A STUDY OF SELECTION OF YELLOW CLEARANCE INTERVALS FOR TRAFFIC SIGNALS

Report TSD-TR-104-69

TRAFFIC and SAFETY DIVISION

DEPARTMENT OF STATE HIGHWAYS
STATE OF MICHIGAN

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

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By

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Conducted by

Traffic & Safety Division
Traffic Research Section

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PREFACE

Stop and go traffic signals using a yellow indication have been in use as traffic control devices for more than 30 years, yet, there is still appreciable difference in practice among states as well as the recommendations in standard texts for selection of the length of the yellow interval. This indicates the need for further research study to refine and standardize the duration of the yellow interval.

This does not pretend to be an exhaustive study of the subject. It is mainly concerned with examining and checking some items in the system used presently in Michigan for the selection of a yellow interval length.

There are many factors affecting this selection of yellow interval length and the drivers' use of it. Some of these factors are listed and discussed briefly in this report. One of the most controversial subjects, when calculating the proposed length of yellow interval, seems to be the perception-reaction time of the driver. Therefore, this was one of the more thoroughly investigated items of the field studies made and discussed in this report.

It is hoped that this study will induce further research on the subject and promote action toward the selection of a national standard yellow interval length.

EXPLANATION OF TERMS

<u>YELLOW INTERVAL</u>: The word <u>yellow</u> is used throughout this report to describe the color of the caution indication because the National Manual on Uniform Traffic Control Devices and the Michigan Manual of Uniform Traffic Control Devices use the word "yellow" rather than the word "amber" and yellow is the description most recognized by the layman.

<u>PERCEPTION-REACTION TIME</u>: The word Perception-Reaction Time, sometimes abbreviated Percep-React Time as used in this report, is to denote all the time from the start of a stimulus (yellow light) to a visible sign of a driver response (brake light). It includes any detection delay, time for discernment, time for recognition, deciding upon an action, and taking the action to a point where it can be detected by the observer with the test methods selected.

<u>SPEED AND VELOCITY</u>: These two words are used interchangeably in this report. The intent is to lead the reader toward consideration of the basic physics of the driving environment in considering operational problems.

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SUMMARY AND CONCLUSIONS

There is great variation in the values used by different states and different references in selection of signal yellow interval length.

By a theoretical and logical analytical approach, including consideration of some human behavior items, this investigation sought to arrive at a reasonable compromise of quantitative values, particularly regarding perception-reaction time, for use in calculating length of yellow for stop and go signals.

The data, taken by the lapsed time motion picture technique, supports the conclusion, based on the 85th percentile figure, that the AASHO recommendation of $1\frac{1}{2}$ seconds perception-reaction time when a stop choice is made is very reasonable. This would lead to a theoretically large percentage increase for yellow interval lengths. However, other variables in the equations have sufficient effect to not support this major change over the one second suggested by the I.T.E. Handbook(1), and other states practices, so the present policy of 1.2 second used by the State of Michigan seems a reasonable and justifiable compromise.

Extensive added research is needed especially in the field of driver behavior and capabilities with regard to use of the yellow interval before the optimum compromise can be reached.

BACKGROUND DISCUSSION

As stated in the Traffic Engineering Handbook[1] the purpose of the yellow interval is two-fold: first, to advise drivers that the green interval is about to end and to permit them to come to a safe stop; and second, to allow vehicles having entered the intersection legally to clear the point of conflict prior to release of conflicting pedestrians or vehicles.

Thus the optimum duration of yellow interval would logically be a function of many variables such as approach speed, width of intersection, decelerating characteristics of the vehicles, and perception-decision-reaction needs and capabilities of the driver. A graphic portrayal of some of these variables and their sequence as the driver approaches a signal is shown in Figure 1. In this figure it is seen that as the driver approaches from the right at some typical approach velocity he reaches a point at which the yellow interval starts. If he is alert and sees it immediately, he may use the minimum driver perception, decision and reaction time, and therefore have the most time available for decelerating. However, if he is not alert and is visually deficient, more time may be needed to perceive, decide, and react to the signal. This additional time can carry on to a point where the minimum distance for a comfortable deceleration is

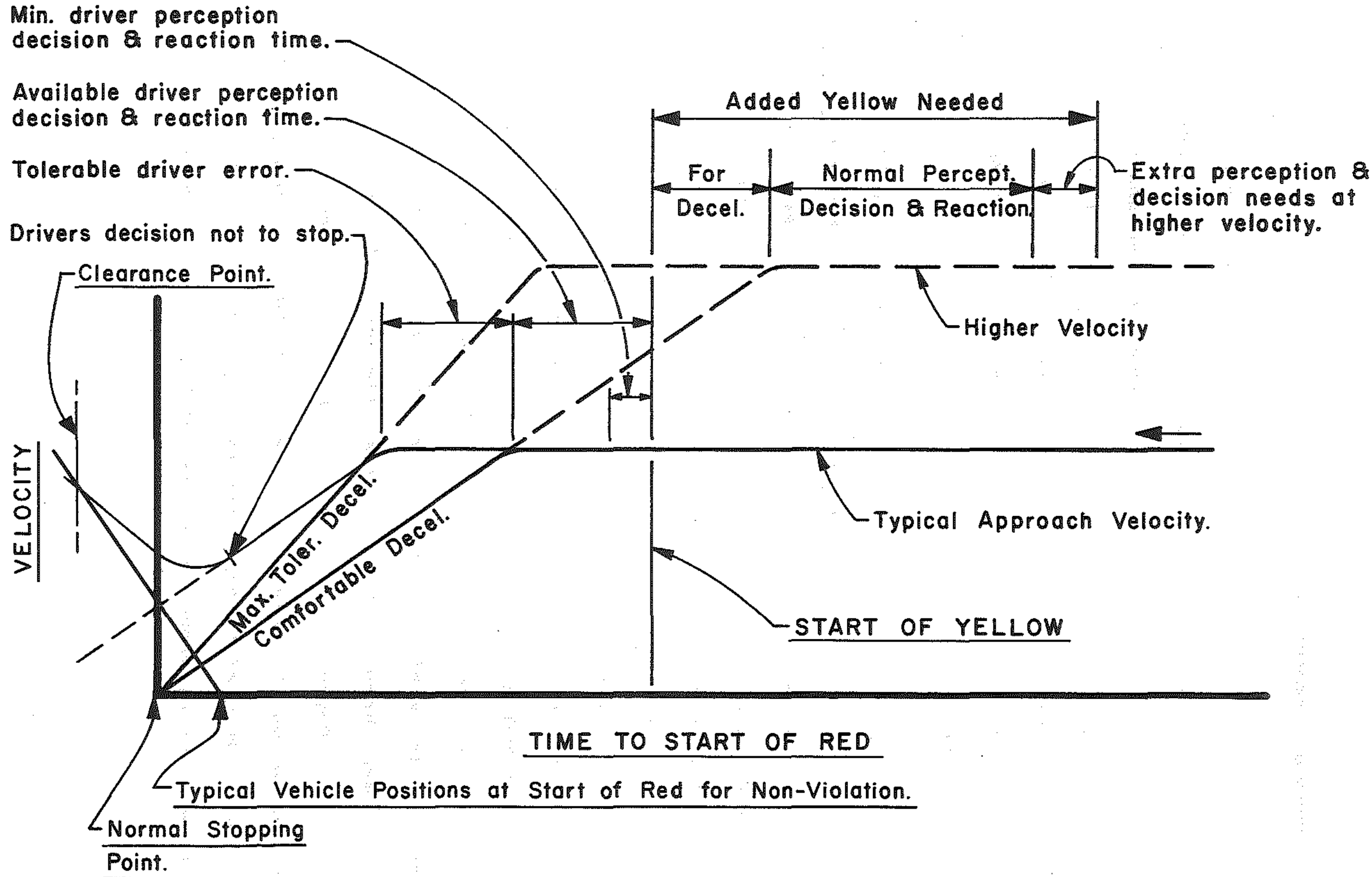


Figure 1: SIGNAL YELLOW PHASE LENGTH INFLUENCING FACTORS

available and even then if a more severe rate of deceleration is acceptable it can carry on to the point where the minimum distance for the maximum tolerable rate of deceleration is reached. If less than the maximum tolerable rate of deceleration is used at this point, the vehicle will carry on into the intersection or a new decision will be made to go on through the intersection in which case the velocity would probably be increased. Of course, most of the factors would be increased for higher approach velocities. In fact, there is indication from car following studies[(3)] that the driver has poorer distance judging ability at higher speeds. This would indicate need for greater time to compensate for judgment errors.

Listed in Appendix I is what the author believes would be a typical sequence of events in driver perception and decision making in connection with yellow interval length and an outline of factors influencing the errors in those items which are believed to be most likely to be misjudged by the driver.

With the many variable influences, listed in Appendix I, it is not surprising that there is considerable difference in opinion and practice in the selection of times for the yellow interval. Appendix III shows the Michigan Department of State Highways present practice in selection of yellow interval length and Figure 2 shows a comparison between this and the

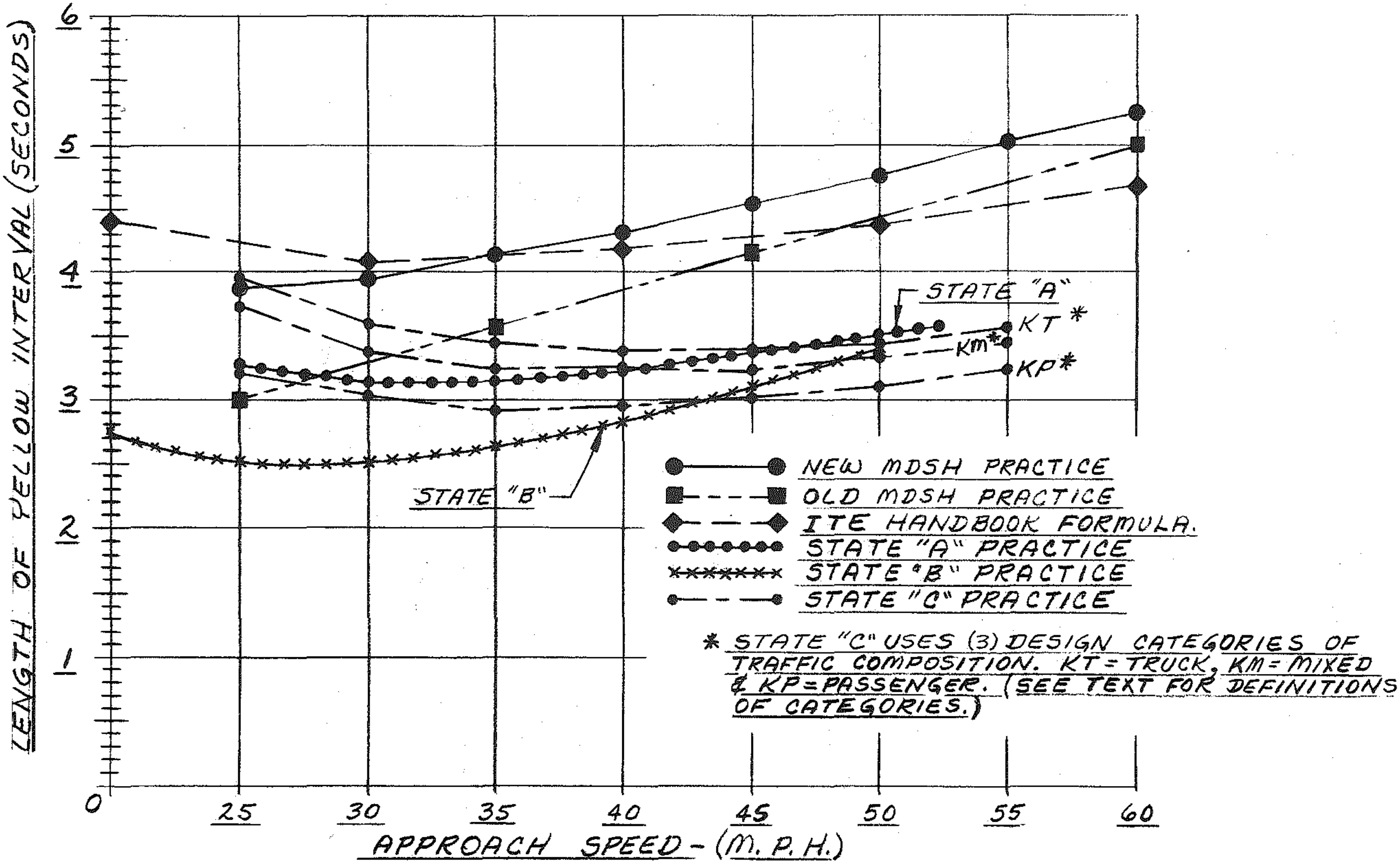


FIG. 2 COMPARISON OF TRAFFIC SIGNAL YELLOW INTERVAL LENGTH PRACTICES FOR TYPICAL 3 LANE CROSSINGS (50' FROM STOP POINT.)

Traffic Engineering Handbook[1] recommendations; typical old values used by the Michigan Department of State Highways; and practice used in three selected states for a typical 50' street.

On this figure, State "C" is indicated as using three different compositions of traffic in calculating the desired length of yellow.

The categories are as follows:

Truck traffic designated K_t and defined as consisting of traffic with more than 150 truck semi-trailer combinations or 500 total commercial vehicles per day (75 to 250 each way).

Mixed traffic designated K_m and defined as consisting of traffic with 20 to 150 truck semi-trailer combinations or 100 to 500 total commercial vehicles per day.

Passenger vehicle traffic, designated K_p and defined traffic containing less than 20 truck semi-trailer combinations or 100 commercial vehicles per day.

VARIATIONS IN PRACTICE AND PROBLEM APPROACH

The reference sources seem to contain appreciable different recommendations as to perception-reaction time. For example, the I.T.E. Handbook[1] recommends the formula $y = t + \frac{v}{2a} + \frac{w+l}{v}$

where y = Proposed duration

t = Perception-Reaction Time

v = Approach velocity

a = Rate of deceleration

w = Width of intersection

l = Assumed length of vehicle

In this reference $\frac{v}{2a}$ is named the "stopping time" which is a slight misnomer because a careful study of the derivation of the formula will show that it is actually the time it would take a driver at constant velocity to cross the stopping distance at that speed. The reference also uses one second perception-reaction time but the AASHO Handbook[2] recommends 1½ seconds perception-reaction time. This 1½ seconds conforms closely with the 85th percentile value for perception-reaction time found from the field data. The basic problem faced by the driver is of course not the choice of two time alternates, it is the choice between time to go through or distance to stop. He may use part of the red time for stopping if the stop alternate is chosen. Once the yellow exceeds that needed to signal the driver to choose, it becomes a study in time required to go through. From basic physics it can be seen that it will always take more time to stop in a given distance than it will to go through but, as stated above, if distance is adequate, the stopping time is always available in the red.

CONFUSION DUE TO LONG YELLOW

One set of curves calculated from Rothery's[4] data indicated that there were more vehicles stopping with a three second yellow than with the higher value. This may be attributed to the fact that with the shorter yellow the driver has a single decision of go or stop and has no other considerations, such as, is there time left to go, is it too late to go, or will the driver ahead stop or go. Since there are no reference objects or indicators to aid in these decisions they may well introduce a large factor of confusion into the use of unnecessarily long yellows. The short all red interval would be preferable because it still maintains the short sharp decision of stop or go and yet allows for the errors of observation, judgment, and urgency that occur in all driver decisions and actions.

PRESENT PROBLEMS

Although considerable investigation has been done on at least parts of the above subjects over the years, the present methods or values leave something to be desired in the way of adequacy of justification and documentation and flexibility to take into account more of the variables, such as, effect of truck volume on needed yellow interval length.

It was the objective of this research to start toward an improved compromise between accidents, capacity, and driver-vehicle capabilities, in the various environments, in the selection of the length of yellow interval. It is anticipated that the latest Department of State Highways policy on Yellow Clearance Intervals for Signalized Intersections, Appendix III, will reduce rear-end type accidents at signalized intersections by use of a more realistic component for perception decision and reaction time than was used in earlier formulas.

The yellow interval is of course, only one way of handling the more basic problem of helping the driver make a correct rapid safe decision and action at the time that the reassignment of right-of-way at the intersection is imminent. However, it seems to be the most practical yet devised. Some of the desired, but as yet unknown, information on driver needs, capabilities, and behavior in connection with the basic problem and the yellow interval length are listed in Appendix II. Considering the magnitude of the national problem of accidents at intersections, it seemed reasonable to seek some improvement, if possible, in the yellow interval without the extensive program that would be required to control and investigate every detail of the items listed in Appendix II.

The following plan of study was carried out to develop some of the needed information to arrive at an improved yellow interval length.

STUDY PLAN

The objective of the study program was to gather data to help evaluate the quantitative effect on accidents, capacity, and driver behavior of various length yellow indications with various approach speeds and traffic compositions, and possibly various approach profiles.

The GM Research Laboratories through R. Rothery[4] performed a series of field tests along similar objective lines. These tests showed a considerable variance between actual driver practice and some of the earlier investigators results. Their method of data acquisition involved an observer perception-reaction interval (the observer manually operated the camera upon seeing the yellow indication start). In a study involving fractions of a second, and for the purpose of studying driver behavior, it appeared that an improvement could be made by use of a motion picture study method. The camera would be started shortly before the yellow indications and run just beyond the beginning of the red indication. With distance calibrations in the picture as the GM Study used, this method would provide information to not only check the GM data of the driver's probability of stopping from various distances when the yellow starts, but would make it possible to get needed data on perception-decision-reaction time which would be indicated by the time lapse (number of frames) between the start of the yellow indication and the start of the brake-light indication on the pictures. The standard movie film speed of 24 frames per second would give a finer time interval than is available in most fixed time dial signal controllers which of course is 1% of the signal cycle.

In studying the state of the art it was planned that concurrent with the usual library source study (see attached bibliography list), a canvas would be made of selected other states for their practice and comments and to canvas the Michigan Department of State Highways Traffic & Safety Division Sections and District Traffic Engineers for their comments regarding the problem, the proposed method of study, and the result desired.

THEORETICAL ANALYSIS

As with many other researches, one way to visualize the problem to be studied is to graphically portray the basic physics (time, rate and distance) relationship in the use of a yellow interval. Such an analysis is shown in Figure 3. This graph shows a comfortable rate of deceleration ($9'/sec^2$), an acceptable rate of deceleration ($12'/sec^2$) and an approximate maximum acceptable rate of deceleration ($15'/sec^2$) as indicated by Olson and Rothery's work[4]. Also plotted are the clearance lines for different lengths of yellow at various approach speeds.

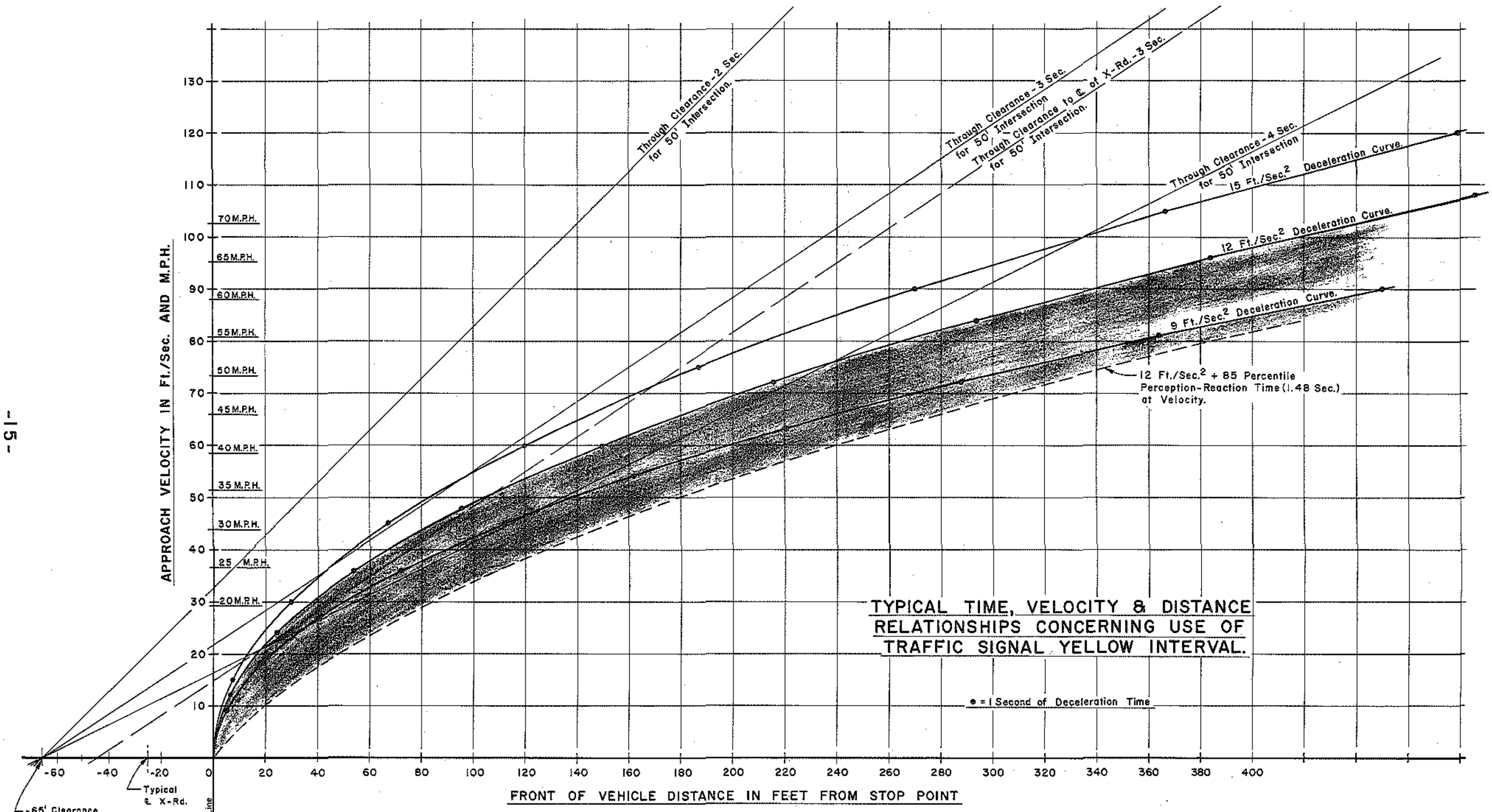


Figure 3. - Time Rate and Distance Relationships.

Although it is presumed that the deceleration rate does not follow a smooth uniform curve due to the driver adjusting his deceleration rate according to the time distance information feed back, for the purpose of this paper, an average constant deceleration rate will be used.

Also plotted on this curve is a band representing the distance traversed during the 85th percentile perception-reaction time according to the data later derived from this project. By use of dividers, scale, templet, or other suitable means, this band width along the abscissa can, of course, be studied in relation to any line.

The relation of the straight lines (clearance lines) to the deceleration curves does, of course, clearly depict the areas where there would be a so-called dilemma zone. From a study of these areas, in relation to the lines, the characteristics of these zones and their rates of change can be visualized. Also, it is evident what speed range is theoretically served adequately by a given length of yellow.

Since the Michigan practice is to calculate on the basis of clearance of the rear of the vehicle to the centerline of the cross street, theoretical analysis of the time planning of a typical crossroad driver was plotted in figure 4. It is assumed in this plot that the crossroad driver is moving and plans to use his green as soon as possible, but that he will never get so close that he cannot stop if he has misjudged the time of commencement of his green. From this curve it appears that at low speed and for very wide intersections, some correction should be considered for most existing formulas. There is, however, a compensating logic in this situation, in that at low speeds the driver could expect to see conflicting traffic in time to stop. Also, in general, where speeds are low, congestion exists and the drivers are stopped on the crossroads.

There is, of course, a perception-reaction time for the stopped driver and a starting time to the edge of the through lane (conflict point). This is indicated by a few samples that were counted from the films of this study and the results are shown on Figure 5. However, this is only an indication because no significant quantitative conclusions can be drawn from such a small sample.

ADDITIONAL CLEARANCE TIME VS. X-RD. WIDTH GRAPH.

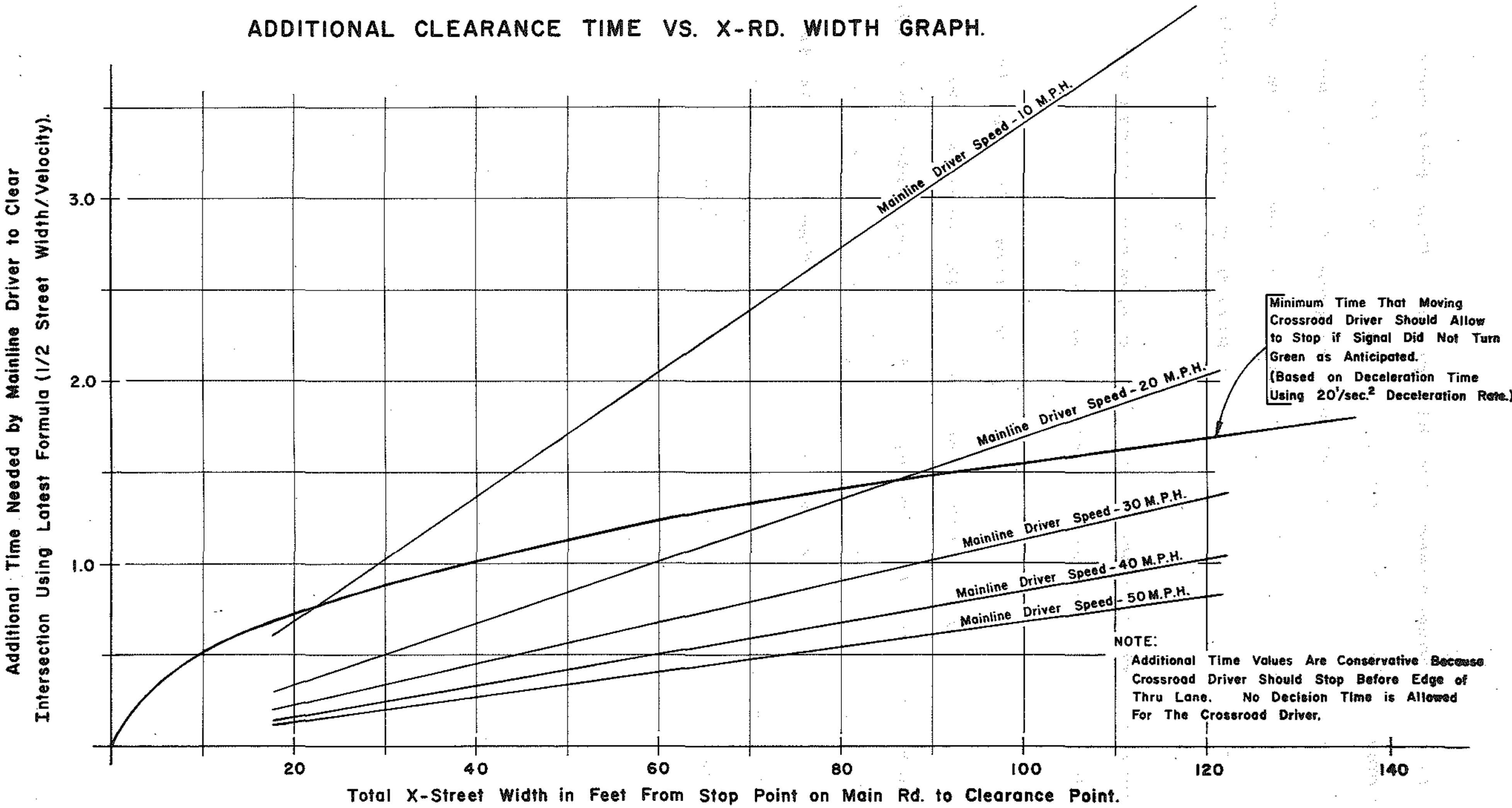


Figure 4. Clearance Time Considerations For Mainline Drivers When Moving X-Rd. Driver Anticipates A Green Signal Indication.

FILM DATA DISTRIBUTIONS FOR TIME FROM START OF CROSSROAD GREEN.

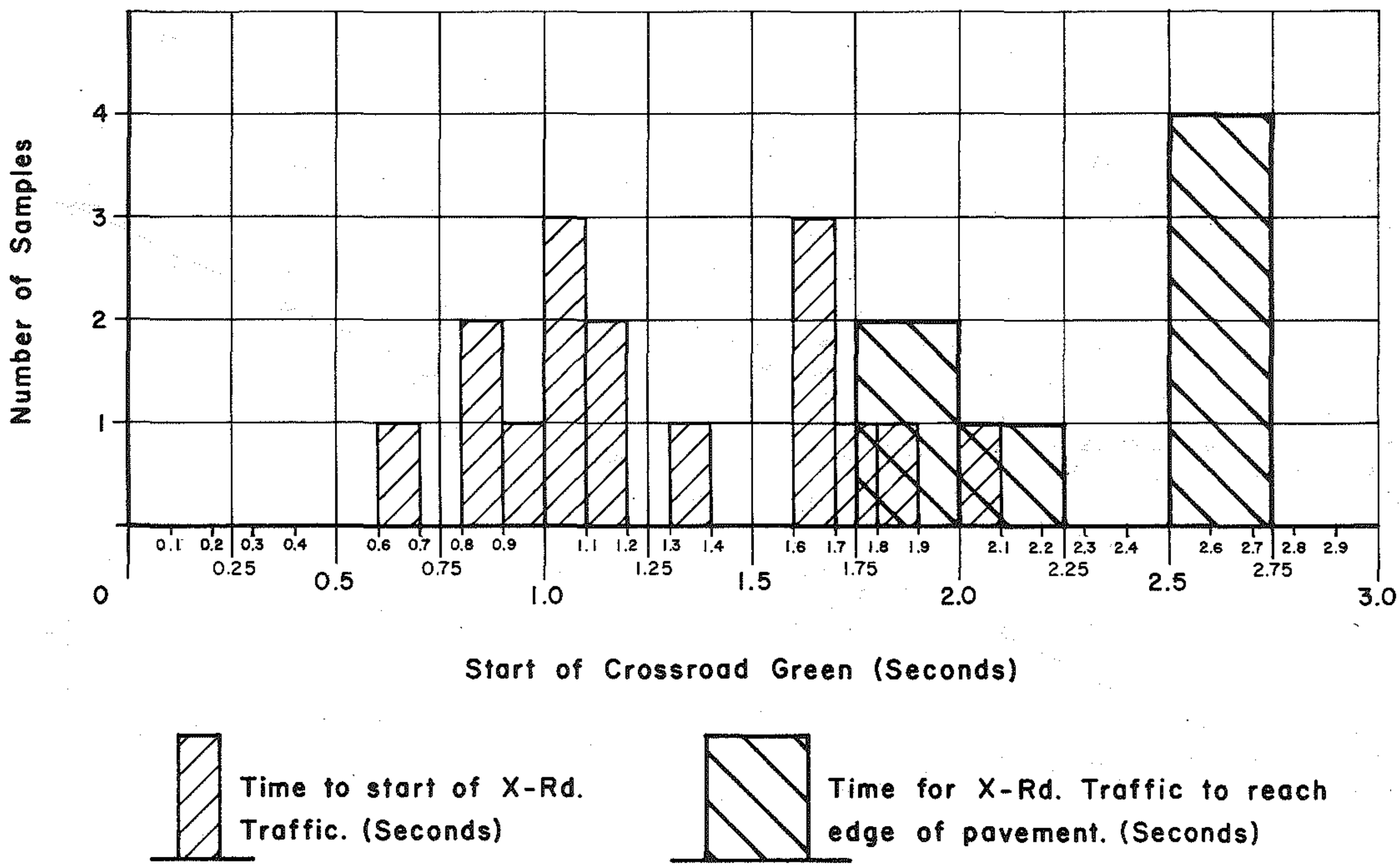
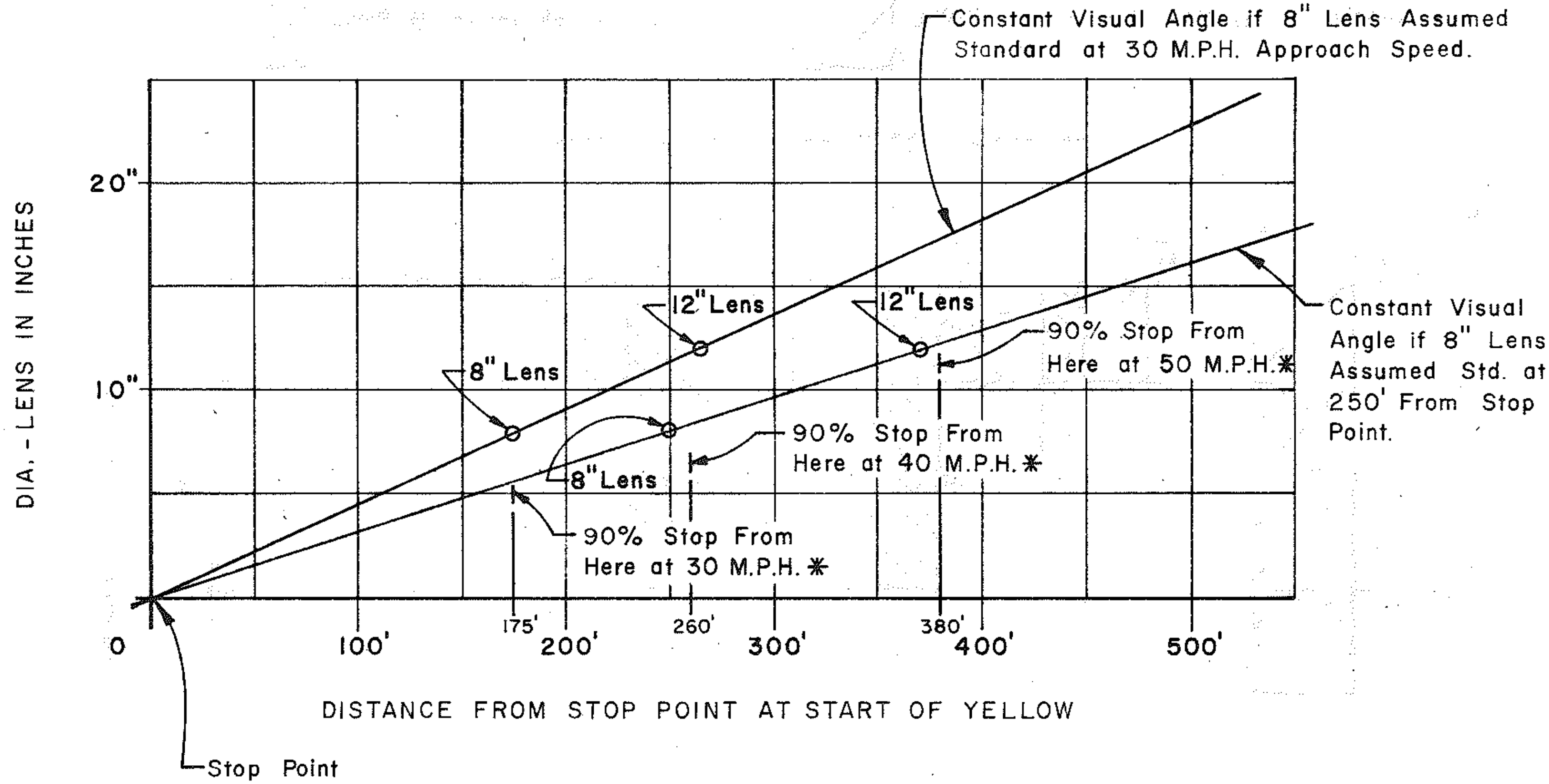


Figure 5. - CROSSROAD TRAFFIC ACTIONS



* - From Report "DRIVER RESPONSE TO AMBER PHASE OF TRAFFIC SIGNALS". (Ref. 4)

Figure 6 - Signal Indication Variable to Give Constant Stimulus.

From consideration of the two curves of Figure 3, it is evident, depending on the location of "start of yellow" line, that the higher speed driver must first decide if he is going to stop and then has a little more time to decide to go through, but, of course, after he has passed the highest acceptable deceleration curve he has no choice except to go through.

Next, as the approach speed is reduced, we see where the curves cross that there is a point of equal choice and the approaching driver at that speed would have equal time to make the decision. This, of course, is contrary to human nature, which in general demads more time to appraise other factors and make a choice when the alternatives are nearer to equal.

As the approach speed is lowered further, it is evident that the driver first makes a choice to go through and, if not, he has a little longer to decide to stop but he has no choice at that point except to stop or violate.

Considering these phenomenon, it is evident that the relative location and shape of these curves and their upper crossing point relative to human characteristics, capabilities, and behavior patterns become of major importance in design of the optimum length of yellow interval.

The present study is neither staffed nor equipped to make driver behavior studies in this area and consequently all conclusions on these factors are pure conjecture or extracted from other researchers works.

THEORETICAL VISUAL CONSIDERATION

It seems logical that it would be ideal to present the driver with a uniform visual stimulation at all signalized locations. Since the approach speeds are different at different locations and all the factors such as grade of approach affect the distance to the point where the visual stimulus should be equal, it would theoretically be ideal to have the diameter, area, and intensity of light variable enough so the driver would always receive the same intensity of colored light subtending the same visual angle at the point where perception-reaction time should begin. Figure 6 shows a plot of a signal indication variable that would theoretically give equal visual angle at various distances. It is, of course, impractical to provide a continuously variable signal indication, and therefore, it is presumed the present standard sizes have been chosen to give coverage within reasonable limits.

From a study of the drivers visual input needs and a consideration of needed increased stopping distances at higher speed, it is also logical to deduce that there is a length of required yellow at which an oversize signal should automatically be provided as part of the visual input system. This should be a subject for future investigation.

In darkness, when reference objects are less clear and plentiful, the subtended visual angle would logically become of greater importance since it is a major clue for distance juding and indirectly in velocity judging. It was originally proposed to run some night studies but discussion with various drivers indicated that failure to notice or stop for signals at night was seldom a problem even though they had missed signals in the daytime, and therefore, it was decided not to run night studies at this time.

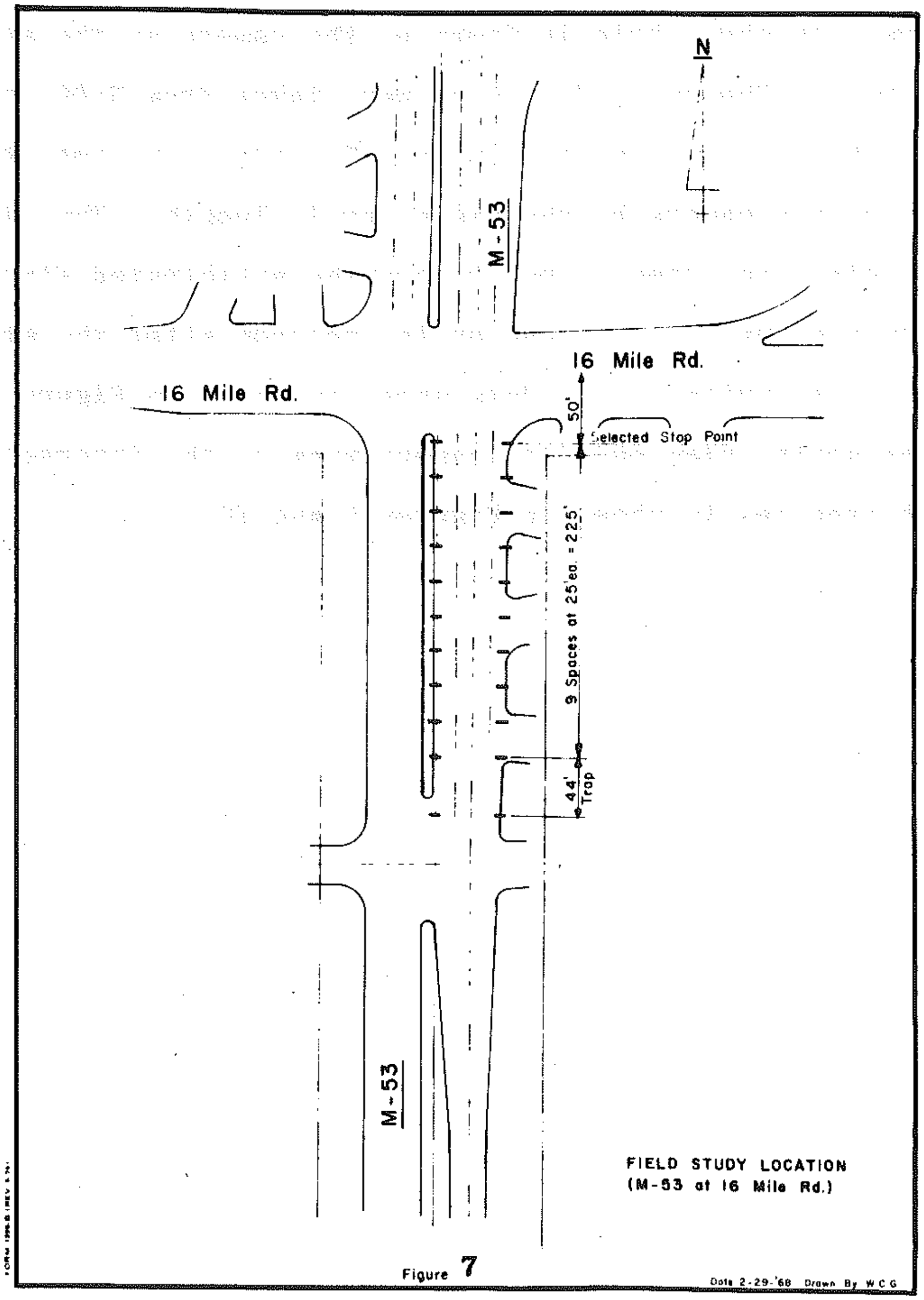
FIELD STUDY PLAN AND PROCEDURE

In order to quantify the value for driver perception-reaction time under realistic conditions, and with unaware drivers, it was decided to use a motion picture technique similar to Olson(4) and Greenshields(5) and Forbes(6). However, to refine the time measure, 15 frame per second photos were taken rather than the two frames or less per second used by the other researchers. This, we felt, was more consistent with the size of time interval to be measured (½ to 1½ seconds). It was interesting to note that at this film speed we could detect the start and full-on of the yellow.

With the intent of trying out the test method, and at the same time gathering useful information, a trunkline location was chosen at which a change in yellow interval length was anticipated in the near future. One leg of the intersection was calibrated as shown in Figure 7 and perception-reaction data was taken. Although it was originally planned to take a larger sample, an analysis of the data showed it to correlate sufficiently well with Gazis'[7] larger sample that it was believed not necessary to take a larger sample at this time. Other researchers had found that there was little change in perception-reaction time with change in yellow length, so the after-phase was abandoned for the present.

The movies were taken from an aerial lift truck such as used for utility service work. From a previous field inspection, it was decided to calibrate the intersection leg as shown in Figure 7, 50' from the centerline of the crossroad plus nine intervals at 25' plus a 44' speed trap and take photos in the late afternoon (high volume period). An approximate 6" by 2' white spray paint mark was used. One edge was marked on the curb and the other was marked in the gutter. Several weeks elapsed between calibrating the intersection leg and taking the pictures, so an appreciable problem developed with dirt washing onto the marks from frequent rains. This was particularly true of the lines in the gutter.

During the cycles that the films were being taken a classified vehicle, count by cycle was also recorded by observers on the ground. The cycle identification was coordinated by a flag signal from the camera operator. The date, time, reel number, and number of cycles taken were recorded on the film by an information sheet held in front of the camera at the start of each reel. Photos of 74 cycles were taken from 3:00 to 4:30 P.M. on a weekday afternoon. The operator timed the start of the camera by the signal cycle length. That is, he would start the camera just before the anticipated start of yellow and run it until one or two seconds after the start of red. A typical field data sheet is shown in Figure 8, and an aerial view and data camera view of the intersection calibrated leg is shown in Figures 9 and 10.



N
M-53
16 Mile Rd.
16 Mile Rd.
50'
Selected Stop Point
9 Spaces at 25'ea. = 225'
44' Trap
M-53
FIELD STUDY LOCATION
(M-53 at 16 Mile Rd.)
Date 2-29-'68 Drawn By W C G

Figure 7

Yellow Interval Test Tally Sheet

Sh ________ of ________ Date ____________________

Location ____

Recorder ____

Leg Counted ____

Time at Start of Test ________________ Time at End of Test ________________

Signal Cycle	Veh. Thru		Veh. Caught	Signal Cycle	Veh. Thru		Veh. Caught	Signal Cycle	Veh. Thru		Veh. Caught
	P	C			P	C			P	C	
1				31				61			
2				32				62			
3				33				63			
4				34				64			
5				35				65			
6				36				66			
7				37				67			
8				38				68			
9				39				69			
10				40				70			
11				41				71			
12				42				72			
13				43				73			
14				44				74			
15				45				75			
16				46				76			
17				47				77			
18				48				78			
19				49				79			
20				50				80			
21				51				81			
22				52				82			
23				53				83			
24				54				84			
25				55				85			
26				56				86			
27				57				87			
28				58				88			
29				59				89			
30				60				90			

FIG. 8 - FIELD DATA SHEET.

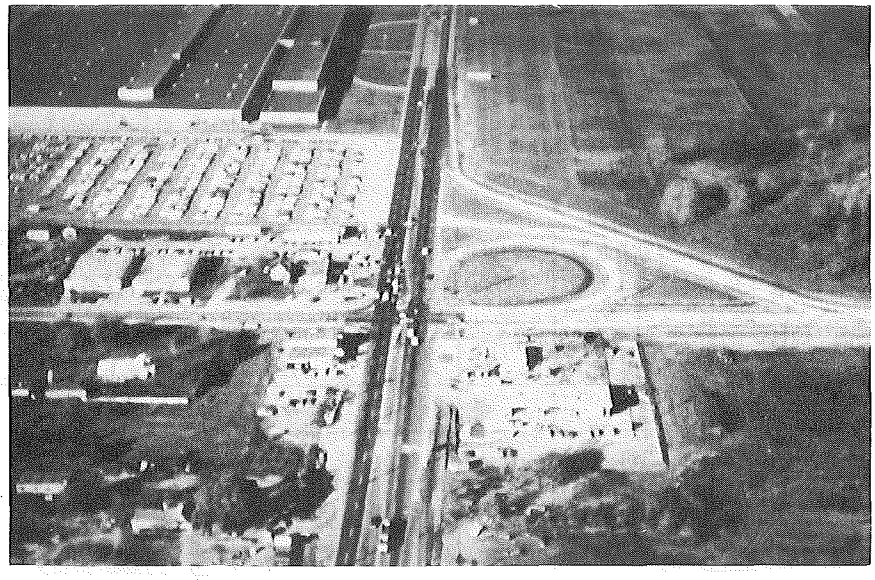


Figure 9. Aerial View of Study Location

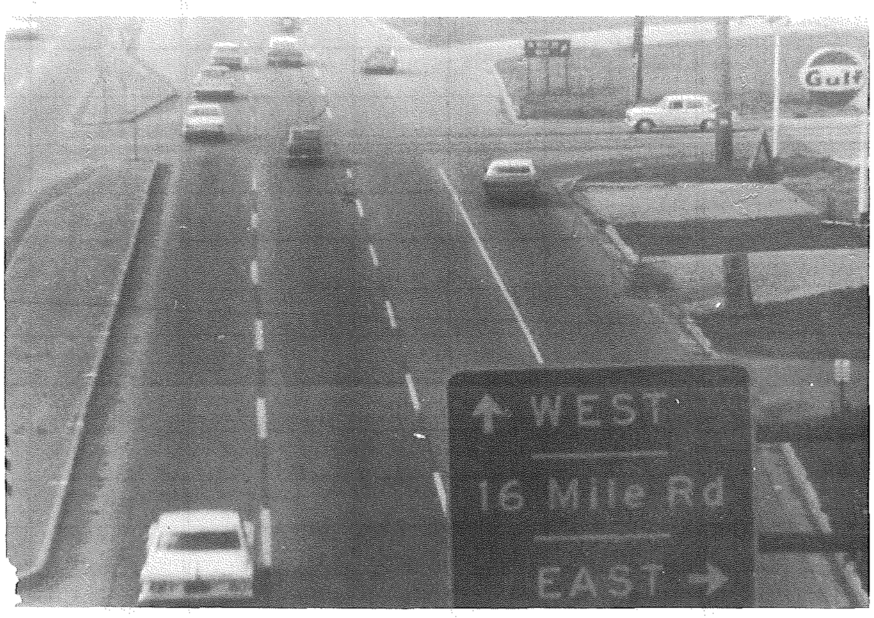


Figure 10. Data Camera View of Calibrated Leg

DATA TAKEOFF SHEET

CS # ____________

Location ____________ Date of Film Take ________ Reel # ______ CS Loc. ____________

Data Recorders ____________ Date of Data TakeOff ________ SH ______ of ________

Distance Ref. Point System ____________ ____________

Film Speed ____________ Signal Cycle & Split ____________ ____________

Cycle #	Veh. #	Veh. Ident.	# in Line	Veh. Type		Frs. in 44' Trap	App. Vel. Ft/Sec.	Fr. to Start of Yel.	Dist. Start of Yel.	Fr. to Start Brk.Lt.	Percep-React. Time	Dist. Start Brk.Lt.	Dist. End Brk.Lt.	Dist. Veh.Stop Point	Fr. to Veh.Stop Point	Dist. Start of Red	Veh. Action														
				P	C												Stop	Go	250	225	200	175	150	125	100	75	50	25	0	-25	-50

FIGURE 11

FILM DATA TAKEOFF

The data takeoff system was similar to the other researchers (Forbes[6]) except that the grid was laid out by use of threads held by gummed tape and aligned by laying onto a projected picture. Measurements for the most part were referenced by use of the lower edge of the rear bumper as recommended by Forbes.[6] In some cases, it was necessary, particularly in counting frames in the speed trap close to the start of yellow, to use other points on the vehicle for that measurement only. For distance from the centerline of intersection at start of yellow, it was necessary to estimate and interpolate or exterpolate between the 25' lines or beyond the calibrated area. An accuracy closer than ± 5' cannot be expected in some of these estimates.

From a few trial checks, it was decided that it was not practical with the location estimating and small counts between calibrations to try to measure deceleration rates by counting frames. It was believed that the configuration of the changing velocity curve was not important to the objective of the study, and average deceleration rates could be calculated if necessary from more accurate and readily available measurements.

For the sake of data identification, it was found very desirable to have a film observer that was familiar with make and style of all late model vehicles.

A sample of the film data takeoff form is shown in Figure 11.

ANALYSIS AND COMPARISON OF DATA

A) Speed and Volume

Figure 12 is a plot of the arrival volume per cycle on the motion picture study location calibrated approach. At times a traffic backup occurred and the observer counted or estimated the number of vehicles in the queue that were caught by the red indication. These are plotted near the lower edge of the graph and give a clue to the capacity of the lanes under the prevailing conditions at this intersection.

The vehicle approach speed tally (Figure 13) indicates the wide variety of speeds that need to be accommodated by the signal yellow length. Since the practice in setting speed zones is to assume that the 85th percentile speed represents the public's belief in what is a safe and prudent speed, and our cumulative distribution curve of perception-reaction time breaks at that area, we propose to use the 85th percentile as a suitable design speed in calculating yellow interval length.

B) Perception-Reaction Time

Figure 14 shows a distribution of first-in-line driver's perception-reaction times as measured by counting 15 frames-per-second pictures from the start of yellow to

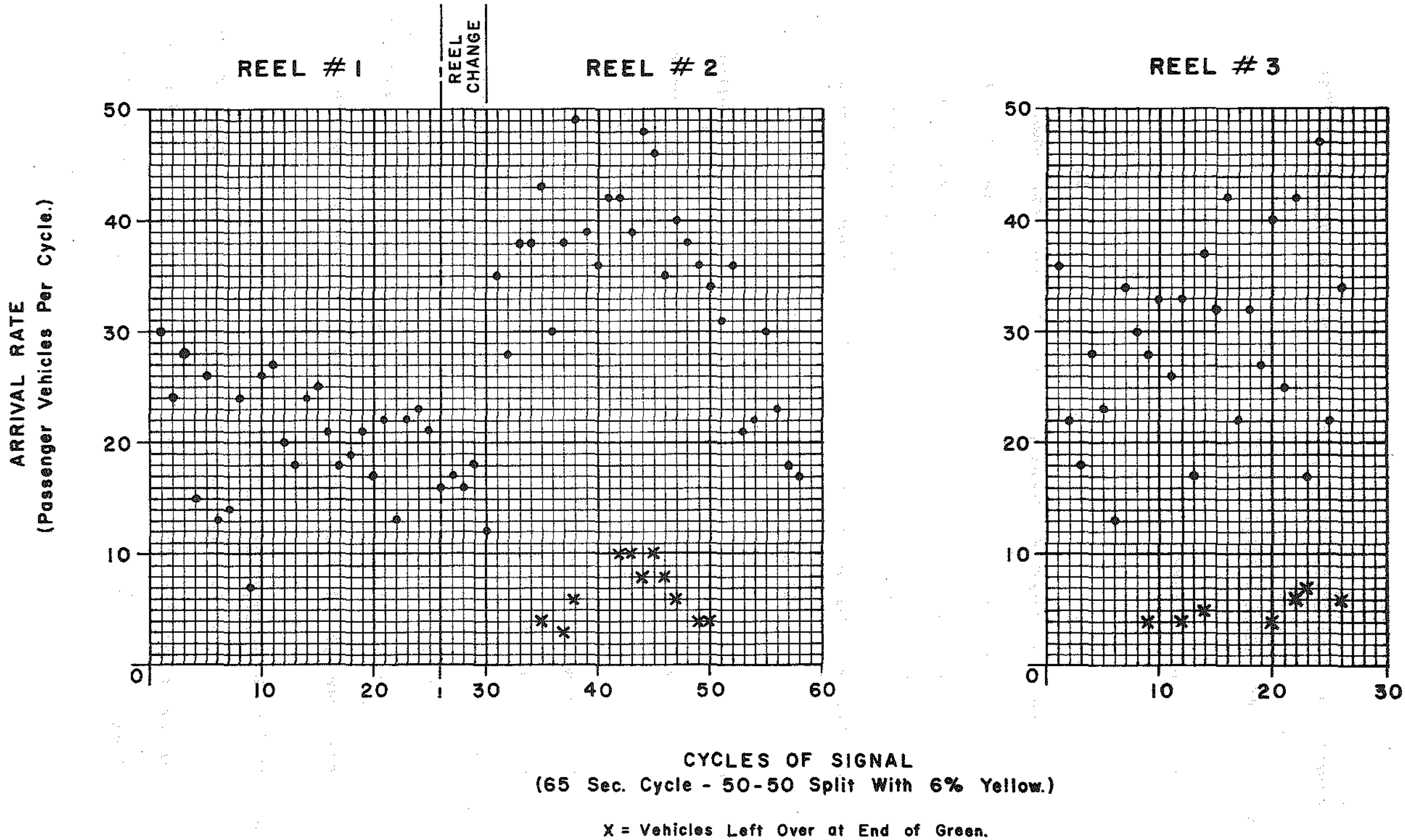


Figure 12. - VEHICLE ARRIVAL RATE. - M-53 (Van Dyke Rd.) at 16 Mile Rd. - Wed. Afternoon 6-7-67.

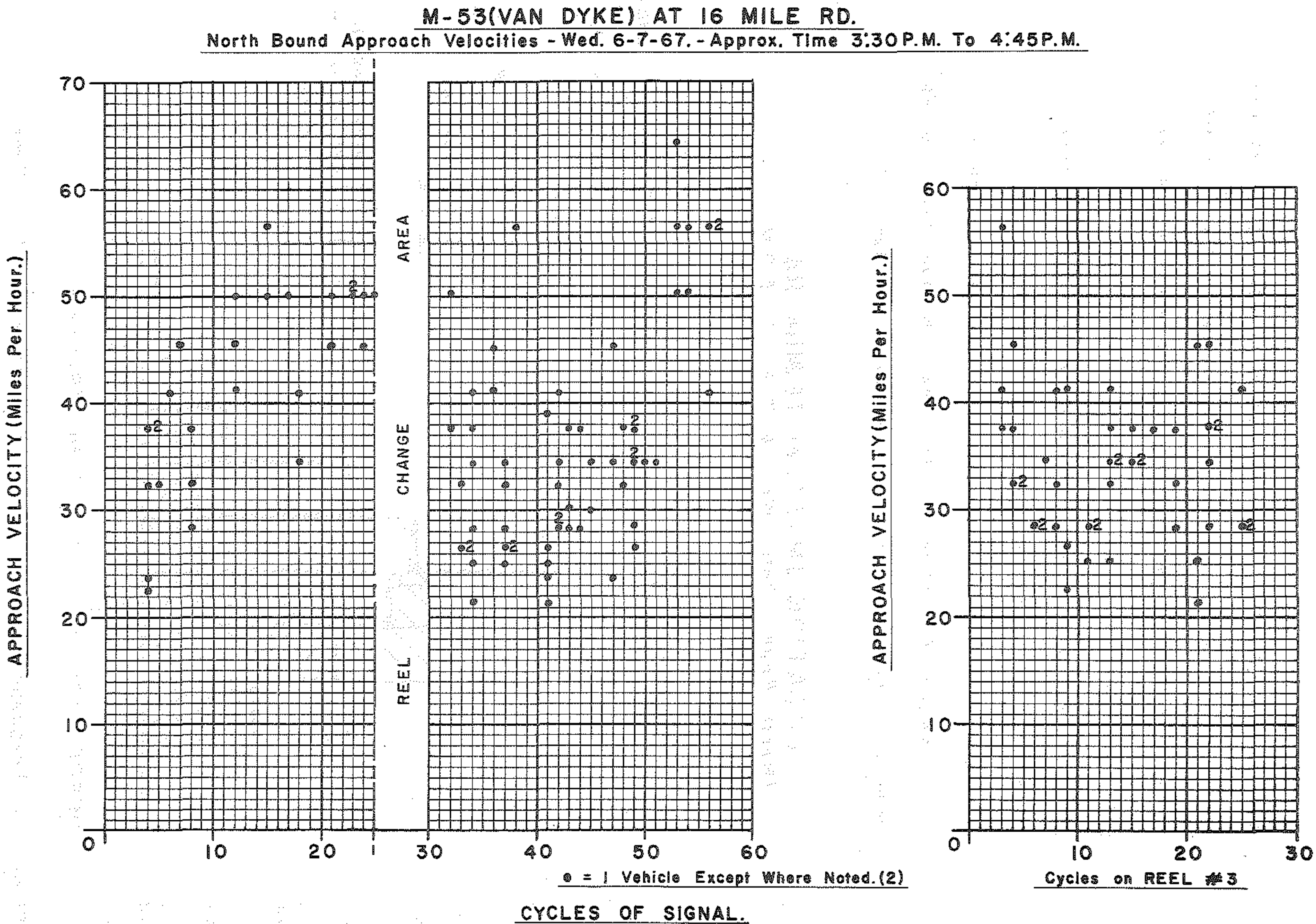


Figure 13 - Vehicle Approach Speed Tally.

the start of brake light indication. Also shown is the distribution of 87 samples taken in the Gazis[7] study. By the analysis shown in Appendix IV, we conclude that they are statistically similar enough so they can be combined and a mean and standard deviation calculated for use in selecting a mean perception-reaction time if the mean were to be chosen as a design value. These latter values are shown by the heavy broken lines on the combined frequency distribution shown in Figure 14.

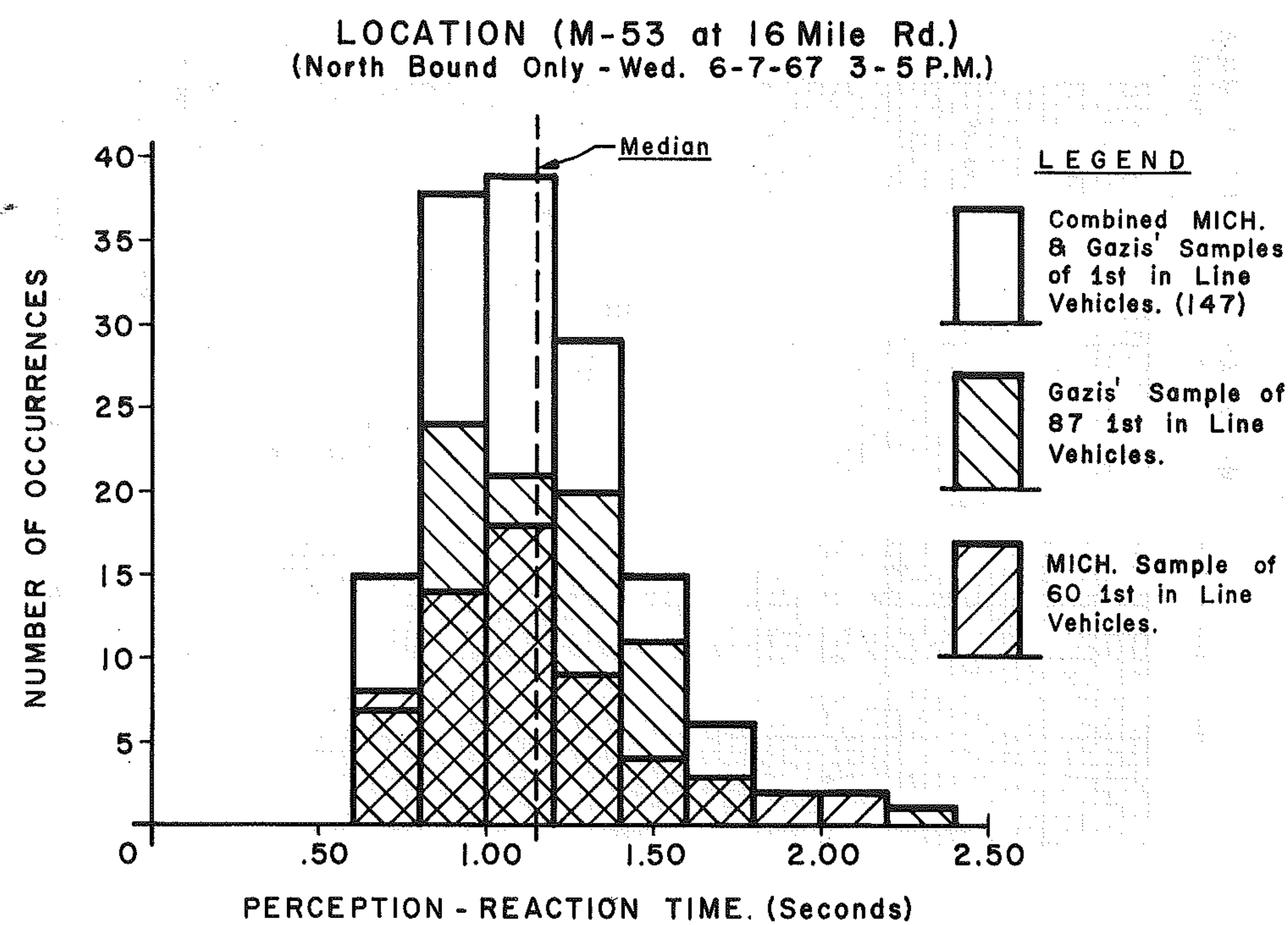


Figure 14. Frequency Distribution of Perception-Reaction Time Calculated From Film Data.

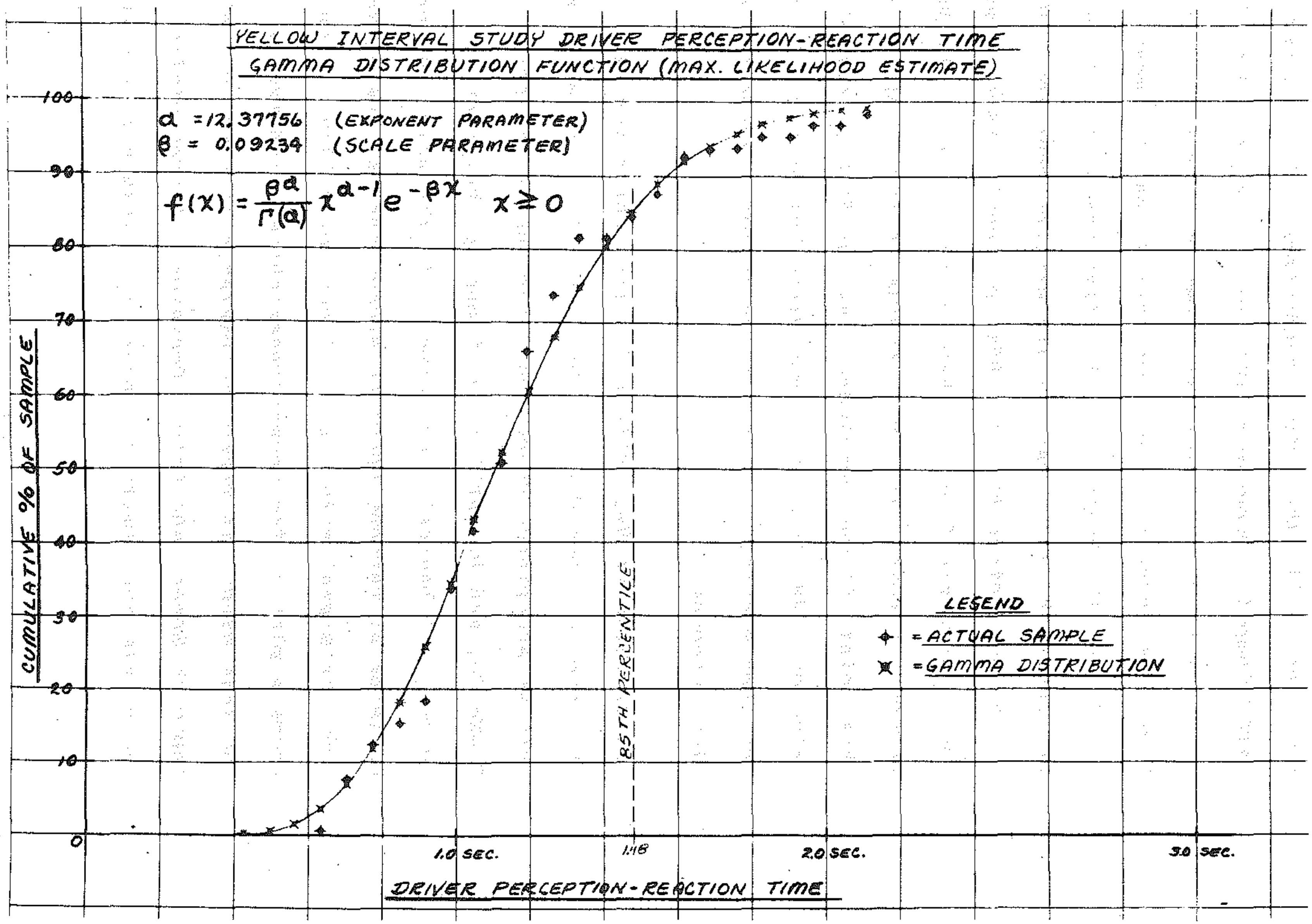


Figure 15. Gamma Cumulative Distribution (Michigan Sample)

The shape of the frequency distribution led to the conclusion that some type of gamma distribution curve would more nearly fit the actual conditions. Such a study (MDSH Computer Program #16059) was run on the data from the film study and the curve shown on Figure 15 resulted. From this curve it is obvious that to use the mean (1.14±) of the Gazis[7] or Michigan sample for design would not cover the major part of the samples behavior. Going on the assumption that the 85th percentile used in speed zone design and from the shape of the curve at the 85th percentile point, the curve starts to break rapidly at this point, it was concluded that the 85th percentile value of 1.48± from the gamma distribution would be the best representation of the driver's performance for design purposes.

C) <u>Driver Decision Vs. Vehicle Position Characteristics</u>

This area of consideration has been listed by other names, such as Acceptance-Rejection, Stopping-Not Stopping, Go-No-Go, and Probability of Stopping, but they are, of course, all basically concerned with the actual driver decision at various approach speeds and various distances from the signal with a given length of yellow. Figure 17 shows a plot of two recent researchers' findings (A. May[9] and this study) in regard to Distance at Start of Yellow; Approach Speed; and Driver Decision. A presentation of the points and limits of spread of points near a visually

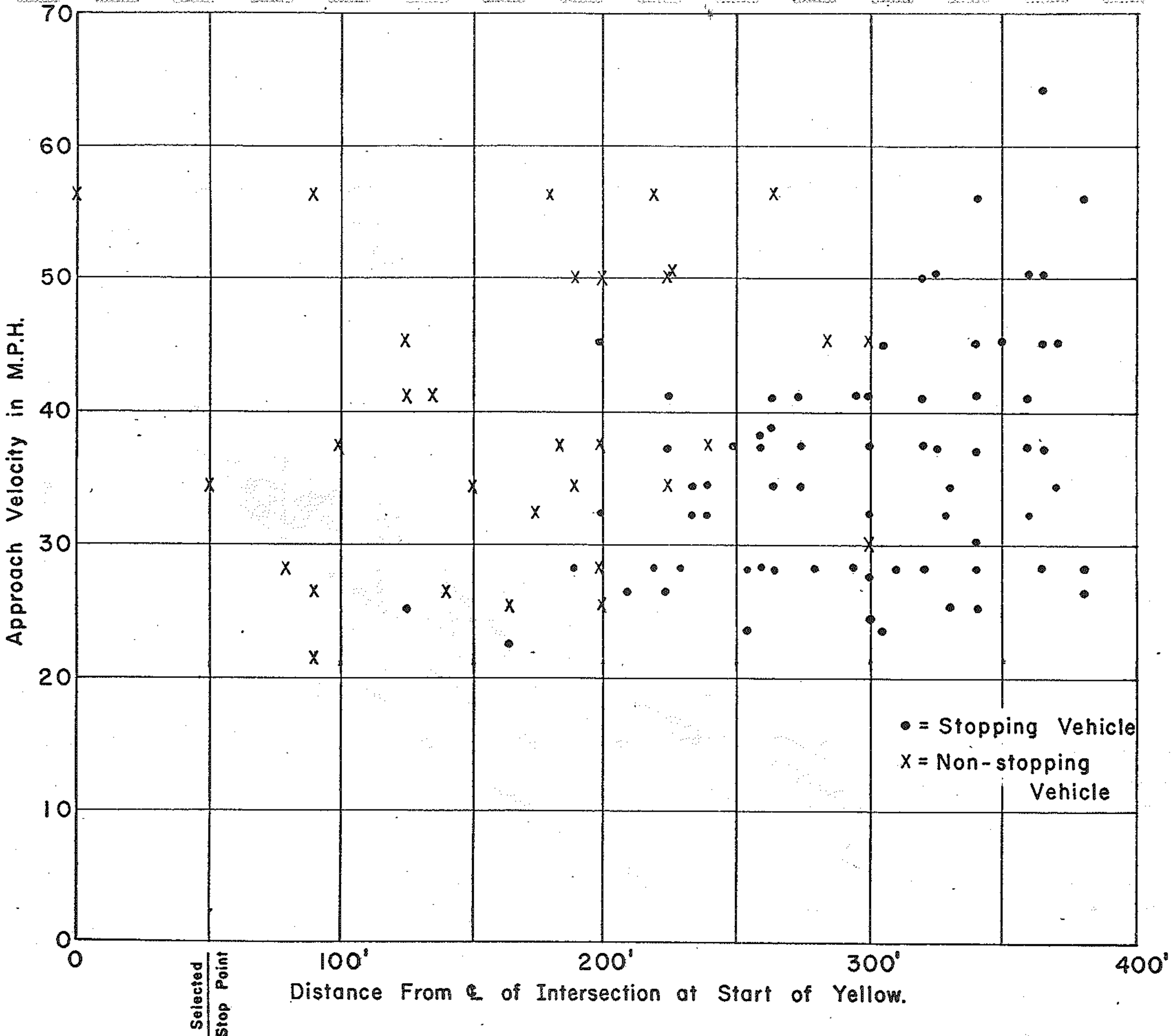


Fig. 16 Velocity & Vehicle Location at Start of Yellow.

From Film Data Taken at M-53 & 16 Mile Rd.

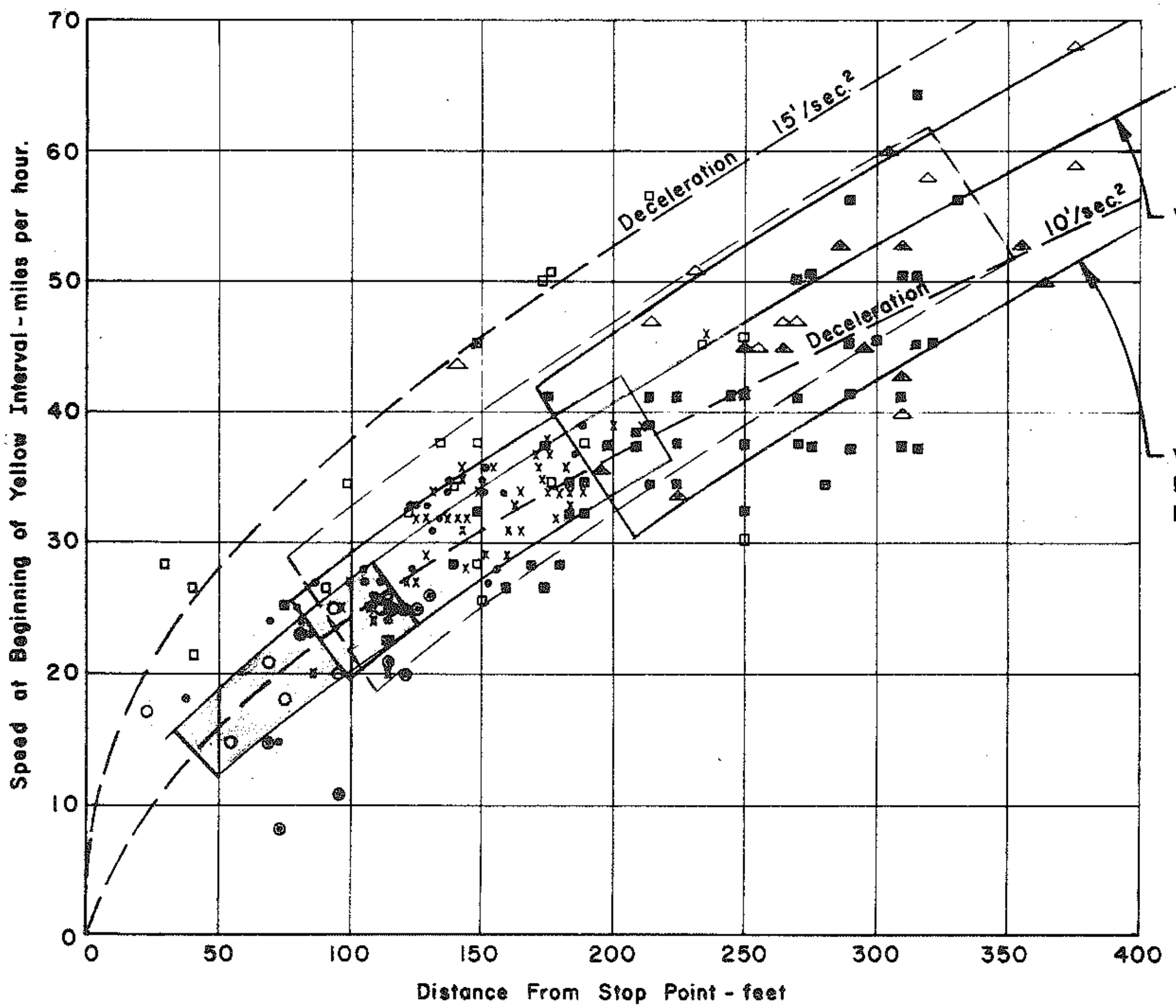


Figure 17 - Velocity & Vehicle Location at Start of Yellow Interval.

fitted split line between Stopping and Not Stopping vehicles is also shown in Figure 17. It is in the position of the split line and the limits of spread that the author believes the critical information regarding optimum length of yellow may be contained.

Figure 18 also shows the actual perception-reaction times found from the films plotted onto the Distance Velocity Acceptance Rejection data of the May Report[9] (a controlled pre-selected driver study) for the five second yellow at an urban intersection. From this plot, it is evident that the one second perception-reaction time assumed by a deceleration rate of $15'/sec^2$ would not be realistic for actual engineering practice in calculating the length of yellow interval.

Similar plots could be made from the work of Webster,[8] the controlled British study, and Gazis,[7] a random driver study, by values calculated from their taken data; however, for the purpose of this project, it was not considered necessary at this time.

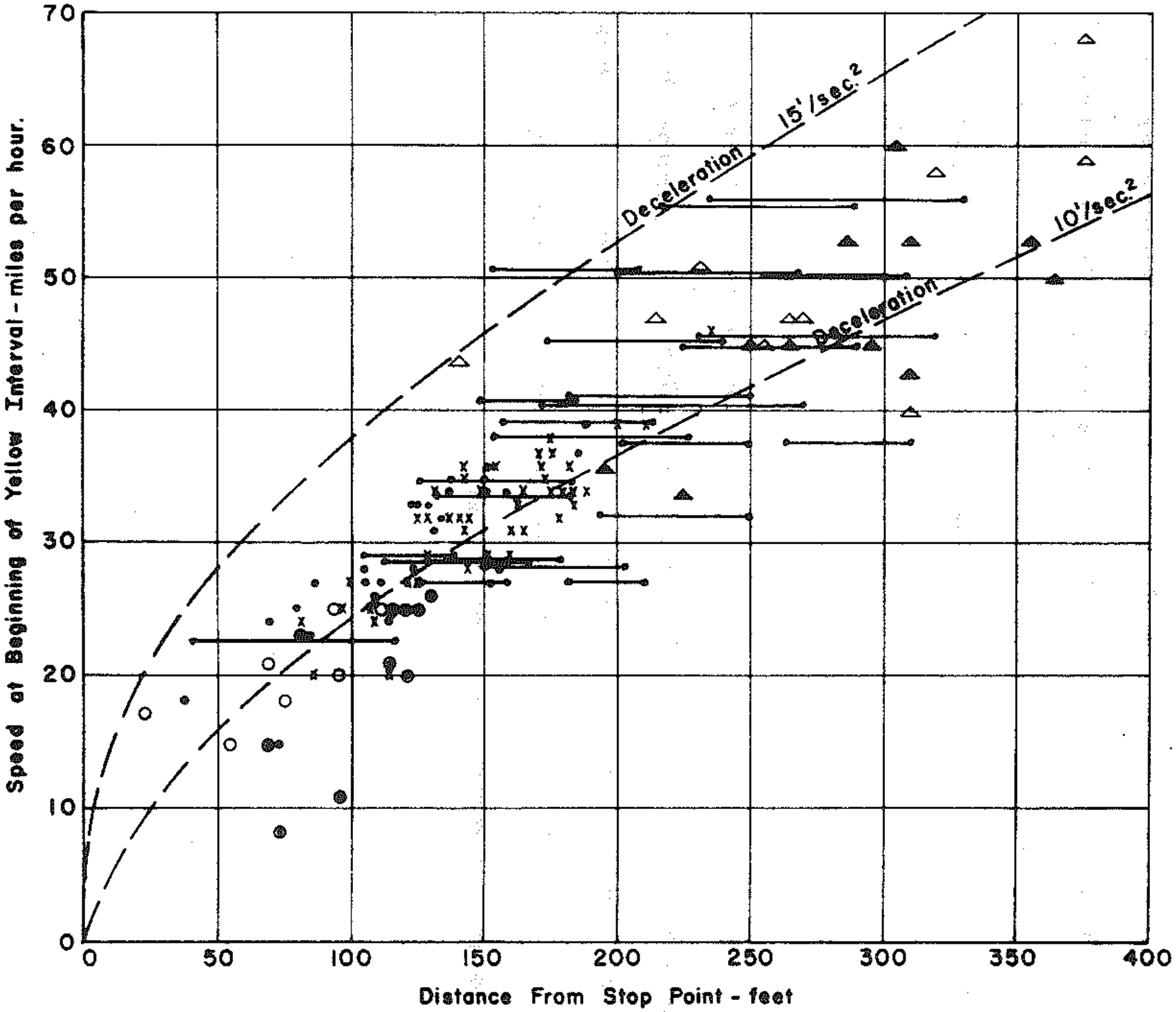


Figure 18 - Sample Perception-Reaction Distances Plotted Upon Distance-Velocity Graph. (Vehicle Acceptance & Rejection of Yellow Interval Points are Also Shown.)

LEGEND

* 5 Sec. Yellow Interval
● = Stopping Vehicle.
X = Non-Stopping Vehicle.

* 3 Sec. Yellow Interval.
○ = Stopping Vehicle.
● = Non-Stopping Vehicle.

* 7 Sec. Yellow Interval.
△ = Stopping Vehicle.
▲ = Non-Stopping Vehicle.

•—• = Perception-Reaction Dist.

* Ref. - Partial re-plot of points in Figures 14a, 14b and 15b from Final Report "STUDY OF CLEARANCE INTERVAL AT TRAFFIC SIGNALS". By Adolf D. May, Jr., I.T.T.E., Univ. of Calif., Jan. 1968.

D) Deceleration Rates

A cumulative distribution of deceleration rates for the motion picture study calculated from the distance at start of yellow and the measured perception-reaction time is shown in Figure 19. It is evident from the mean and 85th percentile that the 15'/sec^2 now used as an acceptable average for calculation of yellow length is considerably higher than actually exists with free choice by the driver. The substitution of the 85th percentile value in the ITE Handbook[1] formula would, of course, modify the results to more nearly fall in line with the present modifications used in Michigan in selecting yellow interval length.

TRAFFIC CONFLICT TECHNIQUE APPLICATION

After Messrs. Harris and Perkins[10] expanded and standardized the method of measuring traffic conflicts by field observation, it appeared that some useful correlation might be obtained by use of their system. However, there were so many variables influencing the results and volumes varied so greatly that it was difficult to find already available data that showed any tendency toward correlation of results with length of yellow interval.

If some greater extremes of length of yellow can be found at representative intersections at a future date, this type of field study should logically be taken to check for any measurable tendencies.

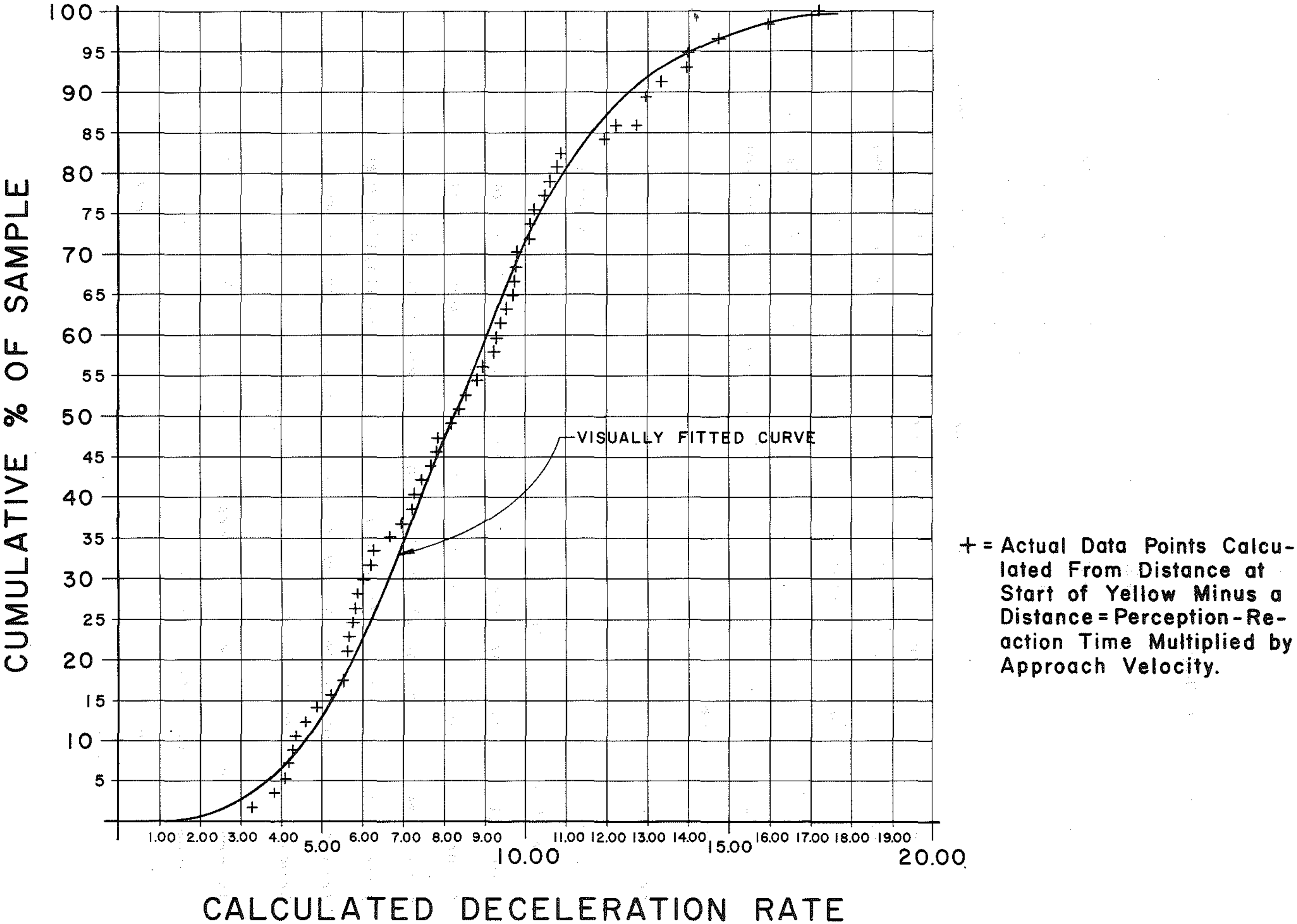


Figure 19. Cumulative Distribution of Deceleration Rates Calculated From Motion Picture Data Taken at the Intersection of M-53 (Van Dyke Rd.) at 16 Mile Rd.

COMMERCIAL TRAFFIC CONSIDERATIONS

The District Traffic Engineers indicated in discussion that they had observed flagrant violation of the beginning of the red by trucks. Also, as indicated in Figure 2, at least one state provides a slightly longer yellow for locations carrying larger volumes of longer trucks and other commercial vehicles. Since this limited research necessitated spending time on only the most pertinent items, a small check was made to see if trucks were actually involved in accidents out of proportion to their percentage in the traffic streams. A study of two locations, one low speed and one suburban, where collision diagrams indicated a larger percentage involvement than percentage commercial showed that there were a few accidents where the fact that the vehicle was a truck might have influenced the occurrence of an accident. However, this was not consistent along the same route even for a few nearby signalized intersections along the same route. Also, the type of accident, as indicated by the collision report statements, seemed to be of the vision obstruction, confusion, or mechanical defect type rather than a commercial vehicle running the red light.

On this basis, it was decided to defer further study of the truck influence on needed yellow length at this time.

OBSERVATIONS AT AN INTERSECTION WITH A SHORT YELLOW ON THE CROSSROAD - US-12 (MICHIGAN AVENUE) AT MILLER ROAD IN WAYNE COUNTY

The study at this location was limited to visual appraisal because it was felt by the study engineer that there was too great a personal hazard to the motion picture technician to operate in the vicinity of the high tension lines which existed on both sides of both legs of the crossroad. Also, the traffic volumes were sufficiently low on the crossroad so that a vehicle was in position to use the yellow indication only about every 15 cycles of the signal. Thus, it would have required an unreasonable time and film footage to get a statistically sound volume of data.

At this location at the time of observation, there was a 60 second cycle with a 70-30 split and a 2.4 second yellow on the crossroad.

The most noteworthy observation at this location was that the short yellow caused crossroad vehicles to sometimes violate after the main line vehicles at the head of the line had started. This, of course, caused a panic stop for the main line vehicle at a time when following vehicles least expected it. It is obvious by basic physics, considering following driver perception-reaction time, that sometimes there would be a rear end collision back in the line. The fact that the major part of the rear end type accidents were one pair of vehicles rather than multiple accidents would tend to bear out the hypothesis that this phenomenon was a factor in the excessive rear end accident experience at this location.

A subsequent observation at this location by the same observer after lengthening the crossroad yellow to 4.2 seconds revealed at least three incidents in one-half hour in which the delay in start of the main line traffic prevented the above-described "false start" phenomenon.

DISCUSSION WITH OTHER OBSERVERS

Discussions with experienced drivers and observers was used as time would permit. There were two things that had general agreement. The first, and often mentioned spontaneously, was the need for a distance reference aid. In fact, several Department employees who were regular commuters from out of town indicated that they had developed their own distance reference aid. That is, if they were nearer than a certain sign or post at the start of yellow at the usual prevailing speed, they could expect to get through the signal before it turned red. If not, they would prepare to stop. Most of those interviewed indicated the need for more advance information than the yellow alone, but they were not sure just what. The many attempts to develop devices, such as the count down signal, bears out the universal feeling of need, but not necessarily the solution. It is the author's firm belief that a distance reference or judging aid should be the direction to pursue in seeking an improvement for the driver. As mentioned previously, the basic decision that the driver must make is time to go through or distance to stop. It is not a question of time alone because if the decision is made to stop, part of the red time can be used for stopping.

The second major item that was gleaned from discussion was that drivers, even strangers in an area, seldom miss a signal at night. On this basis, considering the scarcity of available time and manpower, it was decided not to try to quantify the problem, if any, caused by difference in distance judging ability of the driver at night and in the daytime. Apparently, the reduction in ambient light gives the signal sufficient added visibility to make up for any loss in visible reference aids.

A theoretical analysis by someone well versed and experienced in driver capabilities, in distance judging and decision-making, as the choices approach equal and increase in number and complexity, might find an explanation for and be able to quantify some more of the variables in driver use of the yellow interval. This is an area of research which the author believes would merit some time by a university study team.

It would also seem reasonable to calculate and incorporate minor revisions to the policy to take care of approach grade and large percentages of commercial traffic. Quantifying and developing warrants for these factors would be difficult and of questionable value since correction for downgrade on one side would add error for upgrade vehicles. It would seem that this correction, if used, should be included in an all red interval. However, from recent studies, it appears that all red intervals tend to encourage left turn violations with consequent increase in head-on, left-turn type accidents.

THE DELAYED YELLOW AT A DIVIDED CROSSROAD

The accompanying Figure 20 shows the time vs. width of median relationship presented to the main line driver using a delayed yellow set by latest Michigan practice. There is some possibility that a minimum length of green on the far signal should be provided so the driver can readily identify that it is that type of installation. This is the type of item that would require ironclad consistency in practice to aid the driver in identifying and using the facility.

Further research has been suggested on the sequence and dwell of driver eye movements in the use of the delayed yellow. The object would be to design to cause less confusion to the driver by the far side green. This confusion is believed to cause near side violations. Such research would be difficult, if not impossible, by present known methods, and is certainly beyond the scope of this study.

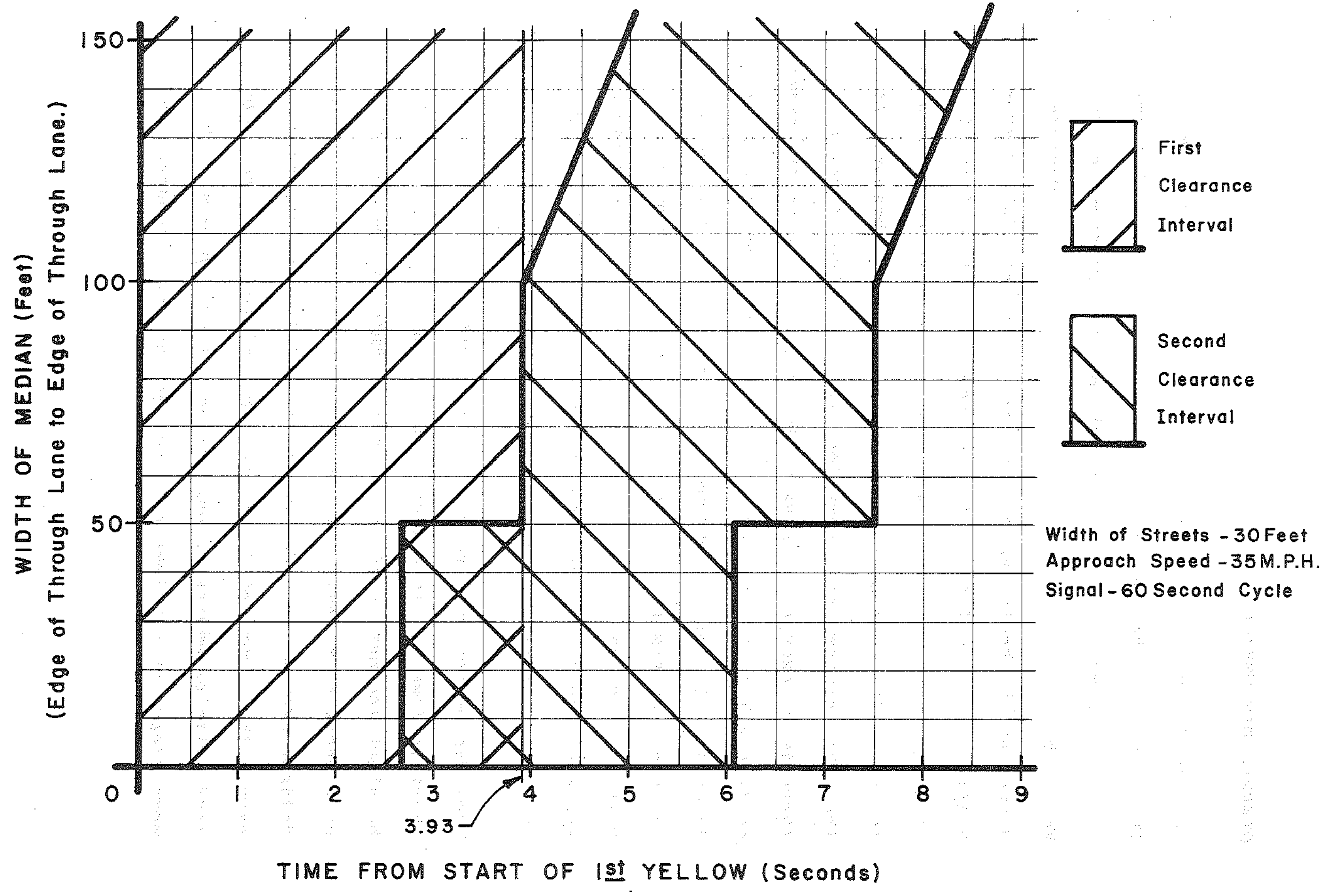


Figure 20 - Typical Delayed Clearance for Divided Highways.
(Using M.D.S.H. Policy.)

GENERAL DISCUSSION

In considering the effects of longer or shorter yellows on the driver, it becomes evident that as the yellow shortens, a greater responsibility is placed on the crossroad driver. Where there is no yellow, it is obvious that the crossroad driver at the beginning of his green must take full responsibility for the safety in the intersection since it is ridiculous to think that there would be no vehicles entering after the red. The consequences of his failure are obvious. At the other extreme with very long yellows, theoretically, there is no excuse for a main line driver to be in the intersection after the red, and, therefore, the crossroad driver theoretically has no responsibility regarding free use of the start of his green. What is a reasonable compromise between these extremes is, of course, difficult to measure and may actually be dictated by the wording of the law or the capabilities and habits of the human being.

From discussion with people who have driven in areas with short yellows, it is obvious that the driver is forced to be alert and make a quick decision. This may be desirable on a short term basis, but would certainly add to the tension fatigue over an extended period of driving and one would expect the errors of judgment to be greater. On the other hand, with excessively long yellows, there appears to be more sloppy or careless decision making and a tendency to "use" the excess over that required to make a simple decision of go or not-go. The last mentioned items appear to be a likely cause for experience, indicating that a short all red interval is preferable to an excessively long yellow.

There is one item, at least, that can be said for the long yellow, and that is, that it helps to clear left turns. Often with the increasing capacity problems, one of the big problem factors is left turn backups. While it is true that the all red would serve the same function, it has the great disadvantage that the left turn driver does not know when it ends. With the yellow, the left turning driver knows when he is no longer safe or legal in the intersection.

In regard to the earlier mentioned stress, decision judgment factors of the human, it is reasonable to presume that somewhere in the space science field, there is applicable information concerning human capabilities in these areas. One logical further research would be to seek out or develop this information.

SUGGESTED FURTHER RESEARCH

There are, of course, many details that it would be desirable to quantify in developing the optimum length of yellow interval; however, it is the author's belief that the following are the areas of greatest need for research to establish standards and aid the driver in the use of the yellow interval:

1. A study into desirability of placing more or less responsibility on the crossroad (stopped) driver.
2. More extensive investigation into the split and mix areas between go and not-go drivers for various approach conditions at the start of yellow for isolated signals and for signals in and out of progression in a system.*
3. Distance and time judging capabilities of the driver under dynamic conditions.
4. Tolerable and desirable minimum limits of visual stimulus from the signal.
5. Eye leading techniques to aid the signal visibility.
6. Development of distance judging aids.
7. Development of time judging aids.
8. Need for and type of time modifications for different volumes of truck and other commercial traffic.
9. Use of yellow and all-red intervals by left turning vehicles.

*The development of a probability model for the split and mixed areas should be undertaken. This model, whose development will require some further field investigations, would provide two very basic building blocks for the selection of an optimum yellow interval given an isolated intersection or adoption of a national standard.

First, with proper documentation, the practicing engineer could use this model to make quantitative judgment on the operation of a yellow interval from a much smaller sample than is possible without such a model.

Second, it would allow the future researcher who is planning a major study in which he intends to observe traffic behavior to intelligently select the size of the sample. Since accurate observations will be expensive, this will be an important decision.

Both of the building blocks should lead to considerable financial return, if applied. Hopefully, a non-parametric model specifically designed for testing this problem would not be difficult to construct or understand.

ACKNOWLEDGMENTS

The author would like to acknowledge with appreciation the use of material from other researchers, particularly Dr. B. D. Greenshields, Dr. T. W. Forbes, Dr. A. D. May, Richard Rothery, D. Gazis and Paul L. Connly whose publications and methods served as reference and guide in planning and carrying out this study. We wish to thank Messrs. J. I. Harris and S. R. Perkins of General Motors Research Laboratories for the consideration of data from their standardized conflict study technique.

Appreciation is also extended to Mr. Frank DeRose, Jr. formerly Engineer of Traffic Research, under whose supervision this project was put in motion. Special appreciation is extended for the cooperation of the Department's personnel, particularly Mr. C. F. Conley for statistical recommendations, Mr. G. E. Wensloff for discussion and original promotion of the project, Mr. H. R. Schoepke for photographic work, Mr. W. C. Grams for preparation of the many graphs, and Mr. N. Bunker, Department Librarian for excellent service in supplying reference and bibliography material.

APPENDIX I

Sequence of events in driver perception and decision making in connection with Yellow Interval Length

1) Detect presence of signal

2) Detect color of signal

*3) Estimate time of change to yellow

*4) Estimate time remaining on yellow

*5) Estimate braking distance at driven speed

*6) Estimate time to clear intersection far enough so starting or moving vehicle on other legs will not contact

7) Estimate discomfort if stop is made

8) Estimate effects of action on others

*9) Decide on action

10) Take action

11) Reappraise all factors

* Items most likely to be in error by driver.

Factors influencing errors in connection with "items most likely to be in error by driver" listed above.

Item (3) Estimate time of change to yellow

a) Short or long term conditioning of driver to non-expressway driving and signal operation

b) Driver familiarity with the specific location

c) Visibility distance of signal

Item (4) Estimate time remaining on yellow

a) Conditioning - same as (3a)

b) Familiarity - same as (3b)

c) When yellow was detected or how long since previous scrutiny of the signal

Item (5) Estimate braking distance at driven speed

a) Conditioning - same as (3a)

b) Familiarity - same as (3b)

c) Type and Condition of surface

d) Knowledge of vehicle characteristics

e) Human capability for distance estimating

f) Availability of estimating aids and cues

Item (6) Estimate time to clear intersection

a) Conditioning - same as (3a)

b) Familiarity - same as (3b)

c) Initial Velocity

d) Knowledge of vehicle accelerating ability

e) Actions of or presence of inhibiting traffic

APPENDIX II

Some desired research information on driver needs, capabilities and behavior in connection with yellow signal interval length and basic problem study.

1. Any benefit from acceptable eye leading methods toward the yellow lens? Is size of lens adequate for distance at higher speeds? Would rapid flashing light be better or worse for eye leading or attention getting?
2. Any shape difference needed from other lenses to help the color blind?
3. How frequently does an urban and rural driver monitor the signal head for indication?
   What effect does frequency and uniformity of yellow interval have on actions before or during yellow interval?
4. Would rapid flashing light give time reference aid to the driver?
   Importance of uniform time and intensity of eye stimulus by yellow interval.
5. How good is driver at estimating braking distances?
   What aid does he use in estimating braking distances?
   Depth perception error as speed increases and distance increases.
   Stop point reference aids.
6. Street width estimating reference aids.
   Effects of clear vision and distractions on estimating.

Possible distance and time estimating aids.

7. Variance in people's idea of discomfort.

   Is driver's choice a straight line deceleration?

8. How many cars are following too close at various points in the sequence?

   Possible reference aids on back of leading vehicle and quantitative effect of each.

9. How does driver tension change with reduction in cues and input information?

   Magnitude and frequency of driver errors as cues such as signal size, distance, reference aids, etc., are changed.

10. What driver action (stop or go) is easiest and quickest?

    Which action (stop or go) does driver choose when all other things are equal?

    Does pre-warning make a difference in choice of action?

APPENDIX III

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

YELLOW CLEARANCE INTERVALS
for
SIGNALIZED INTERSECTIONS

January 1, 1967

Based on Approach Speeds and Street Widths

Electrical Devices Unit, Traffic Division

Approach Speed (MPH)	Time to Stop (1.2Y) (SEC.)	Time to Stop or Clear to Center of Intersection (W=width of St. in ft.) (T in Sec.)						
		W=30	W=40	W=50	W=60	W=70	W=80	W=90
25	2.66	3.61	3.75	3.89	4.02	4.16	4.29	4.43
30	2.96	3.76	3.87	3.98	4.10]	4.21	4.32	4.44
35	3.25	3.93	4.03	4.13	4.22	4.32	4.42	4.52
40	3.56	4.16	4.24	4.33	4.41	4.50	4.58	4.66
45	3.85	4.38	4.46	4.53	4.61	4.68	4.76	4.83
50	4.15	4.63	4.70	4.76	4.83	4.90	4.97	5.04
55	4.45	4.88	4.95	5.01	5.07	5.13	5.19	5.26
60	4.72	5.12	5.17	5.23	5.29	5.35	5.40	5.46

The above charted values are based on the third edition of the Traffic Engineering Handbook article on "Yellow Intervals", pages 407,408, with the exception of two concepts as follows:

1. Instead of using the minimum time to stop defined as Y and equal to t+V/2a, a more comfortable stopping rate was used (in the interest of rear-end-type accidents) by applying a factor of 1.2 to Y or using 1.2Y for time to stop.

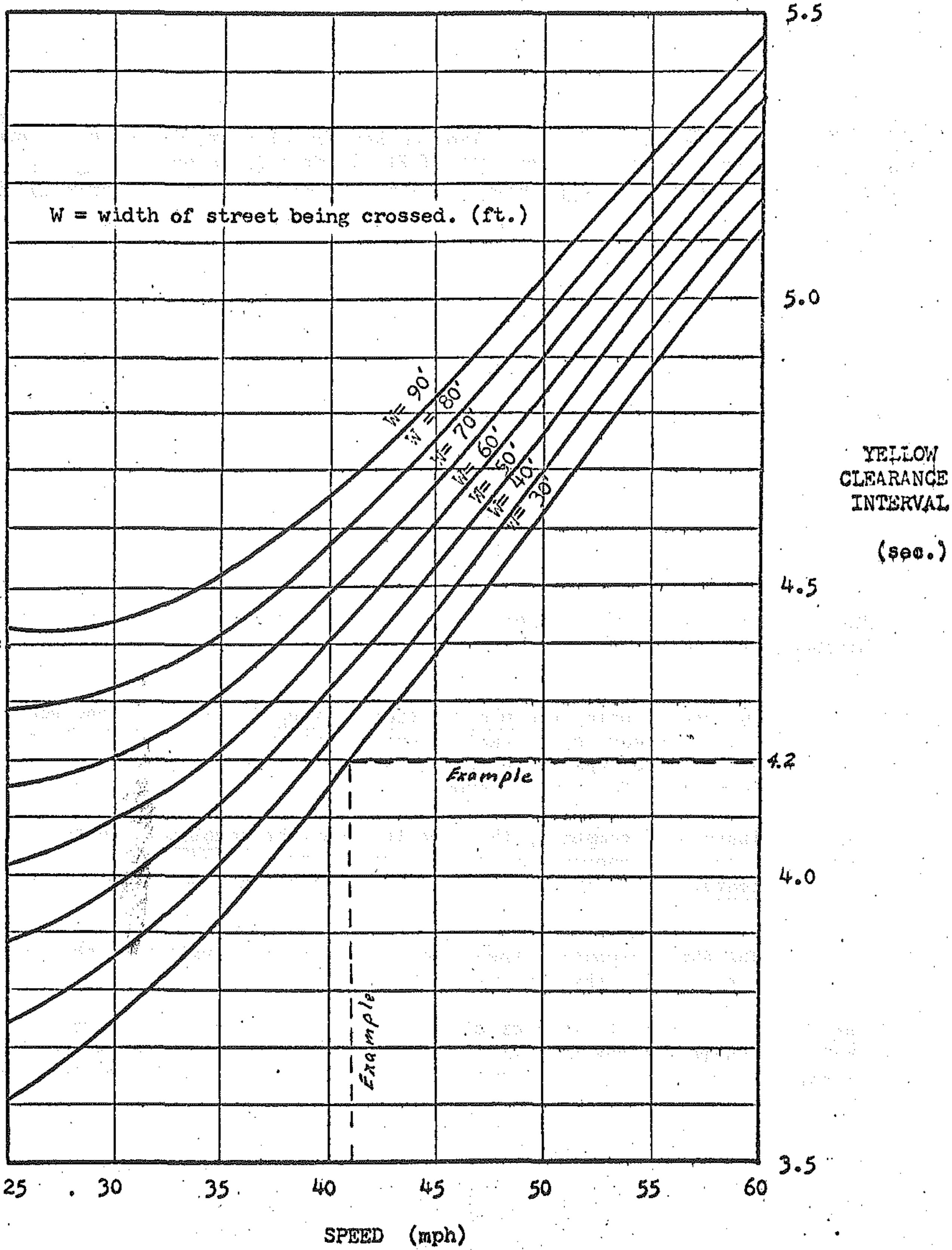
2. Instead of computing the time to clear the complete intersection at a constant approach speed, the above chart is computed to clear the center of the intersection, which changes the book value of (W+L)/v to (W/2+L)/v.

3. The 85th percentile speed, or if this is not available, the posted speed limit, shall be used with the chart.

The formula for time to stop or clear center of intersection becomes T=1.2(t+V/2a)+(W/2+L)/v where t=1=reaction time in seconds, W=width in ft. of street being crossed, L=length of vehicle=20 ft., V and v=velocity in ft/sec, and*a=deceleration in ft/sec/sec.

*In Handbook a= 15'/sec^2

MICHIGAN DEPARTMENT OF STATE HIGHWAYS
YELLOW CLEARANCE INTERVALS
for
SIGNALIZED INTERSECTIONS



EXAMPLE

SPEED = 41mph

WIDTH of INTERSECTION W = 30'

ANS: YELLOW = 4.2 sec

2/21/67

APPENDIX IV

Statistical Comparison of Gazis[7] and Michigan Samples of Perception-Reaction Time

Interval	Gazis Study Freq.	Gazis Study Cumulative	Accumulated % of Sample	MDSH Study Freq.	MDSH Study Cumulative	Accumulated % of Sample
.6-.8	7	7	8.0	1	1	4.7
.8-1.0	24	31	35.6	1	2	9.5
1.0-1.2	21	52	59.7	4	6	28.5
1.2-1.4	20	72	82.7	7	13	61.9
1.4-1.6	11	83	95.4	2	15	71.4
1.6-1.8	3	86	98.8	2	17	80.9
1.8-2.0	0	86	98.8	1	18	85.7
2.0-2.2	0	86	98.8	3	21	100
2.2-2.4	1	87	100	0	21	100

For the purpose of this study it was desirable to combine these two studies if they could be considered as observations from the same population. A general test of this type is the Kolmogorov-Smirnov Test of Goodness of Fit of Empirical Distributions. Ref.: Annal of Mathematical Statistics (1948) 19:280-281.

This test is based on the maximal difference between the Emperical Distribution function. This difference is .31 occurring after 1.0 seconds. It is not significant at the .05 level, the significant value being .330.

Combining the samples was considered justified.

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