Traffic Behavior on an Urban Expressway

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●IN A COMPANION paper, "Accident Analysis of an Urban Expressway" (1), two of the authors present a study of the interaction between influencing factors such as weather and light conditions on type of accident. This paper is an effort to study in detail driver behavior in an urban expressway traffic pattern in terms of velocity, spacing, volume and character.

Although the intent was to relate rear-end collisions and traffic patterns somewhat after the fashion of Belmont (2), the largest portion of the paper deals with typical capacity information (3).

The data collection and reduction was similar to that used by Greenshields, et al. (4). A camera was used to record traffic patterns on all six lanes of the Detroit John C. Lodge Expressway for eight consecutive days around the clock.

Functional relationships were obtained for mean velocity, median and modal spacing, lane distribution, and commercial vehicle distribution as a function of volume. A "trend" relationship between annual rear-end collision rate and volume at time of accident was also established. Quantitative information on the effect of rain and night driving conditions on vehicle velocity was determined.

EXPRESSWAY GEOMETRY

This study was performed in June 1957. The expressway system consisted of the John C. Lodge running approximately north and south and intersected near its midpoint by the Edsel B. Ford running approximately east and west. The system is shown in Figure 1. The location of the camera on the John C. Lodge is also shown. The immediate geometry near the camera location is shown in Figure 2. It was approximately midway between the Grand River and Forest ramps, a distance of 0.63 mi. This location was particularly chosen to be as remote as possible from ramp effects.

The cross-section of the Lodge Expressway includes three 12-ft lanes in each direction with a 10-ft medial strip and two 10-ft shoulders.

DATA COLLECTION

A Cine Special camera modified to a speed of 88 frames per minute was mounted on the roof of a 14-story building overlooking the expressway. Figure 3 shows the camera in position while the details of the mechanism are shown in Figure 4. A typical frame is shown in Figure 5. Reference space markers can be seen alongside each curb lane. These were made of reflecting tape and spaced exactly 30 ft apart. These markers were then used to construct a grid which permitted reading off car positions to approximately ½ ft. The film reader developed by the Ford Motor Company is shown in Figure 6. The film viewer's ground-glass cover is

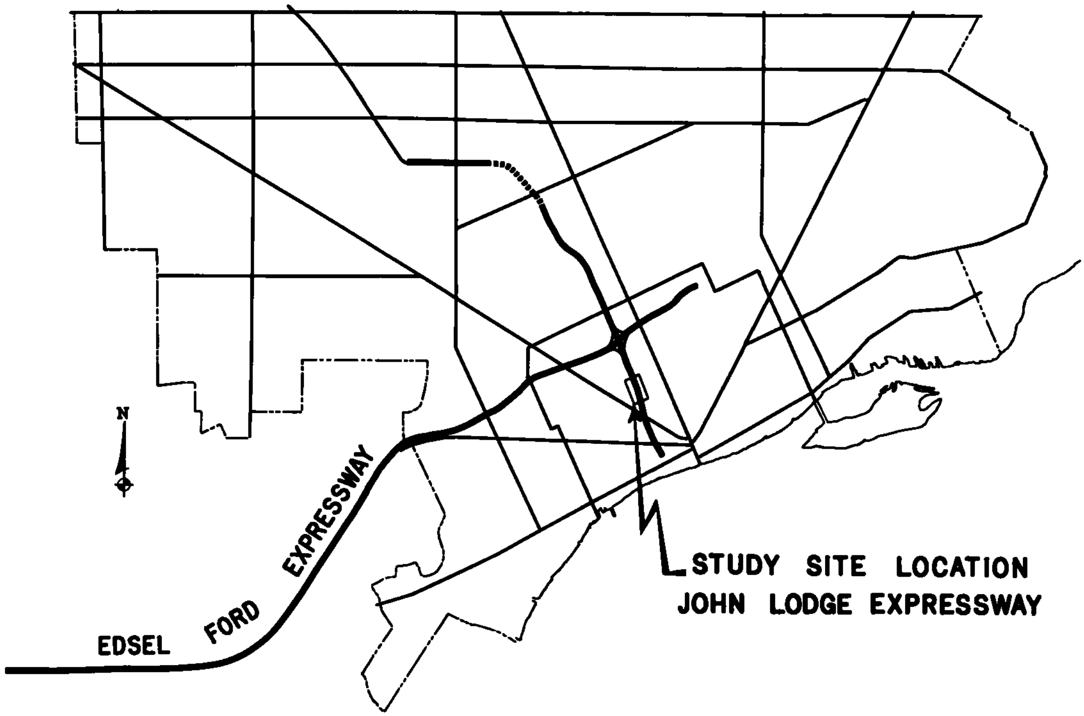


Figure 1.

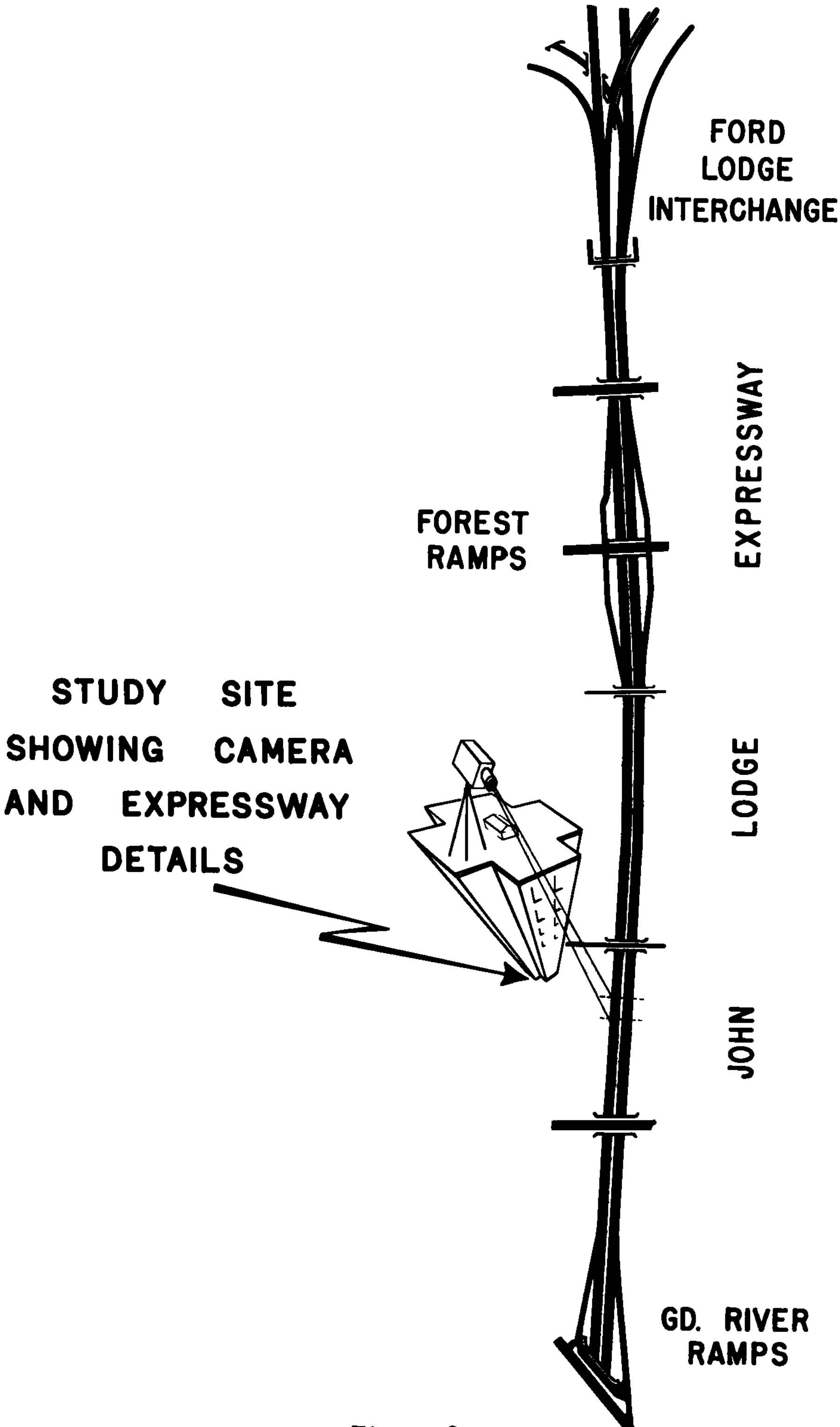
marked with grid lines by which distance between cars and the velocity of each vehicle may be determined readily. The type of vehicle—passenger, truck, bus—was also recorded. All this information was placed on IBM cards for processing on the IBM 650 computer.

Film records were taken each hour for 5 min, 24 hr per day and for eight consecutive days which included one Saturday and Sunday. Fortunately, some rain fell during this time so that this effect could be evaluated. In all, about 64,000 vehicles were recorded on IBM cards.

RESULTS

The first graph, Figure 7, shows the percentage distribution by lane. Each plotted point represents an average of approximately four 5-min samples, i.e., volumes based on 5-min photographic records were grouped into approximately equal volumes and the average of this group determined the value of the abscissa. Similarly, percent of volume is also the mean of the several samples. It can be seen that the middle lanes carry over 40 percent of the three-lane volume while curb lanes carry slightly more than 31 percent and median lanes carry almost 29 percent.

These same samples were further analyzed for the character of the traffic. In Figure 8 the distribution of commercial vehicles per lane as a function of volume is shown. The commercial traffic reaches a high value of 13 percent during low volumes and is reduced to about 2 percent at rush hours. As would be expected the other two lanes carry much less commercial traffic, about 3 percent at the most.


FORD
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AND EXPRESSWAY
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Figure 2.

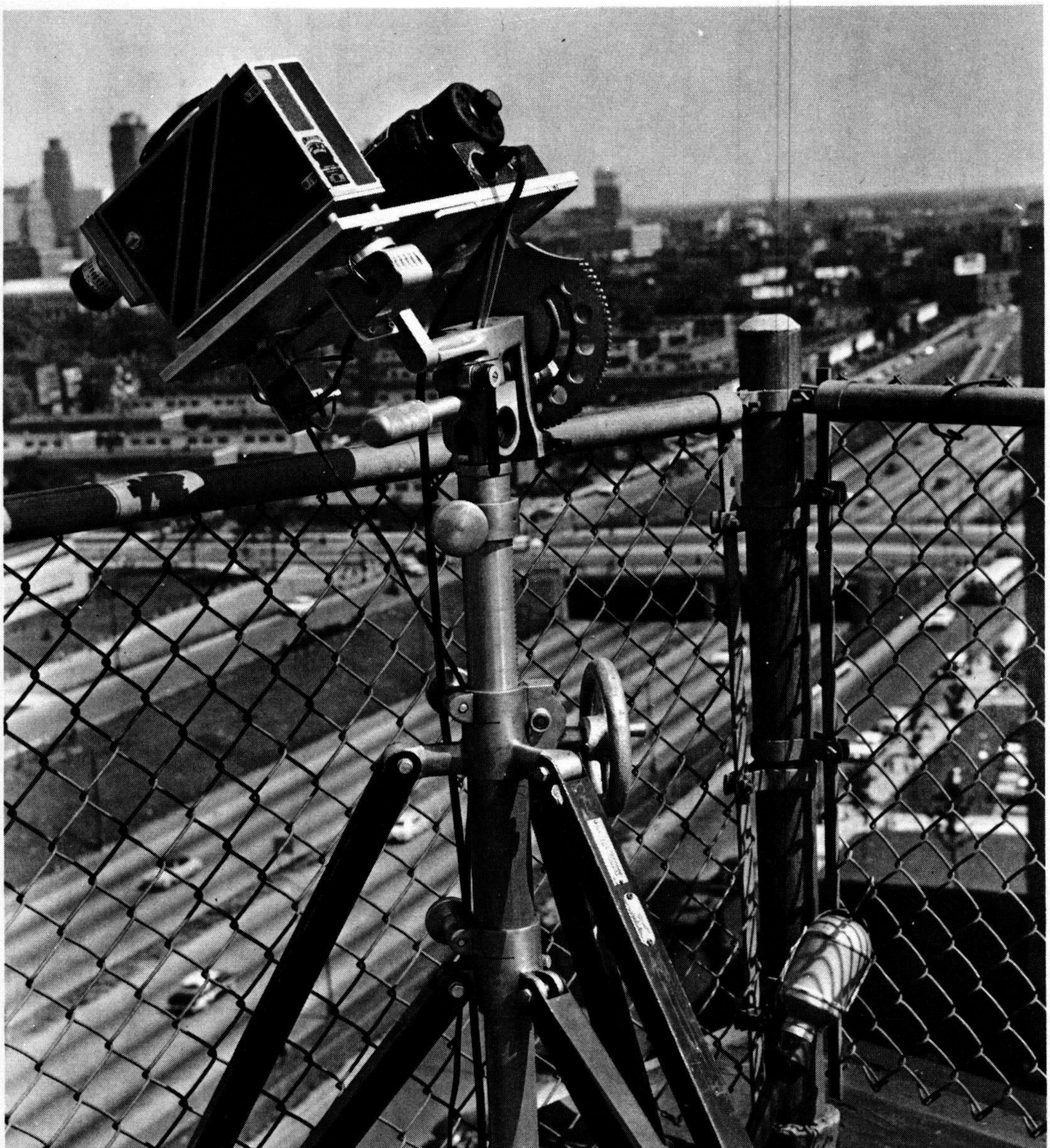

Figure 3.

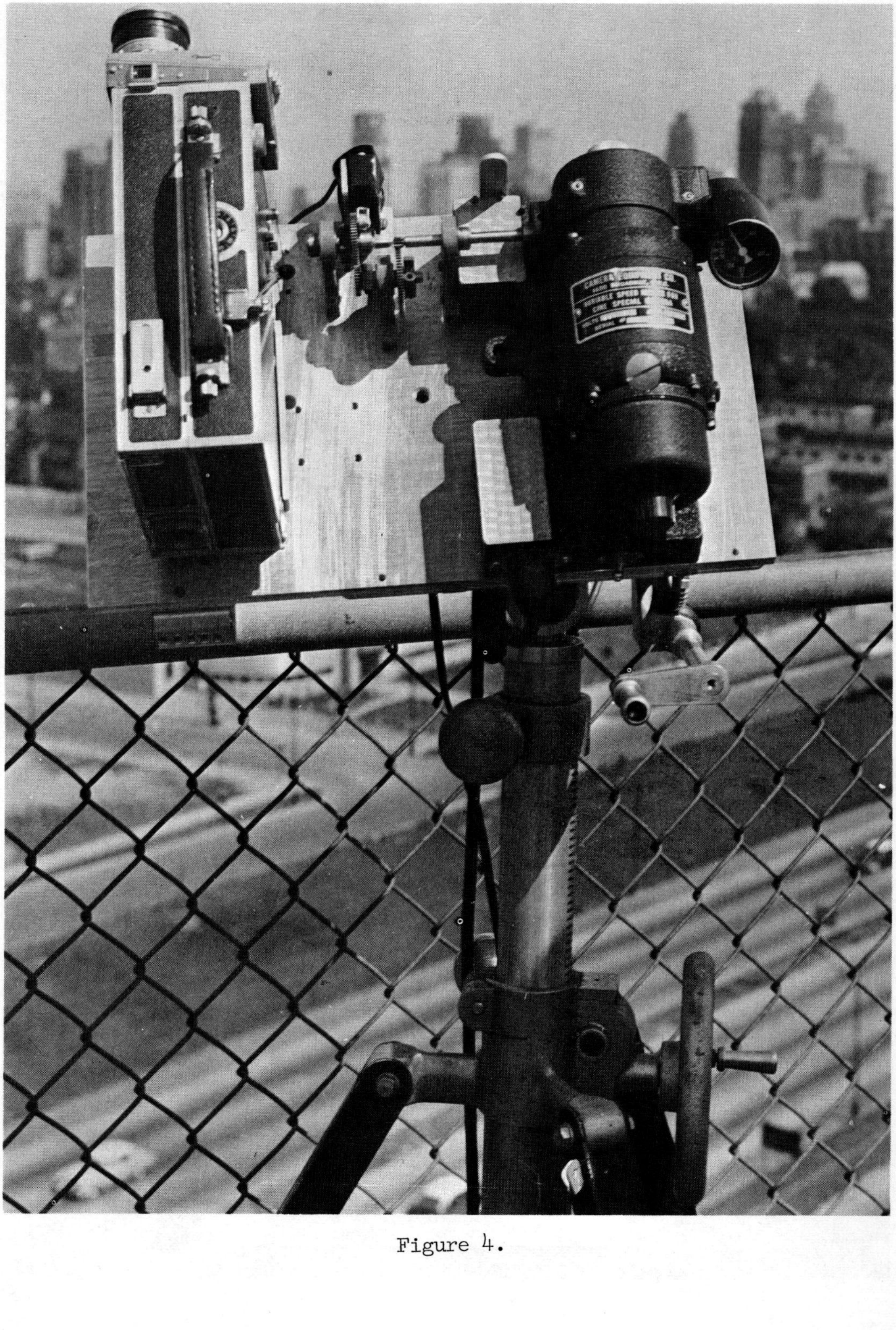

Figure 4.

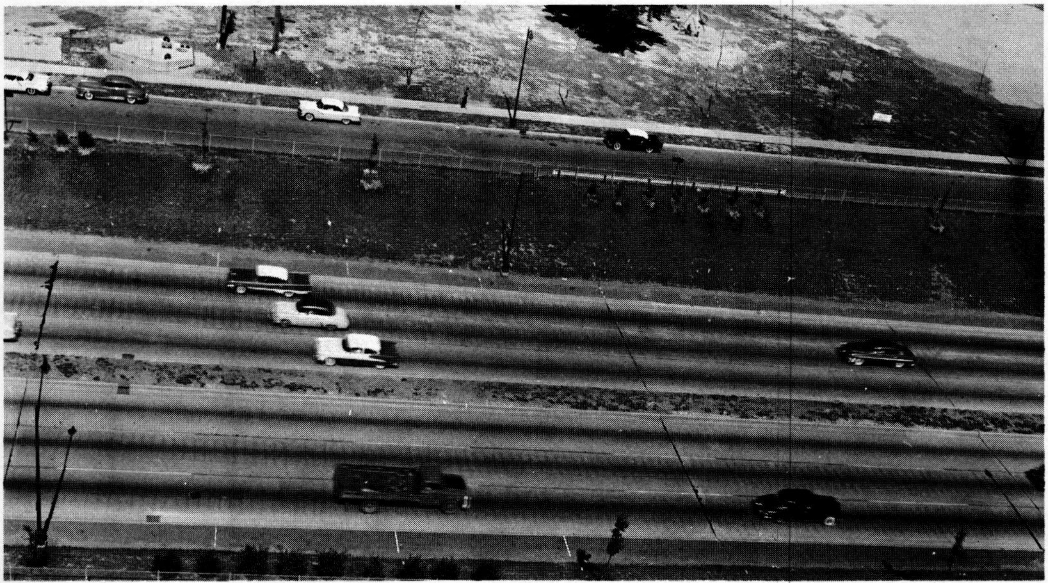

Figure 5.

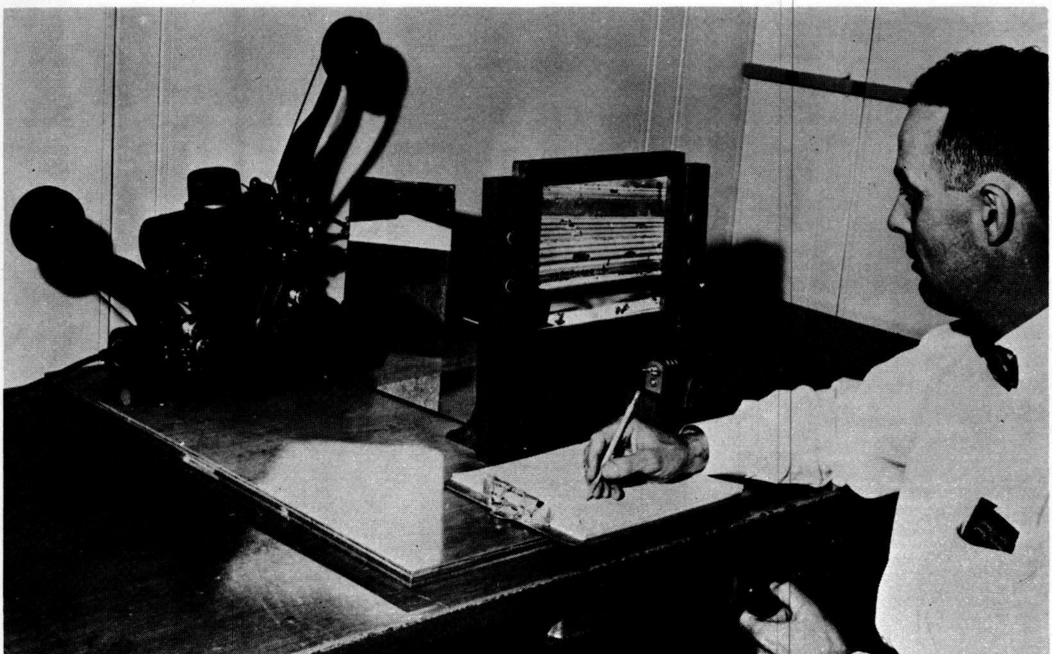

Figure 6.

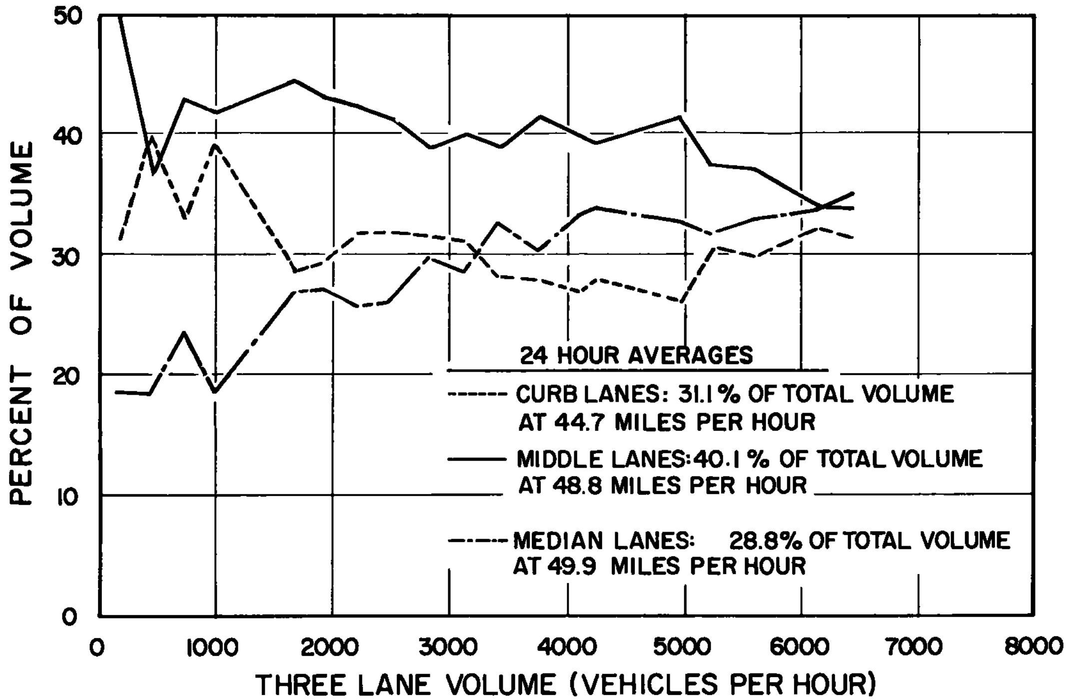

Figure 7. Volume distribution of all vehicles by lane, northbound and southbound—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

Velocity distribution was obtained for all lanes and volumes. A typical result is shown in Figures 9 and 10 for medium and heavy traffic on the middle lanes. It can be seen that the distribution is close to normal. The curves drawn represent the optimum normal distribution that could be fitted to the experimental information. The Detroit expressway system has a posted speed limit of 55 mph and a minimum limit of 40 mph.

Throughout this study, emphasis was placed on describing traffic behavior by mathematical relationships. The advantages are obvious. For one thing, a systems approach may then be used in further analysis. In Figure 11, the mean velocity of passenger vehicles as a function of three-lane volume is plotted. The data represent samples including almost 34,000 vehicles. In this, as in all the curves shown in this paper, each plotted point represents an average of four to eleven 5-min samplings. Further, each point represents the average of a volume class interval of 300 vph. The justification for a parabolic relationship has been suggested by other authors (5). Basically, it depends on a linear relationship between density and mean velocity. A check of this relationship was made and although it is not quite linear, it is very closely so. The data show the largest deviation from a straight line above about 52 mph. Assuming this approximate linearity, and because the curve must go through the origin, a least square fit was made to the data. The relationship on the curve shows how mean velocity may be predicted from volume. The single-sample point is interesting. It was obtained during a particularly congested situation on the expressway caused by rush-hour traffic combin-

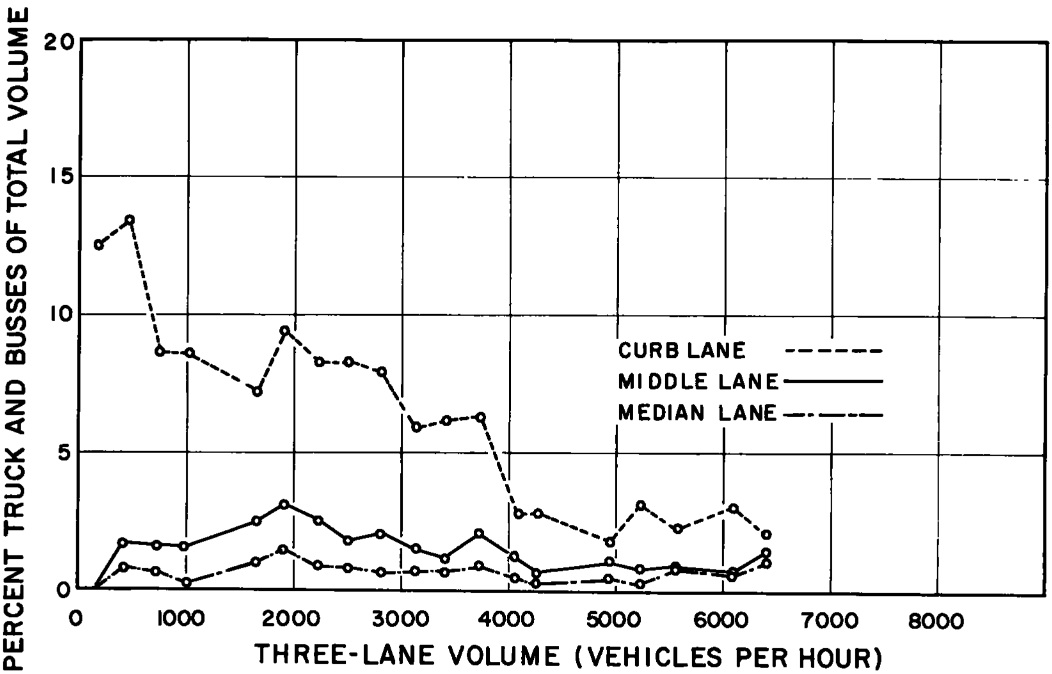

Figure 8. Truck and bus volume distribution by lane, northbound and southbound—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

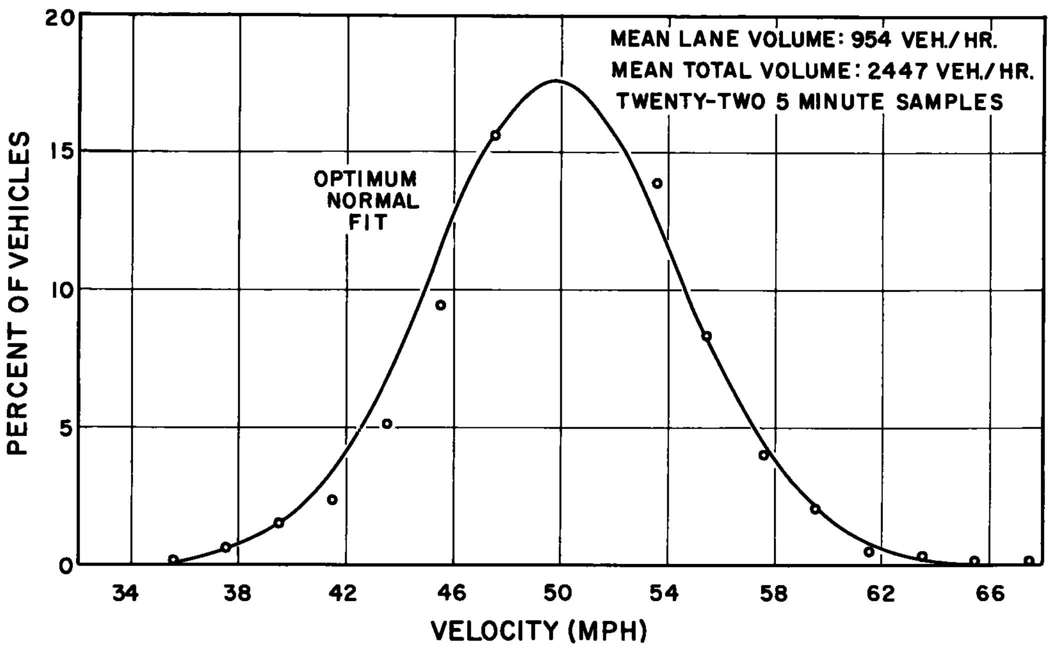

Figure 9. Passenger vehicle velocity distribution, northbound and southbound middle lanes—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

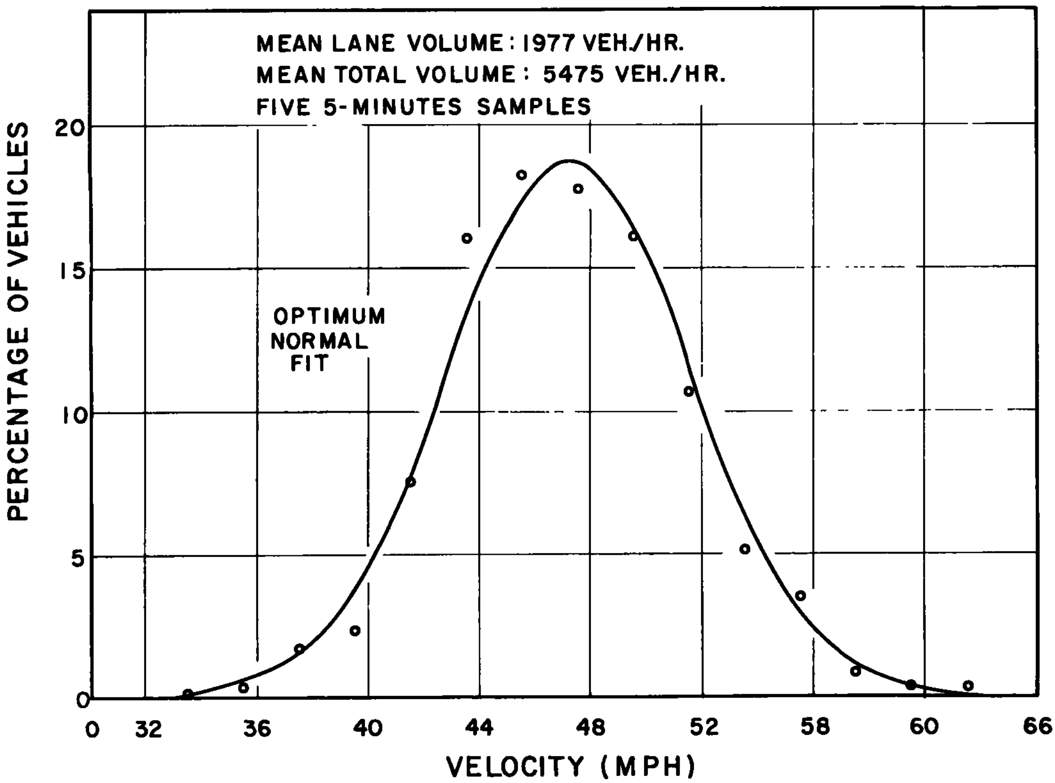

Figure 10. Passenger vehicle velocity distribution, northbound and southbound middle lanes—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

ing with traffic leaving after the end of a Detroit "Tiger" baseball game. Although a single 5-min sample would be statistically of low reliability, it nevertheless shows that a maximum capacity exists. This maximum capacity is at the vertex of the parabola and indicates a value of 8,250 vph traveling at a mean velocity of about 27 mph.

The same type of relationships were found for the individual lanes, i.e., curb, middle and median.

Using the same volume class intervals, the median spacing (50 percentile) was computed as shown in Figure 12. The relationship is hyperbolic and is represented by the mathematical function shown in the figure. It is to be noted that the least square fit is poor at the very low volumes. However, this region is of very little practical value and, furthermore, the data in this region represent only about two or three samples and a mean has little statistical significance. In other words, it was deemed unnecessary to fit a higher order curve just to obtain a better fit in a relatively unimportant region where the data are also less reliable. Again, similar relationships were found for the individual lanes.

Probably of more importance is the modal (most frequent) spacing between vehicles. It was decided in studying the data that probably the best fit to the data would be obtained by two linear relationships inter-

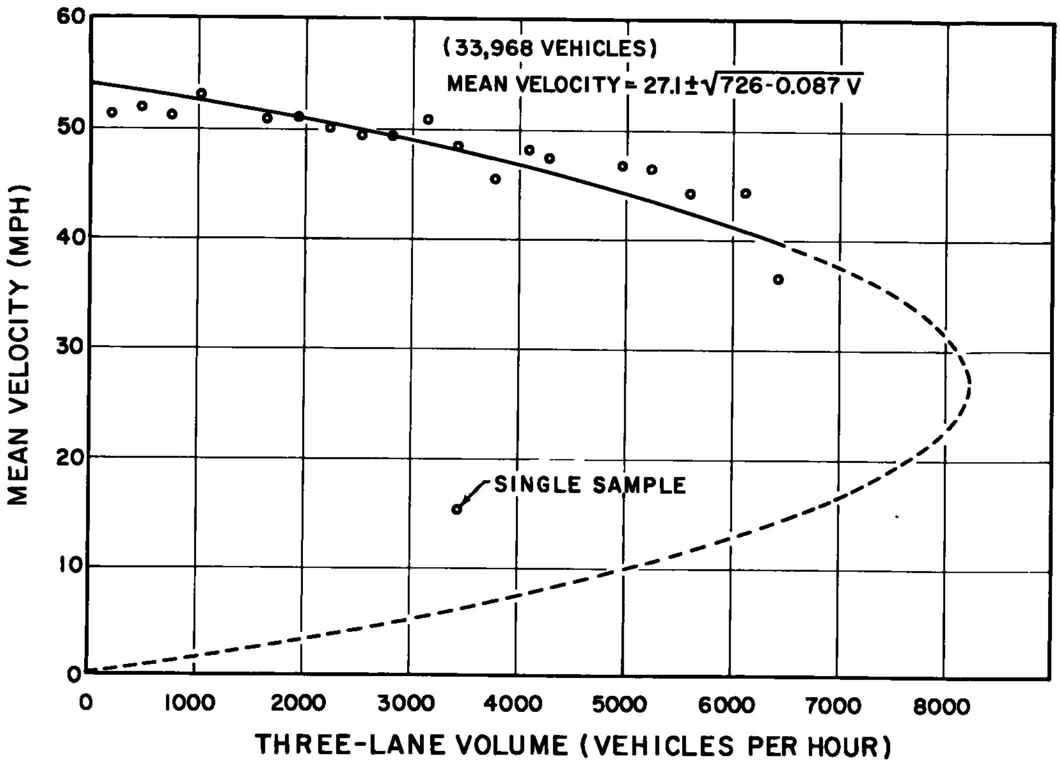

Figure 11. Passenger vehicle mean velocity, northbound and southbound, all lanes combined—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

secting somewhere between a volume of 1,000 and 2,000 vph. The justification for this belief arises from the fact that a Poisson (6,7) spacing distribution fit in the low volume region was probable, whereas beyond approximately a volume of 1,000 vph the distribution was no longer of this type. The relationship between modal spacing and volume is shown in Figure 13. The break point appears to occur at a volume of 1,250 vph. As in the preceding data, the modal spacing was also broken down by lane with similar results. The "break" volumes were 1,000, 1,750 and 1,700 vph for the curb, middle and median lanes, respectively. Much greater variability in the individual lane data was apparent below the "break" volumes. All the above volumes are referred to the total three-lane volume.

Of practical interest is the relationship between modal spacing and mean velocity. In any automatic spacing control system this relationship would be useful in establishing design criteria and still be acceptable to the largest number of drivers. This relationship is shown in Figure 14. It is constructed directly from the empirical mean velocity (volume curve in Figure 11) and the empirical modal spacing (volume curve in Figure 13). There is a discontinuity in the curve of Figure 14 because of the discontinuity in the modal spacing—volume curve near 1,250 vph. Mathematical functions are also shown in the figure that permit prediction of the most frequent spacing if the mean velocity is known.

The vehicle spacing was also analyzed in terms of time, i.e., the

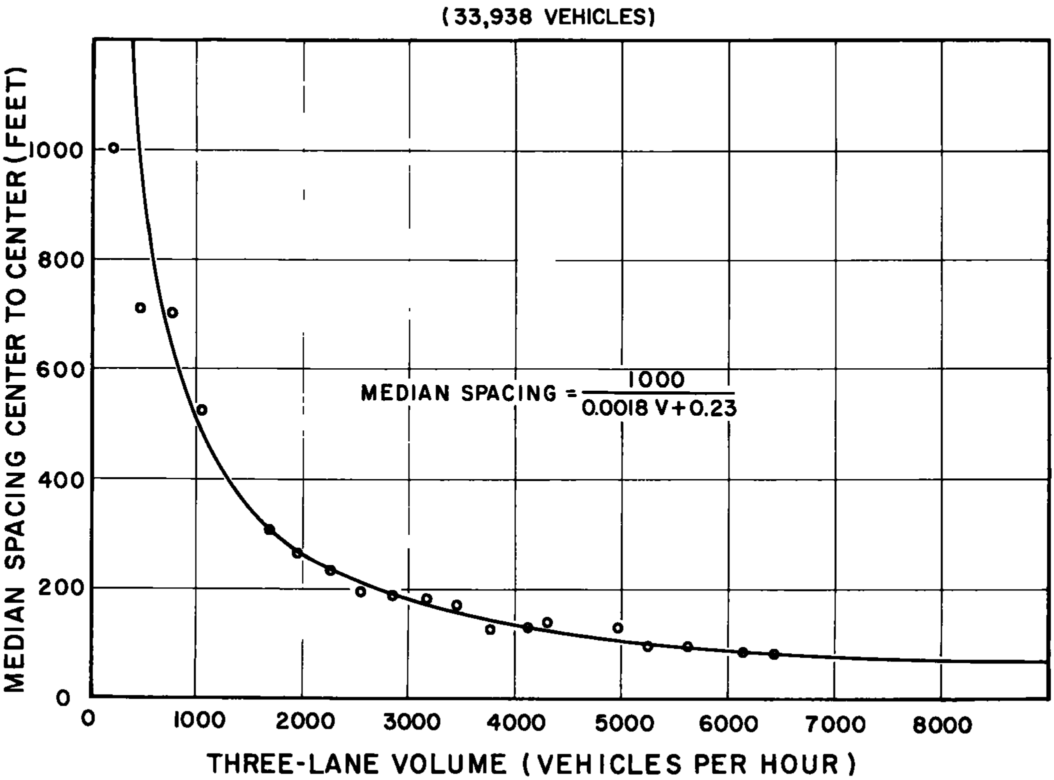

Figure 12. Passenger vehicle median spacing, northbound and southbound, all lanes combined—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

distance to the vehicle in front divided by the velocity of the following vehicle. The result is a linear relationship between time spacing and three-lane volume as shown in Figure 15. At volumes below 1,000 vph the large variability of distance spacing and velocity produced no meaningful information. In general, time spacing decreases linearly with increase in volume.

It is a generally accepted fact that the mean reaction time of a driver in application of brakes is about 0.7 sec (8). The time spacing data were analyzed to determine the number of drivers that space themselves at 0.9, 0.7 and 0.5 or less seconds. The data, as a function of three-lane volume, were fitted to curves as shown in Figure 16. The 0.9- and 0.7-sec curves are parabolic; but the 0.5-sec curve is linear and indicates that about 1 percent of drivers use a spacing $\frac{1}{2}$ sec or less irrespective of the volume.

Another interesting facet developed from the time spacing data. It was found that traffic behavior is somewhat analogous to the charging of an electrical capacitor. Thus, in Figure 17 a family of curves showing cumulative percentage of volume as a function of time spacing with volume as a parameter were fitted to the data. The largest deviation of data from the curve was found at the highest volume and was not larger

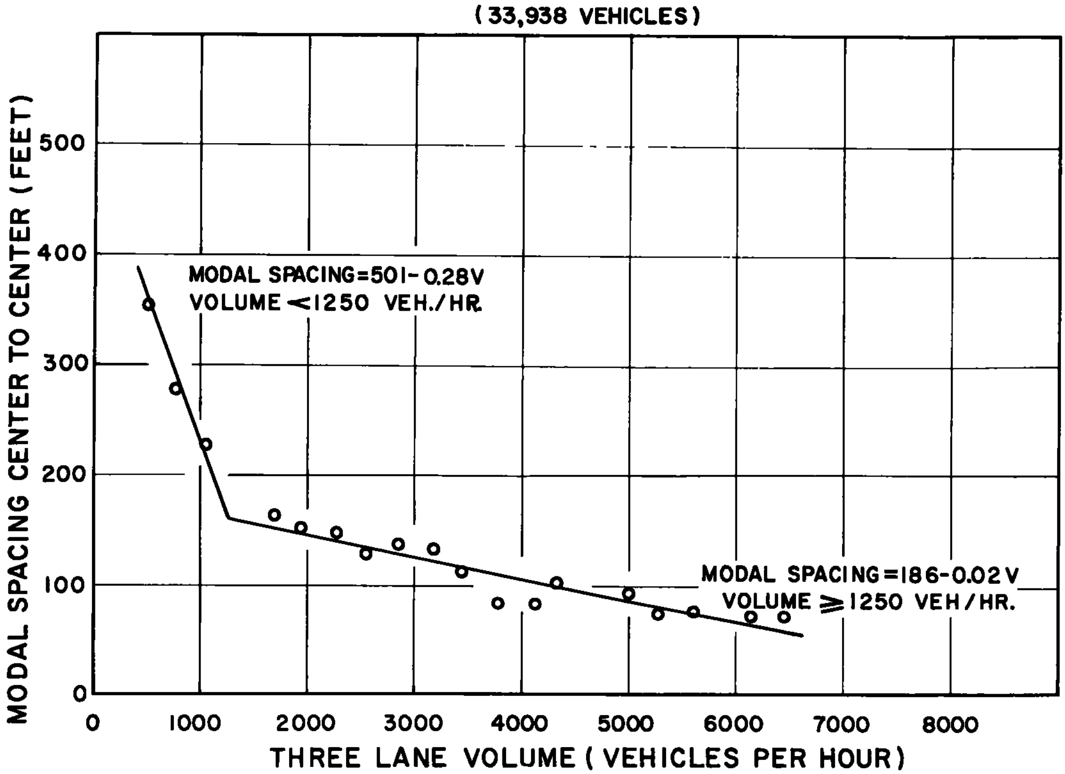

Figure 13. Passenger vehicle modal spacing, northbound and southbound, all lanes combined—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

than 10 percent. The deviation between empirical data and the least square fit diminished as the volume decreased.

For example, at a volume of 3,000 vph it is expected that 74 percent of all vehicles will be spaced at 4 sec or less. The mathematical function that describes the data is of the form

$$\text{Cumulative Percentage} = \left(1 - \Sigma^{-Vt/A}\right).$$

It is, of course, dangerous to interpret this equation literally as exactly the same as that describing the charging of a capacitor in a series capacitance-resistance circuit because the "t" in Figure 17 is not an independent variable, i.e., the cumulative percentage is not changing continuously as a function of time. However, it is interesting to draw the analogy that the constant "A" corresponds to the capacitance "C" of a capacitor and volume (V) corresponds to the conductivity—reciprocal of resistance—of the resistor.

The data discussed thus far were specifically for traffic behavior on dry pavement primarily because rain data during the period of observation were limited. However, a reasonable number (seven) of 5-min samples were taken to establish the effect of rain on the mean velocity for the

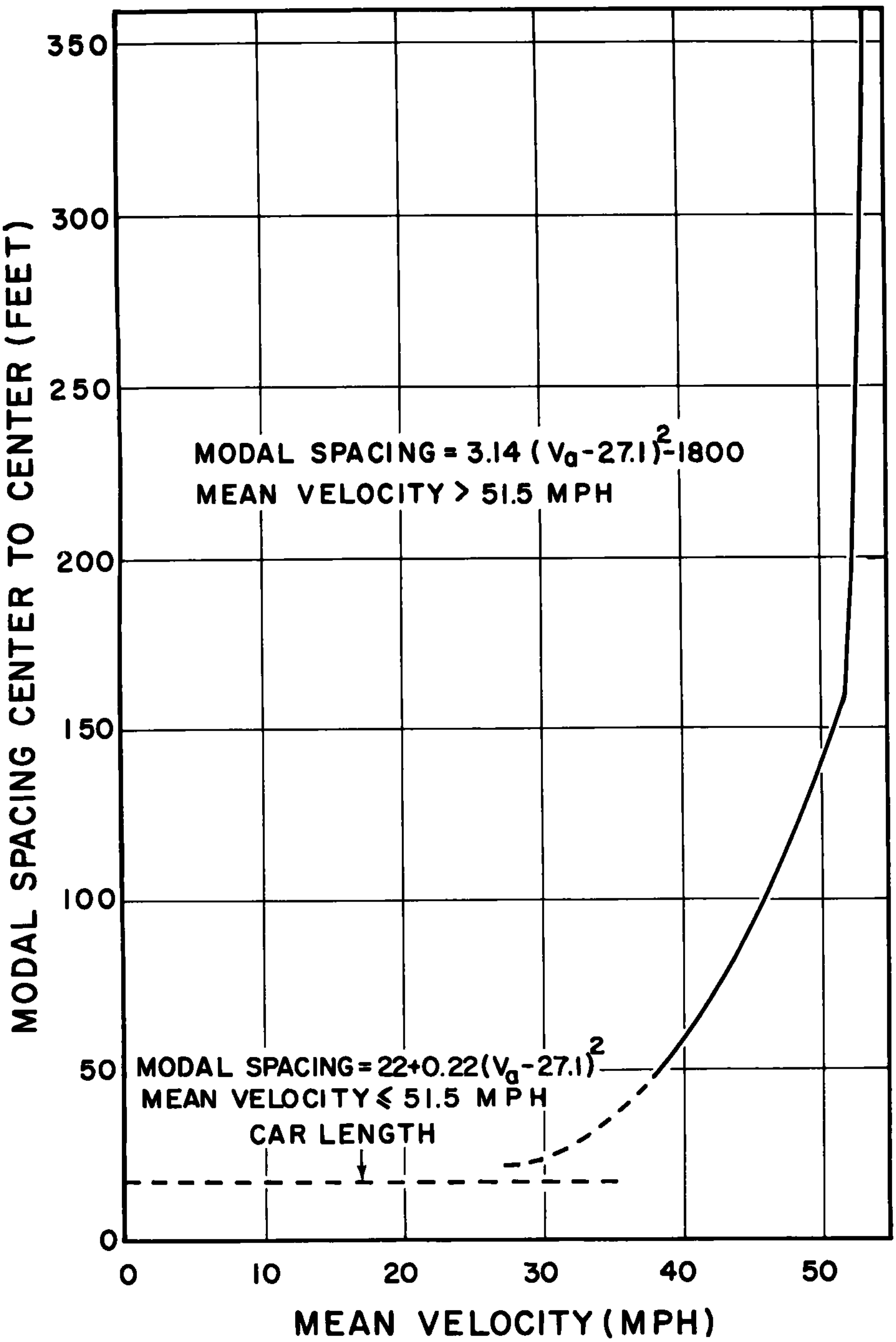

Figure 14. Modal spacing as function of mean velocity, passenger vehicles, northbound and southbound, all lanes combined—John C. Lodge Expressway (normal weekday traffic, 6 A.M. through 7 P.M., dry pavement, June 1957).

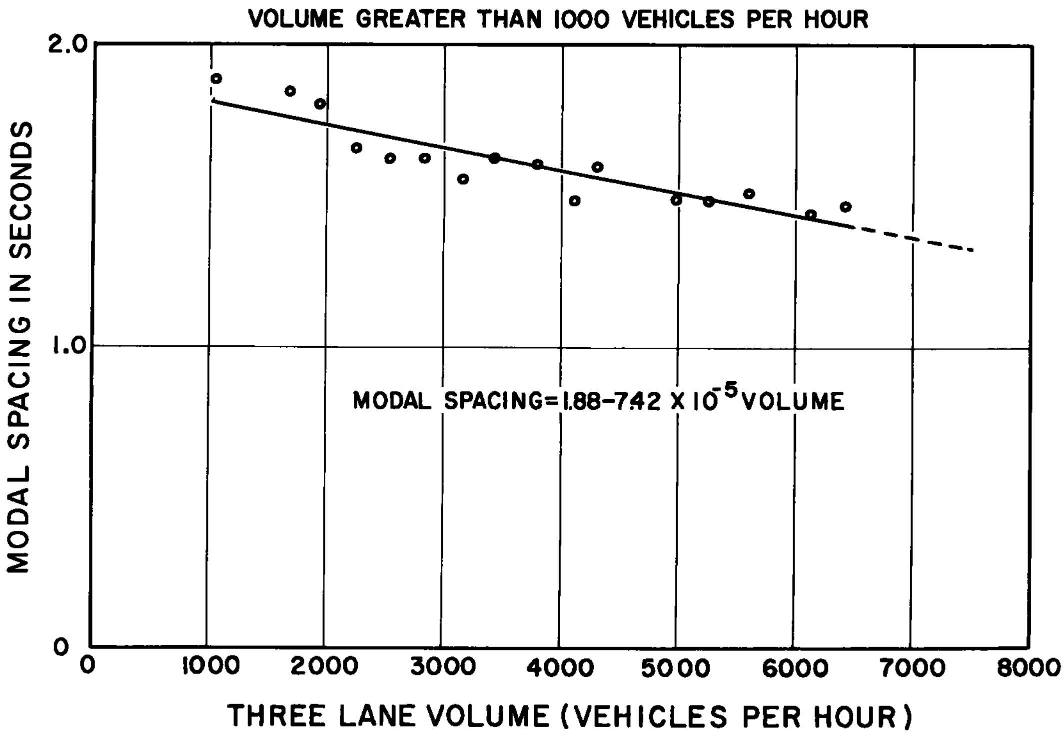

Figure 15. Time spacing, modal vs volume—John C. Lodge Expressway (normal weekday traffic, dry pavement, 6 A.M. to 7 P.M., June 1957).

same volumes that were measured during dry conditions. Table 1 summarizes this information according to lane.

TABLE 1

Lane	Change in Mean Velocity Due to Rain
Curb	-8.7
Middle	-8.6
Median	-12.4

Similar comparison was made between day and night driving during similar volumes. This information is given in Table 2.

TABLE 2

Lane	Change in Mean Velocity at Night
Curb	-4.3
Middle	-4.4
Median	-6.6

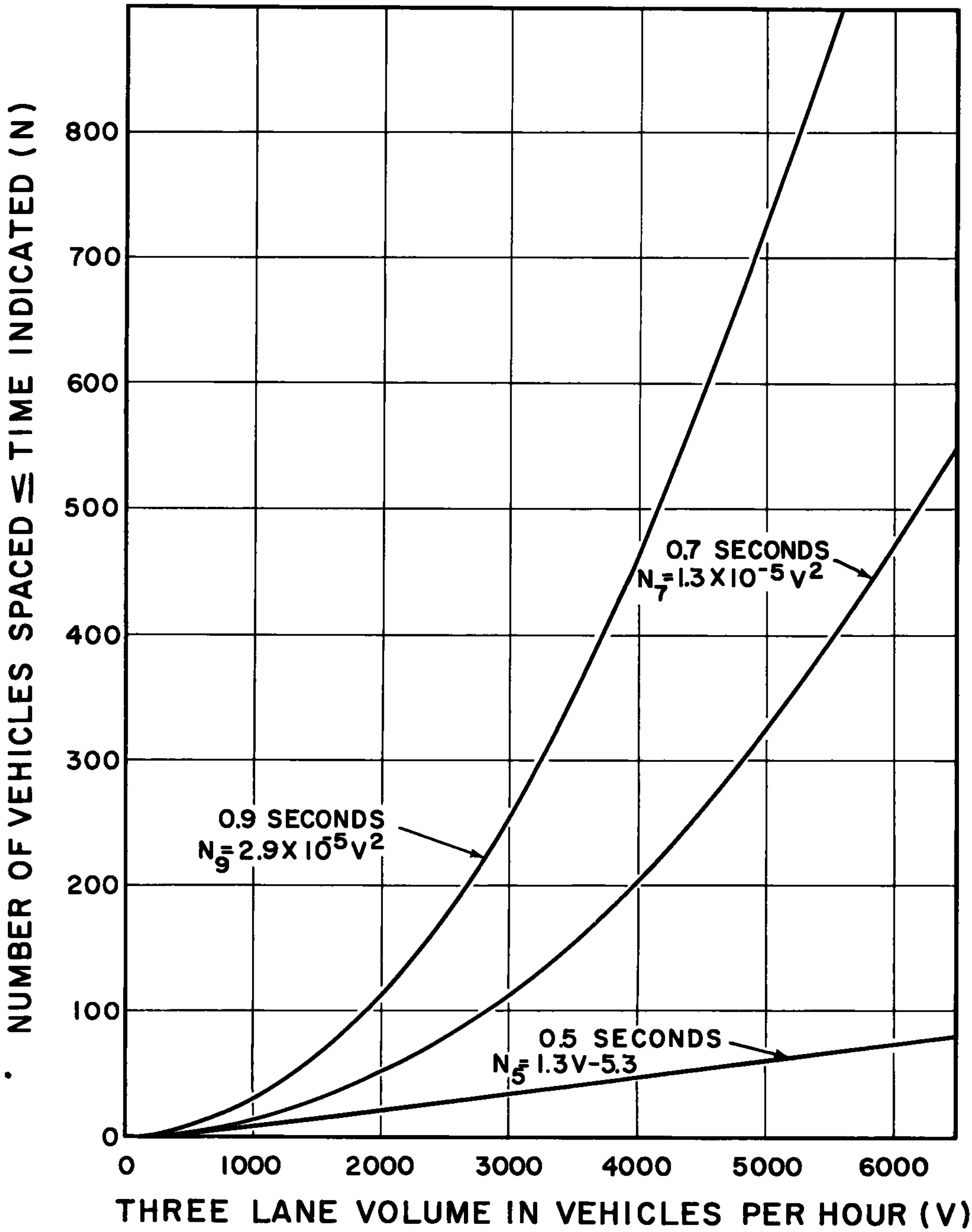

Figure 16. Vehicle time spacing vs volume—John C. Lodge Expressway (normal weekday traffic, dry pavement, June 1957).

No difference existed in mean velocity at similar volumes between weekday and weekend drivers.

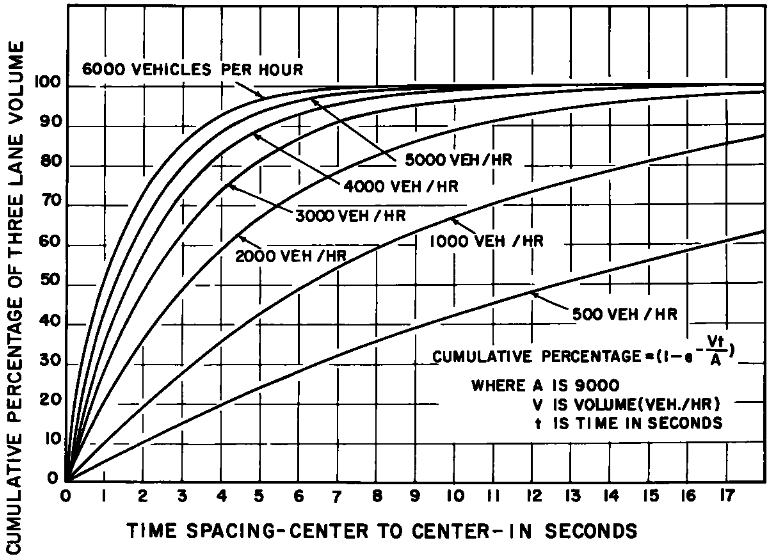

Figure 17. Cumulative percentage vs time spacing—John C. Lodge Expressway (normal weekday traffic, dry pavement, 6 A.M. to 7 P.M., June 1957).

REAR-END COLLISIONS

This paper reports in detail primarily the results of daytime, weekday main roadway traffic behavior. Because of this, only the rear-end collisions during 1956 that occurred under these conditions were used in studying correlation between these accidents and driver behavior. A total of 223 rear-end collisions were reported on the Lodge Expressway during 1956, but only 109 as Table 3 shows, matched the conditions of this study.

TABLE 3

Time	Northbound	Southbound	Total
6 A.M. - 12 Noon	6	34	40
12 Noon - 7 P.M.	11	58	69
	17	92	109

However, all dry pavement, weekday rear-end collisions were used to show the percentage of these rear-end collisions as a function of hour of day (Figs. 18 and 19).

An attempt was also made to establish a "trend" curve between rear-end collisions and volume. A sample of 109 accidents appears too small to establish statistical significance of the relationship. Nevertheless, a regression line was established for the data representing number of rear-end collisions annually during daylight and the volume at time of accident. This is shown in Figure 20. Three points representing night rear-end collisions under otherwise similar conditions are plotted for comparison. The relationship shown is of necessity dependent on the volume distribution, i.e., the percentage of time a given volume would be

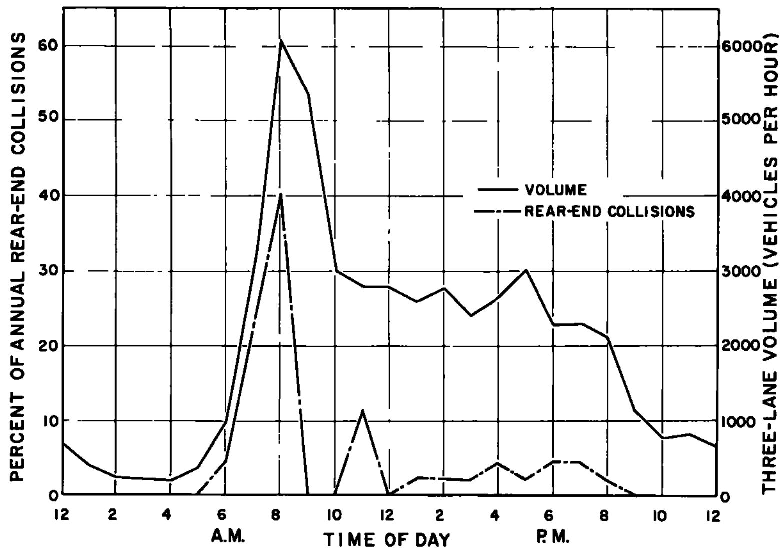

Figure 18. Volume and rear-end collision distribution—John C. Lodge Expressway, southbound (normal weekday traffic, dry pavement, June 1957).

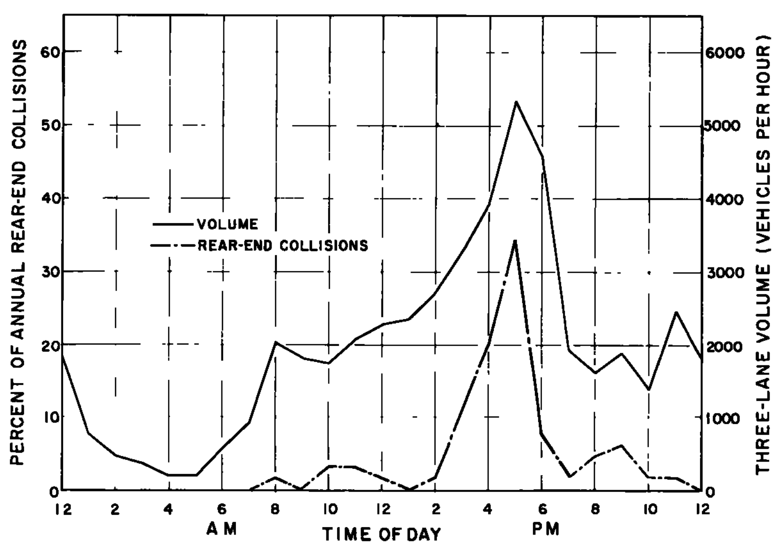

Figure 19. Volume and rear-end collision distribution—John C. Lodge Expressway, northbound (normal weekday traffic, dry pavement, June 1957).

expected. This distribution is also plotted on the same figure. Using previously established relationships between volume and mean velocity, rear-end collisions could be readily plotted as a function of mean velocity.

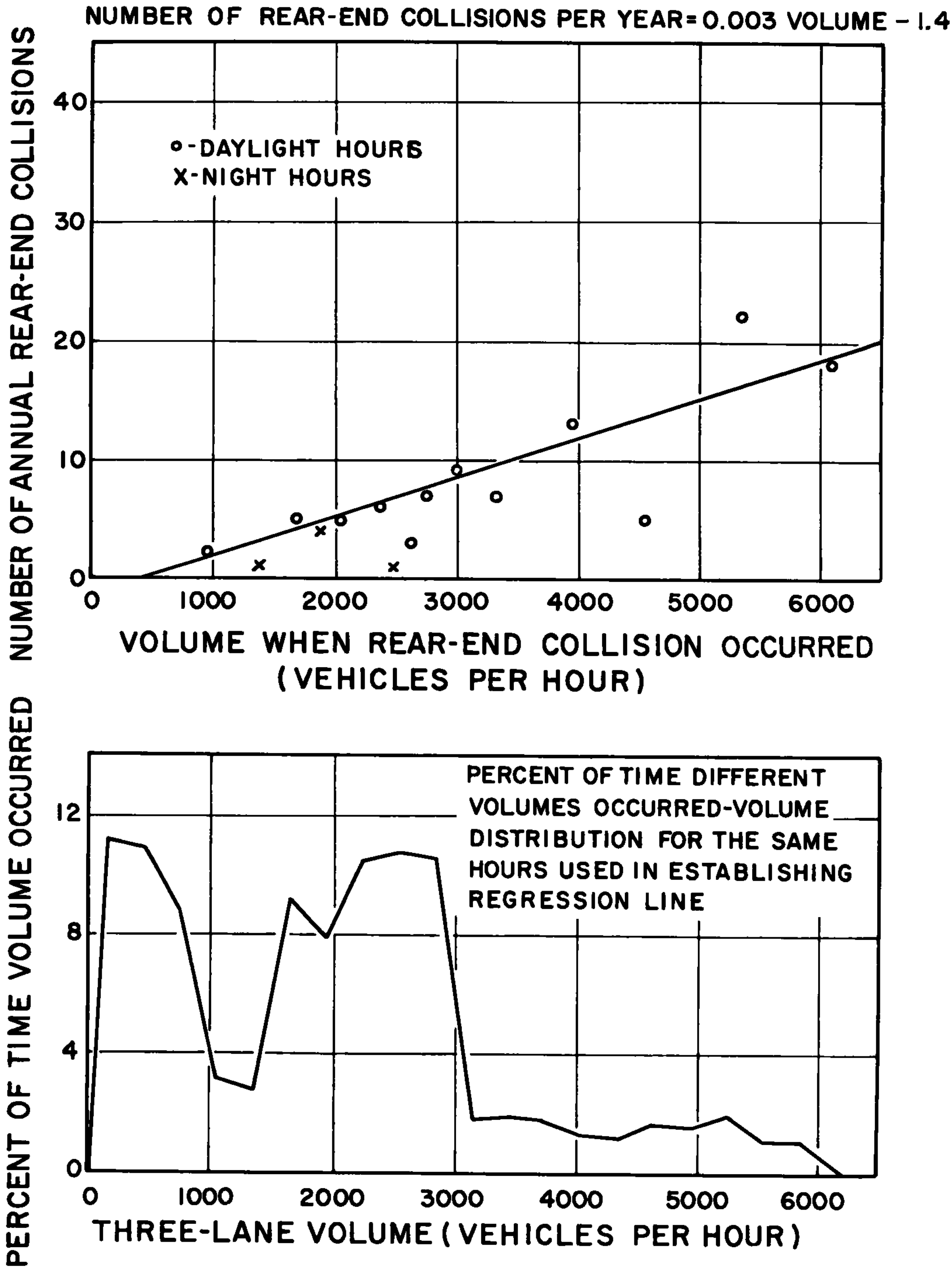

Figure 20. Rear-end collisions vs volume when collision occurred—John C. Lodge Expressway (normal weekday traffic, dry pavement, June 1957).

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