An Investigation of Some Traffic Flow Characteristics

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Some characteristics of the distribution of vehicular spot speeds and the headway characteristics of vehicles on two-lane highways were investigated with the ultimate goal that one of these characteristics might be developed into a suitable criterion for the assessment of traffic congestion. It was determined that, within the scope of the study, the standard deviation of the spot speed distribution had good indication of being a significant traffic flow parameter.

The spot speed and the headway characteristics are discussed under separate headings; a third section is devoted to a discussion of the association of spot speed and headway characteristics.

•ONE of the main goals in traffic engineering is to eliminate or reduce traffic congestion. In the modern mechanized society the importance of smooth and efficient motor vehicle transportation can hardly be overemphasized. Congestion, is usually considered to exist when vehicles cannot flow freely; but what exactly constitutes free flow has not been well defined. There is no widely-accepted quantity which measures the amount of congestion on some section of roadway and which can be used for making comparisons between different sections of roadway.

Traffic density, volume of traffic, and mean speed of traffic are generally considered to be the three basic features of traffic flow (1, 2). However, none of these features alone can be conveniently used as a measure of congestion. A mere statement of volume will not suffice because a high volume at a reasonably high speed is not indicative of congestion; conversely speed alone is not a good criterion. Density, on the other hand, incorporates both volume and speed and is a better criterion than either volume or speed, although it does not specify the particular combination of the two. Another shortcoming of density is that it does not account for the nature or composition of traffic. As a hypothetical example for the latter, 30 passenger cars in a mile of roadway or 30 trailer trucks in a mile of roadway would both be expresssed as 30 vehicles per mile in terms of density. As far as the state of congestion is concerned, however, these two conditions of traffic are not equivalent.

Several studies (3, 4, 5, 6) have been conducted to develop other criteria to measure or describe congestion. All have required extensive data collection and analysis, and none can be used for the detection of congestion as it develops.

It is believed, however, that a characteristic of the traffic stream may be developed into a suitable criterion to be used in the assessment of relative congestion. As an initial investigation two-lane rural highways were considered; this study may serve as a stepping-stone for future research on higher-type facilities.

In many cases, the speed at which a driver travels on a two-lane highway is not the speed he would have set for himself commensurate with the capabilities of his vehicle, the roadway features, and environmental conditions. The presence of other vehicles on the highway forces the driver to deviate from his desired speed. As the number of vehicles on the highway increases, it can reasonably be conjectured that the

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freedom of the individual driver will be increasingly restricted. Therefore, the characteristics of the distribution of spot speeds will change as traffic density increases. Also the time spacing characteristics of vehicles may be expected to be dependent on density. The purpose of this study was to investigate the spot speed and time spacing characteristics on two-lane highways as to their variation with traffic density, with the ultimate goal that one of these characteristics might be developed into a criterion for assessing the relative congestion on such highways. Traffic density was selected as the base for the study because it is a fairly good indication of congestion—certainly better than any other.

SPOT SPEED CHARACTERISTICS

The following characteristics of spot speeds were considered:

1. Amount of skewness of the spot speed distribution.
2. Amount of kurtosis of the spot speed distribution.
3. Deviation of the observed spot speed distribution from a normal distribution as measured by the chi-square test.
4. Mean of the spot speed distribution.
5. Standard deviation of the spot speed distribution.

The skewness of a symmetrical distribution is zero; the skewness of an observed spot speed distribution can be either negative or positive, depending on the direction in which the tail of the distribution extends. Positive skewness results when the tail of the frequency curve extends more toward the higher values of the distribution than toward the lower values, and vice versa.

The kurtosis of a normal distribution has the numerical value 3. Curves more peaked than the normal are called leptokurtic and have kurtosis values greater than 3. Curves flatter than the normal curve are called platykurtic and have kurtosis values less than 3. Thus, the observed kurtosis value provides a comparison with a normal distribution.

The chi-square test indicates whether an observed distribution deviates significantly from an expected distribution. In this study a normal distribution with the same number of observations, the same mean, and the same standard deviation as the observed spot speed distribution was constructed. Subsequently, the normal and the observed distributions were compared with the chi-square test.

The mean and the standard deviation are independent parameters of a distribution. The method of computation for the mean and the standard deviation is given in the appendix, together with those for the first three characteristics.

Correlations were sought between these five characteristics and traffic density. Traffic density was taken as the average over a period of one hour in one lane. The term average lane density is used throughout this report. It was computed by

$$D = \frac{V}{S} \tag{1}$$

in which

D = average lane density, in vehicles per mile;
V = hourly directional traffic volume, in vehicles per hour; and
S = average speed, in miles per hour.

Data Collection

To compute average lane density and the five spot speed characteristics it was necessary to obtain speed data and directional volume counts. Speed data taken by a radar speed meter were recorded on a graphic recorder tape. To be able to distinguish between directions on the tape, and thus enable a directional volume count, a chronograph pen was used in conjunction with the graphic recorder. The chronograph pen

was actuated manually by a telegraph key arrangement and was caused to make a "blip" in the margin of the tape as each vehicle crossed a reference mark on the pavement in the direction under study. The chronograph pen also enabled the measurement of headways; this point is discussed in a subsequent section.

Data were collected on two level and tangent sections of rural two-lane highways, virtually free from on-and-off turning traffic in the vicinity of the data collection spot. Trucks constituted about 15 percent of the traffic at both locations and both had speed limits of 55 mph, which is the absolute speed limit for such highways in Virginia. Weather conditions and visibility were favorable during data collection at both locations. Thus, all conditions that might cause variations in speed distributions between locations were in essence identical.

The study locations are referred to as location I and location II.

Results

It is generally believed that increased traffic densities cause positive skewness, leptokurticity, and deviation from normality (7). In the present study, however, none of these trends was observed. None of the three characteristics had a definite pattern of variation with traffic density. Table 1 gives observed values of skewness and kurtosis, together with observed and significant values of chi-square. No further analyses seemed warranted on the basis of the data in Table 1.

Table 2 gives values of mean speed and standard deviation for different average lane densities. An analysis indicated no significant correlation between the mean speed and the average lane density at either location. Apparently the generally accepted hypothesis that mean speed drops with increasing traffic density does not hold true for such low values of density.

The correlation between standard deviation and average lane density was significant at both locations. The coefficients of correlation were -0.535 with 9 degrees of freedom for location I and -0.736 with 5 degrees of freedom for location II (Fig. 1). These

TABLE 1

SKEWNESS, KURTOSIS AND CHI-SQUARE VALUES

Location	Average Lane Density (vpm)	Skewness	Kurtosis	Chi-Square Value		
				For 95% Significance	Deg. of Freedom	Observed
I	3.08	-0.41	3.84	22.362	13	25.117[1]
	3.87	0.20	4.51	15.507	8	14.730
	4.12	-0.01	2.46	21.026	12	30.196[1]
	4.18	0.36	4.39	19.675	11	12.564
	5.11	0.62	5.47	16.919	9	7.246
	5.47	0.30	4.04	16.919	9	38.480[1]
	5.47	0.12	4.57	21.026	12	20.748
	6.35	0.28	3.51	18.307	10	18.745[1]
	6.65	0.26	3.44	18.307	10	10.369
	8.61	-0.12	3.46	16.919	9	7.973
	9.87	0.21	4.54	18.307	10	26.325[1]
II	2.71	-0.74	4.40	21.026	12	18.561
	4.07	-0.32	2.81	19.675	11	31.759[1]
	5.00	-0.21	2.90	21.026	12	25.309[1]
	6.12	-0.52	3.62	18.307	10	26.344[1]
	6.14	-0.05	3.09	19.675	11	12.789
	7.20	-0.11	2.77	19.675	11	12.180
	8.88	-0.39	3.13	18.307	10	26.512[1]

[1] Significant at 95 percent level.

coefficients, although not very high, were nevertheless significant at the 90 percent level.

The apparent parallelism and the proximity of the two regression lines suggested the testing of the hypotheses that the slopes of the lines were equal and that the intercepts of the two lines were equal. Tests revealed that neither of these hypotheses could be rejected; therefore, the lines could be accepted as representing the same relationship. The line which fit all of the points was determined to be $\sigma = 6.876 - 0.164\ D$ ("composite" in Fig. 1). The coefficient of correlation in this case was -0.526 with 16 degrees of freedom, significant at the 95 percent level. Higher order curves (second, third, and fourth) were fitted to the entire group of data to improve the correlation between the standard deviation and density; however, an analysis of variance on the residual sums of squares from the higher order curves indicated that a significant improvement was not achieved.

TABLE 2

MEAN SPEED AND STANDARD DEVIATION AT DIFFERENT AVERAGE LANE DENSITIES

Location	Average Lane Density (vpm)	Speed (mph)	
		Mean	Std. Dev.
I	3.08	49.65	6.96
	3.87	51.10	5.24
	4.12	50.48	6.44
	4.18	50.03	6.21
	5.11	50.27	5.18
	5.47	50.00	5.15
	5.47	49.03	6.22
	6.35	49.45	5.36
	6.65	49.05	5.81
	8.61	49.62	4.97
	9.87	49.87	5.52
II	2.71	52.49	6.89
	4.07	52.60	6.11
	5.00	52.68	6.83
	6.12	52.72	6.33
	6.14	52.11	6.07
	7.20	51.80	5.75
	8.88	52.24	5.91

The 95 percent confidence limits of a prediction from the correlation between standard deviation and average lane density were computed (Fig. 2).

Figure 2 also shows standard deviations computed from data collected by the Virginia Department of Highways independently of the original study. The locations where these data were collected had roadway and traffic features substantially different from the two original study locations. However, it will be observed that all of the points fell within the 95 percent confidence limits. It is interesting to mention that mean speeds on the two additional locations dropped below those observed on the original locations, even in connection with low densities, because of excessive truck percentage and poor

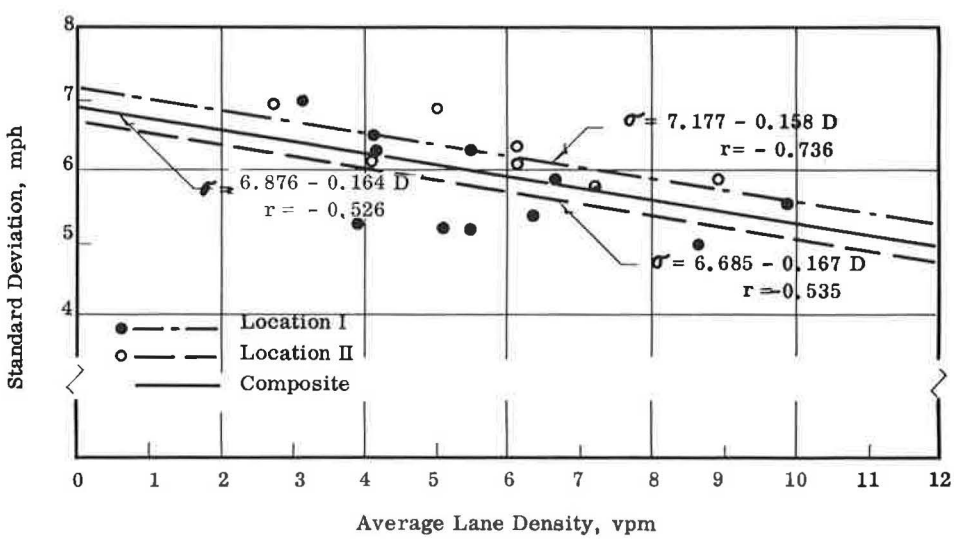

Figure 1. Standard deviation vs average lane density.

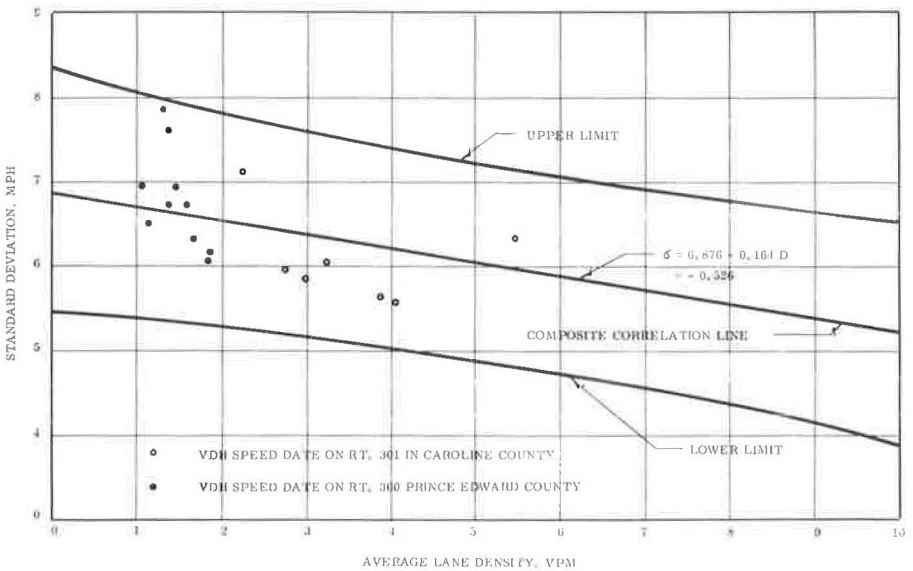

Figure 2. Correlation with 95 percent confidence limits of one observation.

vertical alignment; however, the relationship between standard deviation and density still held.

Discussion

The skewness, the kurtosis, the deviation from normality as measured by a chi-square test, and the mean of the spot speed distribution are not very significant characteristics of traffic flow within the range of densities observed. None of them can be used as a means of assessing the relative congestion on two-lane highways. The standard deviation of the spot speed distribution, on the other hand, is a significant characteristic, as suggested by the data obtained at the two original locations and later borne out by the data from two additional locations. It seems that although the other four characteristics may be influenced by some factors like purpose of trip of the driver or the physical condition of the driver, the standard deviation is free from these influences. That is to say, if it were possible to obtain a partial correlation coefficient of, for example, mean speed versus density, holding all other possible influences constant, that coefficient might be significant. In the present study those influences were altogether neglected. However, the standard deviation showed a correlation with traffic density under identical conditions.

Summary

Among the five spot speed characteristics studied the standard deviation was the only one that showed a significant correlation with traffic density. It was established that the relationships between standard deviation and density obtained from the two locations were not significantly different and that a composite regression line represented all the data better than two individual lines. Confidence limits were set on the composite regression line; it was observed that speed data collected by the Virginia Department of Highways independently of the original study at two locations with different roadway and traffic features conformed to the findings of the original study.

HEADWAY CHARACTERISTICS

The headway characteristics considered were the percentages of vehicles traveling closer than 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 seconds. These percentages were de-

termined for all the density levels at which spot speed distributions were obtained. It is expected that the percentage of vehicles traveling closer than a specified headway will increase as the traffic density increases. Correlation analyses were run between average lane density and the percentage of vehicles traveling closer than each of the headway values stated.

Data Collection

It was mentioned earlier that the chronograph pen enabled the collection of headway data. The tape of the graphic recorder could be run at any of ten different speeds. In this study, after considering the bulk of the tapes and a satisfactory speed trace, a tape speed of 6 in. per minute was used. Because the tape speed was known, the time spacing between vehicles was derived from the distance between "blips" in the margin of the tape.

Results

In general, a high degree of correlation was attained between the percentage of vehicles traveling closer than a specified headway and average lane density. Only the 1-sec headway produced a non-significant result. Table 3 summarizes the percentage of vehicles traveling closer than each headway value. Table 4 gives the correlation coefficients obtained at both locations.

Regression lines were determined (Table 5) for the data on percentage of vehicles traveling closer than 2, 3, 4, 5, 6, 7, 8, 9, and 10 sec and density. The 1-sec headway was omitted because a non-significant correlation was observed in that case.

Figure 3 is a plot of the regression lines given in Table 5. The general parallelism of the lines suggested the testing of the hypothesis that the regression lines for the same headway from the two locations were parallel. The test results indicated that this hypothesis could not be rejected for any of the pairs of lines. Next the hypothesis was set up that the intercepts of the same pairs of lines were equal. This hypothesis, however, had to be rejected in all cases. Therefore, a generalization between the two locations was not possible; in other words, a single composite line would not represent all the points pertaining to the same headway better than two individual lines.

TABLE 3

PERCENTAGE OF VEHICLES TRAVELING CLOSER THAN SPECIFIED HEADWAY

Location	Avg. Lane Den. (vpm)	Percentage of Vehicles Traveling Closer Than									
		1 Sec	2 Sec	3 Sec	4 Sec	5 Sec	6 Sec	7 Sec	8 Sec	9 Sec	10 Sec
I	3.08	10.20	24.83	29.59	35.03	38.77	41.83	44.89	45.57	46.59	48.97
	3.87	8.59	28.12	37.89	43.75	45.70	47.26	50.00	51.95	53.90	56.25
	4.12	8.25	24.75	34.65	41.58	46.20	49.83	51.48	54.45	56.43	59.07
	4.18	6.23	25.90	35.07	41.30	45.24	47.53	50.15	52.12	55.07	56.05
	5.11	10.92	29.68	40.94	46.74	48.45	51.18	53.57	55.96	56.30	59.37
	5.47	7.37	29.81	39.42	43.27	48.72	52.56	56.73	59.29	62.82	65.06
	5.47	12.41	34.63	44.43	49.66	52.27	56.19	57.83	59.13	61.09	61.75
	6.35	5.52	28.56	40.25	47.07	51.29	53.88	56.48	58.75	62.32	65.89
	6.65	8.75	33.75	42.19	48.12	53.12	55.94	60.00	62.50	64.69	67.50
	8.61	9.96	37.36	48.74	56.93	60.13	63.33	68.31	70.45	74.00	77.56
	9.87	8.02	36.72	51.23	58.33	65.42	70.98	73.76	75.61	78.08	80.24
II	2.71	6.25	27.94	37.13	40.44	44.85	47.05	50.36	51.10	53.30	55.14
	4.07	10.90	33.01	42.63	48.40	51.60	55.13	57.37	59.29	60.90	61.86
	5.00	10.67	40.66	48.66	53.66	57.66	60.33	63.33	64.99	66.33	67.33
	6.12	10.90	38.86	48.81	55.45	60.66	64.45	67.29	69.19	71.08	74.40
	6.14	9.63	40.36	50.61	56.82	61.17	63.34	64.89	67.07	68.93	69.55
	7.20	11.43	43.78	57.17	63.05	67.63	69.26	71.22	73.51	75.14	76.77
	8.88	9.61	46.72	56.76	62.00	69.42	72.91	74.66	76.40	77.28	78.15

TABLE 4

CORRELATION OF PERCENTAGES CLOSER THAN SPECIFIED HEADWAY WITH AVERAGE LANE DENSITY

Headway (sec)	Coefficient of Correlation Between Average Lane Density and % of Vehicles Traveling Closer Than Indicated Headway	
	Location I	Location II
1	-0.055	0.048
2	0.874[1]	0.944[2]
3	0.939[1]	0.948[2]
4	0.942[1]	0.941[2]
5	0.980[1]	0.973[1]
6	0.975[1]	0.979[1]
7	0.956[1]	0.974[1]
8	0.984[1]	0.970[1]
9	0.980[1]	0.967[1]
10	0.982[1]	0.951[1]

[1] Significant at 99.9 percent level.
[2] Significant at 99 percent level.

TABLE 5

REGRESSION EQUATIONS FOR PERCENTAGE TRAVELING CLOSER THAN THE SPECIFIED HEADWAY AND AVERAGE LANE DENSITY

Headway (sec)	Regression Lines for Density and Percentage[1] Traveling Closer Than Specified Headway	
	Location I	Location II
2	P = 19.294 + 1.941 D	P = 21.879 + 2.946 D
3	P = 24.311 + 2.819 D	P = 29.718 + 3.334 D
4	P = 28.812 + 3.103 D	P = 33.554 + 3.613 D
5	P = 30.560 + 3.490 D	P = 35.481 + 4.104 D
6	P = 32.005 + 3.797 D	P = 37.974 + 4.155 D
7	P = 34.501 + 3.881 D	P = 41.676 + 3.924 D
8	P = 35.514 + 4.063 D	P = 42.577 + 4.076 D
9	P = 36.557 + 4.286 D	P = 45.038 + 3.931 D
10	P = 38.224 + 4.415 D	P = 46.778 + 3.883 D

[1] P is percentage of vehicles traveling closer than specified headway.

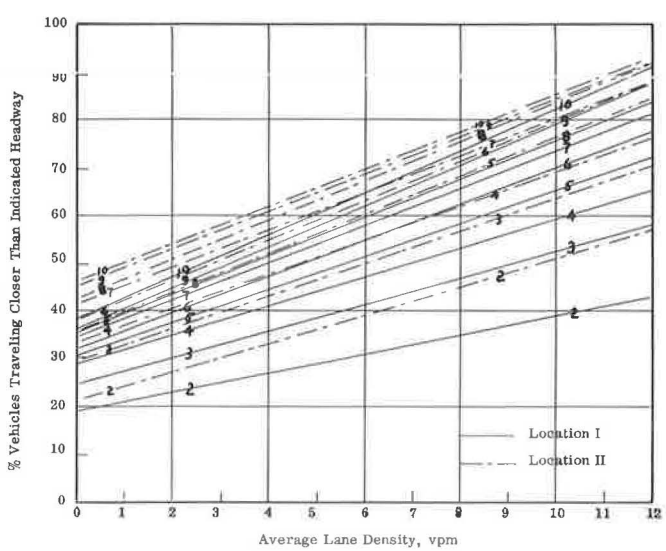

Figure 3. Regression lines for percentage of vehicles traveling closer than indicated headways and average lane density.

Discussion

Analysis of the headway frequency distributions revealed a high degree of correlation between the percentage of vehicles traveling closer than a specified headway and average lane density for headways of 2 sec and greater. The percentages of vehicles traveling closer than 1 sec did not indicate a correlation with traffic density, pointing out the fact that some drivers tend to follow a leading car very closely regardless of the prevailing traffic conditions. The percentage of vehicles traveling closer than a 1-sec headway cannot, therefore, be considered a significant characteristic of traffic flow and can have no applicability in the assessment of relative congestion. The percentages of vehicles traveling closer than headways of 2 sec or greater may be a significant characteristic of traffic flow; however, the fact that the regression lines for the percentage of vehicles traveling closer than a specified headway and average lane density from the two locations were not coincident, although parallel, cannot be overlooked. The purport is that although the rate of variation of the percentage of vehicles closer than a specified headway with density is the same for either location (i.e., the slopes of the lines are equal), there is a factor which influences the distribution of headways in a different manner at different locations. Unfortunately, headway data from other sources were not available to carry this phase of the investigation further.

Summary

Although very high correlations were obtained between average lane density and the percentage of vehicles traveling closer than headways of 2, 3, 4, 5, 6, 7, 8, 9, and 10 seconds at both locations, a generalization between locations was not possible. Headway characteristics may yet be used in assessing relative congestion if the cause or causes of variation between locations can be identified.

ASSOCIATION OF SPOT SPEED AND HEADWAY CHARACTERISTICS

It may be expected that the spot speed characteristics and the headway characteristics discussed in the two previous sections will have a relationship; i.e., as vehicles travel with smaller headways their speeds tend to be more uniform. To investigate

TABLE 6

STANDARD DEVIATIONS AND CORRESPONDING PERCENTAGES OF VEHICLES TRAVELING CLOSER THAN SPECIFIED HEADWAYS

Location	Std. Dev. (mph)	Percentage of Vehicles Traveling Closer Than								
		2 Sec	3 Sec	4 Sec	5 Sec	6 Sec	7 Sec	8 Sec	9 Sec	10 Sec
I	4.97	37.36	48.74	56.93	60.13	63.33	68.31	70.45	74.00	77.66
	5.15	29.81	39.42	43.27	48.72	52.56	56.73	59.29	62.82	65.06
	5.18	29.68	40.94	46.74	48.45	51.18	53.57	55.96	56.30	59.37
	5.24	28.12	37.89	43.75	45.70	47.26	50.00	51.95	53.90	56.25
	5.36	28.56	40.25	47.07	51.29	53.88	56.48	58.75	62.32	65.89
	5.52	36.72	51.23	58.33	65.42	70.98	73.76	75.61	78.08	80.24
	5.81	33.75	42.19	48.12	53.12	55.94	60.00	62.50	64.69	67.50
	6.21	25.90	35.07	41.30	45.24	47.53	50.15	52.12	55.07	56.05
	6.22	34.63	44.43	49.66	52.27	56.19	57.83	59.13	61.09	61.75
	6.44	24.75	34.65	41.58	46.20	49.83	51.48	54.45	56.43	59.07
	6.96	24.83	29.59	35.03	38.77	41.83	44.89	45.57	46.59	48.97
II	5.75	43.78	57.17	63.05	67.63	68.26	71.22	73.51	75.14	76.77
	5.91	46.72	56.76	62.00	69.42	73.91	74.66	76.40	77.28	78.15
	6.07	40.36	50.61	56.82	61.17	63.34	64.89	67.07	68.93	69.55
	6.11	33.01	42.63	48.40	51.60	55.13	57.37	59.29	60.90	61.86
	6.33	38.86	48.81	55.45	60.66	64.45	67.29	69.19	71.08	74.40
	6.83	40.66	48.66	53.66	57.66	60.33	63.33	64.99	66.33	67.33
	6.89	27.94	37.13	40.44	44.85	47.05	50.36	51.10	53.30	55.14

the relationship between these characteristics, correlation analyses were run between the standard deviation of the spot speed distribution and the percentage of vehicles traveling closer than 2, 3, 4, 5, 6, 7, 8, 9, and 10 sec. In these correlation analyses each point represented the standard deviation and the percentage of vehicles traveling closer than the specified headway pertaining to the same density level.

Results

Table 6 gives the standard deviations and the corresponding percentages of vehicles traveling closer than the specified headways.

Table 7 summarizes the results of the regression analysis on data for the standard deviation and on percentage closer than a specified headway. In general, a very high degree of correlation does not exist between the percentage of vehicles traveling closer than a specified headway; however, an overall trend is apparent.

Corresponding lines from each location were compared for parallelism and coincidence. Hypotheses were set up that the slopes and the intercepts of each pair of lines were equal. It was determined that in each case, with the given scatter of points, the hypothesis that the slopes of the two lines were equal could not be rejected. However, the hypothesis that the intercepts were equal had to be rejected. Therefore, for any pair it was impossible to draw a single line that would represent all the points better than two separate lines.

Figure 4 is a plot of the percentage of vehicles traveling closer than 3 sec against the standard deviation for both locations; this plot is representative of those with other values of headway.

Discussion

The results of the attempt to associate the standard deviation of the speed distribution to the percentage of vehicles traveling closer than a specified headway were not very encouraging. The correlation obtained between these two quantities did not reach a high level and in certain instances was below the 90 percent significance level (Table 6). At those values of headway where the correlation was significant, the regression lines from the two locations displayed parallelism in all cases, but none of the pairs was coincident. The effect which was observed to cause the non-coincidence in the case of the regression lines for the percentage of vehicles traveling closer than a

TABLE 7

SUMMARY OF REGRESSION ANALYSES ON DATA FOR STANDARD DEVIATION AND PERCENTAGE OF VEHICLES CLOSER THAN A SPECIFIED HEADWAY

Headway (sec)	Coeff. of Correl. Between Std. Dev. and Percent Closer Than Specified Headway		Line of Best Fit for Data on Std. Dev. and Percent Closer Than Specified Headway	
	Location I	Location II	Location I	Location II
2	-0.500	-0.622	—[1]	—[1]
3	-0.618[2]	-0.731[3]	$P = 74.892 - 6.010\,\sigma$	$P = 123.697 - 11.943\,\sigma$
4	-0.594[3]	-0.758[2]	$P = 82.507 - 6.276\,\sigma$	$P = 139.076 - 13.539\,\sigma$
5	-0.533[3]	-0.741[3]	$P = 85.410 - 6.092\,\sigma$	$P = 150.015 - 14.518\,\sigma$
6	-0.479	-0.737[3]	—	$P = 152.830 - 14.532\,\sigma$
7	-0.518	-0.704[3]	—	$P = 146.660 - 13.160\,\sigma$
8	-0.546[3]	-0.721[3]	$P = 100.133 - 7.227\,\sigma$	$P = 154.114 - 14.066\,\sigma$
9	-0.559[3]	-0.725[3]	$P = 106.043 - 7.852\,\sigma$	$P = 153.416 - 13.694\,\sigma$
10	-0.593[3]	-0.701[3]	$P = 112.430 - 8.547\,\sigma$	$P = 152.356 - 13.292\,\sigma$

[1] Line of best fit not calculated because correlation not significant. [2] Correlation significant at 95 percent level, but not at 98 percent level. [3] Correlation significant at 90 percent level, but not at 95 percent level.

lation developed in the original study between the standard deviation and average lane density.

3. Point 2 accentuates the indication that for two-lane highways in rural areas the standard deviation of the speed distribution is a significant parameter of traffic flow and may be used in assessing congestion.

4. The percentage of vehicles traveling closer than a headway of 1 sec did not indicate a correlation with average lane density. The percentage for headways of 2 sec and greater, on the other hand, were correlated with average lane density to a high degree of significance at both locations. However, the regression lines for the two locations could not be combined to obtain a composite single line. This prevented the possibility of a generalization. Headway data were not available from other sources to investigate this possibility further.

5. It was determined that the percentage of vehicles traveling closer than a specified headway was not significantly correlated with the standard deviation for certain values of the headway, that even for those values where the correlation was significant for both locations a generalization was impossible, and that increasing interference between vehicles tends to make speeds more uniform.

6. The standard deviation seems to be a significant parameter of traffic flow—better than the mean speed and the percentage of vehicles traveling closer than a specified headway—at least in the range of densities studied on two-lane rural highways. In assessing congestion the standard deviation should be the best parameter to specify because indications are that it may be applicable to many kinds of roadway and traffic conditions. Furthermore, the standard deviation of a speed frequency distribution can be readily estimated.

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REFERENCES

1. Greenshields, B.D., "The Density Factor in Traffic Flow." Traffic Eng. p. 26 (March 1960).
2. May, A.D., and Wagner, F.A., "Headway Characteristics and Interrelationships of the Fundamental Characteristics of Traffic Flow." HRB Proc. 39: 524 (1960).
3. Rothrock, C.A., and Keefer, L.E., "Measurement of Urban Traffic Congestion." HRB Bull. 156, pp. 1-13 (1957).
4. Wingo, L, "Measurement of Congestion in Transportation Systems." HRB Bull. 221, pp. 1-28 (1959).
5. Deen, T.B., "The Use of Travel Time as a Factor in Rating Urban Streets." Traffic Eng., p. 13 (Jan. 1960).
6. Brenner, R., Telford, E.T., and Frischer, D., "A Quantitative Evaluation of Traffic in a Complex Freeway Network." HRB Bull. 291, pp. 163-206 (1961).

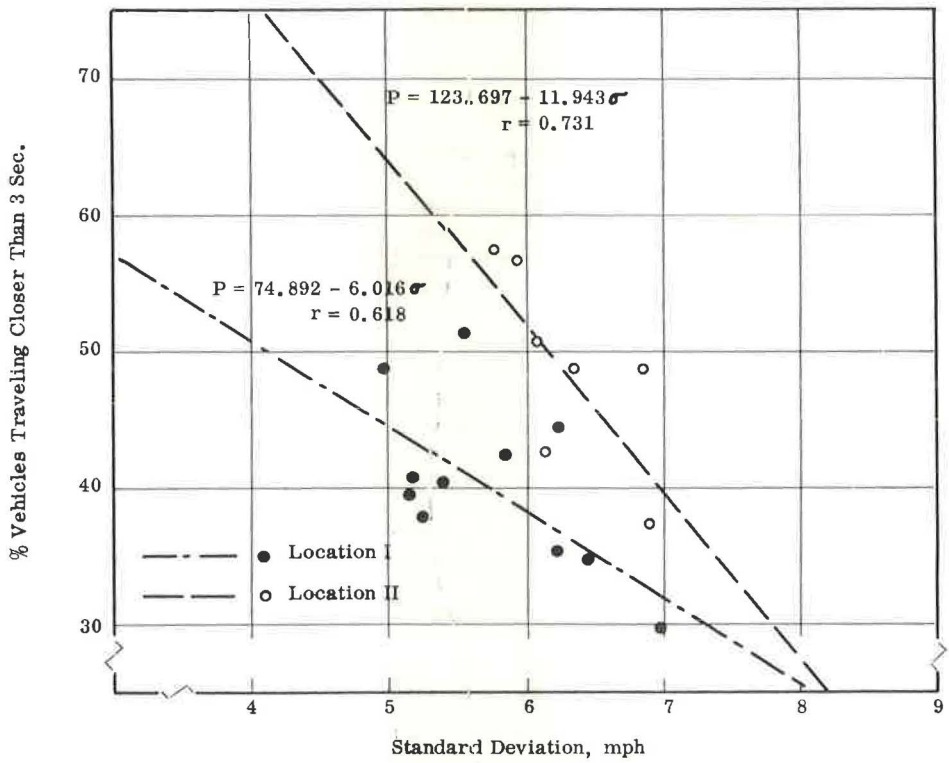

Figure 4. Percentage of vehicles traveling closer than 3 sec versus the standard deviation of the speed frequency distributions.

specified headway and density, apparently influenced this correlation and made a generalization impossible. However, the overall trend of decreasing percentage of vehicles traveling closer than a specified headway with increasing standard deviation, or the converse, indicates that increasing interference between vehicles, will tend to cause increasingly uniform speeds.

Summary

The relationship between the standard deviation of the spot speed distribution and the percentage of vehicles traveling closer than a specified headway is not well defined, although an overall trend is apparent. A generalization of this relationship between the two locations is not possible. The fact that no significant correlations were obtained for certain values of headway does not allow any positive statements.

GENERAL CONCLUSIONS

1. A correlation was not found between average lane density and certain characteristics of the spot speed distribution of vehicles (namely, skewness, kurtosis, deviation from normality, and mean speed) in the range of densities studied; on the other hand, the standard deviation of the distribution correlated with average lane density at each location. Further it was determined that the two regression lines for the standard deviation and density from the two locations could be replaced by one composite line, thus opening up possibilities of generalization.

2. Speed data obtained by the Virginia Department of Highways independent of this study and at two locations having roadway and traffic features quite different from those of the two original locations were analyzed. The computed standard deviation values were seen to fall within the 95 percent confidence range of a prediction from the corre-

Appendix

SAMPLE COMPUTATION FOR MOMENT ANALYSIS AND χ^2 TEST

Given: The speed frequency distribution of Table 8 (at location I).

TABLE 8

SPEED FREQUENCY DISTRIBUTION OBTAINED IN 1 HOUR AT LOCATION I

Speed Class	No. in Class	Speed Class	No. in Class
32 - 33.9	1	52 - 53.9	38
34 - 35.9	3	54 - 55.9	25
36 - 37.9	5	56 - 57.9	16
38 - 39.9	6	58 - 59.9	5
40 - 41.9	14	60 - 61.9	9
42 - 43.9	32	62 - 63.9	2
44 - 45.9	41	64 - 65.9	1
46 - 47.9	43	66 - 67.9	1
48 - 49.9	43	68 - 69.9	0
50 - 51.9	40	70 - 71.9	1

Determine: Mean, speed, skewness, kurtosis, standard deviation, χ^2 value (for deviation from a normal distribution with the same mean and standard deviation); also volume and average lane density to which the distribution pertains.

A mean value of 49.00 mph is assumed and the deviation of the mid-value of each class from the assumed mean is expressed in terms of classes (Table 9).

TABLE 9

DEVIATION OF MID-VALUE OF CLASS FROM ASSUMED MEAN SPEED

Speed Class	Deviation from Mean, d	Number in Class, f	fd	fd^2	fd^3	fd^4
32 - 33.9	-8	1	- 8	64	- 512	4,096
34 - 35.9	-7	3	-21	147	-1,029	7,203
36 - 37.9	-6	5	-30	188	-1,080	6,480
38 - 39.9	-5	6	-30	150	- 750	3,750
40 - 41.9	-4	14	-56	224	- 396	3,584
42 - 43.9	-3	32	-96	288	- 864	2,592
44 - 45.9	-2	41	-84	168	- 336	672
46 - 47.9	-1	43	-43	43	- 43	43
48 - 49.9	0	43	0	0	0	0
50 - 51.9	1	40	40	40	40	40
52 - 53.9	2	38	76	152	304	608
54 - 55.9	3	25	75	225	675	2,025
56 - 57.9	4	16	64	256	1,024	4,096
58 - 59.9	5	5	25	125	625	3,125
60 - 61.9	6	9	54	324	1,944	11,664
62 - 63.9	7	2	14	98	686	4,802
64 - 65.9	8	1	8	64	512	4,096
66 - 67.9	9	1	9	81	729	6,561
68 - 69.9	10	0	0	0	0	0
70 - 71.9	11	1	11	121	1,331	14,640

The terms that have significance in the following computation are defined as follows:

σ = standard deviation, mph;
a_3 = skewness;
a_4 = kurtosis;

$\Sigma f = 326$; $\Sigma fd = 8$; $\Sigma fd^2 = 2,750$; $\Sigma fd^3 = 2,309$; $\Sigma fd^4 = 80,078$; $M'_1 = \Sigma fd/\Sigma f = 0.02454$; $M'^2_1 = 0.00060$; $M'^3_1 = 0.00001$; $M'^4_1 = 0.00000$; $M'^2 = \Sigma fd^2/\Sigma f = 8.43558$; $M'_1 M'_2 = 0.20701$; $M'^2_1 M'_2 = 0.00508$; $M'_3 = \Sigma fd^3/\Sigma f = 7.23926$; $M'_1 M'_3 = 0.17381$; $M'_4 = \Sigma fd^4/\Sigma f = 245.63804$;

$$\underline{\underline{S}} = S_0 + i\,M'i = 49.00000 + 2 \times 0.02454 = \underline{\underline{49.04908}}$$

$M'_2 = M'_2 - (M'_1)^2 = 8.43498$; $M'_2 = 2.90430$;

$$\underline{\underline{\sigma}} = i\sqrt{M'_2} = 2 \times 2.90430 = 5.80860$$

$(M'_2)^{3/2} = 24.49771$; $(M'_2)^2 = 71.14870$; $M'_{33} = M'_3 - 3M'_2 M'_1 + 2(M'_1)^3 = 6.46481$; $M'_4 = M'_4 - 4M'_3 M'_1 + 6(M'_1)^2 M'_2 - 3(M'_1)^4 = 244.97328$;

$\underline{\underline{a_3}} = \dfrac{M'_3}{(M'_2)^{3/2}} = 0.26377$; $\underline{\underline{a_4}} = \dfrac{M'_4}{(M'_2)^2} = 3.44312$; $\underline{\underline{V}} = \dfrac{\Sigma f}{k} \times 6 = 326$ vph; $V = f = 326$; $\underline{S} = 49.05$ mph; $\underline{\underline{D}} = \dfrac{326}{49.05} = 6.65$ vpm.

Part I of the χ^2 test is mostly self-explanatory. Col. 4 is the probability of observing the specified or a greater speed if the distribution were normal. Col. 5 is the difference in successive probabilities in Col. 4; i.e., the probability of each group. Col. 6 is obtained by multiplying the probabilities in Col. b by Σf. Because the χ^2 test introduces a bias when the expected number in a class is less than 5, the tails of the expected distribution are added up until a value greater than 5 is obtained.

In part II of the χ^2 test each value in Col. 5 is multiplied by the corresponding value in Col. 4, and the products are summed. The sum is the χ^2 value. The degrees of freedom can be computed by subtracting three from the number of items contributing to the χ^2 value; i.e., the number of rows in part II of the χ^2 test. There are 13 rows; therefore, the degrees of freedom are 10, 3 degrees of freedom being lost because the original and fitted data are made to agree as to total number, mean, and standard deviation. The χ^2 value was not significant in this case.

χ^2 TEST (PART I)

S = 49.04908 mph σ = 5.80860 mph

(1) Lower Limit of Class	(2) Dev. from Mean	(3) Col. 2 / Std. Dev. (z)	(4) P(z)	(5) $P(z_1) - P(z_2)$	(6) Expected Number in Class
$-\infty$	$+\infty$	$+\infty$	1.0000		
32	17.0491	2.93	0.9983	0.0017	0.5542
34	15.0491	2.59	0.9952	0.0031	1.0106
36	13.0491	2.25	0.9878	0.0074	2.4124
38	11.0491	1.90	0.9713	0.0165	5.3790
40	9.0491	1.56	0.9406	0.0307	10.0082
42	7.0491	1.21	0.8863	0.0537	17.5062
44	5.0491	0.87	0.8078	0.0791	25.7866
46	3.0491	0.52	0.6985	0.1093	35.6318
48	1.0491	0.18	0.5714	0.1271	41.4346
50	- 0.9509	-0.16	0.4364	0.1350	44.0100
52	- 2.9509	-0.51	0.3050	0.1314	42.8364
54	- 4.9509	-0.85	0.1977	0.1073	34.9798
56	- 6.9509	-1.20	0.1151	0.0826	26.9276
58	- 8.9509	-1.54	0.0618	0.0533	17.3758
60	-10.9509	-1.89	0.0294	0.0324	10.5624
62	-12.9509	-2.23	0.0129	0.0165	5.3790
64	-14.9509	-2.57	0.0051	0.0078	2.5428
66	-16.9509	-2.92	0.0018	0.0033	1.0758
68	-18,9509	-3.26	0.0006	0.0012	0.3912
70	-20.9509	-3.61	0.0002	0.0004	0.1304
72	-22.9509	-3.95	0.0000	0.0002	0.0652
$+\infty$	$-\infty$	$-\infty$	0.0000	0.0000	0.0000

χ^2 TEST (PART II)

(1) Speed Class	(2) Expected Number	(3) Observed Number	(4) Exp. - Obs.	(5) (Exp. - Obs.) / Exp.
38	9.3562	9	0.3562	0.0381
38 - 40	10.0082	6	4.0082	0.4005
40 - 42	17.5062	14	3.5062	0.2003
42 - 44	25.7866	32	6.2134	0.2410
44 - 46	35.6318	41	5.3682	0.1507
46 - 48	41.4346	43	1.5654	0.0378
48 - 50	44.0100	43	1.0100	0.0229
50 - 52	42.8364	40	2.8364	0.0662
52 - 54	34.9798	38	3.0202	0.0863
54 - 56	26.9276	25	1.9276	0.0716
56 - 58	17.3758	16	1.3758	0.0792
58 - 60	10.5624	5	5.5624	0.5266
60	9.5844	14	4.4166	0.4607

χ^2 = 10.369 (observed), D.F. = 10; χ^2 = 18.307 (0.05, 10)