EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ROADWAY MARKINGS ON VEHICLES STOPPING IN PEDESTRIAN CROSSWALKS

By

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ACKNOWLEDGEMENTS

The cooperation of Mr. J. Robbins, Traffic Engineer, the City of Ann Arbor, in facilitating the study and his helpful discussions are appreciated.

ABSTRACT

The purpose of the experiment was to identify some of the roadway, vehicle, and driver factors influencing the stopping position of vehicles at a traffic signal controlled intersection and to extend the findings of an earlier survey study in order to suggest effective means to prevent vehicles from coming to a stop in the pedestrian crosswalk area.

The site chosen for this study was the intersection of a one-way and a two-way street, controlled by a traffic light. Measurements were made of the distance from the intersection to the stopping point of the first vehicle which pulled up to a red traffic signal. The markings on the two streets and the height of the traffic signal were systematically varied to determine their influence on stopping position. The effects of driver sex, type and size of vehicles, direction taken after stopping, traffic flow, one-way/two-way street, and lane position were also studied.

It was found that greatest control of stopping position, with minimum vehicle encroachment in the crosswalk, was achieved by the use of a stop line across the traffic lane which was not nearer to the intersection than 20 feet.

INTRODUCTION

In a previous study (Mortimer and Nagamachi, 1969) it was found that for vehicles which were the first to arrive and stop at a red traffic signal, encroachment on the pedestrian crosswalk area was related to the roadway marking at the intersection and to certain other variables such as driver and vehicle type.

That study consisted of measuring the stopping position of vehicles at a number of traffic signal controlled intersections in Ann Arbor, Michigan. The intersections selected for study differed in the variables of interest, such as the number of traffic lanes and, particularly, the pavement marking (consisting of crosswalk lines, crosswalk and stop lines, and the end of the center line). It was found that fewer vehicles stopped in the crosswalk when the pavement was marked with a crosswalk and a stop line than when the other delineations were used. Based on the distribution of stopping positions, recommendations were made for the placement of stop lines from the intersection. However, underlying these recommendations was the assumption that there would be little change in the distribution of stopping positions when the stop line delineation was moved further from or closer to the intersection, other than moving the whole distribution with the position of the delineation.

In addition, since several different intersections were compared in order to infer how differences in stopping position were affected by existing markings, it was felt that other differences in the intersections may have influenced stopping position in an unknown manner. Evident differences in the intersections were used as independent variables, but others may not have been recognized and controlled.

For these reasons it was felt advisable to conduct a second, more closely controlled experimental investigation of some of these and other variables. This study was designed to employ conventional experimental control procedures and to provide information on the actual shift in stopping position distributions when markings are systematically relocated on the pavement.

METHOD

A traffic signal controlled intersection in downtown Ann Arbor was cleared of all markings for use as the test site. One of the streets (East William Street) was two-way and carried four lanes with metered parking on both sides. The other street (South Division Street) was one-way, four lanes, with metered parking. The layout of the intersection in shown in Figure 1. The traffic signals were mounted overhead in the intersection.

Two 8-mm movie cameras were used to record the position at which each first arriving vehicle stopped for the red traffic signal. Each camera observed across the traffic lanes in one of the two streets. The cameras, located close to a building at the southwest corner of the intersection, were concealed from drivers with a cardboard box. As soon as the first vehicle stopped for the red signal a single-frame photo was taken. Marks on the opposite curb and the center line were used to provide distance reference points in the photographs. The accuracy of this method was computed by comparing photographically derived distances with those obtained by tape measure. An absolute mean difference of 0.18 feet was found and considered a negligible error

THE INDEPENDENT VARIABLES

The principal variable of interest in this study was the roadway marking. However, because the effect of roadway marking may be modified by other factors, the independent variables listed below were also examined:

(1) Type of marking
(2) Distance of marking from intersection
(3) Height of traffic signal
(4) One-way/two-way street
(5) Vehicle type

(6) Vehicle size

(7) Sex of driver

(8) Direction proceeded after stop

(9) Lane position in street

(10) Traffic flow

The nature of the levels of each of these factors is described below.

(1) Type of Marking (4 levels). Four types of markings were laid on the pavement using 4-inch wide, white, reflectorized tape. This material could be applied and removed rapidly, permitting flexibility in varying this experimental condition. The four types of markings were:

(A) End of center line

(B) End of center line and crosswalk

(C) End of center line and stop line

(D) End of center line, crosswalk, and stop line

The crosswalk was 9.0 feet wide and located within the area 3.0 feet and 12.0 feet from the intersection. The stop line was 12.0 inches wide.

(2) Distance of Marking from Intersection (3 levels). The marking was placed at three different distances from the intersection: 16 feet 20 feet, and 24 feet. Figure 2 shows the 12 combinations of type of marking and distance as they appeared in the one-way street. In the two-way street the configurations were the same except that the stop line extended over the right lane.

The actual appearances of these marking conditions on the one-way street (South Division Street) are shown in Figures 3-6 and on the two-way street (East William Street) in Figures 7-10.

(3) Height of Traffic Signal (2 levels). Stopping position was also felt to be a function of the height of the traffic signal because of the driver's visibility through the upper segment of the windshield. The height of the signals above the pavement was 15 feet 2 inches and 16 feet 2 inches. Figure 11 shows the appearance of the signals at both heights from the two streets.

(4) One-Way/Two-Way Street (2 levels). The differences in stopping distances from the intersection in the two streets were believed to be influenced by the effect of one-way and two-way traffic.

(5) Vehicle Type (2 levels). Vehicles were identified as passenger cars or trucks.

(6) Vehicle Size (3 levels). Vehicles were categorized as small, medium, or large. For example, most European cars were considered small; U.S. compacts and specialty-sports type cars medium; and others large.

(7) Sex of Driver (2 levels). Drivers were categorized as male or female.

(8) Direction Proceeded After Stop (3 levels). The direction taken by the target vehicle when it left the intersection was specified as left turn, right turn, or straight.

(9) Lane Position in Street (2 levels). This factor applies only on the one-way street since cars could be stopped in either the left or right lane.

(10) Traffic Flow. A count of total traffic flow on the green signal was made for each street in each data collection session. Traffic flow varied between about 450 and 950 vehicles per hour.

THE DEPENDENT VARIABLE

The single-frame, 8-mm film was analyzed to obtain the distance from the curb line at which each vehicle stopped. A total of 4,192 data points was obtained.

PROCEDURE

The initial height of the traffic signals was 15 feet 2 inches, and this condition was retained for the first set of measurements, a half replication of the experiment.

The selection of markings was made on a semi-random basis. Those markings which included the crosswalk (B and D) and the others (A and C) were used in blocks of six treatments. Thus, on one street a random order of two markings times three distances was used first with the remaining six treatments following in a random order. The opposite scheme was used on the other street. This simplified the procedure since the crosswalk either remained in place for six consecutive treatments or was not used.

When the height of the traffic signal was changed to 16 feet 2 inches the measurements were repeated in a balanced order of treatments across this variable.

One set of observations was made for each treatment beginning in the early afternoon and lasting about two hours.

Before each red phase of the signal one of the experimenters stood at the curb, ostensibly a pedestrian waiting to cross the street as the first car arrived. In addition, the number of vehicles on each street passing through the intersection on the green signal was counted to obtain a measure of traffic flow. Data concerning the type and size of vehicle, sex of driver, direction taken after stop, and lane position were also recorded.

It would have been desirable to keep each marking condition set up for a lengthy period. However, this was not possible because the study had to be completed in a reasonable time and because factors such as seasonal variations in weather and the driver population could have confounded the results. Each marking condition was kept in place for almost 48 hours between observations. This was done by taking observations in the afternoon and changing the marking that evening. It was in place one day and observations were made the following afternoon. Saturdays and Sundays were not used for observations or counted as elapsed days for driver familiarization with marking conditions. Observations were only made on clear, dry days.

RESULTS

Because the design was not balanced with respect to the number of data entries in each cell the analysis of the data was carried out in two steps. The first step was a single classification analysis of variance on each of the factors, with subsequent individual comparisons made by the Tukey test (Bowker and Lieberman, 1963). The second step involved the use of the AID (automatic interaction detector) algorithm to determine the occurrence of significant interactive relations between factors.

SINGLE CLASSIFICATION ANALYSIS OF VARIANCE

The main effects that were significant at the 1 percent level or less were:

(1) Type of marking
(2) Distance of marking from intersection
(3) Type and size of vehicle
(4) Sex of driver
(5) Direction proceeded after stop
(6) Traffic flow

Table 1 shows the mean stopping distances from the intersection for the four types of markings. Vehicles stopped closest to the intersection when the marking consisted either of the end of center line and crosswalk or of the end of center line alone. For these types of markings, stopping distances were not affected by the distance of the marking from the intersection. On the other hand the use of a stop line with or without a crosswalk resulted in stopping distances related to the distance of the stop line from the intersection.

In addition, stopping distances were greater for passenger cars than for trucks, and they were greater for larger vehicles than for smaller vehicles in each category. Generally females stopped significantly further back from the intersection than males. Vehicles which turned right stopped significantly closer than those continuing straight or turning left.

There appeared to be a curvilinear effect of traffic flow density upon stopping distances which peaked at a rate of about 700 vehicles per hour as shown in Figure 12.

TABLE 1. MEAN STOPPING DISTANCE (FEET) FROM THE INTERSECTION AS A FUNCTION OF TYPE AND DISTANCE OF MARKING

Type of Marking	Distance of Marking From Intersection (feet) 16	20	24	Mean
A. End of Center Line	21.25	20.31	20.79	20.8
B. End of Center Line and Crosswalk	18.99	19.20	18.73	19.0
C. End of Center Line and Stop Line	21.49	24.18	25.53	23.7
D. End of Center Line, Crosswalk, and Stop Line	21.01	23.06	25.41	23.1
Mean	20.7	21.7	22.6	

AID ANALYSIS

The AID analysis separates a body of data into a number of subgroups using the criterion of maximum explained sums of squares of variability. The technique proceeds sequentially to smaller subgroups; it therefore orders the variables in their importance and also suggests interactions.

Figure 13 shows the results of the AID analysis, indicating the independent variables that explained the largest amount of variability in the stopping position. Note that the first split occurred between markings A and B (end of center line; end of center line and crosswalk) and C and D (end of center line and stop line; end of center line, crosswalk, and stop line). The next split in the subgroup 2 data was between marking A and B, showing that drivers stopped further from the intersection with marking A than with B. No further effects on these markings were found to be of consequence. Both the subgroup 3 and subgroup 5 data split on the distance of the marking. These splits show that for the markings using a stop line, the distance of the markings from the intersection had a great effect on stopping position.

A test of significance between the final blocks in this analysis (subgroups 4, 6, 7, 8, and 9) was carried out using Tukey's procedure for multiple comparisons of main effect means. Each of these subgroups was considered a treatment level of a one-way analysis of variance. Thus, in effect, the AID algorithm was used to define a map from the original independent variables to a new variable. This new variable contained the significant main effects and the interaction effects of the original variables. For each level of this new variable an estimated error variance and corresponding degrees of freedom were available. These were used as parameters in the Tukey test for multiple comparisons in a manner which minimized type II error, i.e., stating that a significant difference exists when it does not (Edwards, 1958). It was found that subgroups 4 and 7 (markings C and D at 16 feet and marking A) were not significantly different, all other differences between mean stopping positions being significant.

DISCUSSION

Effects of lesser interest which were found in this study by the analysis of variance and which did not directly relate to the marking conditions were the sex of the driver, the type and size of vehicle, and traffic flow. Because these variables did not appear in the AID analysis it was evident that they were of minor importance.

The previous study (Mortimer and Nagamachi, 1969) found that, overall, females stopped closer to the intersection than males; this study found the reverse tendency.[1] Both studies found that trucks stopped closer than passenger cars, that vehicles which made a right turn stopped closer than those continuing

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[1] illustrating the unpredictability of females

straight, and that there was no difference between one-way and two-way streets.

The major effects of interest concerned the roadway markings and the height of the traffic signal. The latter did not affect stopping position, perhaps because the height was only varied 1 foot. Given an upward visibility angle of 20 degrees through the windshield of a closed vehicle (Road Research Laboratory, 1963) and the driver's eye height of 48 inches above the road, lowering the traffic signal from 16 feet 2 inches to 15 feet 2 inches should have decreased, from about 52 to 49 feet, the distance from the red signal at which the driver could see it. Since the traffic signals were about 28 feet inside the intersection drivers should have stopped 24 and 21 feet, respectively, from the intersection to retain visibility of the signal. These values are close to the mean stopping positions. Analysis of the distribution of the stopping position data showed that over 50 percent of drivers stopped closer than 21 feet with markings A and B, and hence may have had difficulty in seeing the signal (dependent upon their actual upward visibility as affected by the vehicle structure, their seated position, and anthropometric characteristics); whereas with markings C and D at 24 feet from the intersection less than 18 percent of drivers would have been affected, providing another measure of the effectiveness of the latter markings.

With regard to the types of markings used, there appears to be a good deal of agreement between this study and the earlier one. Both studies found that using the end of center line and the crosswalk produced shorter stopping distances than using the end of center line alone, and both these markings resulted in shorter stopping positions than the use of a stop line.

Since this study has shown that mean stopping position was affected by the distance of the marking from the intersection only for markings using a stop line, it appears that other features of the intersection were also active in determining stopping position when the other markings were used and that the effectiveness of the other markings is probably small.

Figures 14-17 show the cumulative percentage distributions of vehicle stopping distance from the intersection for the three marking distances. The mean crosswalk line in all cases was 12.0 feet from the intersection. The percentage of vehicles which stopped within the crosswalk area (i.e., closer than 12.0 feet) can be readily seen from these distributions and is shown in Table 2.

TABLE 2. PERCENT OF VEHICLES WHICH STOPPED IN THE CROSSWALK FOR EACH MARKING TYPE AND DISTANCE

Type of Marking	Distance of Marking From Intersection (feet)		
	16	20	24
A. End of Center Line	4	7	4
B. End of Center Line and Crosswalk	4	3	4
C. End of Center Line and Stop Line	1	0	0
D. End of Center Line, Crosswalk, and Stop Line	2	1	0

These data indicate that in order to insure that no more than about 5 percent of the vehicles come to a stop on the crosswalk, virtually any of the markings in this study could be used. To keep the number of vehicles down to 1 percent or less a stop line, not less than 8 feet from the crosswalk line, should be used. This assumes a crosswalk line of 12.0 feet from the intersection. If no crosswalk is to be marked, this distance should be taken into account.

The present findings suggest greater latitude in positioning the pavement markings to reduce encroachment of vehicles on the crosswalk than was found in the previous study which inferred that the stop line should be about 9.0 and 12.0 feet from the near crosswalk line for 5 percent and 1 percent control respectively. However, it should be remembered that the crosswalk in this experiment was located in a fixed area between 3 and 12 feet from the intersection; this crosswalk was wider and further from the intersection than was generally the case in the previous study. In addition, new, easily visible markings were used which may have resulted in better control of vehicles for all markings. However, both studies clearly support the superiority of the stop line in controlling the vehicles, and this should be the recommended form of marking.

Both studies found that the minimum distance of 4 feet between the crosswalk line and the stop line recommended in the Michigan Manual of Uniform Traffic Control Devices, is not adequate to reduce the frequency of vehicles stopping on the crosswalk to 1 percent. To maintain unimpeded pedestrian flow on the crosswalk, the stop line should be located at least 8 feet from the crosswalk line.

REFERENCES

Bowker, A.H. and Lieberman, G.J. Engineering Statistics. Prentice Hall, New York, 1963.

Edwards, A.L. Statistical Analysis. Rhinehart and Co., New York, 1958.

Mortimer, R.G. and Nagamachi, M. Effects of Roadway Markings on Vehicles Stopping in Pedestrian Crosswalks. The University of Michigan, Highway Safety Research Institute, Ann Arbor, Michigan, Report HuF-2, 1969.

Road Research Laboratory. Research on Road Safety. H. M. Stationery Office, London, 1963.

Sonquist, J.A. and Morgan, J.N. The Detection of Interaction Effects. Monograph No. 35, Survey Research Center, The University of Michigan, Ann Arbor, Michigan, 1964.

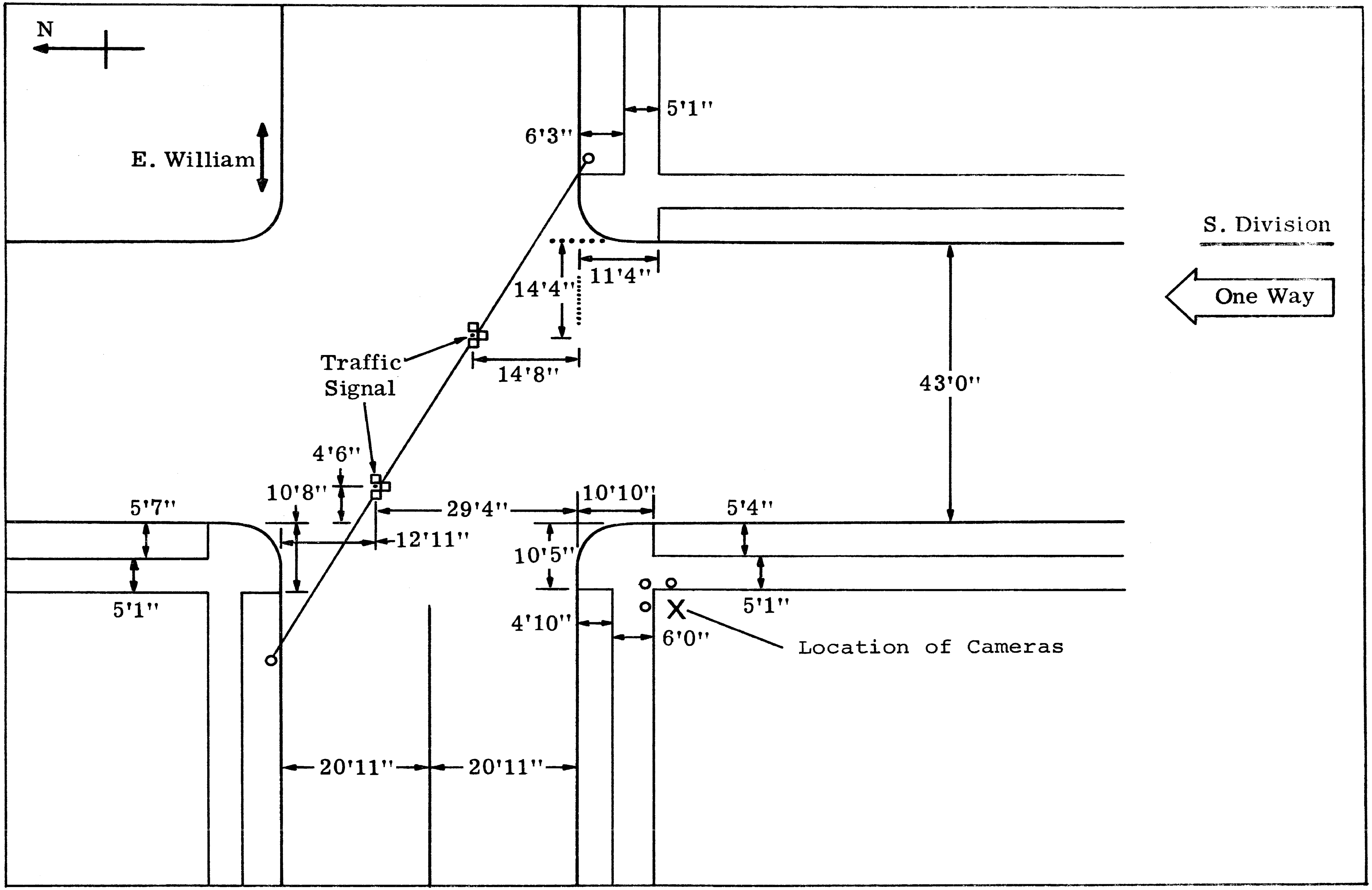


Figure 1. The layout of the intersection of East William and South Division used in the study.

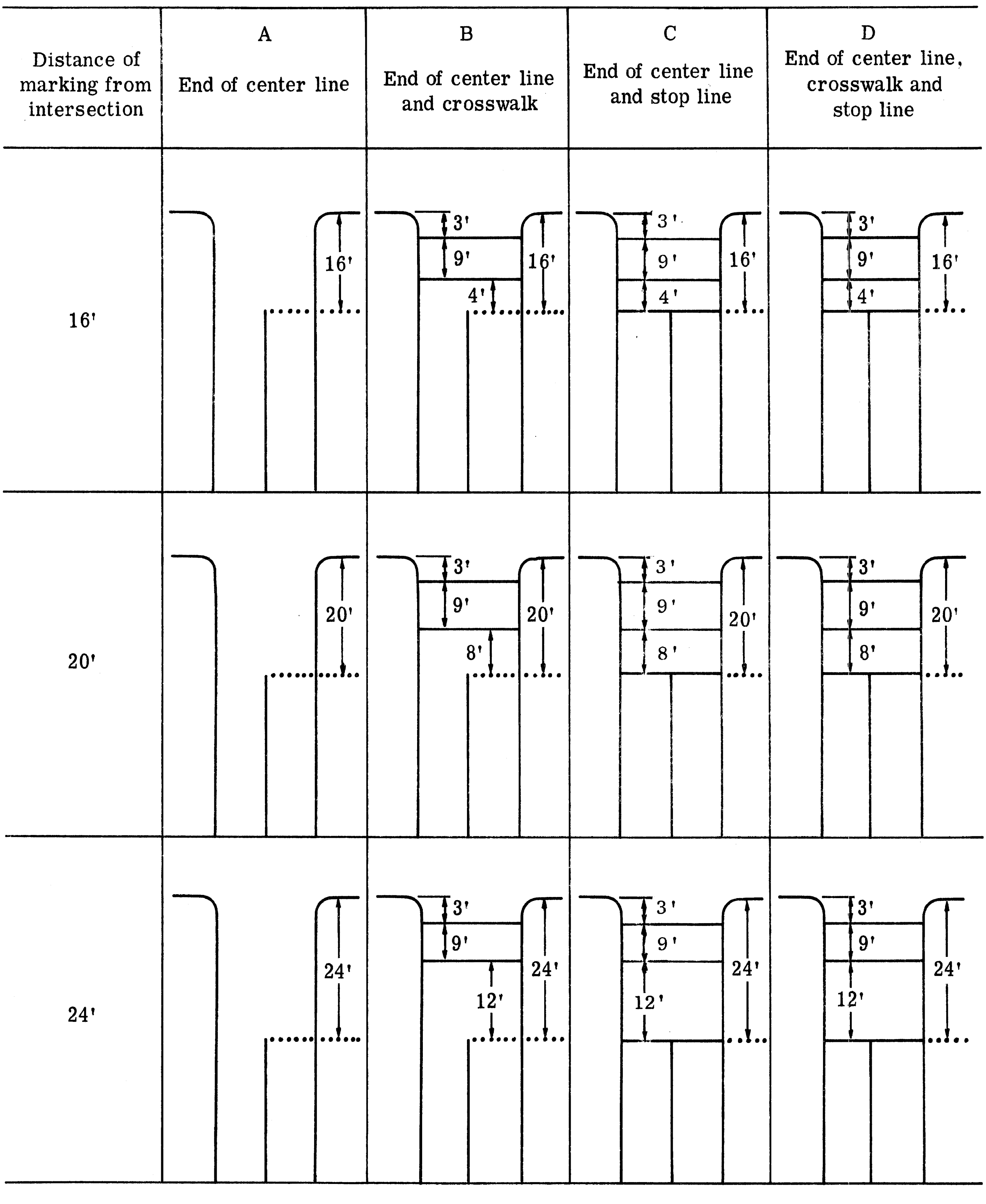
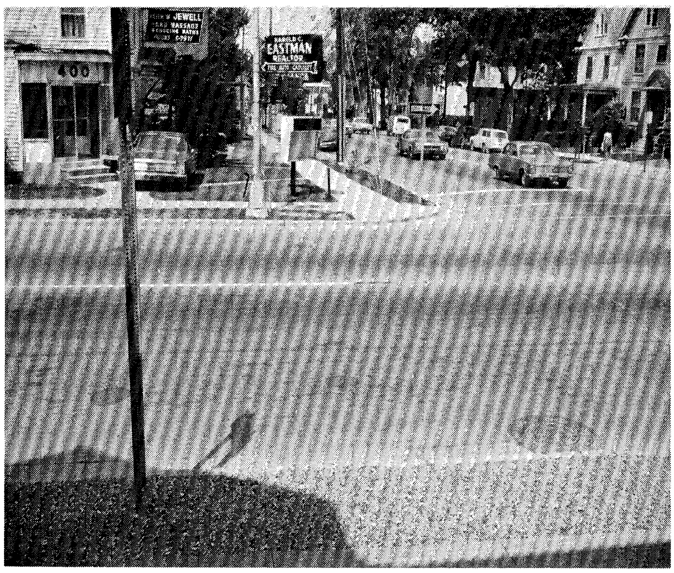
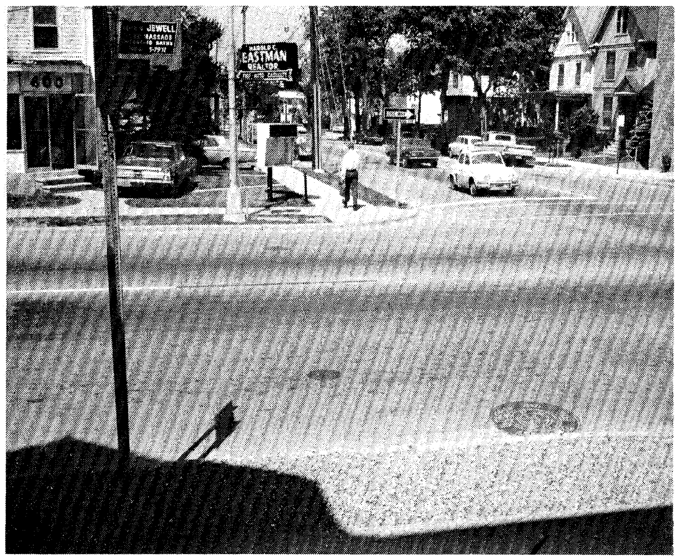


Figure 2. The marking types and distances as they appeared on the one-way street.



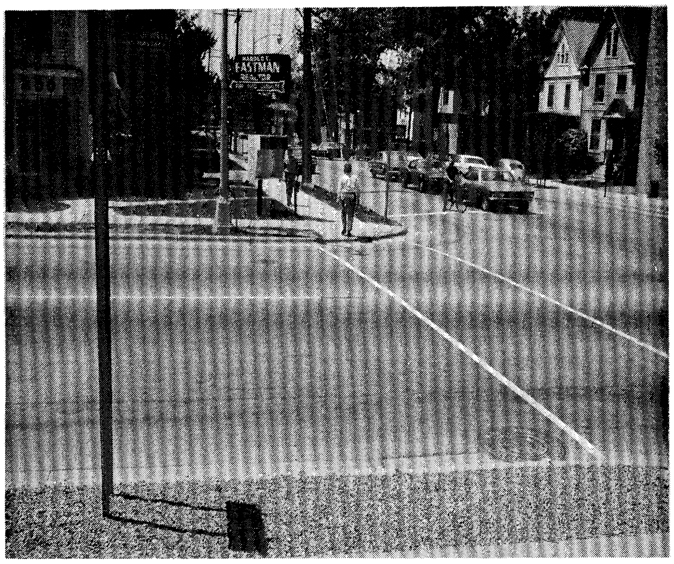
16 feet

20 feet

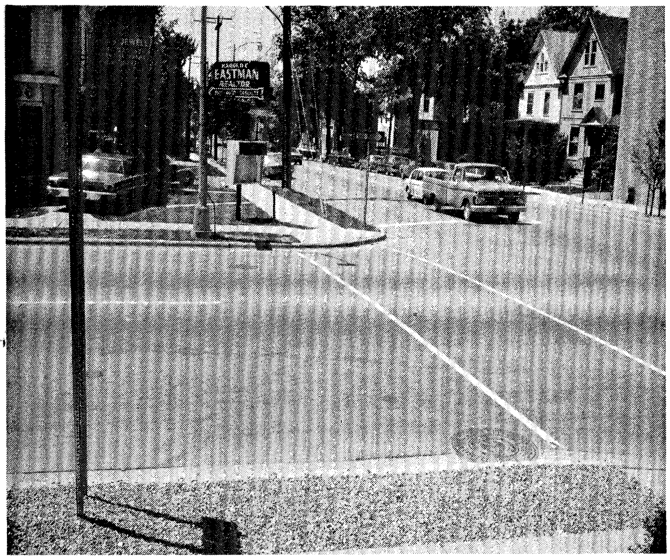


24 feet

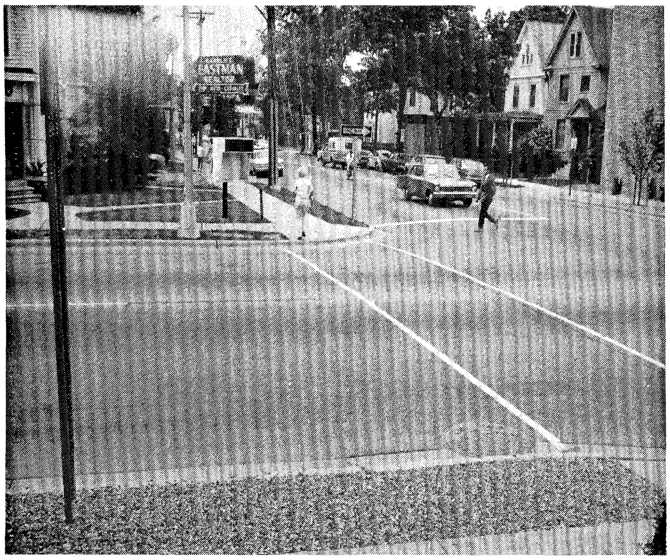
Figure 3. Marking condition A: end of center line on one-way street.



16 feet

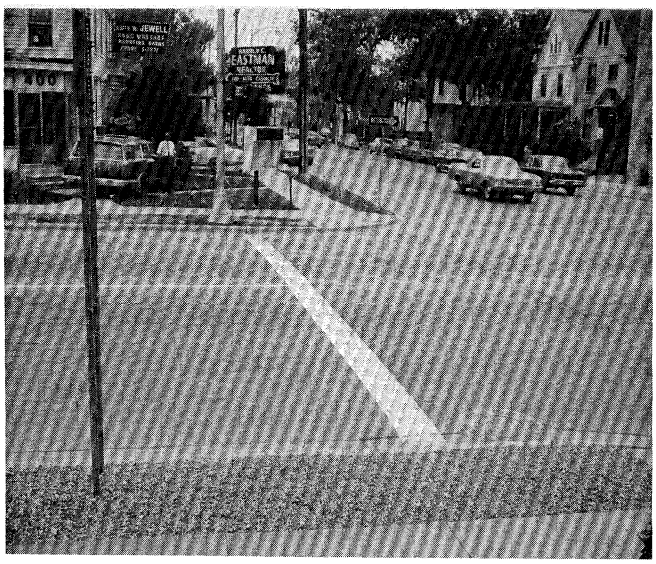


20 feet



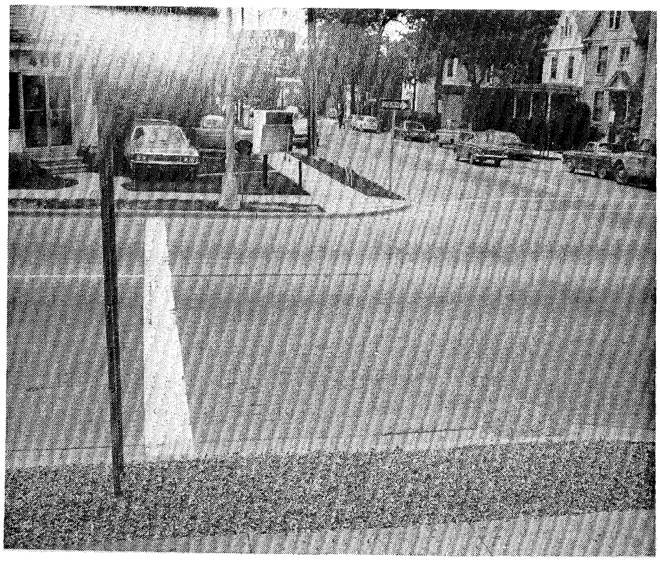
24 feet

Figure 4. Marking condition B: end of center line and crosswalk on one-way street.



16 feet

20 feet



24 feet

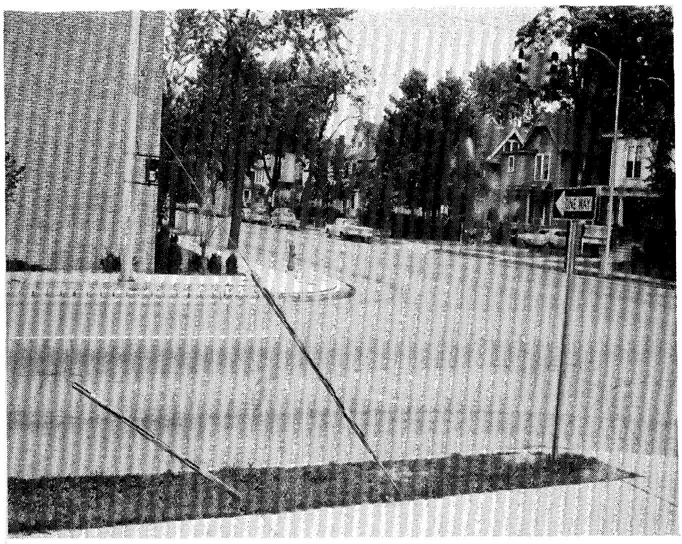
Figure 5. Marking condition C: end of center line and stop line, on one-way street.

16 feet

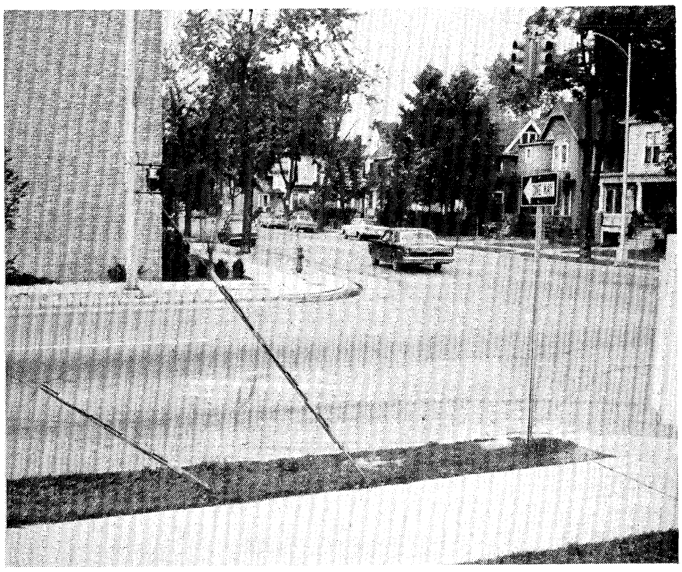
20 feet

24 feet

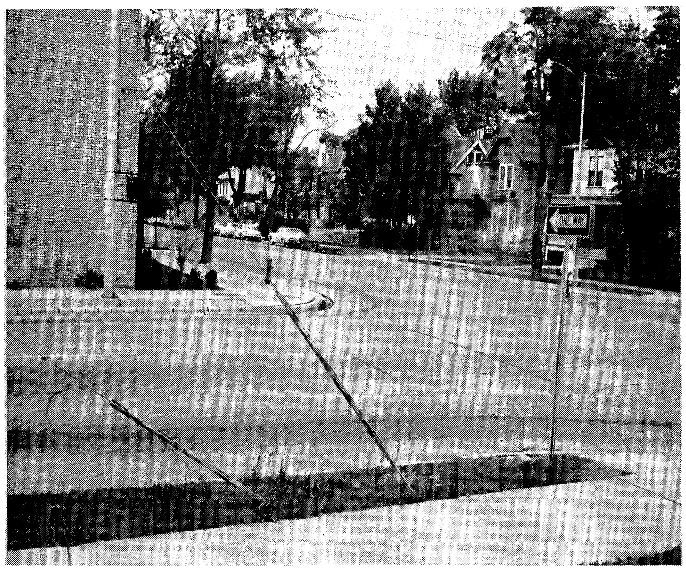
Figure 6. Marking condition D: end of center line and crosswalk and stop line, on one-way street.



16 feet



20 feet

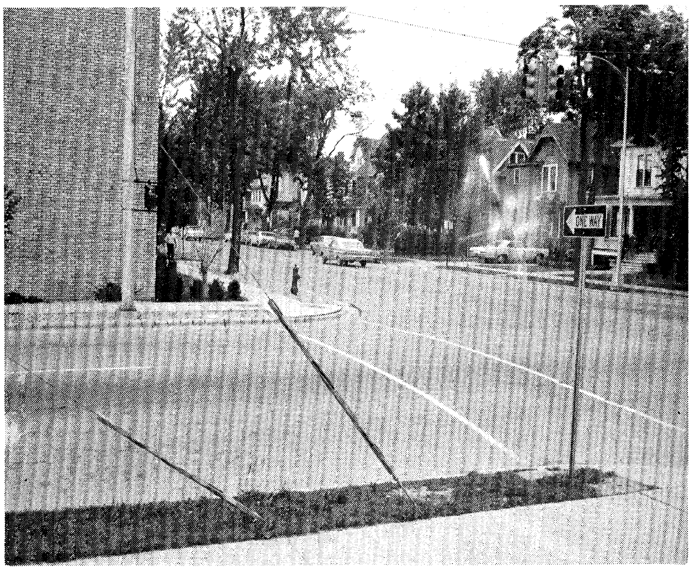


24 feet

Figure 7. Marking condition A: end of center line, on two-way street.

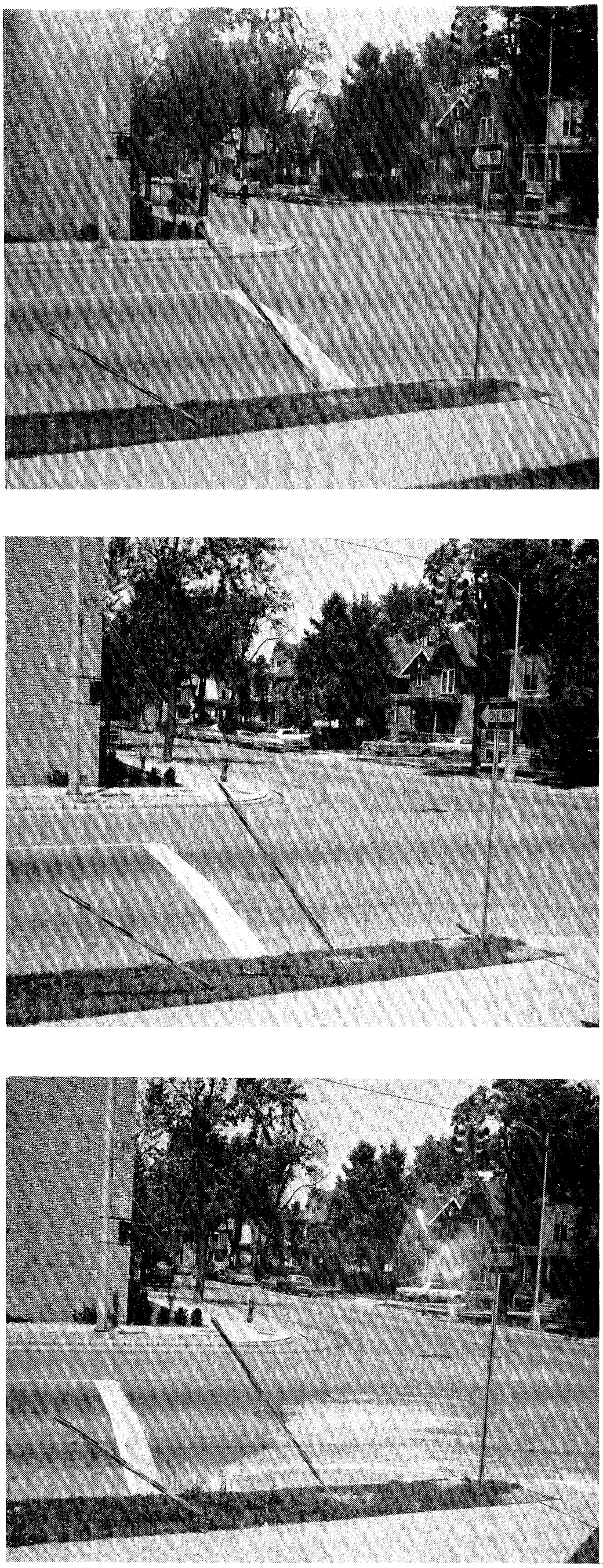
16 feet

20 feet



24 feet

Figure 8. Marking condition D: end of center line and crosswalk, on two-way street.

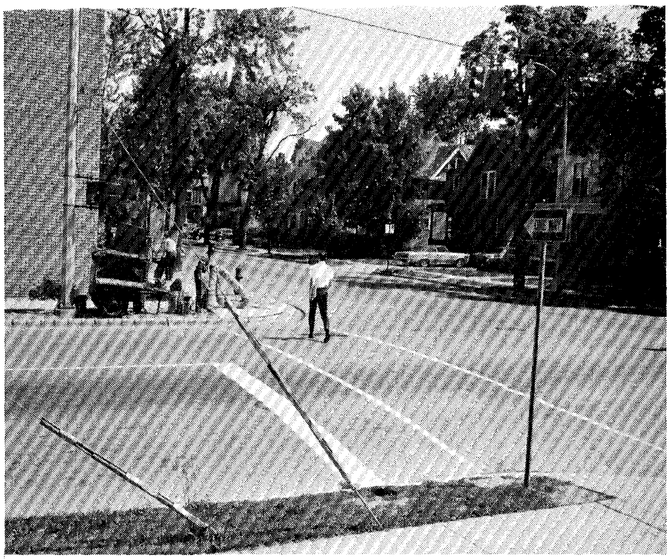


16 feet

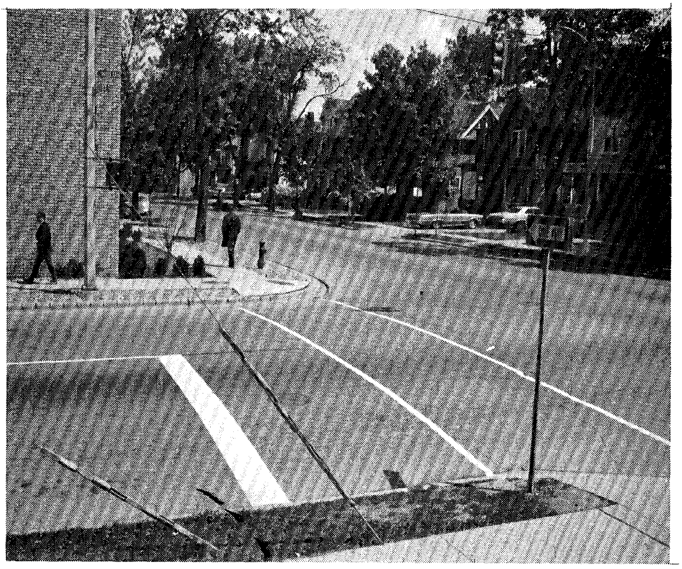
20 feet

24 feet

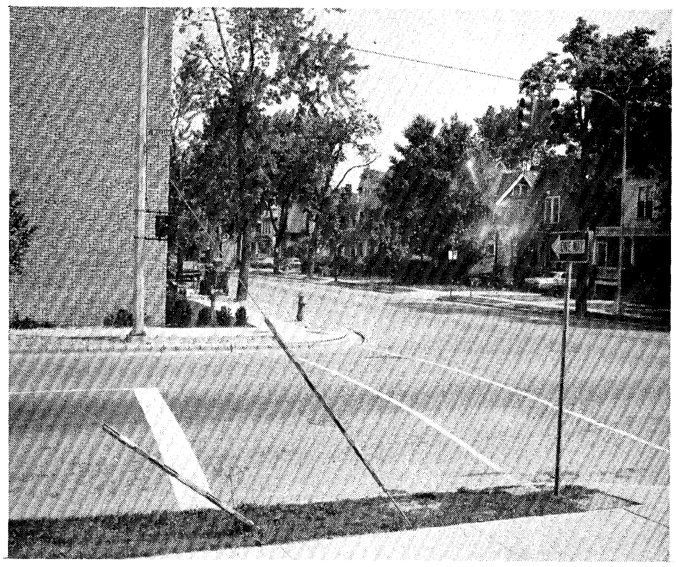
Figure 9. Marking condition C: end of center line and stop line, on two-way street.



16 feet

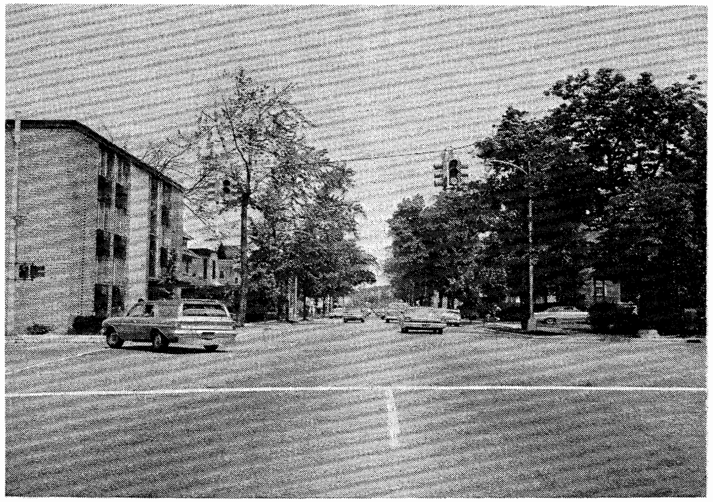


20 feet

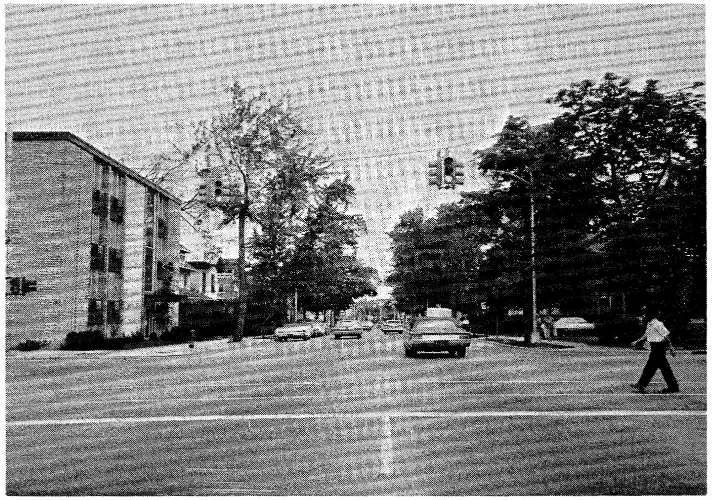


24 feet

Figure 10. Marking condition D: end of center line and crosswalk and stop line, on two-way street.

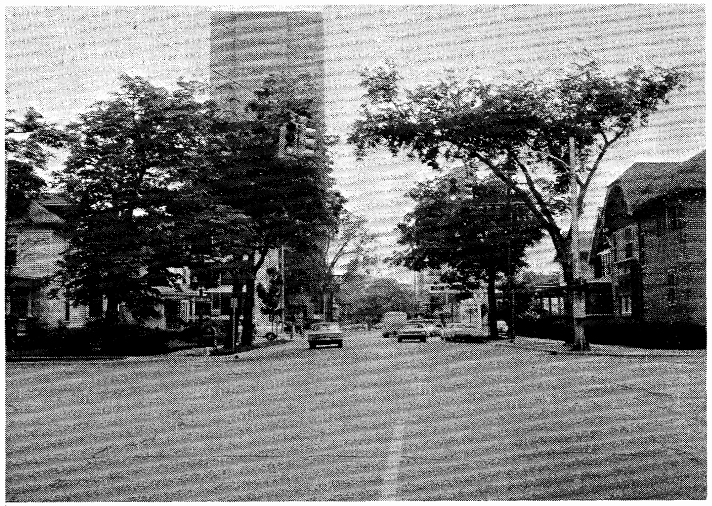


(a) One-Way Street, 15 feet 2 inches



(b) One-Way Street, 16 feet 2 inches

(c) Two-Way Street, 15 feet 2 inches



(d) Two-Way Street, 16 feet 2 inches

Figure 11. Traffic signal height as seen from one-way and two-way streets.

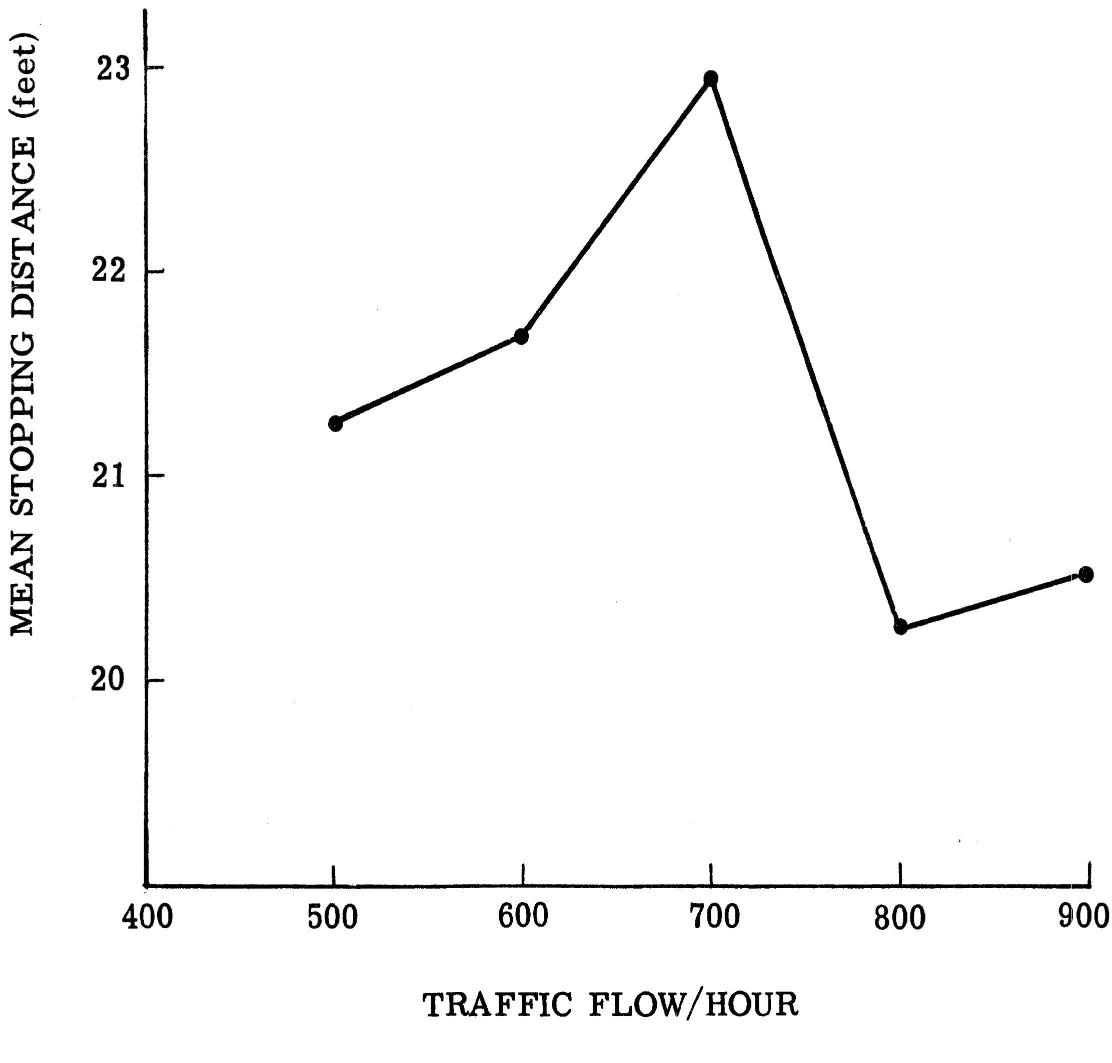


FIGURE 12. STOPPING DISTANCE AS A FUNCTION OF TRAFFIC FLOW

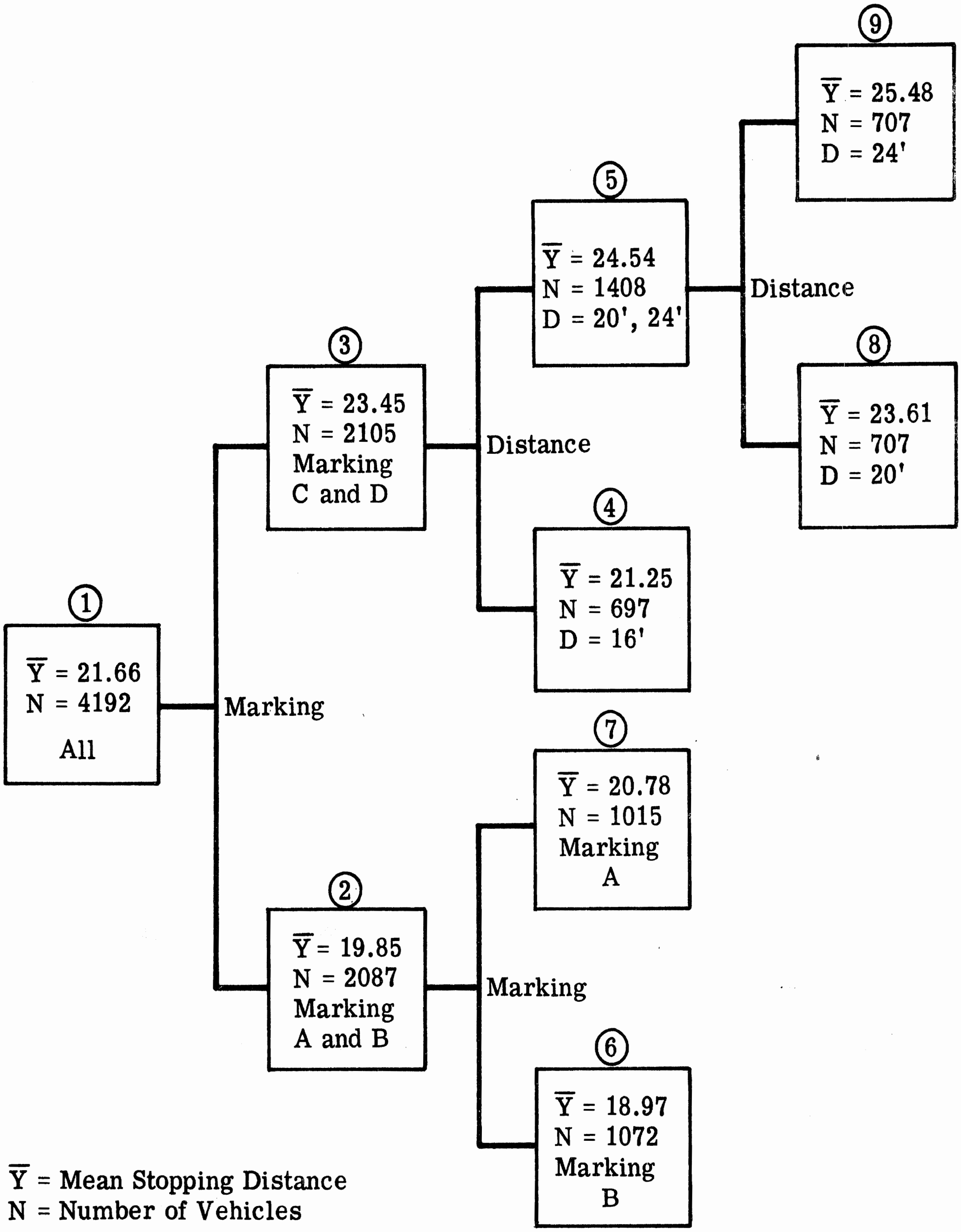


Figure 13. The major effects found in the AID analysis

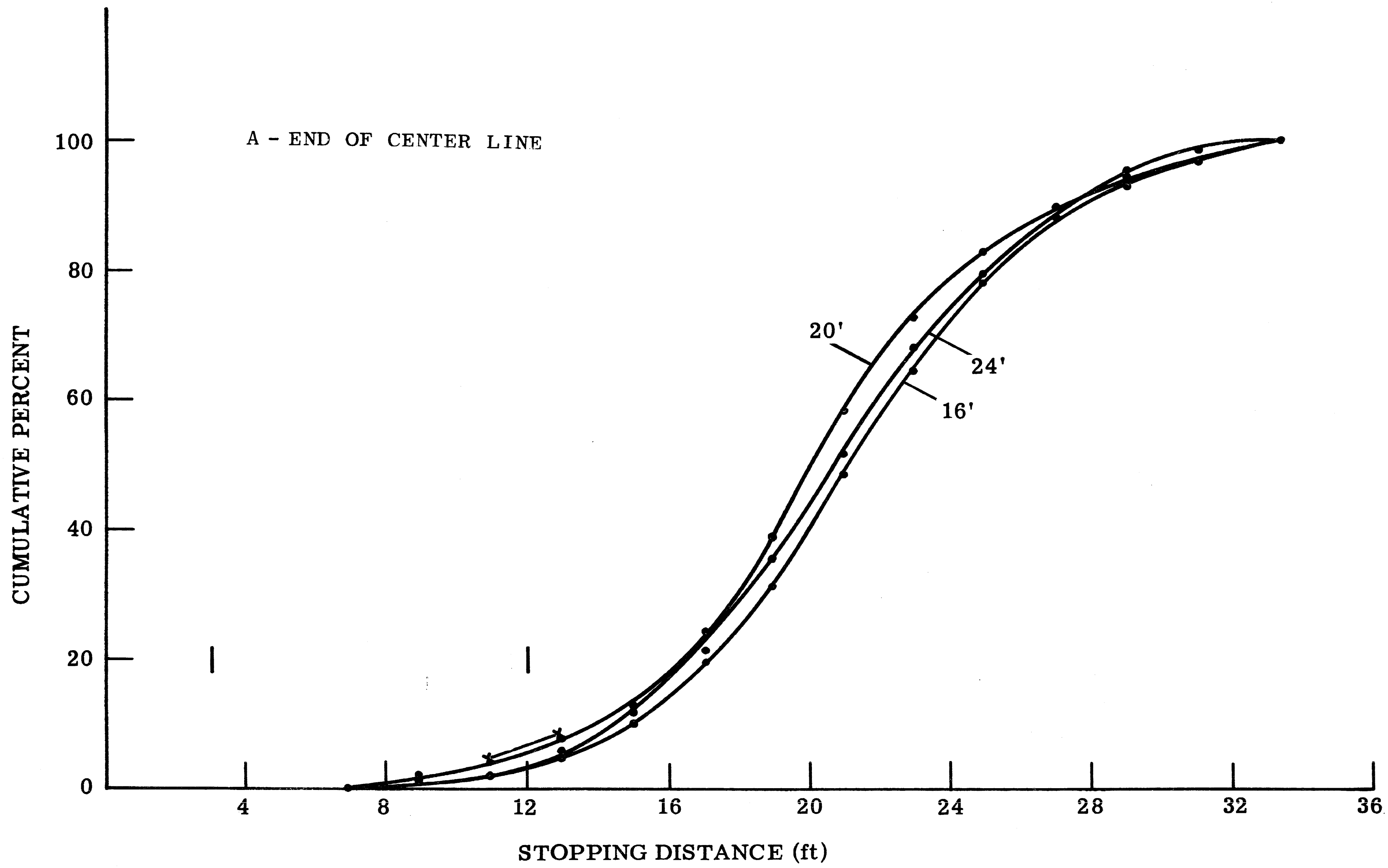


Figure 14. Cumulative percent distribution of stopping distance for end of center line marking at each distance.

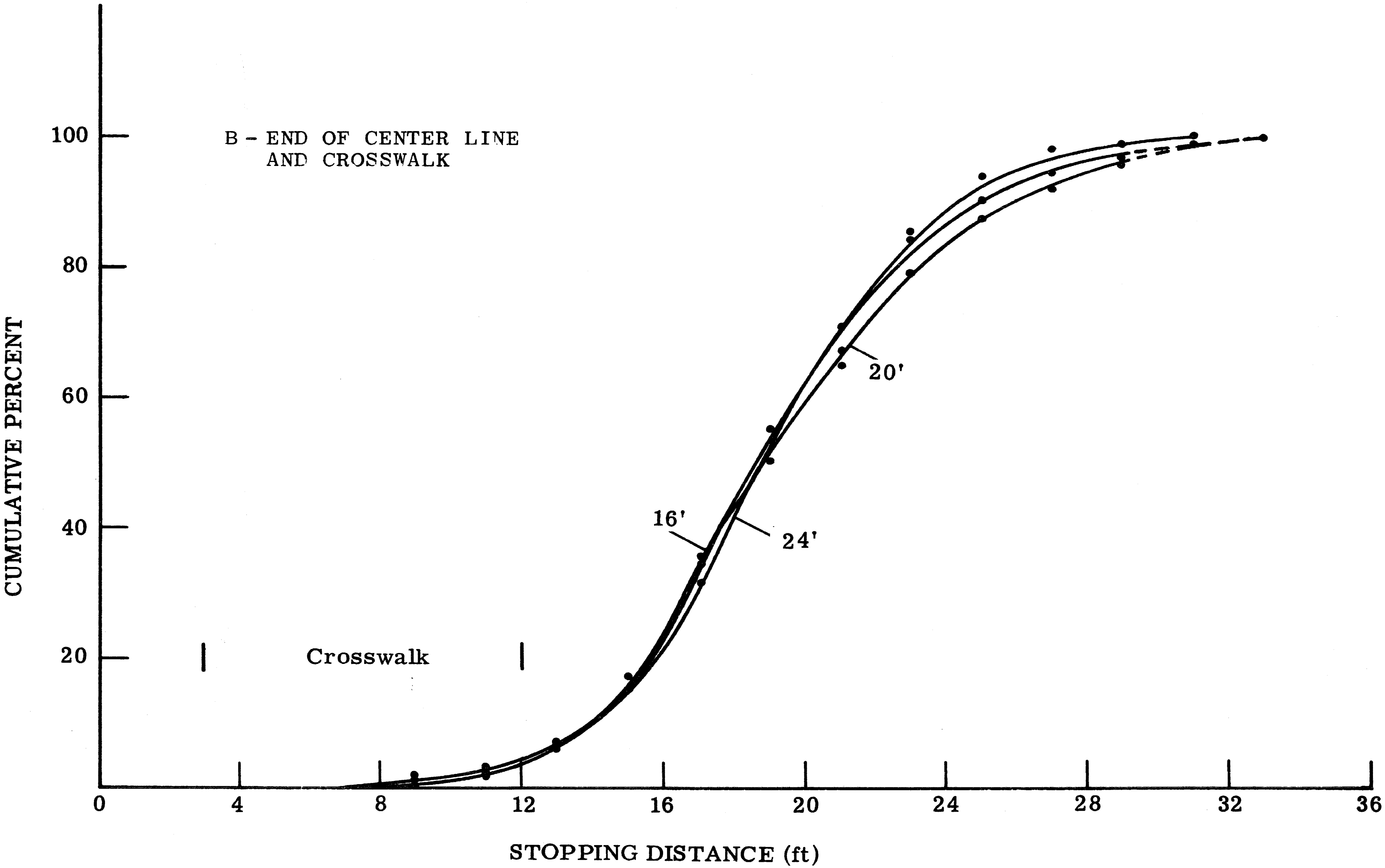


Figure 15. Cumulative percent distribution of stopping distance for end of center line and crosswalk markings at each distance.

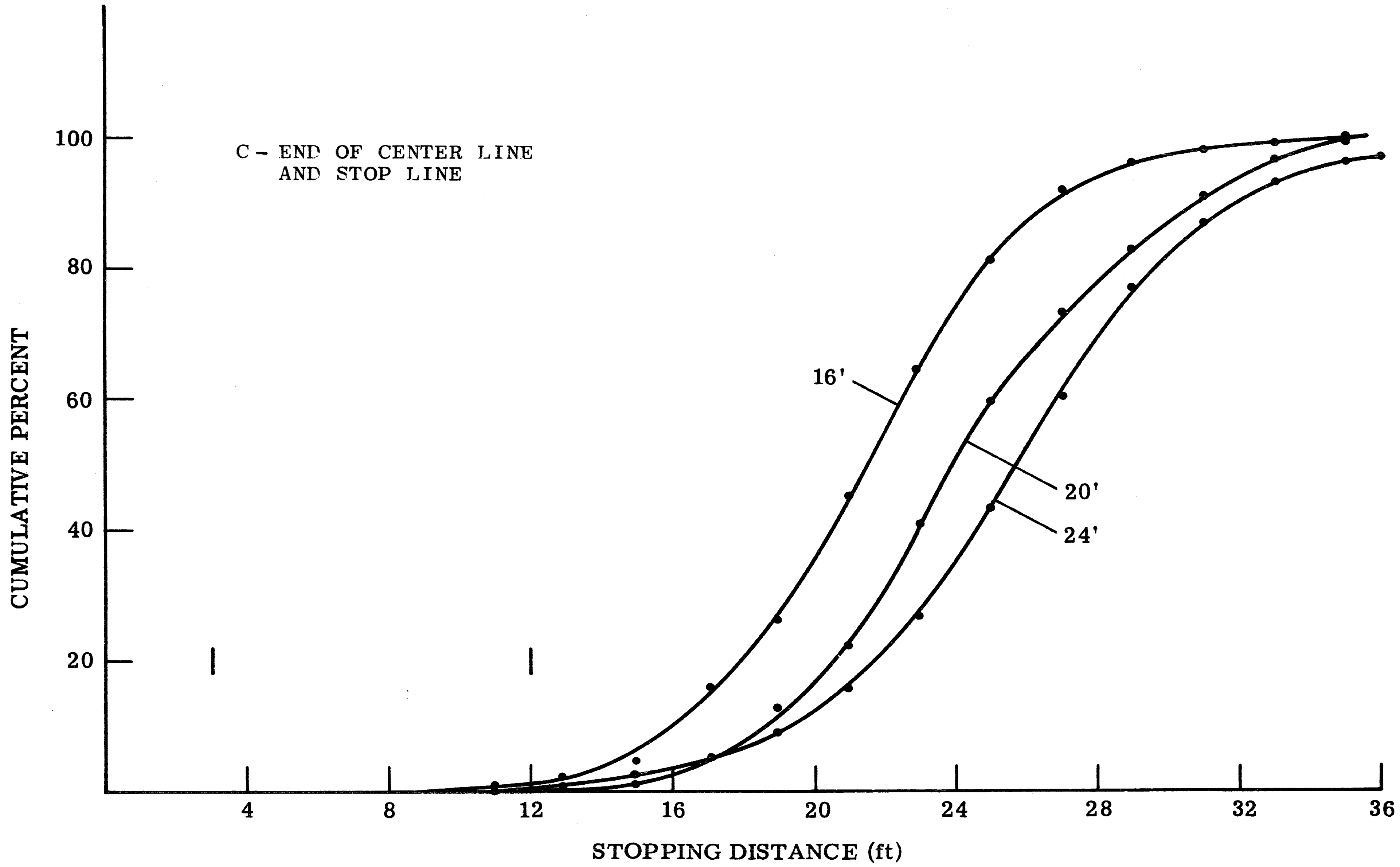


Figure 16. Cumulative percent distribution of stopping distance for end of center line and stop line markings at each distance.

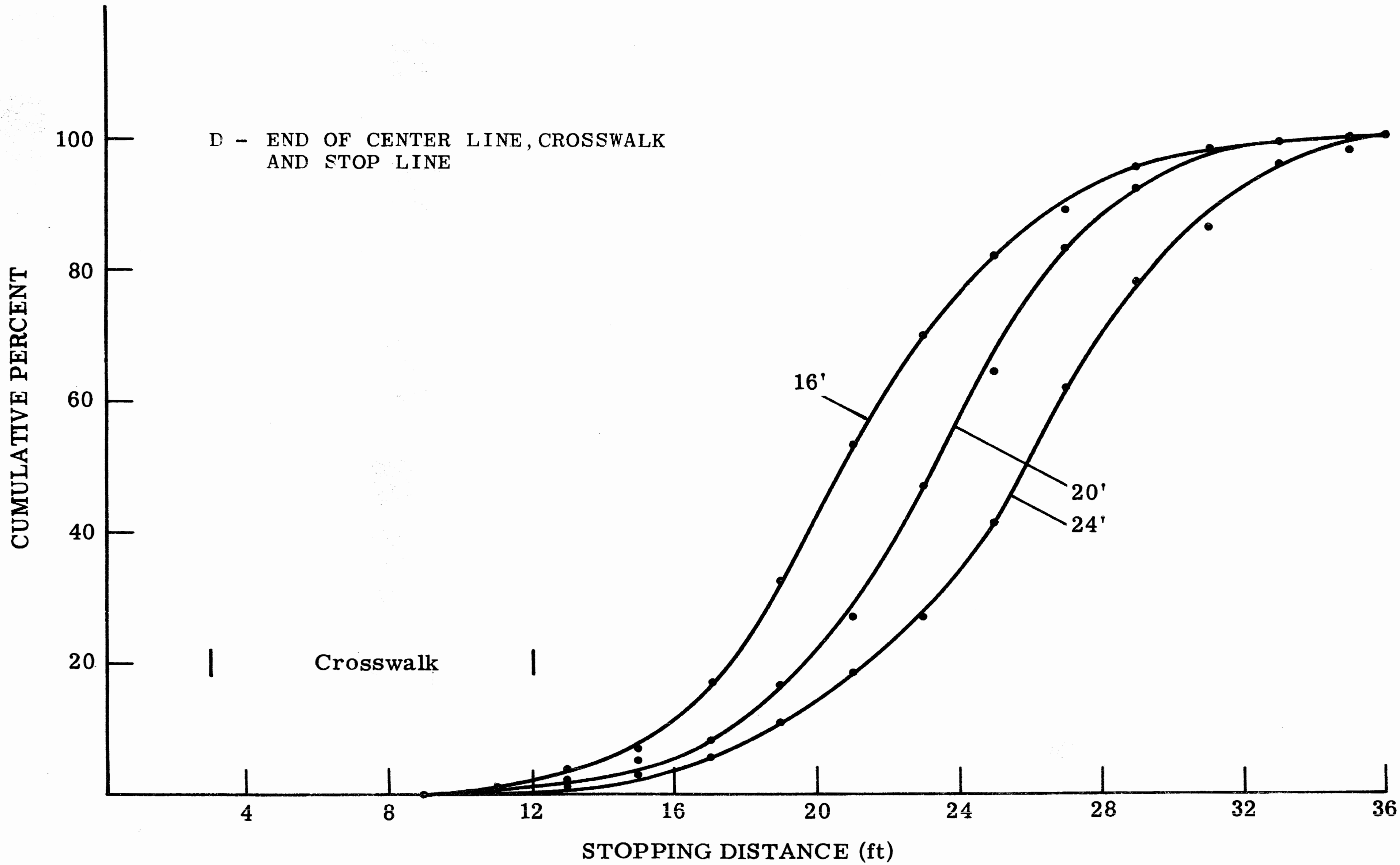


Figure 17. Cumulative percent distribution of stopping distance for end of center line, crosswalk, and stop line markings at each distance.