh/hr/lane.

The collected AVI data were then classified into different groups based on the probe volume in 10 minute duration in order to analyze the effect of the different probe volume levels on the headway distribution. In this study, data were classified to 10 volume ranges.

The analyses were performed from two aspects: the goodness of fit test and the suitable shifted value. For the goodness of fit test, the headway data of each volume range were tested with three theoretical distributions, namely Shifted Negative Exponential (SNE), Lognormal (LOG), and Pearson type III (PEAR). The test was made based on Chi-square test at 0.05 level of significance with the shifted values ranging from 0.0 to 3.0 seconds at an increment of 0.1 second. The suitable shifted value for each theoretical distribution was chosen as the one that gave the highest number of passing fit test from all volume ranges. This number of passing fit test was used to represent how well each theoretical distribution fit with probes' headway.

3.2 Results and Discussions

The summary results of the Chi-square tests are shown in Table 1. It is observed that SNE and PEAR are the best distribution, while LOG is the worst. This result may be attributed to the fact that the hourly volume of AVI probes per lane was low. It has been shown by a

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number of researchers that Negative Exponential (NE) and SNE generally provide a good fit for traffic data under low volume conditions (i.e. random) [1, 2]. It should be noted that NE and SNE are also a specific form of PEAR. Accordingly, it can be hypothesized that when the volume of probe vehicles is low, time headway of probes follows the NE or SNE. This hypothesis will be examined again in section 4.

Table 1. Summary Results of Chi-square Test of AVI Time Headway Data

Distribution Type	Suitable Shifted Value (sec)	Number of passing fit test
SNE	0.0 - 2.0	9 (10)*
LOG	0.0 - 0.9	1 (10)*
PEAR	0.0 - 0.3	9 (10)*

* The number in parenthesis represents the total number of volume ranges

Note that in Table 1 not only single but multiple numbers were found to be the suitable shifted value(s). In addition, it is observed that the suitable shifted values are very low. This result seems acceptable because the minimum allowable headway of probe vehicles on a single lane should be similar to that of general vehicles' headway. It is also observed that the suitable shifted value does not have any systematic relationship with the distribution types.

The fit tests for AVI vehicle's headway during peak period were also done and the results are shown in Table 2. During the morning peak period (i.e. 6:30~8:30), the average speed of the test bed freeway was about 35~50 km/hr, implying that the level of traffic congestion (general vehicles) was severe. From Table 2, it can be seen that the AVI vehicle's headway of this period tends to follow SNE and PEAR because the number of passing fit test are eight out of nine. It is noted that the number of volume range is not the same as previous since only the morning peak data was considering. In this sense, it is also hypothesized that even if the level of traffic congestion is not light, if the volume level of probes is low, the probes' headway follows the SNE and/or PEAR. In other words, if the volume level of probes is low, the probes' headway follows the SNE and/or PEAR regardless of the volume level of general vehicles.

Figure 1 demonstrates the frequency distributions of probes' headway superimposed with theoretical distributions.

4. INVESTIGATING PROBE'S HEADWAY BY SIMULATION

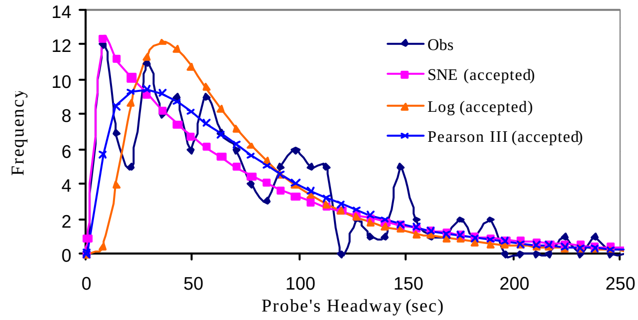
4.1 Experimental Study Design

For the simulation, it was assumed that there is no interaction between general vehicles (and also between probe vehicles since they are subset of general vehicles). The distribution of general vehicles' headway (type of distribution function, mean (m), standard deviation (s), and shifted value (Δ)) and the market penetration of probe vehicles, r, were first assumed. The series of general vehicles' headway were generated based on the assumed distribution. They were then converted into the observed passing times of general vehicles at the observation point. Geometric distribution was then used to classify the generated vehicles as non-probe vehicle or probe vehicle based on the assumed value of r. The probes' headway was calculated by finding the difference between the passage times of the current probe and the next probe. The next probe vehicle was again treated as the current probe vehicle. By repeating this process, a set of probes' headway on a single lane was obtained.

Table 2. Summary Results of Chi-square Test of AVI Time Headway Data during Peak Period

Distribution Type	Suitable Shifted Value (sec)	Number of passing fit test
SNE	0.0 - 2.0	8 (9)*
LOG	-	0 (9)*
PEAR	0.0 - 0.3	8 (9)*

* The number in parenthesis represents the total number of volume ranges during the peak period



Volume range 9-10 veh(probe)/10min, shifted = 0.0 sec

Figure 1. Example of THD of AVI Vehicles

Ten values of V were assumed in this study. They were then classified as low (less than 400 vphpl), medium (400–1,200 vphpl), and high (greater than 1,200 vphpl) traffic conditions following Al-Ghamdi [3]. The distribution functions for the low, medium, and high traffic conditions were assumed as SNE, PEAR, and LOG, respectively, based on the previous researches [1, 4, 5]. In addition, m (which is measured from origin and equal to the shifted mean headway plus shifted value, $m' + \Delta$) was assumed to have the relationship with V as shown in the following equation:

$$m = \frac{3600}{V} \quad (1)$$

By assuming Δ, the values of m' corresponding to each V were calculated by subtracting Δ from m. The value of s was estimated based on the following Al-Ghamdi [3]'s formula in Equation (2).

$$s = -0784 + 0.777m' \quad (2)$$

At each value of V, there were two values of Δ (i.e., 0.5 and 1.0 seconds) and five values of r (i.e., 0.2, 0.4, 0.6, 0.8, 1.0). Therefore, the total number of cases in this study was 100 (i.e., 10 volume levels x 2 shifted values x 5 market penetrations).

For each case, ten different simulations were performed and at each simulation, 40,000 of probes' headway data were generated. The first half of data set (the first 20,000 data) was used to calculate m^p and s^p. Then, the second half of data set was used for the goodness of fit test with three theoretical distributions (i.e. SNE, PEAR, and LOG) with m^p and s^p obtained from the first half data set. The test was made based on Chi-square test at 0.05 level of significance with the Δ^p ranging from 0.0 to 3.0 seconds at an increment of 0.1 second.

Since each case consists of ten different simulations, this study used the summary results instead of showing all results. That is, the number of passing fit test was categorized into two categories: 0-5 and 6-10. Similar to the real-world probe data analysis of Section 3, the number of passing fit test was counted at the shifted value(s) which provides the highest number of passing.

4.2 Result Analysis and Discussion

4.2.1 Fit Results

The fit results were summarized in Table 3 for the cases of Δ equal to 0.5 and 1.0 seconds. For low traffic condition, it is observed that SNE and PEAR are considered to be the good distribution to fit at any value of market penetration of probes. For medium traffic condition, SNE and PEAR provided the good fit when only the market penetration is low (0.2 & 0.4). For high traffic condition, it is observed that SNE and PEAR provided the good fit at *r* equal to 0.2 and Δ equal to 0.5 sec. In addition, it is also observed that overall LOG does not provide the good fit.

When comparing the results of this simulation with those of real world part (in section 3), it may be seen that SNE provides the good fit with probes' headway when *V* is up to medium level with low market penetration.

From the above results, it is hypothesized that *V* and *r* are important factors to the distribution of probes' headway. In addition, SNE and PEAR seem to well represent probes' headway distribution at both low and medium traffic volume levels, particularly with low value of *r*. It should be noted that the value of *r* in the real world part was also low as less than 0.2. This result is similar to the finding of the real-world data part in Section 3 where SNE and PEAR were found as the best distribution among three theoretical distributions to fit well with probes' headway. It is also observed that LOG does not fit well with probes' headway at all traffic volume levels, which confirms the finding of Section 3.

4.2.2 Relationship Between Parameters of General Vehicles' and Probes' Headway

First, the values of m^p obtained from simulation were thoroughly analyzed in order to understand the trend of how they related to the other parameters of general vehicles' headway. Next, some relationships were developed and tested by the actual values of m^p.

Table 3. Summary of Simulation Results

Traffic Volume Level	V (vphpl)	THD of general vehicles*	r	Distribution with the Number of Passing Fit Test Greater than 5*	
				Δ =0.5 sec	Δ =1.0 sec
Low	200	SNE	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6	Sne. Pear	Sne. Pear
			0.8	Sne. Pear	Sne. Pear
			1.0	Sne. Pear	Sne. Pear
	300	SNE	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6	Sne. Pear	Sne. Pear
			0.8	Sne. Pear	Sne. Pear
			1.0	Sne. Pear	Sne. Pear
	400	SNE	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6	Sne. Pear	Sne. Pear
			0.8	Sne. Pear	Sne. Pear
			1.0	Sne. Pear	Sne. Pear
Medium	600	Pear	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6		
			0.8		
			1.0	Pear	Pear
	800	Pear	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6		Sne. Pear
			0.8		
			1.0	Pear	Pear
	1000	Pear	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	Sne. Pear
			0.6		
			0.8		
			1.0	Pear	Pear
	1200	Pear	0.2	Sne. Pear	Sne. Pear
			0.4	Sne. Pear	
			0.6		
			0.8		
			1.0	Pear	Pear
High	1400	Log	0.2	Sne. Pear	
			0.4		
			0.6		
			0.8		
			1.0	Log	Log
	1600	Log	0.2	Sne. Pear	
			0.4		
			0.6		
			0.8		
			1.0	Log	Pear. Log
	1800	Log	0.2	Sne. Pear	**
			0.4		**
			0.6		**
			0.8		**
			1.0	Log	**

* Pear and Log are used to represent Pearson type III and Lognormal, respectively

** This case is not applicable since the calculated is s^p negative

To examine how well the developed relationships are, the Average Percentage Error (APE) and the Maximum Percentage Error (MPE) were employed. The APE was defined as the average relative error between the actual and the estimated value in percent and the MPE was defined as the maximum relative error between the actual and the estimated value in percent.

The relationship of m^p with parameters of general vehicle headway was found as Equation 3.

$$m^p = \frac{m' + \Delta}{r} \quad (3)$$

The estimated m^p using Equation 3 and the actual m^p were compared as shown in Table 4. From Table 4, it can be seen that both APE and MPE are very low under all traffic conditions. Thus, it might be reasonable to conclude that Equation 3 represents well the relationship between m^p and the parameters of general vehicles' headway.

Table 4. Comparisons between Estimated and Actual m^p

Traffic Condition	APE (%)	MPE (%)
Low	0.54	1.67
Medium	0.40	2.00
High	0.32	1.44
Unified*	0.42	2.00

Unified*: The comparisons were done by accounting estimated and actual m^p from all volume levels

In order to find the relationship between s^p and the parameters of general vehicles' headway, the similar procedures as above were done. However, it seems very difficult to develop any systematic relationship which provides a good estimated value of s^p for all situations except the case when the traffic condition is low. The proposed equation of s^p for the low traffic condition is given in Equation 4. The comparison between the estimated value and the actual value is found to be 0.78% and 2.83% for APE and MPE, respectively.

$$s^p = \frac{s + \Delta}{r} - \Delta \quad (4)$$

Another way of estimating s^p for all traffic conditions was tried by doing regression analyses between the s^p and m^p. This approach is seemed reasonable since the value of m^p for all situations can be estimated from Equation 3 with a very small error. The obtained relationships between s^p and m^p from the regression analyses and their corresponding R-square values, APE, and MPE were shown in Table 5.

Table 5. Relationships between s^p and m^p, R-square, APE, and MPE

Traffic Condition	Relationship	R-square	APE (%)	MPE (%)
Low	$s^p = 1.0022m^p - 0.7945$	0.9997	1.41	3.80
Medium	$s^p = 1.0063m^p - 2.0518$	0.9970	8.11	32.37
High	$s^p = 1.0476m^p - 1.6938$	0.9956	22.95	259.41
Unified*	$s^p = 1.0188m^p - 1.7263$	0.9989	12.44	210.02

Unified*: Regression analyses were done by accounting the m^p and s^p from all volume levels

It is observed from Table 5 that the R-square values for all cases are very high (>0.99). However, the MPE values are also quite high, particularly for the cases of medium and high traffic conditions while the APE values are acceptable (low) except only the cases of medium and high traffic conditions. It is also observed that the estimated equations of s^p for the low traffic condition are considered acceptable in terms of both APE and MPE. It is suggested that the individual (low, medium, and high) regression equations should be used in practice rather than using the unified equation. Since, in particularly for the low and medium traffic condition, the errors are substantially lower compared with those estimated from the unified equation. From the above results, it can be summarized that m^p and s^p are affected by r and V (since m' and s can be calculated from V)

5. CONCLUDING REMARKS

This paper examined the distribution and its parameters of probe vehicles time headway on a single lane. In the real world part, SNE and PEAR were found to give the closest fit to the observed THD of probes compared with another distribution type (LOG). It was also found that, if volume level of probes is low, regardless of volume level of general vehicles, the probes' headway follows the SNE or PEAR. In the simulation part, it was found that THD of probes does not necessarily follow the same distribution of THD of general vehicles but depends on many variables, i.e., volume level of general vehicles, and market penetration of probe vehicles. However, when volume level of general vehicles is low, probes' headway tends to follow SNE (which is the same as the THD of general vehicles) and PEAR at all levels of market penetration. It is recommended that the study can be extended by i) collecting the probe data which includes the information of general vehicles, and ii) collecting the probe data under various market penetration of probes.

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