Headway Groupings

PATRICK ATHOL
Assistant Director, Illinois Expressway Surveillance Project

•THE DATA analyzed in this paper are primarily time headways, the elapsed time between the leading edges of successive vehicles. The intent of the analysis is to go beyond the curve-fitting stage of headway distributions and use instead these headway measurements to understand the behavior of the traffic in terms of its component parts. Considerable analysis has been done on the curve fitting of headway distributions, but so far there does not appear to be one completely satisfactory continuous solution with respect to volume. Detailed studies of headways (1) show a significant difference between traffic flow under congested and noncongested conditions at the same volume levels. The search for one distribution to suit all these conditions tends to smooth out the differences, rather than acknowledge their presence. These differences will be reviewed in greater detail here.

PLATOONS AND GROUPS

An initial premise of this paper is that traffic flow is made up of various behavioral component parts forming the total population. The various component parts may behave in a predictable manner and fluctuate individually with respect to traffic conditions. These component parts may be thought of as a series of conditional constraints on the total headway distribution.

The task was then to study the headway data and to define and isolate the various interdependent components. A summary examination indicated that for the scope of this report two components, platoons (interdependent vehicles) and groups (all remaining vehicles), would be the extent of the classification used. The designation of platoons applies to all successive vehicles traveling at or less than a critical headway, this critical headway to be called the platoon definition. The relationship then between the overall headway distribution and the varying levels of traffic operations, free flow to congestion, were investigated in terms of the behavior of the component parts. It was hoped that a more practical and informative headway distribution would be obtained and the masking effect of combining all vehicles together under varying traffic conditions would be circumvented. The knowledge of the behavior of the component parts may be valuable in the design of freeway traffic control schemes and simulation models.

The purpose of this report is to shed more light on the general understanding of traffic behavior rather than to collect voluminous headway data. As with the general curves of headway distribution, the component makeup of the traffic stream proposed is of such a general and averaging nature as to make excessive data collection unwarranted.

Platoon Definition

To assist in the choice of a platoon definition, it was arbitrarily determined that a platoon should be required to show stability under all conditions of traffic. The platoon should be considered the stable portion of traffic throughout the spectrum of traffic behavior and the group, the complement of the platoon, would be the variable in the system.

The thought behind the selection of a platoon definition was more inclined to an order of magnitude corresponding to reaction and response time than a larger definition

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at which, no doubt, there is an interdependence, but perhaps of a less critical nature. This reasoning is, of course, strongly influenced by the use in this analysis of high-volume freeway data.

Accordingly, samples of data were examined for platoon definitions of 1.2, 1.5, 2.1 and 2.7 sec. The primary comparisons were made on the distribution of (a) the platoon sizes, i.e., the number of vehicles with successive headways less than the platoon definition; (b) the headways between successive platoons, i.e., the time of arrival between the lead vehicles of successive platoons; and (c) the relative proportion of platoon vehicles corresponding to volume. Subjectively, and primarily on the basis of linearity in the proportion of platoon vehicles vs volume, the 2.1-sec definition was chosen for further analysis. For random arrivals the relationship between the number of headways greater than a given value and the volume level follows a negative exponential. As the platoon definition increases, the volume vs percentage of headway greater than the platoon definition more nearly approaches the negative exponential curve (2). Some measure of the rate at which the curves approach the negative exponential could perhaps establish a platoon definition. The concept of platoons requires that the curves should not closely resemble the negative exponential because it is desired to show dependence and not independence. The development of the 2.1-sec platoon definition was based on a limited sample of data; however, the subsequent investigations were carried out using a 2.1-sec platoon definition. In the conclusions the platoon definition was reviewed in the light of the total analyses presented. Most of the data were then segregated into platoons and groups, yielding headway summaries of platoon and group vehicles, the numerical size of platoons and of groups, and the total length of individual platoons and groups.

Figures 1 and 2, respectively, illustrate the effect of platoon definition on the numerical size of platoons and on the headways between successive platoons. A numerical size of two occurs around a single headway and is thus the minimum platoon size. These figures corresponded to a volume level of about 1,500 vph/lane.

Platoons

The relative proportion of vehicles in platoons and groups at varying volume levels is shown in Figure 3. Each data point is the summary of 1 hr of data. As plotted, the data show the percentage of group vehicles at various volume levels. Using only two categories, the proportion of platoons is the complement of the percentage of groups. There is a noticeable linear trend with volume, and this trend is more pronounced with the lower platoon definition.

If the straight-line trend is projected to intercept the lane volume axis, then for the 2.1-sec platoon definition the lane volume intercept was approximately 2,500 vph/lane. This intercept condition requires all vehicles to be traveling in platoons. As it happens, the choice of 2.1 sec made before plotting Figure 3, yields an all-platoon volume corresponding very reasonably with the maximum lane volumes that may be

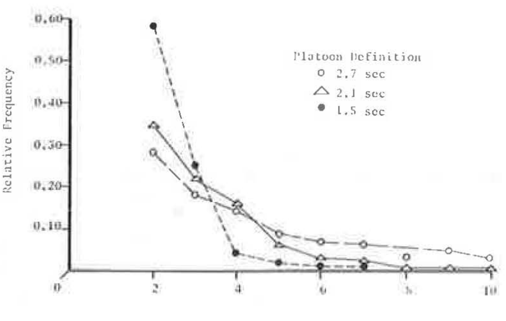

Figure 1. Platoon definition vs platoon size.

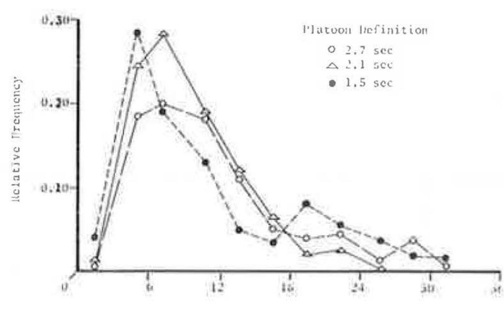

Figure 2. Platoon definition vs inter-platoon headways.

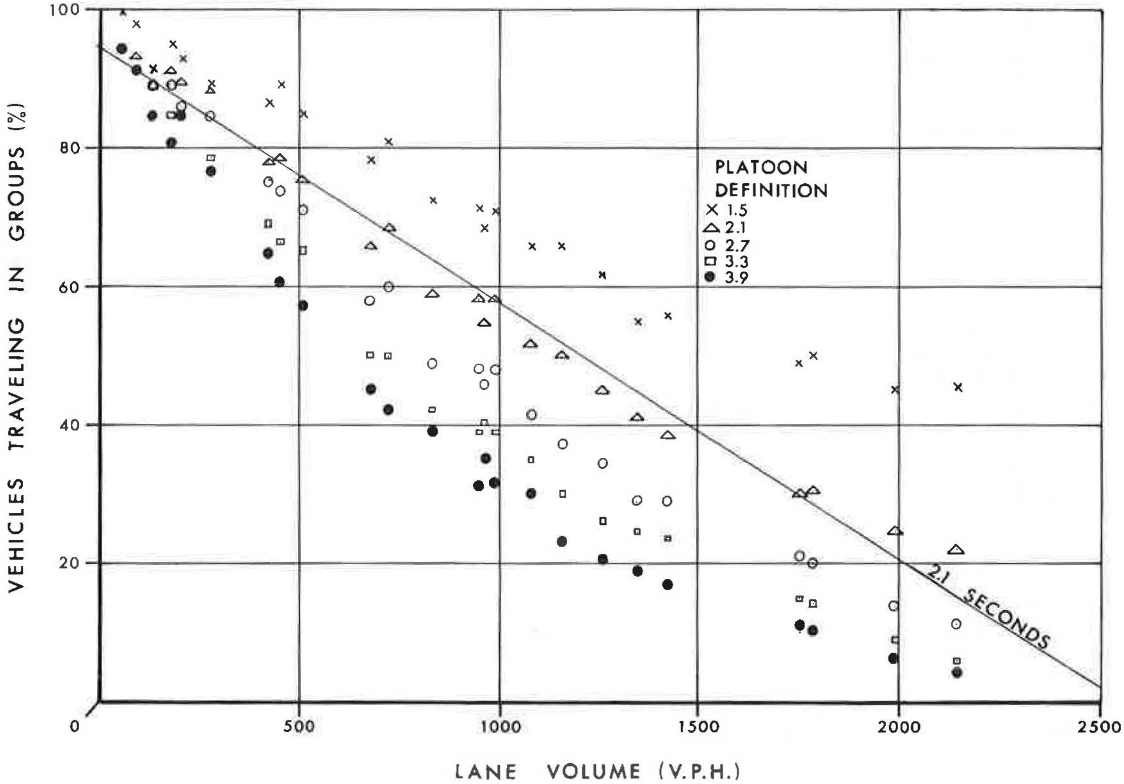

Figure 3. Proportion of vehicles traveling in groups.

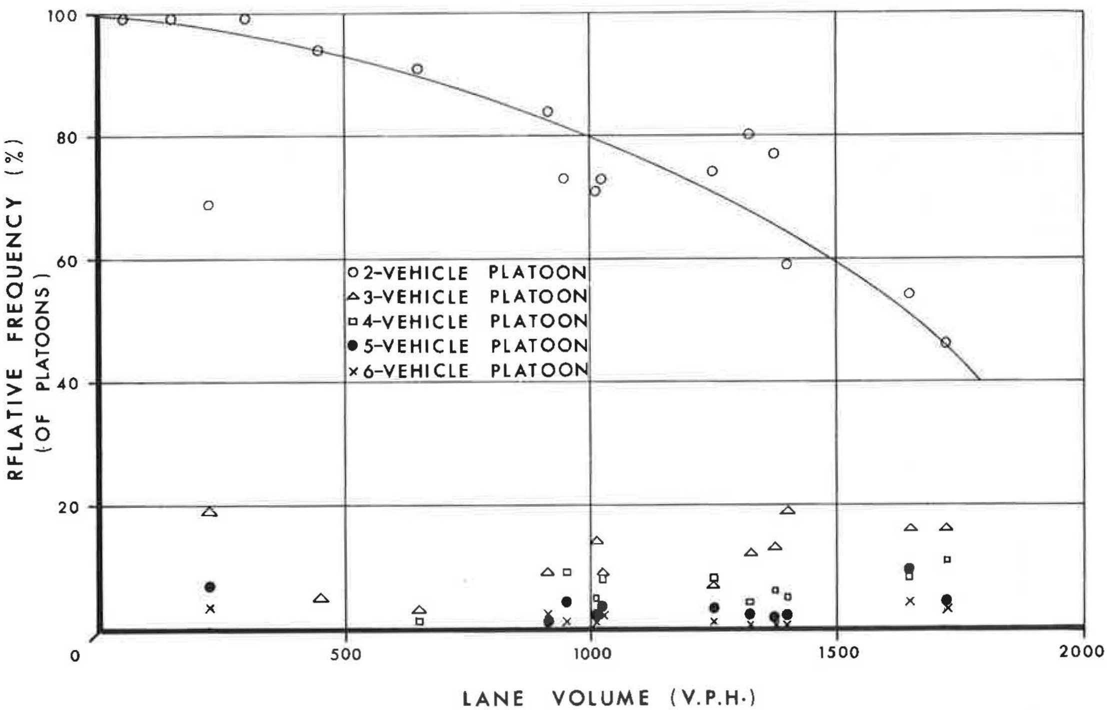

Figure 4. Distribution of platoons.

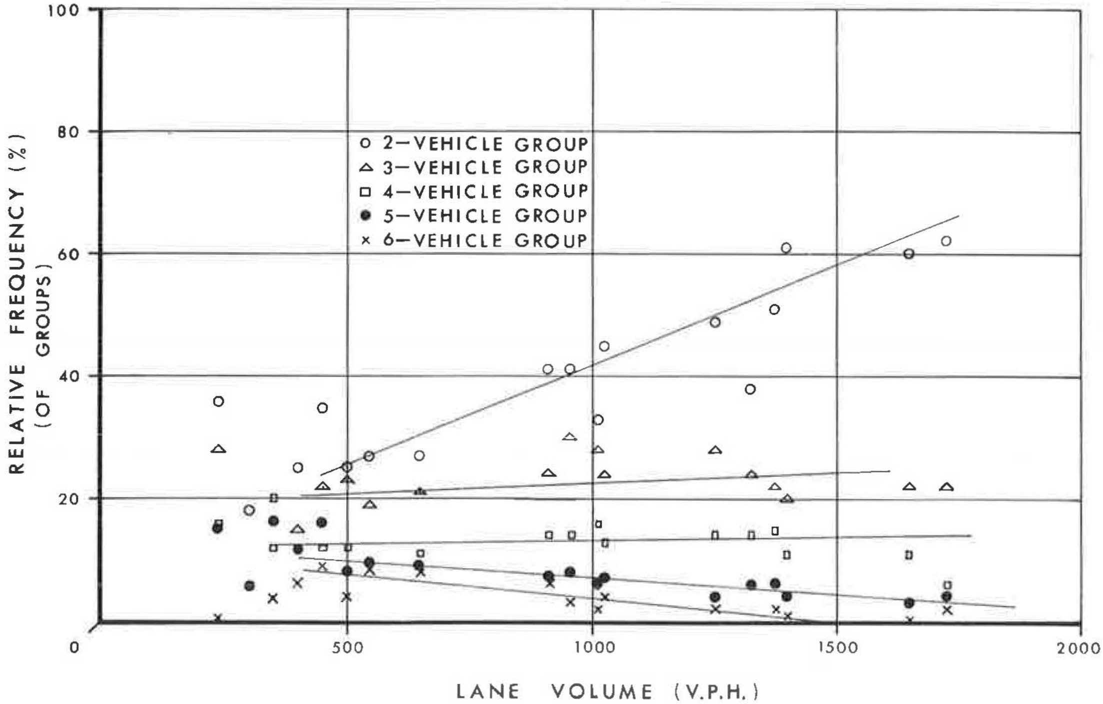

Figure 5. Distribution of groups.

achieved in practice. If the intercept were to fall at more nearly 2,000 vph/lane, the platoon definition would need to be increased.

Platoon Sizes

The platoons and groups were further recorded according to their numerical sizes. The numerical size of a platoon is the number of consecutive vehicles traveling with headways less than or equal to 2.1 sec and is by definition, the number of consecutive headways plus one. Similarly, the numerical group size is the number of vehicles traveling together with consecutive headways greater than 2.1 sec. Figures 4 and 5 show the variation of numerical size in the composition of traffic for platoons and groups, respectively. These graphs show the relative frequency of the various platoon and group numerical sizes at the varying levels of volume, which should not be confused with relative frequency of volume; i.e., 50 percent 2-vehicle platoons and 25 percent 4-vehicle platoons correspond to a 50-50 split in volume. As noted in Figure 3, the volume of group vehicles diminishes with volume, and conversely, the volume of platoon vehicles increases with volume.

The platoon data are dominated by the 2-vehicle platoon. These account for 50 percent or more of all platoons up to volumes of 1,700 vph. For volumes over 1,700 vph, there appears to be a more even mix in the numerical platoon size. Inversely, the mix in the numerical group size diminishes with increasing volume levels, up to the theoretical limit of no groups. Approaching the limit of the intercept volume, the relative frequency of 2-vehicle groups approaches 100 percent, at which time it represents the small number of headways separating platoons.

Individual Headways Within Groups and Platoons

The individual headways within platoons and groups are shown in Figures 6 and 7. As an example, the headway distribution for 6-vehicle platoons includes all the individual headways within the total sample of 6-vehicle platoons, i.e., 5 × number

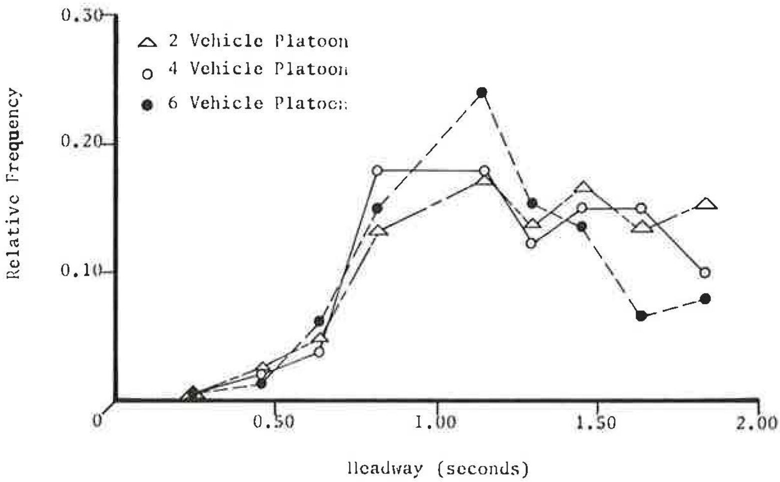

Figure 6. Individual headways in platoons.

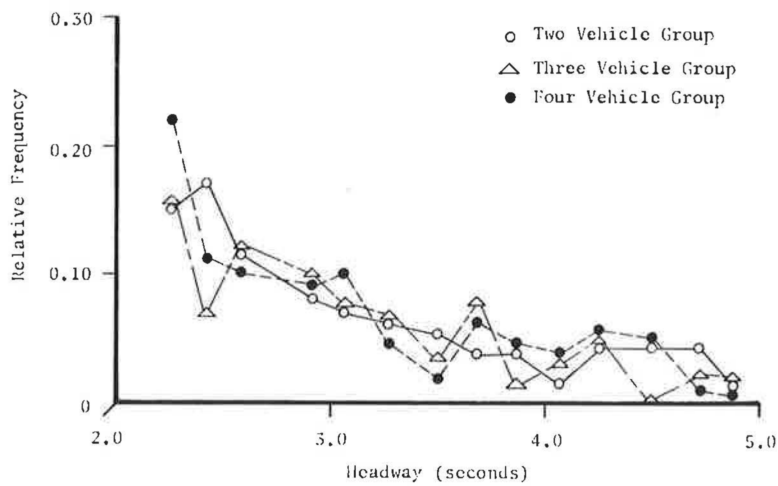

Figure 7. Individual headways in groups.

of 6-vehicle platoons. The sample sizes of headways within the platoon sizes vary from 100 to 200. For platoons, it appears that the headway distributions are independent of the numerical size. With regard to headway distributions for the groups, again there appears to be little difference between the numerical group sizes. The distribution starts at 2.1 sec and is unconstrained at the greater end. These results suggest that the headway distributions are independent of the numerical size (of the platoons or groups) in which the headway occurs.

Relative Position in Platoon

The initial platoon definition was established on the basis that platoons would be stable throughout the range of traffic operations. By choosing the value of 2.1 sec, platoons occurring at various volume levels are equally constrained. However, for the group sample, the mean headway will vary as a function of the volume. The headways between vehicles traveling as groups will obviously increase at lower volume

TABLE 1

MEAN AND VARIANCE OF HEADWAYS IN PLATOONS

Sample Size	Relative Position in Platoon																	
	1		2		3		4		5		6		7		8		9	
	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.
93	1.40	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
68	1.49	0.14	1.45	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	1.40	0.17	1.37	0.14	1.41	0.15	-	-	-	-	-	-	-	-	-	-	-	-
38	1.36	0.11	1.48	0.10	1.47	0.14	1.35	0.16	-	-	-	-	-	-	-	-	-	-
28	1.30	0.12	1.39	0.14	1.34	0.12	1.41	0.11	1.38	0.12	-	-	-	-	-	-	-	-
28	1.41	0.13	1.34	0.15	1.34	0.08	1.34	0.10	1.28	0.20	1.48	0.17	-	-	-	-	-	-
9	1.23	0.08	1.27	0.11	1.31	0.11	1.33	0.17	1.22	0.15	1.17	0.04	1.24	0.17	-	-	-	-
7	1.45	0.08	1.21	0.24	1.12	0.08	1.62	0.10	1.30	0.09	1.57	0.08	1.14	0.10	1.22	0.18	-	-
10	1.29	0.07	1.26	0.09	1.14	0.09	1.50	0.13	1.29	0.17	1.45	0.22	1.25	0.10	1.27	0.16	1.56	0.10

rates. Initially, it may also be expected that the headway within the platoon may vary as a function of volume, although to a lesser degree.

Table 1 gives the mean headway and variance of those headways occurring at differing relative positions within the platoon and also at differing numerical platoon sizes. There will be the mean headway of all the third position headways within a 5-vehicle platoon and a mean headway for all the third-position headways within a 10-vehicle platoon, etc. Figure 6 suggested a headway mean independent of platoon length. Table 1 summarizes this in greater detail and further illustrates the effect of the mean headway at varying positions within the platoon. It is evident that there was agreement between the headway position for all numerical platoon sizes. The significance of the difference between the means may be tested using the means and variance tabulated.

Significant difference at the 0.05 level is given by:

$$\frac{M_1 - M_2}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}} \geq 1.96 \qquad (1)$$

where

M_1, M_2 = means;

σ_1^2, σ_2^2 = variances; and

N_1, N_2 = sample sizes.

Thus, the significant difference for 5-vehicle platoons, comparing the fourth and fifth positions (Table 1), is given by:

$$\frac{1.47 - 1.35}{\sqrt{\frac{0.14}{38} + \frac{0.16}{38}}} = 1.3 \qquad (2)$$

Therefore, there is not a significant difference at the 0.05 level. These results suggest that for vehicles traveling within a platoon, with a platoon definition of 2.1 sec, the mean headways within the platoon are not significantly different for either the relative position of the headway within the platoon or the numerical platoon size. This finding is noteworthy, especially in problems of controlling vehicle entry into a moving traffic stream.

TABLE 2

NUMERICAL SIZE VS TIME SIZE

Time	Lane Vol (vph)	Mean Headway of 2-Veh Platoons (sec)	Mean Time Size / Mean 2-Veh Platoon (veh)				Mean Headway of 2-Veh Group (sec)	Mean Time Size / Mean 2-Veh Platoon (veh)			
			2	3	4	5		2	3	4	5
7-8 AM	1,536	1.4	1.0	2.0	2.9	3.9	3.6	1.0	2.0	3.1	5.1
8-9	1,013	1.4	1.0	2.0	3.0	3.8	4.9	1.0	2.1	3.1	4.0
9-10	802	1.4	1.0	2.1	2.9	3.8	4.7	1.0	2.3	3.7	4.4
10-11	992	1.4	1.0	2.1	3.1	4.0	4.8	1.0	2.3	3.3	4.4
11-12	1,072	1.4	1.0	2.0	3.1	4.1	4.6	1.0	2.0	3.3	4.0
12-13	1,068	1.5	1.0	2.0	2.8	3.9	4.4	1.0	2.1	3.5	4.9
13-14	1,166	1.5	1.0	1.9	2.8	3.8	4.7	1.0	2.0	3.0	3.9
14-15	1,456	1.5	1.0	1.9	2.8	3.5	3.7	1.0	2.4	3.2	5.1
15-16	1,726	1.5	1.0	2.0	2.9	3.8	3.3	1.0	2.1	3.1	4.3
16-17	1,872	1.4	1.0	2.1	3.0	4.0	3.2	1.0	2.1	2.9	3.9
17-18	1,636	1.5	1.0	2.1	3.0	4.0	3.1	1.0	2.1	3.3	4.7
18-19	1,432	1.4	1.0	1.9	2.8	3.8	4.0	1.0	2.0	3.0	3.9
19-20	1,210	1.4	1.0	1.9	2.9	3.8	3.9	1.0	2.3	3.2	4.5
20-21	1,040	1.5	1.0	1.8	2.9	3.7	5.0	1.0	2.0	3.0	3.9
21-22	1,050	1.4	1.0	2.0	2.9	4.3	4.7	1.0	2.1	3.3	5.0
22-23	926	1.5	1.0	1.9	2.6	3.9	5.2	1.0	1.9	3.4	4.0
23-24	848	1.5	1.0	2.0	2.9	3.9	6.3	1.0	1.7	3.2	3.5
24-1 AM	674	1.5	1.0	1.9	2.9	3.4	6.8	1.0	1.7	4.0	3.8
Column means		1.45	1.0	2.0	2.9	3.9	Variable	1.0	2.1	3.3	4.3

Time Size

The expression 'time size' refers to the sum of the individual headways within the group or platoon. Table 2 summarizes the data in the following manner. For each hour of data, the time mean headways of the platoons and the groups are recorded. In addition, the time size of each platoon and group is adjusted by dividing the mean time size of a group or platoon by the mean headway for the corresponding 2-vehicle condition. For both platoons and groups, the 2-vehicle condition serves as a base and the ratio of the time size to 2-vehicle headway is unity. The remaining figures are then the ratios of the mean time size to the mean 2-vehicle headway. If headways were not influenced by numerical size, the ratios would be 1, 2, 3 and 4; instead, the table gives the recorded data for one location. The platoon data appear more stable than the group data in this instance.

The results presented in Table 2 suggest that the time length of a platoon is directly proportional to the number of headways included and the mean of the two-vehicle condition:

$$\text{time size} \propto (\text{numerical size} - 1) \times \text{mean 2-veh headway}$$

This applies to both platoons and groups.

Figures 8 and 9 present the distribution about the mean of time size. There are no striking points to make here except that it may be shown, but not included here, that the component headway distributions when combined as independent distributions do closely resemble these distributions. In other words, given a headway distribution of single headways, with the probability of a headway t equals $P(x=t)$, the probability of a 3-vehicle condition of time size t + t equals $[P(x=t)][P(x=t)]$.

Under free-flow conditions, the characteristic headway is essentially constant with time and volume for a given set of conditions. As congestion develops, the characteristic headway increases and, therefore, the characteristic volume for free flow is never achieved. Generally, the characteristic headway refers to the free-flow condition. The changes in the characteristic headway under congested flow may, by its own nature, be considered a measure of the degree of congestion present at the time of data collection. Thus, the characteristic headway changes its usefulness from a measure of potential volume under free-flow conditions to one of degree of congestion

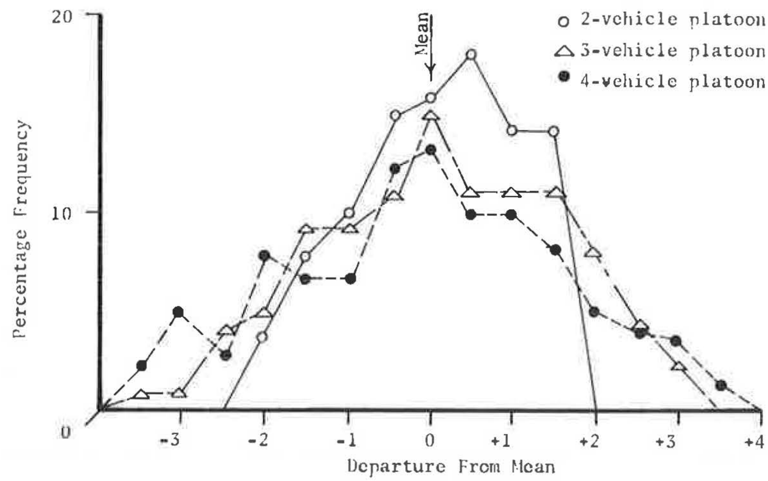

Figure 8. Time size of platoons.

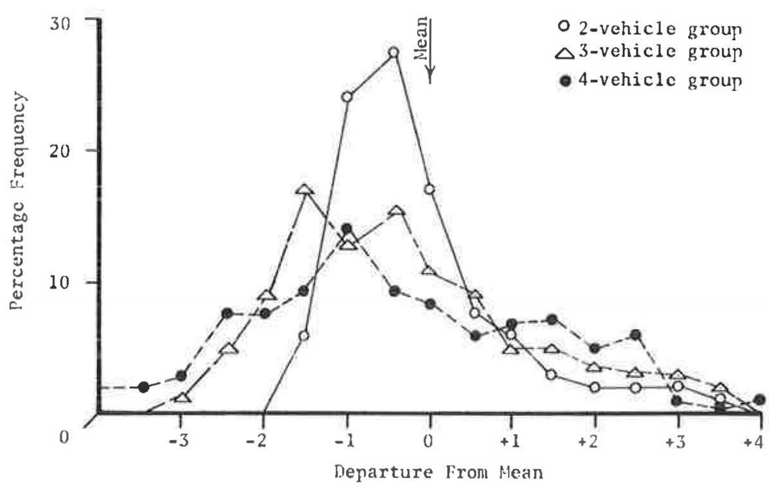

Figure 9. Time size of groups.

under congested conditions. Indeed, because of its constant value at free-flow conditions, it can be considered a criterion for determining the presence of congestion. This aspect of a relative scale of congestion has not been explored herein, although it appears to show promise.

The characteristic headways at a given location on a given day with constant weather and traffic conditions has a constant value based on a 2.1-sec platoon definition. The values in Table 3 show 6 hr of 1.3-sec mean and the remaining 4 hr were influenced by congestion. The constant characteristic headway may prove very useful from a practical standpoint.

CONGESTION AND CAPACITY

Platoons and Groups

Using the linear equation for the relative composition of platoons in the traffic stream of Figure 3, there is an intercept volume at which all vehicles are traveling in platoons. This becomes the limiting condition of volume.

TABLE 3

CHARACTERISTIC HEADWAYS

Platoon Definition (sec)	Characteristic Headways (sec)									
1.5	1.1	1.1	1.3	1.2	1.0	1.1	1.1	1.0	1.0	1.0
2.1	1.3	1.4	1.7	1.6	1.4	1.3	1.3	1.3	1.3	1.3
2.7	1.5	1.6	1.9	1.8	1.5	1.5	1.5	1.5	1.5	1.5
3.3	1.6	1.7	2.1	2.0	1.7	1.7	1.7	1.7	1.7	1.7
3.9	1.7	1.9	2.2[a]	2.2[a]	1.8	1.8	1.8	2.0	1.9	2.0

[a]Signifies congestion.

TABLE 4

PROPORTION OF VEHICLES TRAVELING IN PLATOONS

Location	Platoon Definition (sec)	Percent Veh. in Platoons[a], Y	Intercept Vol.[b] (vph/lane)	Characteristic Vol. (vph/lane)
Cicero Avenue	1.5	1.45 + 0.0290V	3,380	3,280
	2.1	2.43 + 0.0406V	2,400	2,580
	2.7	5.19 + 0.0456V	2,080	2,250
	3.3	8.94 + 0.0496V	1,840	2,000
	3.9	12.25 + 0.0522V	1,680	1,800
Des Plaines Avenue	1.5	2.16 + 0.0275V	3,560	3,600
	2.1	5.03 + 0.0375V	2,530	2,900
	2.7	7.00 + 0.0431V	2,160	2,470
	3.3	10.15 + 0.0455V	1,970	2,200
	3.9	13.33 + 0.0466V	1,860	1,960

[a]V = volume, vph/lane.
[b]At Y = 100 percent.

There is, however, another measure of limiting volume. This is derived by assuming that at the limiting condition of all vehicles traveling in platoons, the volume is the inverse of the mean headway of vehicles traveling in platoons. This limiting volume is called the characteristic volume, V_{ch}. In the same manner, the mean headway of vehicles traveling in platoons is called the characteristic headway, H_{ch}. Therefore, by definition,

$$H_{ch} = \text{mean of platoon headways,}$$

$$V_{ch} = \frac{\text{Total Sample Time}}{H_{ch}}, \text{ and}$$

$$V_{ch} = \frac{3,600}{H_{ch}}$$

where V_{ch} is given in vehicles per hour per lane and H_{ch} is given in seconds.

In view of the assumptions of the regression analysis and the visible curvature displayed in the relative composition curve for higher platoon definitions (Fig. 3), the characteristic volume (as opposed to the intercept volume) will be the volume used in computations.

The characteristic headway data are given in Table 3; this is also the source of the corresponding characteristic volume data. Each characteristic headway is based on 1 hr of data.

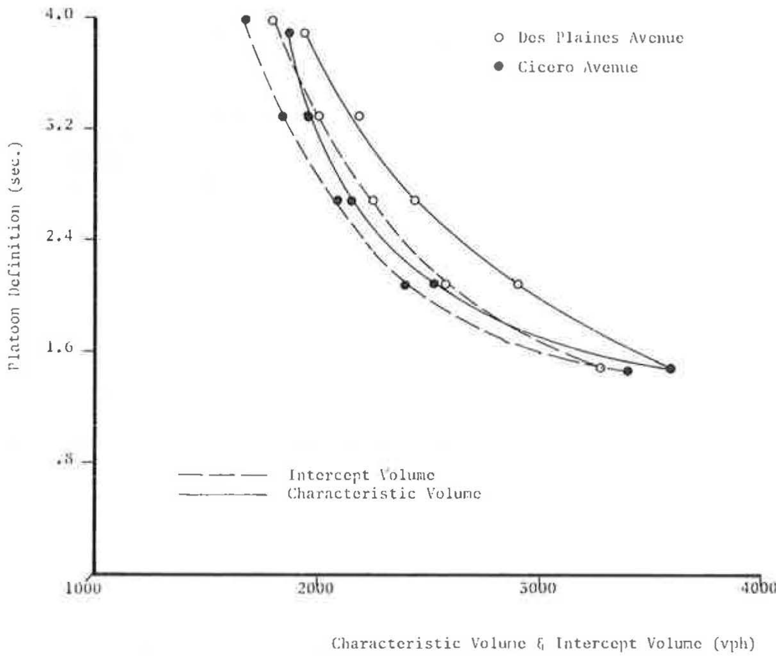

Figure 10. Comparison of characteristic volume and intercept volume.

The relative split between platoons and groups was shown in Figure 3, and the regression analysis applied to these data is presented in Table 4.

For the example of a 2.1-sec platoon definition at Des Plaines Avenue,

$$Y = 5.03 + 0.0375V \tag{3}$$

where Y is percentage of vehicles traveling in platoons and V is volume, in vehicles per hour per lane. The number of vehicles traveling in groups = $V[100-(5.03 + 0.0375V)] = 94.97V - 0.0375 V^2$. This has a maximum value at $V = 94.97/2 \times 0.0375 = 2,530/2$. The maximum volume of group vehicles occurs at one-half the intercept volume. The variation of intercept volume and characteristic volume with varying platoon definitions is shown in Figure 10.

Characteristic Volume and Capacity

As previously defined, the characteristic volume, derived from the mean headway of vehicles in platoons, may be compared to the concept of capacity. Use of characteristic volume in lieu of capacity in describing lane volumes on multilane freeway facilities may prove easier to handle than such terms as maximum, possible, probable, practical, ad infinitum capacities, all of which might not be unreasonable if there were anything like consistent readings over the whole length of a freeway. It must surely be agreed that we have sufficient knowledge to know that location, lane position, geometric design, drivers, and vehicles make it misleading to attempt to embrace all these conditions under one mystical figure of capacity. A numerical value of capacity needs so much qualification that the advantage of its brevity is lost in its inaccuracy.

It is proposed that the characteristic volume serve as a relative measure of limiting volume, which may be evaluated as soon as a completely controlled experiment is conducted; however, the inclusion of the human driver probably excludes a completely controlled experiment and inclines more towards a statistical expression. In any section of highway, the relative performance between successive sections must surely be the governing factor.

TABLE 5

COMPARISON OF PERFORMANCE

Location	Characteristic Headway	Characteristic Volume
Cicero Ave., left center lane, 4-lane section	1.40	2,570
Des Plaines Ave., center lane, 3-lane section	1.23	2,930
Harlem Ave., center lane, 3-lane section	1.36	2,650

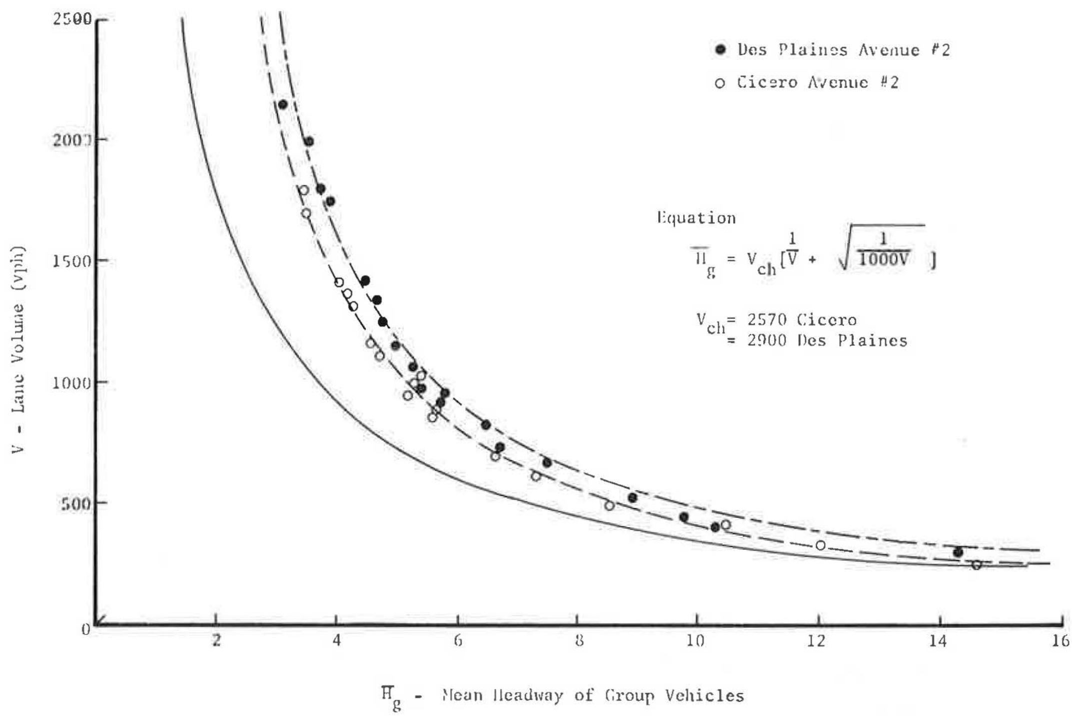

Figure 11. Distribution of mean headway of groups.

Determining limiting volumes generally requires measurements at the time of critical operations; this may become a complex task under many conditions. This is perhaps the cause of conflicting values described as capacity. It is hoped that the characteristic volume will provide a technique by which to estimate limiting volume from data collected at various noncritical levels of operation.

Accuracy in measurement is another very important factor. It would appear that 0.01 sec is desirable. This should be the true accuracy, relating the data output to the actual conditions and should include all sensing and recording errors. Table 5 gives a comparison of performance at three locations at the same hour of day. This comparative technique may be applied to the sum of adjacent lanes, effects of geometric design, weather, environment, and perhaps driver characteristics.

Group Mean Headway

In contrast to platoon headways, group headways are expected to vary with volume levels; for the total population the mean headway is the reciprocal of volume. Because the platoon headway is essentially constant at free-flow conditions, the group

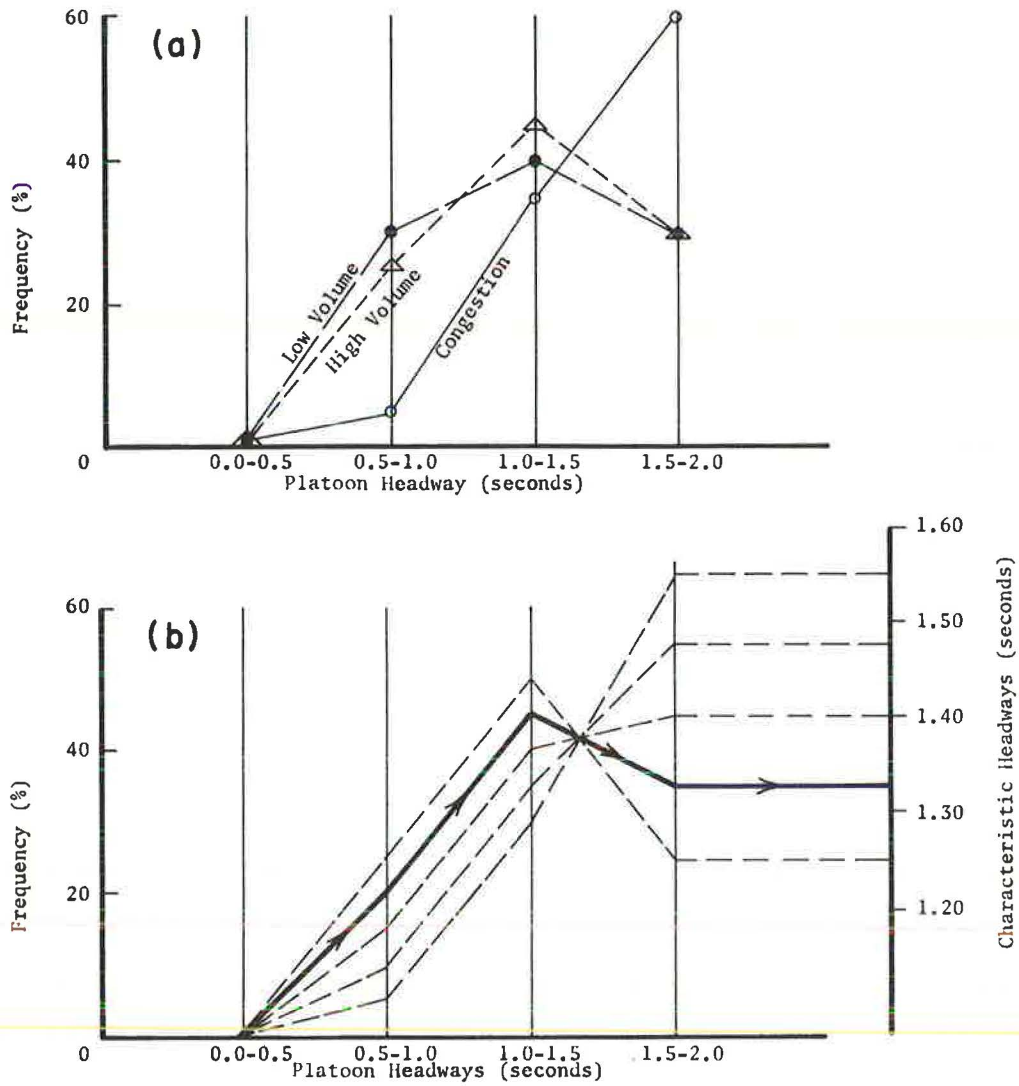

Figure 12. (a) Platoon headway distribution; and (b) characteristic headway.

mean headway, $\bar{H}_g$, is influenced by the volume and the number of vehicles traveling in platoons.

In an attempt to predict the mean headway of groups, the data are grouped in Figure 11 and compared to the equation

$$\bar{H}_g = V_{ch} \left(\frac{1}{V} + \sqrt{\frac{1}{1000V}} \right) \tag{4}$$

There are two points to be illustrated here: the inclusion of the term V_{ch} (characteristic volume) and of the term $\sqrt{\frac{1}{1000V}}$. The equation is empirical and was not derived from any assumed distribution. The inclusion of V_{ch} relates the group data to those of the platoons and underlines their obvious interrelationship. The term $1/V$ is the direct relationship between volume and headways and the term $\sqrt{\frac{1}{1000V}}$ includes the shift for the exclusion of platoons. The data appear to fit the equation chosen, perhaps showing greatest discrepancy at lower volumes where, in fact, the accuracy may be less critical.

Congestion

Congestion is considered here the condition existing after speed inversion has occurred. Speed inversion has been defined (3) as the sudden change in speed in a moving traffic stream occurring at high volumes. For the purpose of this report, the result is a condition of equal volume at differing speed levels.

The principal effects of congestion show themselves in the following areas:

1. Headway distribution. —Figure 12a shows a generalized summary of the variation of headways within platoons. The lower the free-flow volume, the higher the relative incidence of shorter headways; as volume increases, the incidence of shorter headways diminishes. Congestion appears as the third step in the progression, but although it generally includes the higher volumes, 1,000 vph and over, it could, on occasion, include lower volumes. Congested flow may often occur at about 1,500 vph, whereas the high free-flow volumes may reach 2,000 vph and over. Obviously, the shift in distribution has a corresponding effect on the mean headway of platoon vehicles. Figure 12b shows the variation of the mean headway of platoons with varying headway distributions. The range illustrated may be considered limited; the data presented previously at Cicero Avenue, with a platoon definition of 2.1 sec, showed values from 1.3 in free flow to 1.7 sec in congestion. The headway distribution of groups also has a similar shift; however, in this case the shift is to a lower mean.

This may be related to the platoon change under congestion by the reduction in the characteristic volume. The characteristic headway of 1.70 sec gives a characteristic volume of 2,120 vph, compared to 2,770 vph at 1.30 sec. The corresponding change in the mean headway of the groups is 2.75 sec congested and 3.60 sec free flow at a volume level of 1,800 vph.

2. Relative proportion of platoons. —The effects of congestion here depend on the shift in headway distribution. In the example shown in Figure 13, there are two headway distributions for the same volume level—congested flow and free flow; both have equal areas under the curves. With the varying platoon definitions, a, b, c, selected at critical geometric points, the effect of congestion at a platoon definition, a, reduces the relative proportion of platoons. At some point, b, there is no change in the relative platoon composition. For values greater than b, there is an increase in relative proportion of platoons which reaches a maximum difference at c, after which the difference continually diminishes. The selected platoon definition of 2 to 2.1 sec might be expected to fall in the range, a to b, thereby generally diminishing the proportion of platoons in congestion.

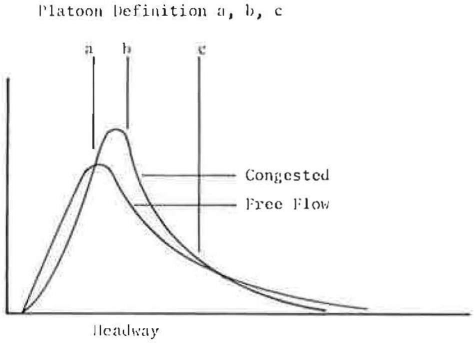

Figure 13. Effect of congestion.

HEADWAY DISTRIBUTIONS

Consideration of headways has been so far restricted to two conditions, platoons and groups. Having broken down the headway distribution, we can now attempt to rebuild it, but this time incorporating the conditional restraints developed previously.

Platoon Headways

The following were the conditional restraints relating to platoons:

1. The characteristic mean headway is constant for free flow but changes with congestion.

2. The proportion of vehicles traveling in platoons may be predicted by the formula, $Y = 2.43 + 0.0406V$, where Y is the percentage of vehicles in platoons and V is the lane volume in vehicles per hour.

3. The headways do not vary with numerical platoon size, time platoon size, or position within a platoon.

4. The distribution of headways varies with volume level and degree of congestion (Fig. 12a). There are many platoon headway distributions which can give a characteristic headway in free flow.

Close examination of headway distributions at various locations, lanes and conditions suggest that the headway distribution may fluctuate considerably without apparent reason. It is more nearly probable that the causes of fluctuation are unknown and probably unrecorded. Consequently, it is seriously suggested that there are insufficient data to predict accurately the platoon headway distribution. Figure 12a gives an average condition for low volume (1,000 vph and less), and free-flow and congested high volumes, and these will be used to describe the general trends in the headway distribution. Frequently, however, recorded data will severely contradict these simplified distributions. With a platoon definition as small as about 2 sec, the precise distribution within that time may not be very critical. Accordingly, the platoon headway distribution will be as shown in Figure 12a. This distribution is discrete with 0.5-sec intervals.

Group Headways

The following were the conditional restraints relating to groups:

1. The mean headway of the groups is given by Eq. 4.
2. The proportion of vehicles traveling in groups may be predicted by a formula of the form, percent group vehicles = $100 - (2.43 - 0.0406V)$.
3. The headways do not vary directly with numerical and time sizes of groups.
4. The distribution of group headways is of the general type, $e^{-\rho x}$, as seen in Figure 7. This distribution is continuous from the platoon definition to infinity (infinite headway at zero volume).

If $e^{-\rho x}$ describes the distribution within groups, it must also satisfy the equation for the mean headway of groups. The mean of $e^{-\rho x}$ may be calculated from

$$\frac{\int_a^\infty x e^{-\rho x}\, dx}{\int_a^\infty e^{-\rho x}\, dx} = a + \frac{1}{\rho} \tag{5}$$

where a is platoon definition in seconds and ρ is a variable coefficient.

For a given volume level, $\overline{H}_g$ may be computed and this in turn is equated to $(a + \frac{1}{\rho})$. With a platoon definition of 2.1 seconds,

$$\frac{1}{\rho} = \frac{1}{\overline{H}_g - a} \tag{6}$$

Substitution for $\overline{H}_g$ yields

$$\frac{1}{\rho} = V_{ch}\left(\frac{1}{V} + \sqrt{\frac{1}{1000V}}\right) - a \tag{7}$$

The distribution of group headways must be further adjusted so that the area under the curve of $e^{-\rho x}\big|_{a-\infty}$ is equal to the proportion of vehicles traveling in groups. Thus,

$$K_1 \int_a^\infty e^{-\rho x}\, dx = (100 - 2.43 - 0.0406V) \tag{8}$$

and

$$K_1 = \frac{[100 - 2.43 - 0.0406V]}{\int_a^\infty e^{-\rho x}\, dx} \tag{9}$$

Numerical Solutions

1. Free-Flow Condition. —For volume = 1,400 vph, platoon definition = 2.1 sec, and characteristic volume = 2,580 (Table 3),

$$\overline{H}_g = 2580\left(\frac{1}{1400} + \sqrt{\frac{1}{1000 \times 1400}}\right) = 4.03 \text{ sec}$$

From Eq. 6,

$$\overline{H}_g = a + \frac{1}{\rho} \tag{10}$$

and therefore,

$$\rho = \frac{1}{4.03 - 2.1} = 0.58$$

The proportion of vehicles in groups = (100 - 2.43 - 0.0406V) = (100 - 2.43 - 0.0406 × 1400) = 41 percent; therefore,

$$K_1 = \frac{0.41}{\int_{2.1}^\infty e^{-0.58x}\, dx} = 0.80$$

2. Congested Condition. —For volume = 1,400 vph, platoon definition = 2.1 sec, and characteristic volume = 2,117 (Table 3),

$$\bar{H}_g = 2117 \left(\frac{1}{1400} + \sqrt{\frac{1}{1400 \times 1000}}\right) = 3.32 \text{ sec}$$

Substitution of this value for $\bar{H}_g$ and 2.1 sec for a in Eq. 10 yields:

$$\rho = \frac{1}{3.32 - 2.1} = 0.82$$

The proportion of vehicles in groups is again 0.41 and, therefore,

$$K_1 = \frac{0.41}{\int_{2.1}^{\infty} e^{-0.82x} dx} = 1.88$$

Assuming the platoon headway distribution for high free-flow volumes, congested flow and a 0.59 proportion of platoon headways, the resulting distributions for 1,400 vph are shown in Figure 14a.

3. Free-Flow Condition. —For volume = 700 vph, platoon definition = 2.1 sec, and characteristic volume at Cicero Avenue = 2,580 vph,

$$\bar{H}_g = 2580 \left(\frac{1}{700} + \sqrt{\frac{1}{1000 \times 700}}\right) = 6.75 \text{ sec}$$

Substitution of $\bar{H}_g$ = 6.75 sec and a = 2.1 sec in Eq. 10 yields:

$$\rho = \frac{1}{6.75 - 2.1} = 0.21$$

The proportion of vehicles in groups = (100 - 2.43 - 0.406 × 700) = 69 percent; therefore,

$$K_1 = \frac{0.69}{\int_{a}^{\infty} e^{-0.21x} dx} = 0.23$$

Assuming a low-volume platoon headway distribution and 31 percent platoon headways, the distribution is shown in Figure 14b. In this instance recorded data are compared to the theoretical distribution.

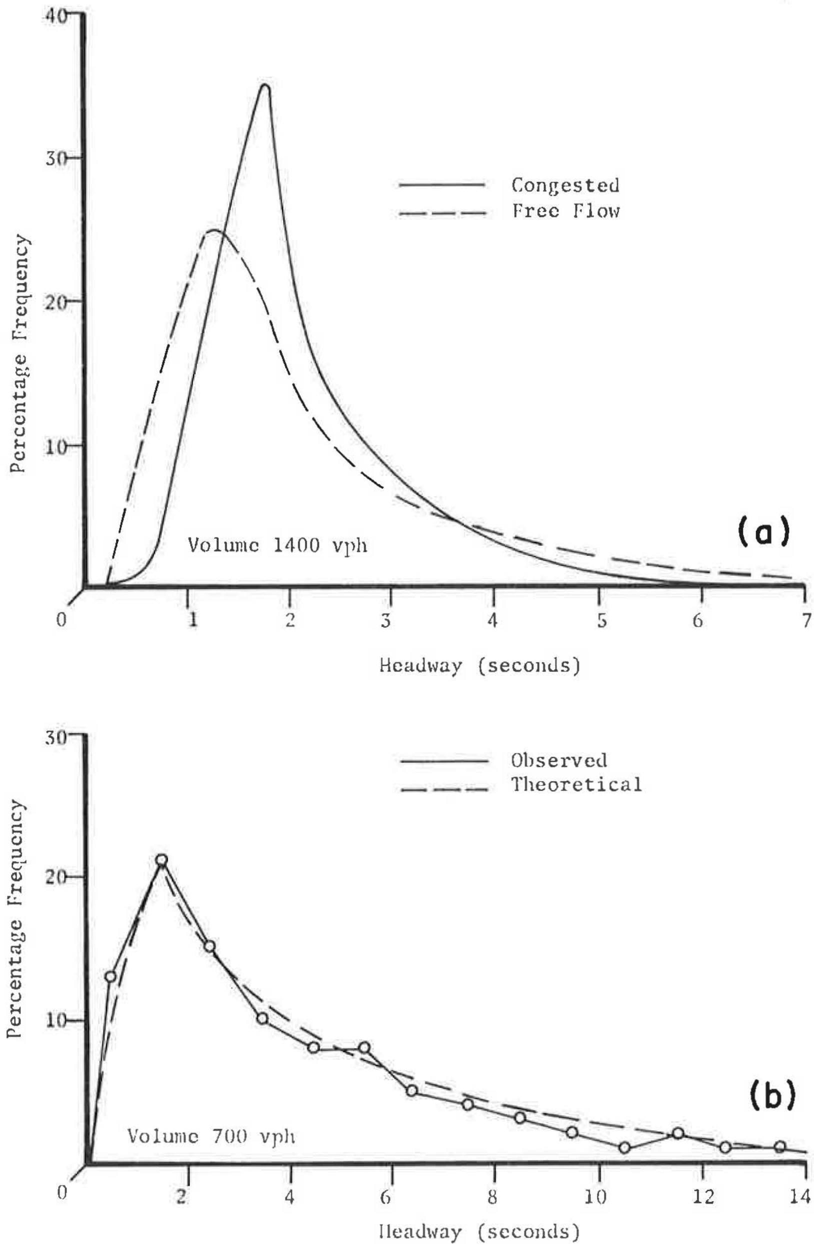

Figure 14. Headway distributions.

Poisson Distribution

The negative exponential equation used previously may be compared to the Poisson distribution. In Figure 15, a comparison is made between the group headway distribution and the corresponding Poisson values. It may be readily seen that the two equations are more nearly equal at the lower volumes.

The composite headway distribution of platoons and groups gives a mode equal to or less than the platoon definition. This result is expected at high volumes but perhaps not at the lower volume levels. Limited data collected do, however, support the

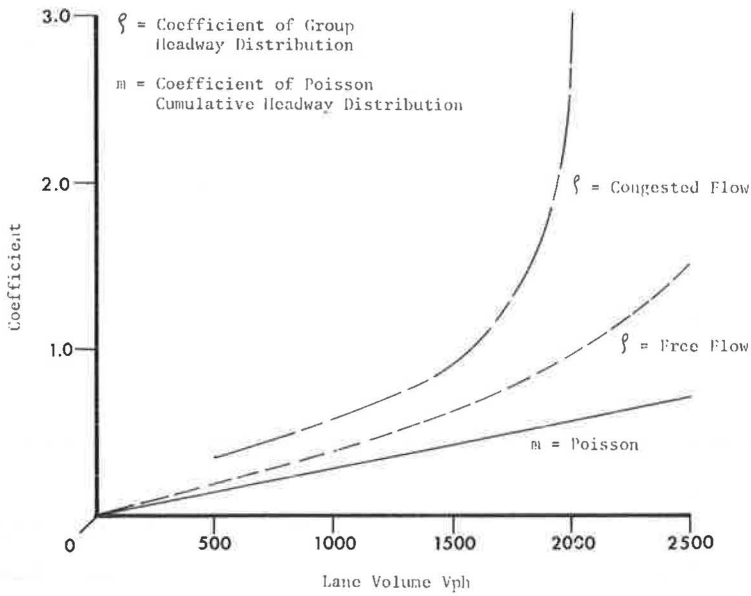

Figure 15. Comparison with Poisson distribution.

idea of a mode headway at a value close to the platoon definition. For a very low volume, there is no singular mode, but this does not contradict the preceding.

CONCLUSIONS

1. Traffic may be effectively divided into platoons and groups in the study of traffic performance. The platoon definition is a noteworthy parameter.
2. Platoon headways may be considered independent of both the numerical size of the platoon in which they occur and their relative position within that platoon.
3. Characteristic volume, derived from time mean headway of platoons, gives a practical and consistent measure of limiting volume and may afford a relative measure of the variation in limiting volumes. The characteristic volume enables comparison of geometric design, location, lane position, weather, and possibly various driver groups.
4. The effects of the degree of congestion on the total headway distribution are numerically accounted for by the inclusion of the characteristic volume in the determinations.
5. Adequate headway distributions may be synthesized from individual platoon and group headway distributions.
6. The independence of platoons and groups infers that prior knowledge of a preceding platoon or group does not effectively aid in the prediction of the character of a succeeding platoon or group. This result is significant when considering any type of predictive control system.
7. In the observation recorded, it appears that the platoon definition may be adjusted within certain limits without loss of generality in the conclusions drawn. The following conditions may be weighted in the selection of a platoon definition: (a) constant characteristic headway at free-flow conditions; (b) linearity in the relative proportion of platoons vs volume; (c) consistency in the relative proportion of platoons for congestion and free flow at the same volume levels; and (d) goodness of fit for the composite headway distribution of platoon and groups. A practical point in the selection of a platoon definition is the need to be within the class interval of the headway distribution. In this study the interval was 0.5 sec. Platoon definitions of 2.0 or 2.5 sec appear to be the best choices.

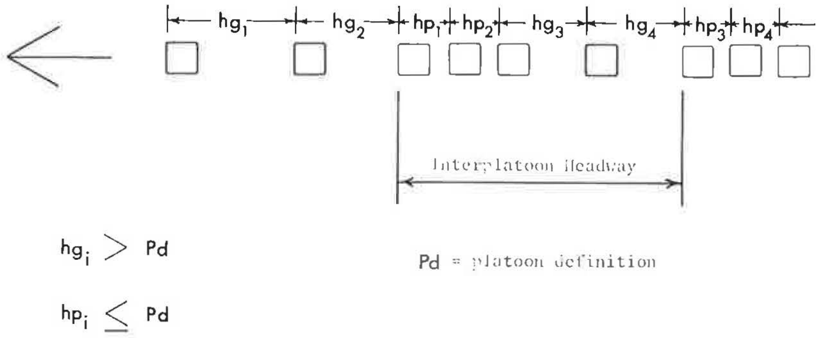

Figure 16. Traffic stream.

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Appendix

DEFINITIONS

Platoon. —A series of consecutive vehicles traveling at headways less than a critical value called the platoon definition.

Group. —A series of consecutive vehicles traveling at headways greater than the platoon definition.

Platoon Headway. —A headway less than or equal to the platoon definition.

Group Headway. —A headway greater than the platoon definition.

Characteristic Headway. —H_{ch}, mean of all the platoon headways constant for free-flow conditions.

Characteristic Volume. —V_{ch}, volume corresponding to the characteristic headway, $3600/H_{ch}$ for an hourly volume rate and a characteristic headway in seconds.

Two-Vehicle Platoon. —Single headway between successive groups, constrained from a minimum of approximately 0.3 sec to a maximum of the platoon definition.

Two-Vehicle Group. —Single headway between successive platoons, constrained only to exceed the platoon definition.

Numerical Size. —Number of vehicles forming the group or platoon, one greater than the number of headways.

Time Size. —Sum of individual headways within group or platoon.