EFFECTS OF ROADWAY MARKINGS ON VEHICLES STOPPING IN PEDESTRIAN CROSSWALKS

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ABSTRACT

The purpose of this study was to determine the effect of roadway markings with regard to vehicle encroachment on crosswalks at signal-controlled intersections.

The seven intersections selected for study were such as to permit evaluation of the effects of number of lanes, one-way versus two-way traffic, and pavement markings (crosswalk, crosswalk and stop line, end of center line). Sex of driver, type of vehicle, and vehicle direction after stopping were other variables investigated. A 16-mm. movie camera was used to record the stopping point of each vehicle.

Vehicles which stopped close to intersections tended to be driven by females, to be trucks rather than passenger cars, and to turn after stopping. Vehicles were also likely to stop farther from the curb line on four-lane than on two-lane roads. Stopping points on one-way and two-way roads were not discernibly different. The percentage of vehicles stopping on crosswalks was found to be smallest at intersections marked with a crosswalk and a stop line.

A tentative recommendation is made for a placement of stop lines likely to reduce vehicle encroachment on crosswalks to acceptable levels.

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INTRODUCTION

In 1966, 25% of pedestrian fatalities in Michigan reportedly occurred at intersections (1). On the basis of data for 1962, it is estimated that 20% of such fatalities (5% of the total) took place when the pedestrian was crossing with the signal at a signal-controlled intersection. The percentage of pedestrians killed while walking against the signal was approximately equal.

Pedestrians struck by vehicles while crossing with the signal may have been victims of drivers who did not see them or the red signal in time to stop. It is also possible that some of them were struck by vehicles in the cross-traffic stream while walking around a car or truck stopped on the crosswalk. Statistical data are not sufficiently detailed to ascertain the frequency of these events. However, about 3% of the pedestrians fatally injured at Michigan intersections in 1962 were categorized as crossing diagonally. It is possible that some of these were actually moving around a vehicle which was obstructing the crosswalk.

Obviously, more detailed statistics from accident reports would have to be compiled to determine the significance to pedestrian safety of vehicles stopping on crosswalks. However, we do know that about 50% of urban pedestrian fatalities occur at places other than intersections. Assuming that most pedestrians cross the street at intersections, it is important that pedestrians be encouraged to use crosswalks, where the fatality rate is undoubtedly lower. This makes it all the more desirable to increase the actual and psychological safety of crosswalks and to design crosswalks to provide adequate pedestrian flow.

Because these goals cannot be realized if vehicles continue to stop on crosswalks, the present study sought to measure the extent of such intrusions and the effect on them of various roadway markings.

The Michigan Vehicle Code (2) stipulates that crosswalk lines shall be 6 inches wide, that stop lines shall be not less than 12 nor more than 18 inches wide and placed at least 4 feet from the near crosswalk line, and that center lines shall be not less than 4 nor more than 6 inches wide.

These specifications have no basis in research. For example, it is evident that a stop line placed too close to or far from the crosswalk will not stop vehicles within the desired distance. The most effective position for the stop line can be decided only after taking relevant measurements of driver behavior. By varying the width of the stop line, Marvin (3) found that a width of 9 inches allowed the best control of vehicle stopping position as measured by the number of cars that encroached upon the crosswalk area. In that study, crosswalk lines were 9 feet apart and the stop line 4 feet in front of the crosswalk.

There has been no research effort to consider the other variables in roadway markings which may affect car stopping position.

The purpose of the present study was to observe the stopping position of the first car to approach an intersection on the red signal, and the effects of variations in roadway markings, sex of the driver, type of vehicle, and direction taken after leaving the intersection.

METHOD

The major purpose of this study was to determine the effects of certain roadway delineations upon car stopping position. However, it was assumed that other roadway characteristics might also affect driver behavior in stopping for red lights. In our selection of seven intersections in the City of Ann Arbor, we attempted to obtain some control over these other variables. Table 1 shows

TABLE 1.

CHARACTERISTICS OF SELECTED INTERSECTIONS

Intersection	Number of Lanes	Way	Road Marking
I_1	2	Two	Crosswalk
I_2	2	Two	Crosswalk and Stop
I_3	2	Two	End of Center Line
I_4	2	One	Crosswalk
I_5	2	One	Crosswalk and Stop
I_6	2	One	End of Center Line
I_7	4	Two	Crosswalk and Stop

the number of lanes, one-way or two-way road, and type of marking at each intersection measured. Figures 1-7 show the kinds of markings present at each intersection and the distances of markings from the intersections. (See below

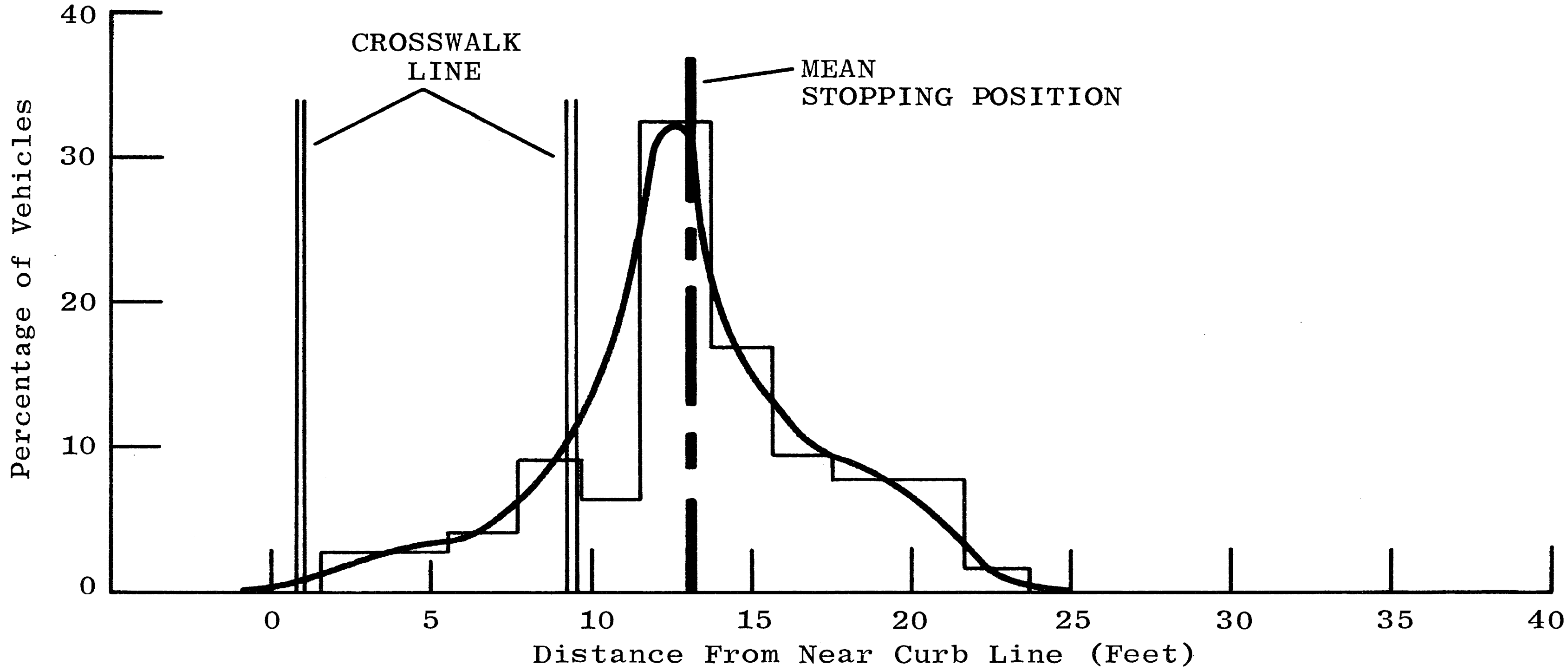


Figure 1. Vehicle Stopping Position at I_1

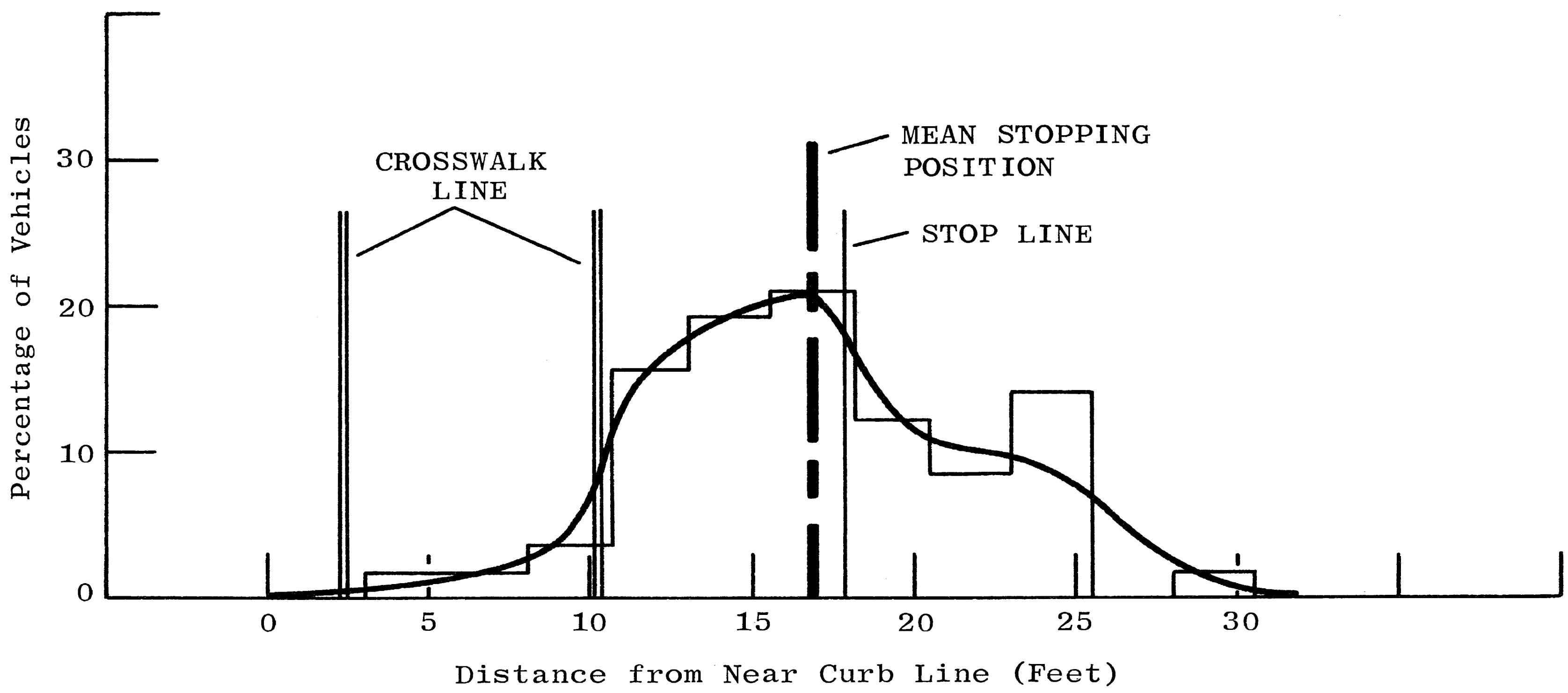


Figure 2. Vehicle Stopping Position at I_2

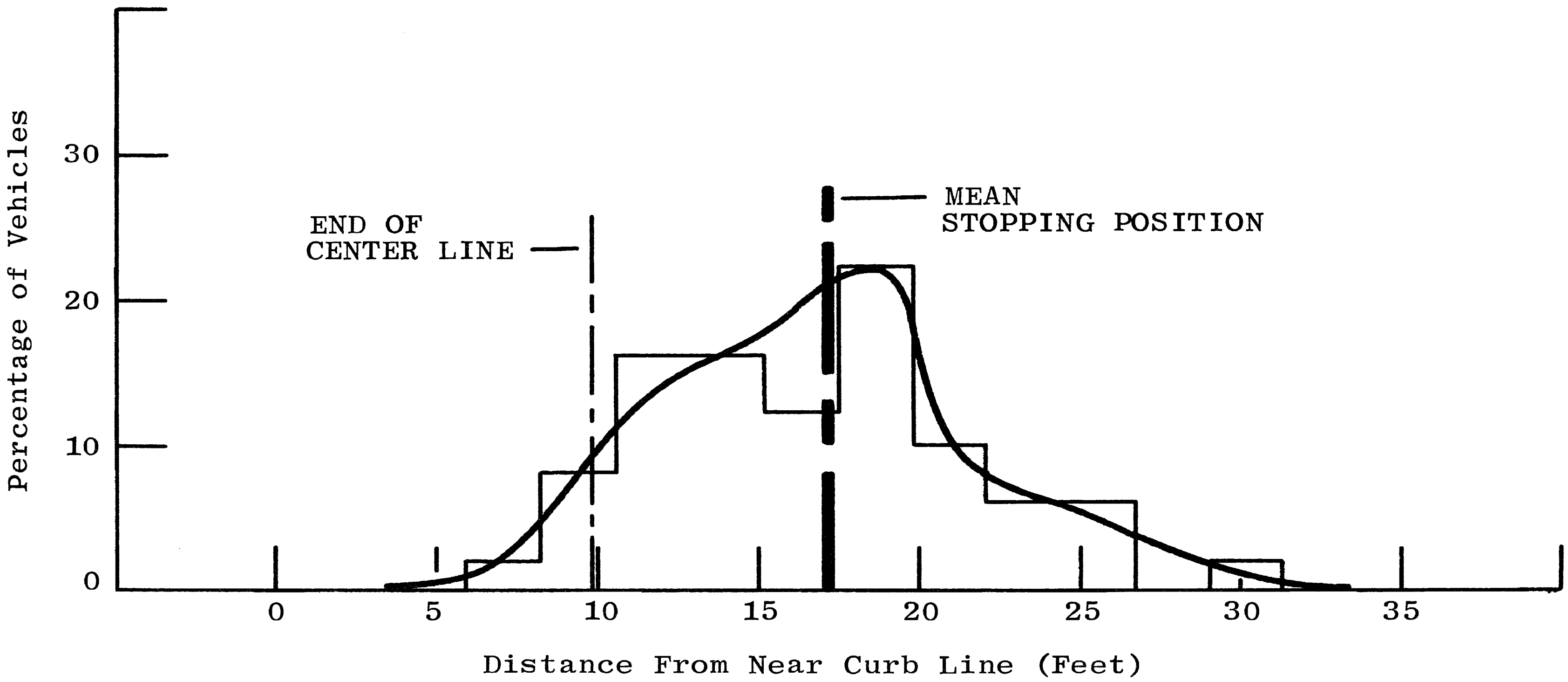


Figure 3. Vehicle Stopping Position at I_3

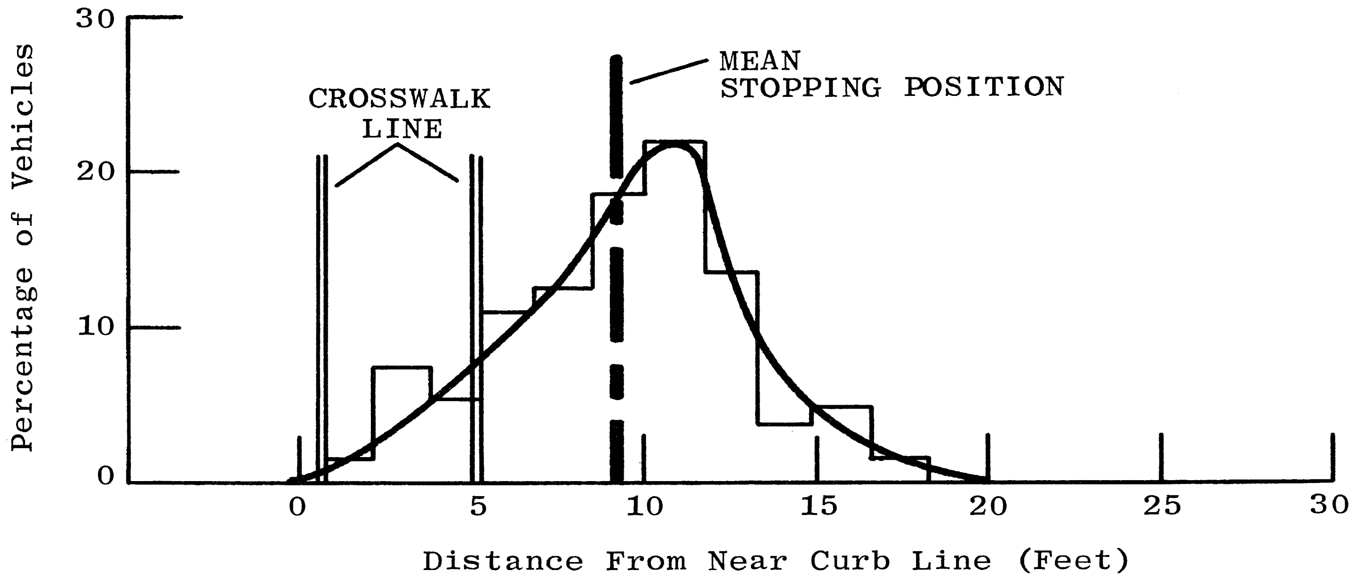


Figure 4. Vehicle Stopping Position at I_4

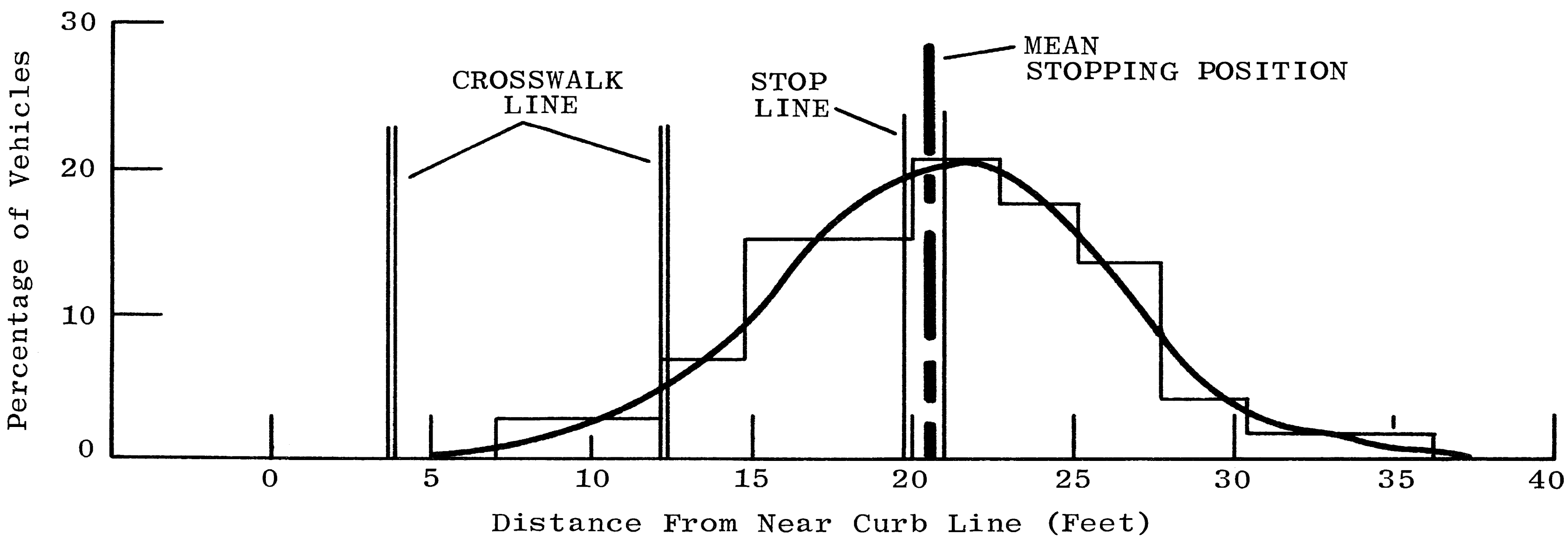


Figure 5. Vehicle Stopping Position at I_5

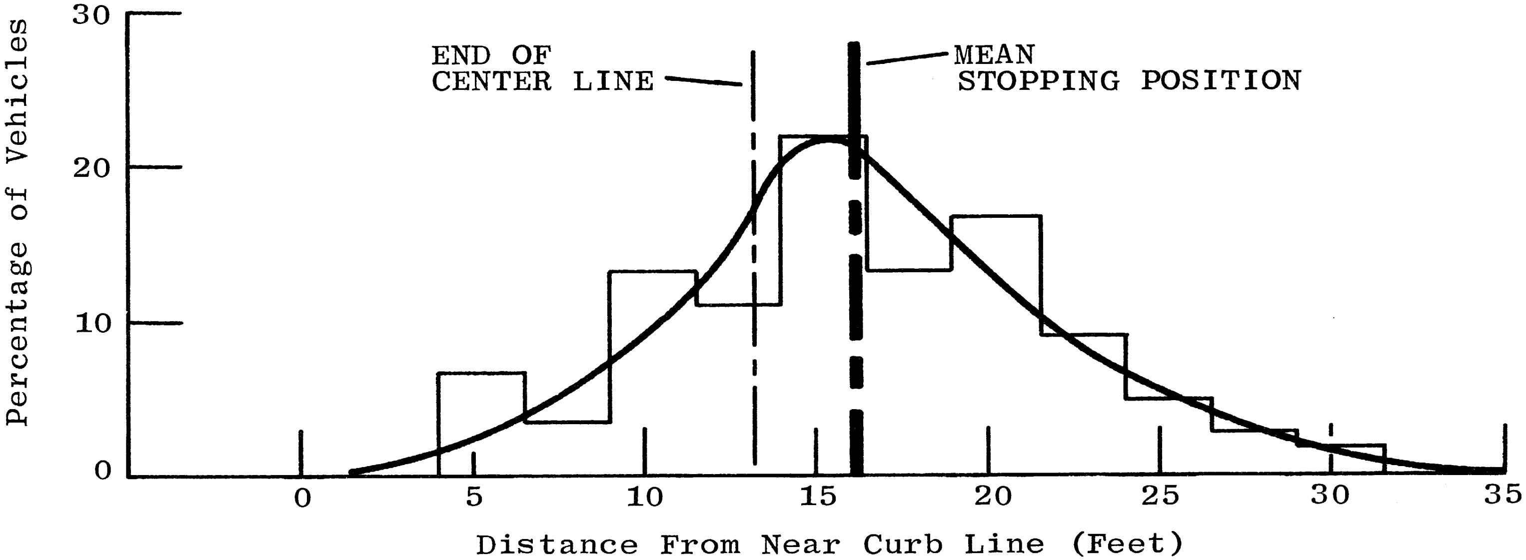


Figure 6. Vehicle Stopping Position at I_6

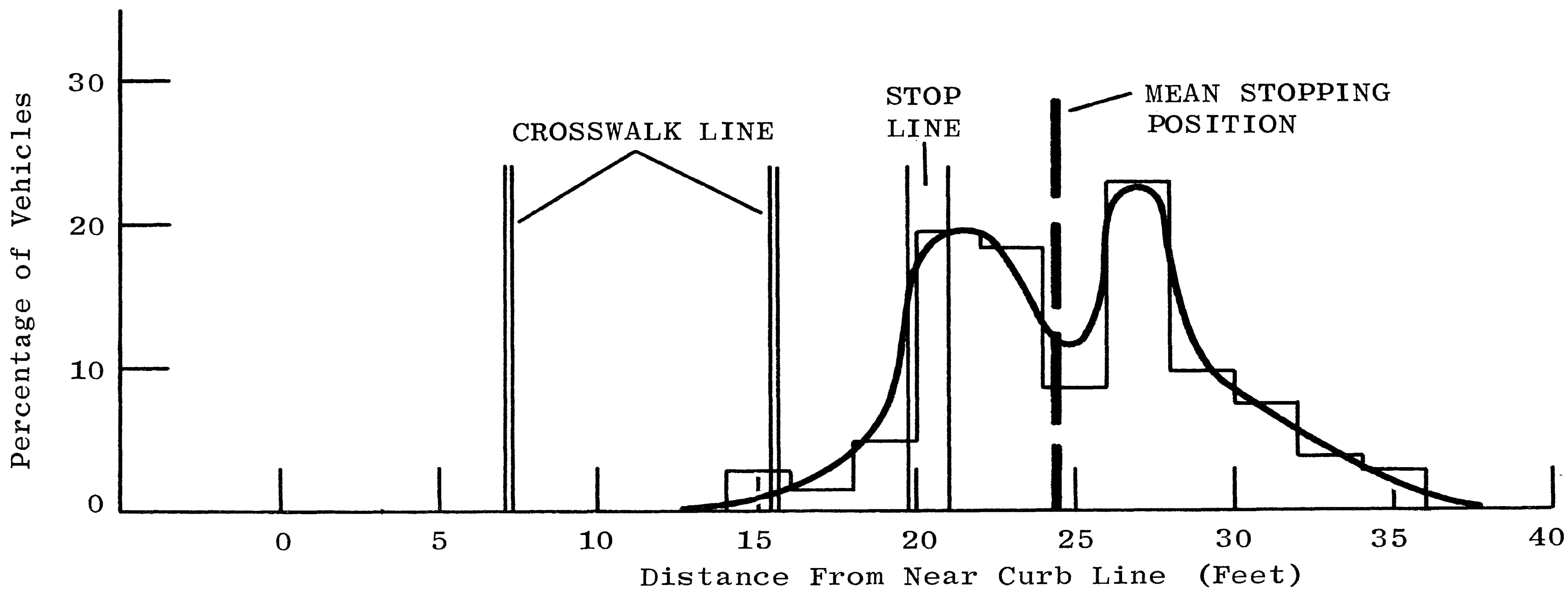


Figure 7. Vehicle Stopping Position at I_7

for definition of terms.)

A 16-mm. movie camera was used, in single-frame mode, to take pictures of vehicles after they had come to an initial stop in response to the red traffic signal at the intersections. Each intersection was measured for approximately two hours on each of two days, starting at 8:30 a.m. on one day and at 10:30 a.m. on the second. Days and times of measurement were assigned at random to given intersections.

For purposes of measurement, the following definitions were used.

Vehicle stopping position: the position of the front bumper at the initial stopping point in front of the traffic signal.

Curb line: an imaginary extended line from the curb of the road intersecting that on which the vehicle is stopped.

Crosswalk lines: the continuous white lines across the road delineating the pedestrian crossing area.

Near crosswalk line: the crosswalk line which is further from the curb line and nearer to a vehicle stopped in front of the crosswalk.

Stop line: the white line painted across the lane at least 4 feet in front of the near crosswalk line.

Prior to measurement, pictures were taken of one-foot markings placed on both curbs and on the center line of the road. These were used to develop a scale on a projection screen for data reduction from the pictures of stopped vehicles. The accuracy of this technique was checked by comparison of measurements taken by the photographic technique and by tape measure. The absolute average error attributable to scaling and photographic data reduction was one inch, a magnitude considered tolerable for the kind of measurement being made.

So that drivers would not notice that they were being photographed, the movie camera was covered with a box and mounted on a tripod, located inconspicuously beside a building, and operated by remote control through a radio transmitter.

The number of pedestrians who walked across the intersection during the red phase of the traffic signal was counted, as well as the number of cars which passed through on the green. The type of vehicle photographed (car or truck), the sex of the driver, and the direction the vehicle took on leaving the intersection were also recorded.

Although every effort was made to ensure that the intersections were as similar as possible with respect to variables in roadway markings, such as the width of the crosswalk and its distance from the edge of the intersection, there was some variability among the intersections. In the subsequent data analyses, these variables were taken into account as much as possible.

RESULTS

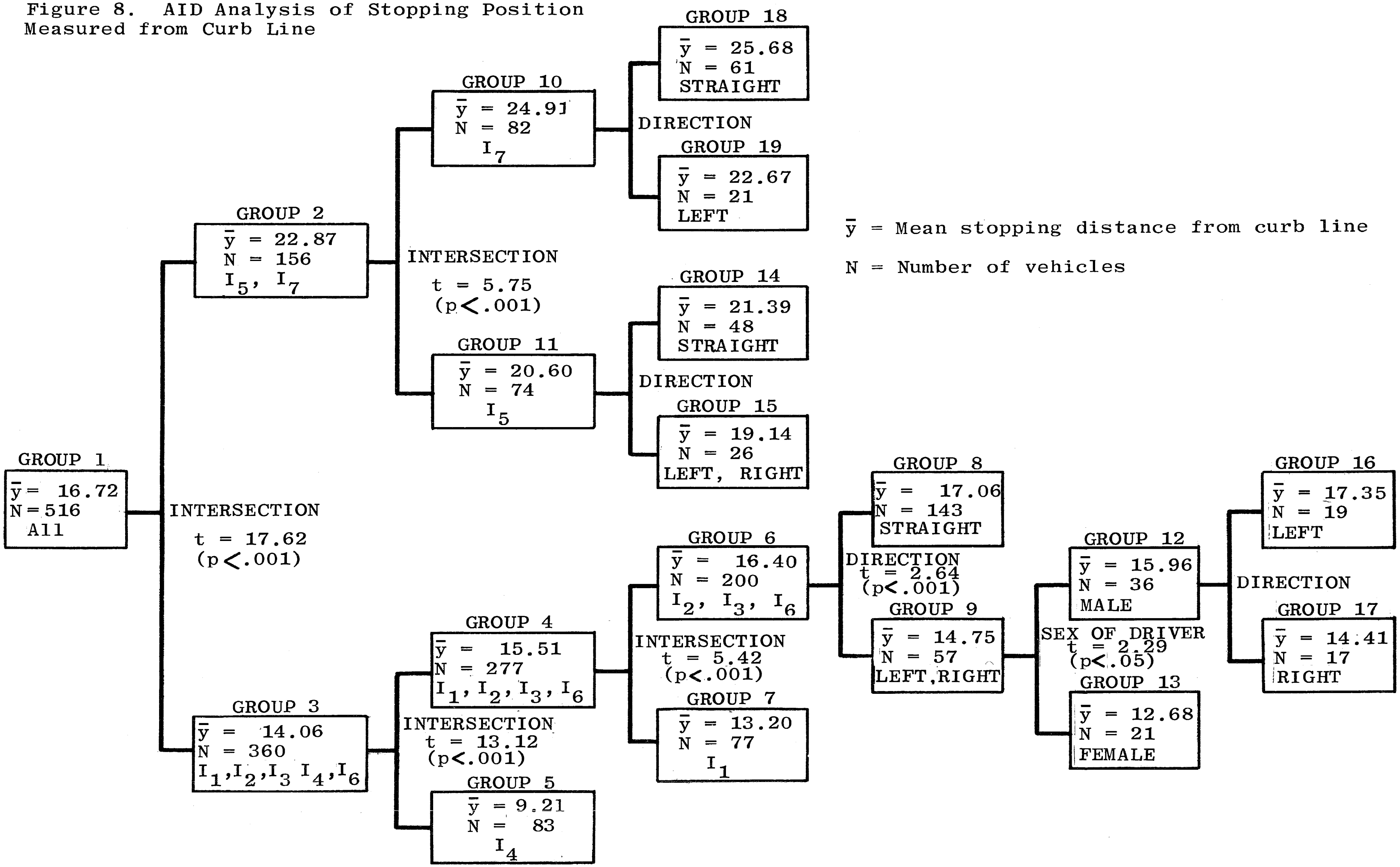
The major variables of this study were: the nature of the intersection (number of lanes, one-way or two-way road, kind of markings used); the sex of the driver; the type of vehicle; and the direction of the vehicle after the stop.

The first analysis was concerned with identifying those of the factors measured which most affected vehicle stopping position. The computer program used was one developed by Sonquist and Morgan (4), the Automatic Interaction Detector (AID), which tests all possible combinations of factors to determine those to which variance in the dependent variable is most attributable. For example, the AID program has also been used by Carlson (5) to predict the characteristics of high accident-frequency drivers.

AID ANALYSIS: DISTANCE FROM CURB

The AID analysis was first carried out using the distance of the vehicle stopping point from the curb line as the dependent variable. The results of this analysis are shown in Figure 8, which also shows the results of the t tests run after each split by the program. It will be noticed that the first split was made between intersections I_5 and I_7 (Group 2) and the remaining intersections, I_1, I_2, I_3, I_4, and I_6 (Group 3). A t test between the means of Group 2 and Group 3 data was highly significant. Subsequent splits for the Group 2 data between I_7 and I_5 indicated that vehicles stopped significantly farther in front of the curb line at I_7 than at I_5. The analyses for the Group 2 data are shown in Groups 18, 14, 19, and 15, in which the split was based on the direction the vehicle took when it left the intersection. The effect of direction at I_5 and I_7 was not significant. Returning to the Group 3

Figure 8. AID Analysis of Stopping Position Measured from Curb Line



data, a split was made to derive Groups 4 and 5, reflecting significantly shorter mean stopping distances at I_4 than at intersections in Group 4. The split of Group 4 data indicated that at I_1 the mean stopping distance from the curb line was significantly shorter than at I_2, I_3, and I_6. The split of Group 6 to obtain Groups 8 and 9 was based on the directions vehicles took upon leaving the intersection; it will be noted that vehicles which continued on a straight path stopped significantly farther from the curb line than vehicles which turned either left or right. The split of Group 9 data on the basis of the sex of the driver showed that males tended to stop significantly farther from the intersection than females. The final split was based on the direction taken by male drivers. Here the difference was not statistically significant, although there was an indication that drivers who turned left were somewhat farther from the intersection than those who turned right.

The results of the analysis (Figure 8) indicated that vehicles stopped nearest to the curb line in intersection I_4, where the nearest marking (the near crosswalk line) was closer to the intersection than in the other locations. Next in order was I_1, where the nearest marking, again the near crosswalk line, was slightly farther from the intersection than at I_4. At I_2, I_3, and I_6, stopping distances were not significantly different; here the first marking the driver would encounter was farther from the curb line than in I_4 or I_1, at about the same distance in all three. The first marking encountered by the driver was farthest from the curb line in intersections I_5 and I_7, in ascending order. Thus there was a direct relationship between a driver's stopping distance and the distance from the intersection of the first marking he encountered. A rank-order correlation between the distance of the first marking from the curb line and the mean stopping distance showed a correlation coefficient of 0.89. Also, it was noticed that at I_2, I_3, and I_6 drivers who later proceeded straight ahead stopped significantly farther from the curb line than those turning left or right. And, of those drivers who turned left or right, males stopped significantly farther from these intersections than females.

AID ANALYSIS: DISTANCE FROM FIRST MARKING

Since one of the findings of the first analysis was a significant relation between the distance of the marking from the intersection and stopping position, the second analysis was carried out using as dependent variable the distance at which the vehicle stopped from the first marking. This marking could be the near crosswalk line, the stop line, or the end of the center line. Assuming that drivers are influenced to stop their vehicles at the mark involved, the effectiveness of a marking can be determined, to some extent independently of other intersection characteristics, by measuring the deviation of vehicle stopping positions from the mark.

Figure 9 shows the results of an AID analysis in which the dependent variable was the stopping distance of the vehicle from the end of the center line, near crosswalk line, or stop line, whichever was encountered first. It will be seen that the first split in the analysis was between intersections I_2 and I_5 and the others. The result indicates a significant difference in the deviation of the stopping distance from the road marking between these intersections, and shows that the stop line at intersections I_2 and I_5 was effective in stopping the vehicles close to it. The next split for I_2 and I_5 was made by

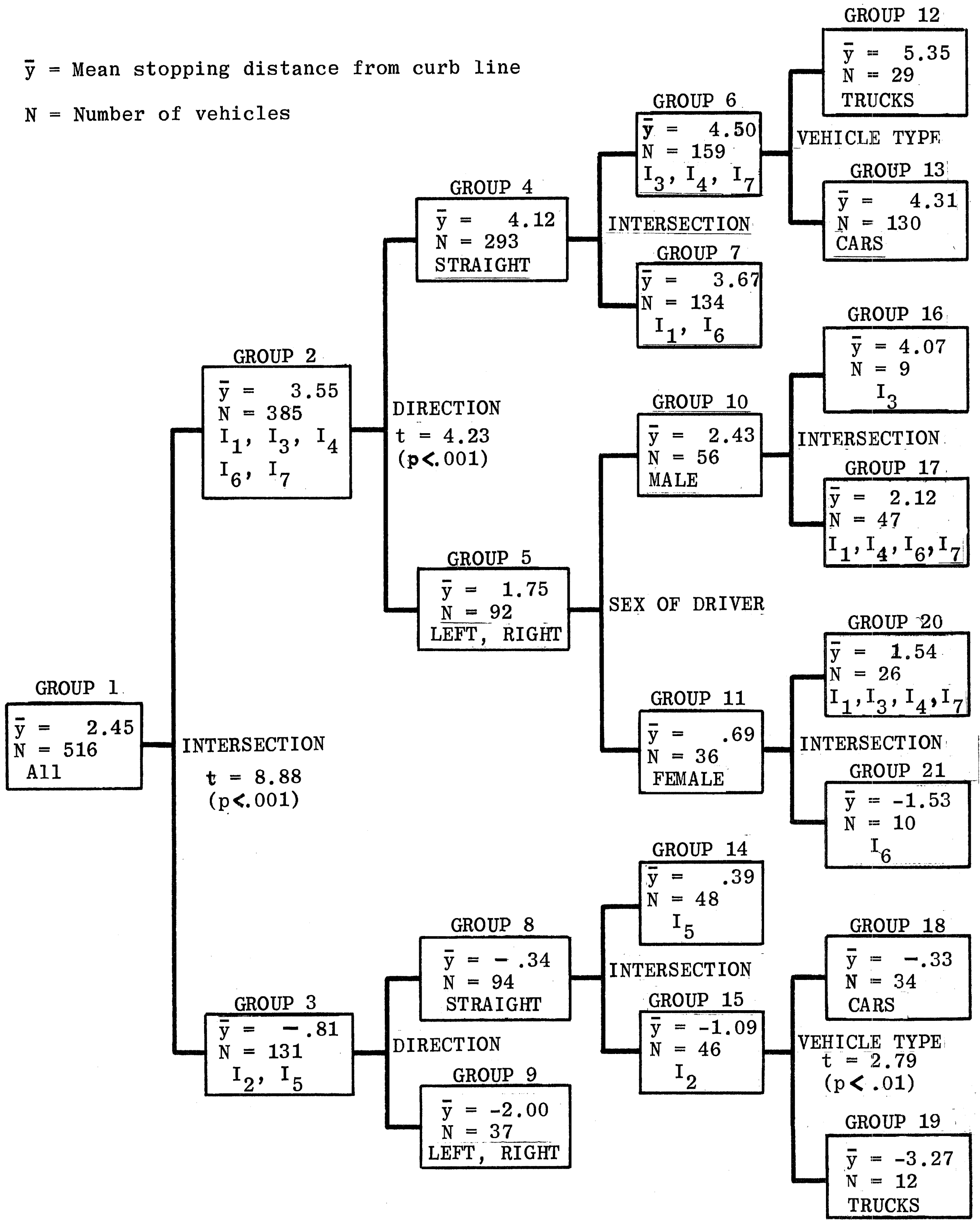


Figure 9. AID Analysis of Stopping Position Measured from Near Crosswalk Line, Stop Line, or End of Center Line

direction and showed that vehicles which continued straight stopped closer to the stop line than those which turned. The difference was, however, not significant. For the Group 2 data a significant split occurred, as shown by Group 4 and Group 5 data, on the basis of the direction factor; this indicated that vehicles which continued in a straight line stopped significantly farther from the marking than those which turned left or right. The only remaining significant split was made for the Group 3 data and involved the type of vehicle. This analysis shows that, among vehicles which continued straight after leaving I_2, passenger cars stopped significantly closer to the stop line than trucks (Groups 18 and 19).

The results of this analysis (Figure 9) can be summarized by stating, first, that vehicles tended to stop closer to the stop line than they did to the crosswalk or the end of the center line. Second, the stopping positions at intersections with the stop line were not significantly affected by the subsequent direction taken by the vehicle. Third, at other intersections there was a tendency for those drivers going straight to stop farther from the marking than those turning left or right. Fourth, trucks stopped significantly farther from the stop line (at intersection I_2 only) and closer to the intersection than cars.

ROADWAY MARKING AND CROSSWALK ENCROACHMENT

Figures 1-7 show the structure of each intersection and the distribution and mean of the positions at which the vehicles came to a stop. The mean stopping positions are summarized in Table 2. It will be noted that the distribution for I_7 (Figure 7) is bimodal, showing that driver stopping behavior at a four-lane intersection marked

TABLE 2.

MEAN VEHICLE STOPPING DISTANCE

Intersection	Distance From Curbline	Distance From First Marking*
I_1	13.16 ft.	3.58 ft.
I_2	16.58 ft.	-1.33 ft.
I_3	16.81 ft.	3.81 ft
I_4	9.25 ft.	4.00 ft.
I_5	20.60 ft.	-0.40 ft.
I_6	16.01 ft.	2.76 ft.
I_7	24.46 ft.	3.82 ft.

*Positive values are distances in front of the marking.

with crosswalk and stop line was affected by variables not found at other intersections. This road was wider than any of the others studied, and it is possible that this affected stopping position. The percentage of cars that stopped within the crosswalk at each intersection is shown in Table 3. It will be seen that for intersections which had a stop line (I_2, I_5, and I_7) the values were considerably lower than for the others.

ONE-WAY VERSUS TWO-WAY STREETS. In comparing I_1 with I_4, I_2 with I_5, and I_3 with I_6, no statistically significant differences were found between two-way and one-way roads.

TABLE 3.

PERCENTAGE OF VEHICLES STOPPED WITHIN CROSSWALK

Intersection	Cars Stopped Within Crosswalk
I_1	18.2%
I_2	7.1%
I_{3}*	6.0%
I_4	14.5%
I_5	5.4%
I_{6}*	14.0%
I_7	2.4%

*For these intersections, we extrapolated the crosswalk to be the same as in I_1.

NUMBER OF LANES. A comparison of I_2 and I_5 with I_7 shows the mean stopping position at I_7 (4 lanes) to be significantly farther from the curb line than that at I_2 or I_5 (2 lanes).

MARKING. A comparison of I_1 with I_2 and I_4 with I_5 shows the effect of the stop line at intersections with crosswalk markings. At the two intersections which had a stop line, vehicles stopped significantly farther from the near crosswalk line. However, there was no statistically significant difference between the pairs of intersections I_2-I_5, which had a stop line, and I_1-I_4, which did not.

Similarly, comparison of I_1 with I_3 and I_4 with I_6 indicates that the mean stopping distance from the curb line for intersections marked only by the end of the center line was significantly greater than that for intersections marked only by the crosswalk.

A comparison of the stopping distance from the curb line at I_2 and I_3 shows the effect of crosswalk plus stop line compared to that of the end of the center line alone; the difference in the mean stopping position was not significant. However, at I_5, which has a crosswalk plus stop line, the mean stopping position measured from the curb line was significantly greater than at I_6, which was delineated only by the end of the center line; but it should be noted that the stop line was somewhat farther back than the end of the center line.

PEDESTRIAN AND VEHICULAR TRAFFIC FLOW. Analysis of flow data showed that neither the density of pedestrian traffic on the crosswalk nor the density of vehicular traffic affected vehicle stopping position.

DISCUSSION

Analytical results indicate that drivers tend to stop some distance in front of the intersection for each of the three types of markings investigated.

TYPES OF MARKING

CROSSWALK LINES. For those intersections which were marked only by a crosswalk (I_1 and I_4) the distribution is leptokurtic, with the mean stopping position fairly close to the near crosswalk line and with a fairly large number of encroachments of the vehicle upon the crosswalk. In these intersections drivers seemed to use the near crosswalk line as a guide in determining their stopping position and, as a result, a fairly large percentage stopped within the crosswalk.

CROSSWALK AND STOP LINE. By comparison, at intersections which were marked with a crosswalk and a stop line (I_2, I_5, and I_7) there were far fewer encroachments of vehicles within the crosswalk area, and the mean stopping position was very close to the stop line. This indicates that drivers use the stop line as a cue for determining the stopping position, but because it is some distance from the crosswalk they allow themselves a fair amount of latitude around the stop line itself. For this reason the variances in stopping position were fairly large, but the stop line was evidently quite effective in reducing crosswalk encroachment.

END OF CENTER LINE. The end of the center line alone (I_3 and I_6) appeared also to be effective in stopping drivers at a reasonable distance from the intersection, so that encroachment upon the area that would be used for a crosswalk was moderate. In these intersections the mean stopping position was a reasonable distance from the curb line, although the distributions were again quite broad.

PSYCHOLOGICAL EFFECT OF MARKINGS

Because there was no control (undelineated) condition in this study, it is possible that the effect of the end of the center line and the crosswalk lines alone was insignificant compared to the absence of markings at an intersection. This seems unlikely, however, since the distributions for intersections marked with crosswalks alone are distinctly different from those marked with the end of the center line, and the end of the center line did have a significantly beneficial effect upon the mean stopping position.

It appears, therefore, that each of the three delineations investigated exerts some psychological pressure upon drivers in deciding their stopping position. It is hypothesized that the near crosswalk line suggests to the driver that he may stop close to it, but preferably in front of it, and this leads to a mean stopping position close to the near crosswalk line with a substantial spillover into the crosswalk area. On the other hand, the stop line may influence the driver to stop near it and not to go beyond the next marking encountered--which is the near crosswalk line. This is suggested as a possible cause of the large variance in stopping position found at the intersections marked with the stop line. With the end of the center line as the only marking present, there was no clear frame of reference to indicate the area that might be used by pedestrians for crossing the road; hence the wide variance of car stopping positions.

DIRECTION. It is also of interest to note that, overall, drivers who continued straight after leaving the intersection tended to stop farther back than those who made either left or right turns (Figure 10). This suggests that drivers wishing to turn desire a greater field of view of the intersection and hence experience additional pressure which may lead them to encroachments within the crosswalk area. It is interesting to note that at two of the intersections which were marked with a stop line (I_2 and I_5) there was no significant effect upon stopping position due to the direction which the driver took after leaving the intersection. This tends to reinforce the finding that the stop line is indeed effective in holding vehicles back from the intersection and the crosswalk.

SEX. A tendency was also noted at some intersections for females to stop closer to the curb line than males. This may reflect a difference between the sexes in attitude or knowledge of traffic regulations. The mean stopping position for male and female drivers is shown in Figure 10.

VEHICLE TYPE. There was a minor, but significant, tendency for passenger cars to stop closer to the stop line than trucks. Trucks tended to stop closer to the intersection.

PLACEMENT OF STOP LINE. The most important result of this study is an indication: (a) that roadway markings do affect vehicle stopping position, and (b) that of the markings investigated the stop line is most effective, although in every case the first marking the driver encountered influenced his stopping position.

For intersections marked by a stop line and a crosswalk, it is possible to make theoretical estimates of the effects upon car stopping position of moving the stop line toward or away from the intersection. The assumption would have to be made that the stopping position is independent

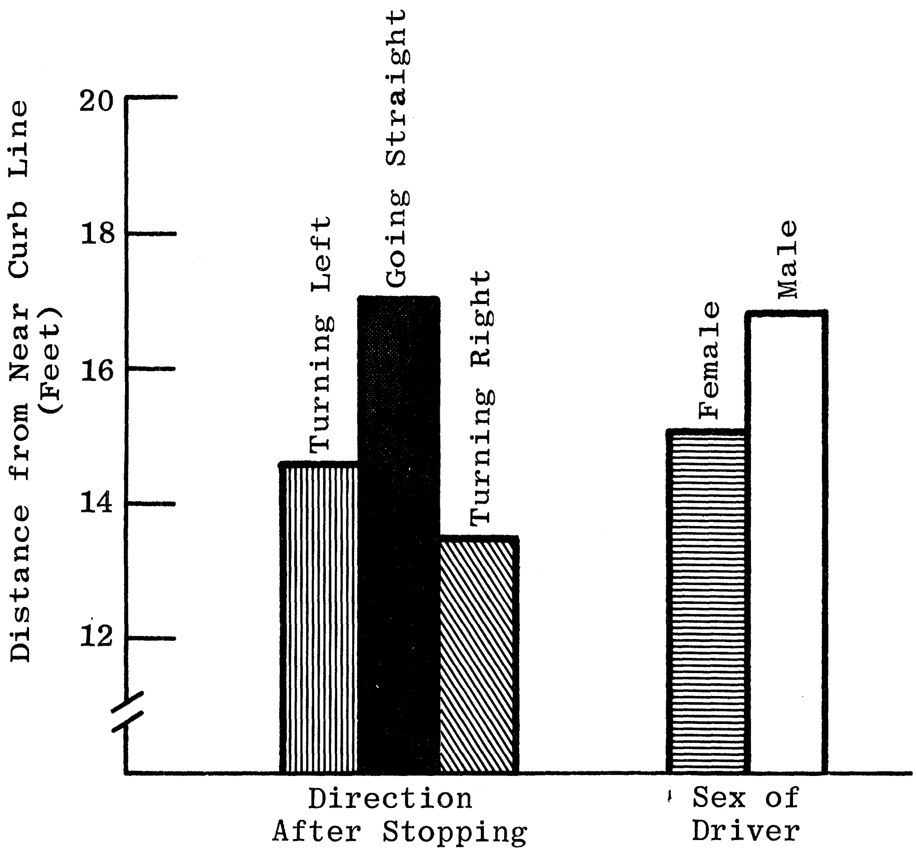


Figure 10. Mean Stopping Position as Functions of Direction Taken after Stopping and Driver's Sex

of other factors and that drivers are influenced only by the location of the stop line. If such a hypothesis were taken to its extreme, as by placing the stop line 50 feet from the intersection, it is doubtful that it would retain its effect. The distribution of stopping distance would undoubtedly change, with the mean no longer close to the position of the stop line itself. However, within limits, it is felt that the present data could be used to suggest the distance between the stop line and the near crosswalk line likely to result in any given percentage of vehicles encroaching within the crosswalk.

Using the data obtained for intersections I_2 and I_5 and assuming that moving the stop line would result only in a change in mean stopping distance from the curb line, without a change in the variance, then it can be computed that, if 5% of the cars are to be permitted to stop within the crosswalk, the stop lines in these two intersections should be 9.08 feet and 8.86 feet, respectively, from the near crosswalk line. These distances include the width of the stop line. Similarly, if only 1% of vehicles are to stop within the crosswalk area, then the distances from the near crosswalk line to the stop line, including the width of the latter, should be 12.28 and 12.35 feet, respectively.

These data suggest that the current specification in the Michigan Manual of Uniform Traffic Control Devices (2), which recommends a minimum distance of 4 feet between the near crosswalk line and the stop line, may not be optimal. The results of the present study indicate that the near edge of the stop line should be 9 to 12 feet from the near crosswalk line to obtain small predicted numbers of cars stopping on the crosswalk. This recommendation applies only to traffic signal-controlled intersections, and would not be advised or considered practical for intersections not so controlled.

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