PSYCHOLOGICAL FACTORS IN HIGHWAY DESIGN AND TRAFFIC CONTROL PROBLEMS [1]

EVALUATION OF DESIGN DATA FOR CROSSOVER DISTANCES

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SYNOPSIS

This paper presents the results of a research project designed to determine whether the driver behavior characteristics exhibited in crossing over from one highway lane to the next adjacent one could be evaluated for guidance in design problems The methods used in the field and in the statistical analysis were intentionally made as simple as possible in order to encourage similar projects on the part of highway departments with limited resources and personnel. The statistical analysis of the 1472 vehicles observed, at speeds between 15 and 65 miles per hour, indicate a remarkable conformance to a regular law Expressed as an equation, the crossover distance for the 90th percentile of the sampled population is

$$D = 43.9274 + 7.3857V - 0.01776V^2$$

when D is the distance in feet and V is the speed in miles per hour

Engineers must agree that in a great many highway accidents the cause lies solely with the driver. The vehicles and highways of today have potentialities far beyond the ability of the average driver to safely use them. Highways have for a long time been designed in terms of the mechanics of moving vehicles with certain known characteristics and assumed actions as controlled by their drivers. Since so much in safety is dependent upon the driver, we are inevitably led to consideration of the human factor as the most important variable Psychology in highway design has certain quite obvious applications and a great many possibilities which have been in the past quite generally overlooked. In the design of signs and signals the importance of the psychology of vision can be easily proved. However the very best designed sign may fail completely in its desired function by reason of faults in its placement. The same consideration of the psychology of vision must be given to sign placement as went to design In channelization design the human factor is definitely the primary consideration with the intent that the driver's decisions be reduced to one at a time and that the proper traffic action becomes almost instinctive. There are numbers of additional possibilities for the application of human factors in highway design and traffic control problems, arising either from the characteristics of the drivers as vehicle operators or from consideration of driver and passenger comfort. In thinking along these lines the author has been led to the belief that certain design factors should in the interests of safety come from statistical analysis of the driving population, making the design such that the desired movement is that which would be made by the majority of drivers if they were not influenced by other elements. An example of this kind of application is the design of decelerating lanes. In order not to produce interference with normal traffic flow a decelerating lane should parallel the principal artery for a sufficient distance to allow vehicles to leave the major stream at the usual highway speed and to get complete lateral clearance before begin-

[1] A dissertation presented as partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

ning deceleration. The problem then is how great a length should be provided for weaving or crossing over from one lane to the next adjacent one at any definite design speed. In line with the theory just mentioned, this crossover distance would be determined not from consideration of an assumed reverse curve of crossover involving only vehicular mechanics but rather from a determination of what drivers actually will do. During the past year the author undertook to determine whether field observations of drivers crossing over from one lane to the next adjacent one would yield a natural law for distance as a function of speed.

The observation method selected was as follows: A vehicle with a calibrated speedometer, carrying an observer in addition to the driver, "floated" in traffic until a crossover was noticed in the stream. At the inception of the crossover maneuver the observer started the mechanism of a stop watch, reading to one-tenth second, and recorded the elapsed time at the completion of the maneuver. In order to get the speed of the crossing vehicle the observation car driver was instructed to pace it at a constant clearance distance while reading his own speedometer. The observer thus had a record of the speed of the "crossing over" car and the time it used in making the cross-

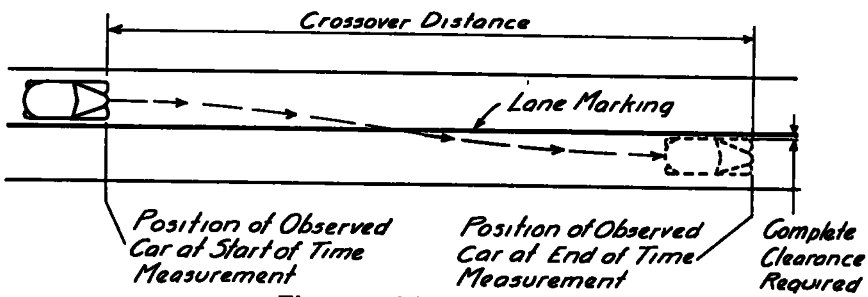

Figure 1. Field Technique

ing. Figure 1 shows the observation technique diagrammatically. The pacing method was used in order to eliminate a variable differential of speed between the crossing car and the observation car whenever the crossover accompanied a passing maneuver.

OBSERVATION TECHNIQUE

In planning the method of collecting data some type was sought which would give representative and conclusive data. Methods involving a small number of instructed drivers were discarded immediately in favor of a type of observation which could be made on any driver without his knowledge, thus enabling one to secure data on a representative sample of the driving public. Likewise, fixed locations for observation posts were decided against in favor of methods which would give a representative sample of actual highway conditions as well as of the drivers themselves. With these two decisions formulated, the only feasible observations were those made from a car "drifting" in traffic.

The observers were instructed to place a check mark in the interference column of the field sheet for any vehicles forced by traffic to enter the new lane or forced to return to their original lane after starting a crossover. In other words, the observed vehicles in all cases made a purely voluntary movement. This was necessary in order truly to measure driver habits. All items so checked in the interference column were discarded in taking off the data from the field sheets. Of the

1472 vehicles observed, 83 showed interference, leaving 1389 for the statistical analysis.

The time observed was wholly without relation to the transverse distances involved except that complete clearance of an observed vehicle inside the entered lane was counted as completion of the crossover movement The variation in lane widths and the clearances allowed by the various drivers observed were thus absorbed in the sample as one of the variables to be evaluated in the statistical analysis The collected data therefore be criticized for inaccuracy, the results of a comparison of speeds so taken with the readings of a fifth wheel electric speedometer on the General Motors Proving Ground at Milford, Michigan, indicate less than one half of one per cent inaccuracy, with skilled observers, at any vehicle speeds under 70 m p h. Also a slight and probably fairly constant error is of no consequence in a statistical analysis of this type where frequency distributions by definite speed ranges must be used. Figure 2 shows a typical field form sheet.

VEHICLE LATERAL VELOCITY STUDY

Date- Weather- Pavement Condition- Location-

Vehicle- Driver- Observer-

No	Speed mph	Time sec	Int	Veh Obs Other	Veh Obs Own	Remarks	No	Speed mph	Time sec	Int	Veh Obs Other	Veh Obs Own	Remarks

Figure 2

give the relation between longitudinal velocity and the time required to cross over, either right or left, into the adjacent traffic lane with clearance for the stream just left. Observations were made in average traffic conditions in Michigan, Indiana, Kentucky and Illinois. Most of the lower speeds were taken in the Chicago metropolitan area. Seven different observation cars and eleven different drivers were used in the collection of the data, with the bulk of the material coming from three sets of especially proficient observers.

The speedometers of the observation vehicles were calibrated by the use of Eno reflector boxes on a measured base course. While the Eno box method might

ANALYSIS OF DATA—GENERAL DESCRIPTION

As the data began coming in from the field a scatter diagram was started, in which the crossover times, in seconds and tenths, were plotted against speeds in miles per hour. This was done in order to determine whether the observations would show any regular grouping which would indicate a possibility of correlation between the crossover time and the longitudinal speed. After some 600 items had been plotted, extending over the range of speeds from 15 to 60 m.p h., a trend toward a regular curve of time could be discerned. The time items apparently were grouping about a line through the 4-sec. mark for all speeds

Accordingly, it was decided to make the statistical analysis by frequency distributions for the observed items grouped into 5 m p.h classes The class ranges were split on the halfway point between multiples of 5, thus making the class marks multiples of 5, e.g., class range 27.5 to 32.5 m p.h ; class mark equals 30 m p.h Summary sheets were designed for taking off the data from the field sheets which provided spaces for tally marks for the observed times in seconds and tenths. (See Fig 3.) From study of these sheets it was apparent that further grouping into time classes would be advisable in order to bring out the characteristics of distribution for the statistical study. The time grouping was made by classes of nine tenths of a second with open limits, thus making the class average mark fall on the 0 45 division between successive seconds; e.g , class 3.0 to 3.9 sec , class mark equals 3.45 sec. Open limits were preferred since their use avoided any difficulty in recording the field data for there was a specific position for any observed time in seconds and tenths.

For each summary sheet a statistical analysis was made, using the following standard statistical measures and nomenclature:

x = Any variate

f = Frequency of occurrence of any variate

N = Total number of items observed

M = Arithmetic mean

M_e = Median

$$\sigma = \text{Standard deviation} = \sqrt{\frac{(x-M)^2}{N}}$$

ϵ = Probable error of mean

$$= 0\ 6745 \times \frac{\sigma}{\sqrt{N-1}}$$

In order to aid visualization of the distribution of the observed items a frequency histogram and a cumulative frequency distribution curve were drawn for each of the speed ranges. These curves are shown as Figures 4 to 14 inclusive

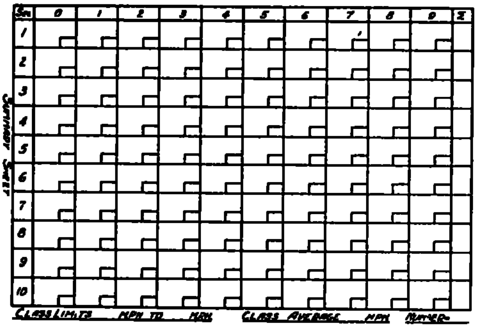

Figure 3

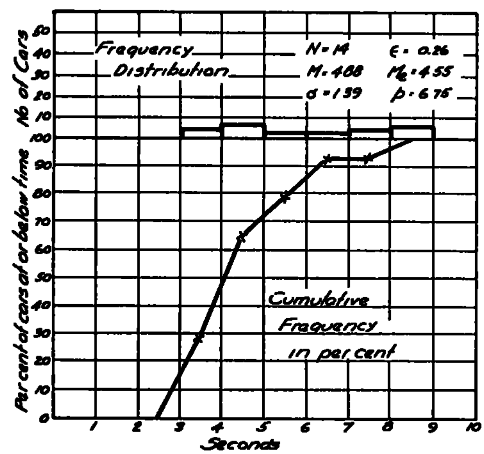

Figure 4. 15 m.p.h. Class, Frequency Distributions

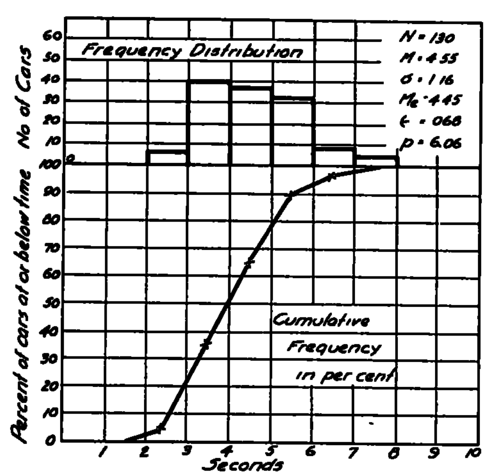

Figure 5. 20 m.p.h. Class, Frequency Distributions

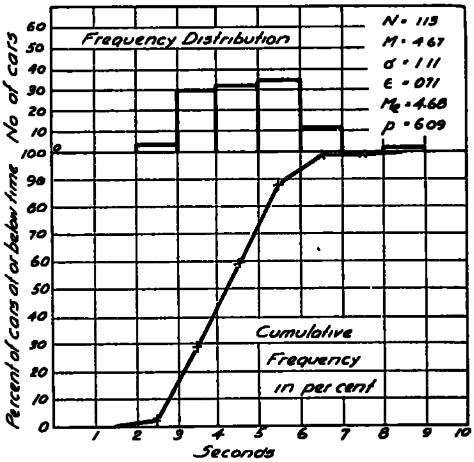

Figure 6. 25 m.p.h. Class, Frequency Distributions

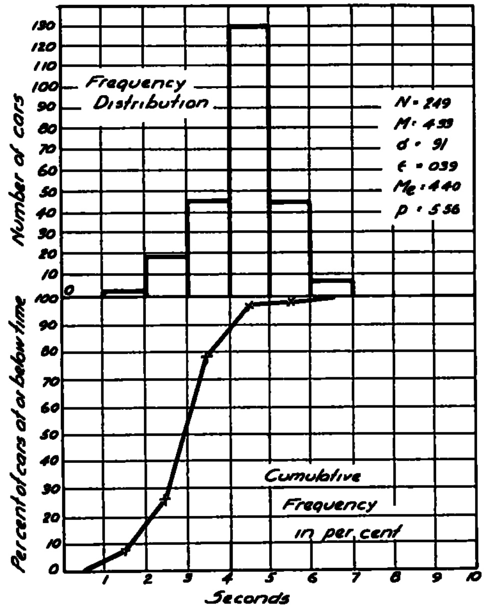

Figure 8. 35 m.p.h. Class, Frequency Distributions

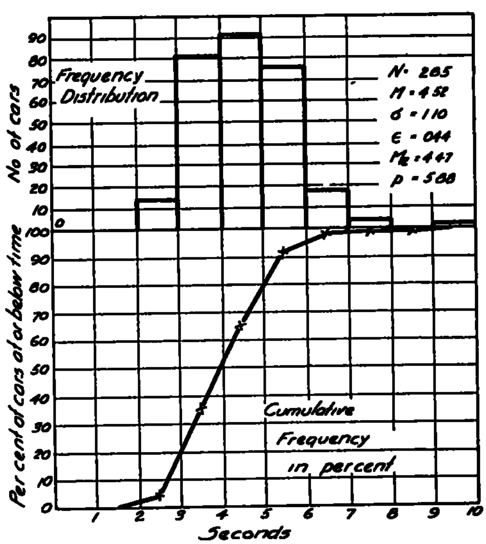

Figure 7. 30 m.p.h. Class, Frequency Distributions

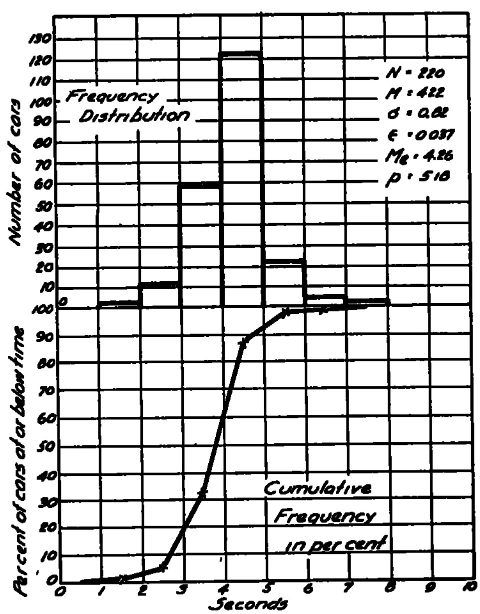

Figure 9. 40 m.p.h. Class, Frequency Distributions

All the statistical measures for the entire speed range covered in the research are presented in Table 1

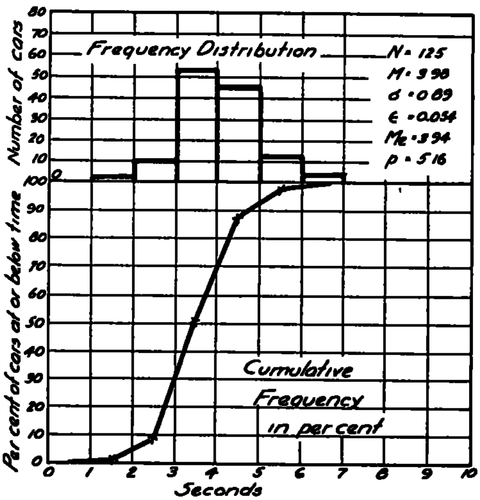

Figure 10. 45 m.p.h. Class, Frequency Distributions

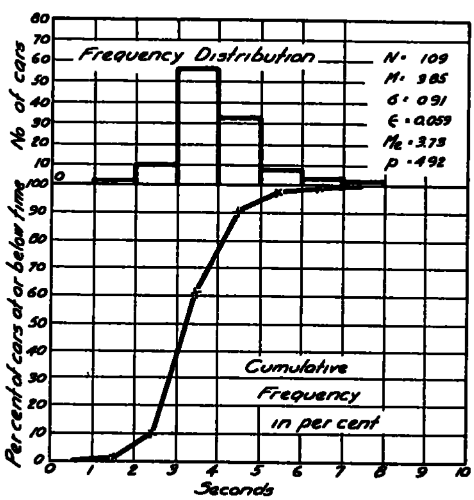

Figure 11 50 m.p.h. Class, Frequency Distributions

Figure 4. This same criticism could be made of the 65 m.p.h. class in which the number of observations was 9. The small

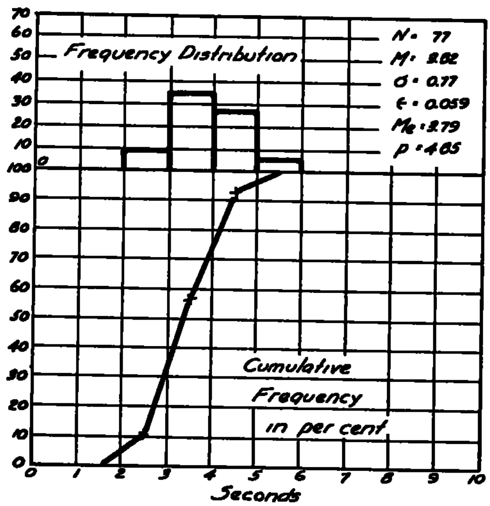

Figure 12. 55 m.p.h. Class, Frequency Distributions

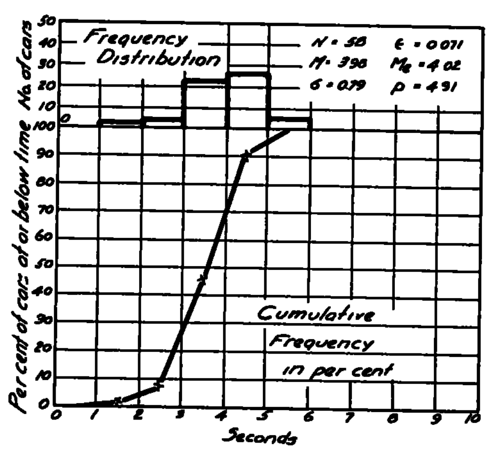

Figure 13. 60 m.p.h. Class, Frequency Distributions

DISCUSSION OF INDIVIDUAL SPEED CLASS STATISTICAL MEASURES

The 15 m.p.h. class, with 14 observations, showed a relatively poor distribution, both on the frequency histogram and on the cumulative frequency curve of number of these observations is due to the rather infrequent occurrences of the cross-over maneuver at these speeds. The number of observations in each speed class up to and including 40 m p.h. are in themselves indicative of speed distribu-

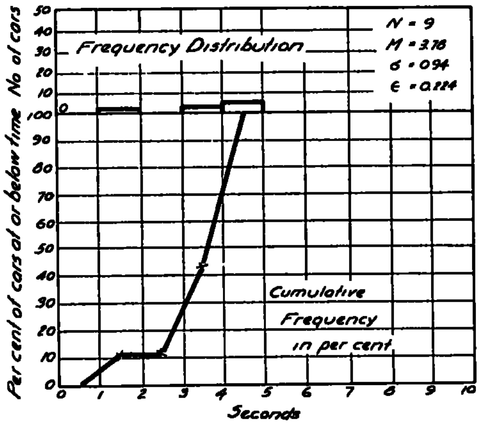

Figure 14. 65 m.p.h. Class, Frequency Distributions

found, indicating that a relatively small percentage of all drivers operate in this speed range. The probable error of the mean of the 15 m.p h and the 65 m.p h classes was approximately four times as large as that of the other groups. These errors were 0 260 sec. and 0.224 sec. for the 15 m p h and 65 m p h. classes, respectively, whereas all the other speed classes showed probable errors around 0.050 sec. This last named error value being one half the fineness of readings on the stop watches, was considered as indicating an adequate sample of the driving population had been obtained in each speed class.

TABLE 1

SUMMARY OF ALL OBSERVATIONS

Class m p h	N	M sec	σ sec	ε sec	M_e sec	p sec	Crossover distances in feet for p time	
							As observed	By equation
15	14	4 88	1 39	0 260	4 55	6 75	148 50	150 72
20	130	4 55	1 16	0 068	4 45	6 06	177 74	184 54
25	113	4 67	1 01	0 071	4 68	6 09	223 32	217 47
30	285	4 52	1 10	0 044	4 47	5 88	258 72	249 52
35.	249	4 33	0 91	0 039	4 40	5 56	285 39	280 68
40	220	4 22	0 82	0 037	4 26	5 18	303 91	310 95
45	125	3 98	0 89	0 054	3 94	5 16	340 56	340 32
50	109	3 85	0 91	0 059	3 73	4 92	360 78	368 81
55	77	3 82	0 77	0 .059	3 79	4 85	391 25	396 39
60.	58	3 98	0 79	0 071	4 02	4 91	432 08	423 13
65	9	3 78	0 94	0 224				
	1389							

tion within metropolitan areas for no especial care was taken to secure a definite number of observations in each class. (Note the distribution of numbers in each class as shown in Table 1.) The observations above 40 m p.h. quite obviously would come from rural areas only. The observers were sent into rural traffic for the higher speed observations, which invalidates any attempt which might be made at analyzing the overall observations of speed characteristics of the 1389 items. From the opinions of the author's crew of observers and other drivers, speeds around 65 miles per hour rarely are

Excluding the 15 and 65 m.p.h. classes, all the frequency distribution histograms (Figs. 5 to 13 inclusive) showed excellent conformations as compared to a standard probability curve. The closeness of the values of the means and medians in each class, as shown in Figure 15 and in Table 1, likewise indicated a very slight skewness from a normal probability distribution The constancy of the standard deviation at around one second also indicated a similar order of dispersion in all the various classes. The cumulative frequency curves plotted at time class marks (0.45 sec. between seconds) showed a closeness to the standard probability ogee curve for all speed classes, as was expected from other considerations, except the 15 m.p.h. and the 65 m.p.h. whose faults already have been discussed.

Plotting the mean time of crossover as ordinates against speed as abscissae on Figure 15 gave a definite indication of a correlation between crossover time and speed. From the lowest speed range

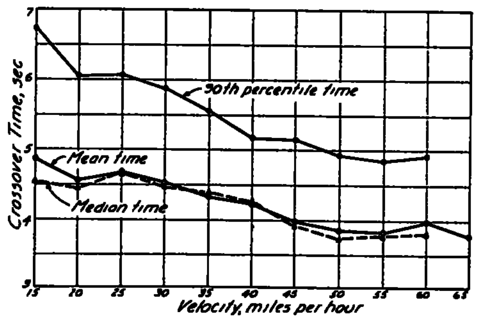

Figure 15

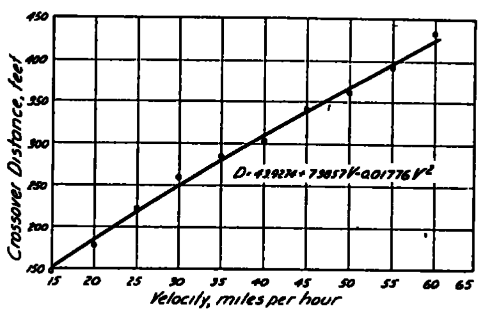

Figure 16

up to 50 m.p.h. the relation is nearly linear. Above 45 m.p.h. the slope of the curve apparently would decrease. This seems logical for with a continued increase in speed obviously the crossover time cannot continue decreasing. The relation between mean crossover time and speed therefore is probably quadratic. The 90th percentile crossover times, plotted in Figure 15 also gave an indication of a quadratic relationship. Figure 16 shows crossover distances for 90th percentile times plotted against speeds. Due to the multiplication of each particular time by its proper speed in feet per second and the resulting change in scalar relations in making Figure 16, the quadratic curve is much more clearly indicated

FINAL ANALYSIS FOR CROSSOVER DISTANCE

In common with other investigators in the traffic engineering field, the author feels that the 90th percentile value is a proper one to use for design purposes wherever design data are taken from driver behavior. The design will in such cases be satisfactory for 90 per cent of all drivers and the 10 per cent remaining can conform with ample margin of safety

In the crossover distance design, values based on the 90th percentile time thus will be sufficiently long for all except the high speed 10 per cent who will have to accompany their crossover with a slight deceleration.

While the curve of Figure 16, faired on to the plotted distance points, would be satisfactory for design usage, the writer felt that determination of an equation for the curve would be advisable. Due to the slight downward convexity of the curve the quadratic equation most likely to fit would be of the form: $D=a+bV=cV^2$. Observation equations in this form were written for each of the speed range classes except the 65 m.p.h., thus providing 10 equations in the three unknowns a, b, and c. By the methods of least squares these observation equations were reduced to three normal equations and the most probable value of the constants, a, b and c, determined. The values so found were.

$$a=+43.9274$$
$$b=+\ 7.3857$$
$$c=-\ 0.01776$$

The equation of crossover distance with these most probable values is therefore:

$$D=43.9274+7.3857V-0.01776V^2$$

where D is in feet and V is in miles per hour.

The constant, 43.9274, indicates, of course, that the equation does not hold at the lower limit, i.e., as V approaches zero, but since crossovers at the extreme low speeds are of no particular interest the equation is satisfactory in its present form. The author feels, also, that the extrapolation of this curve to speeds up to 70 miles per hour would be perfectly satisfactory in its results

Crossover distances computed from this equation are shown in the last column of Table 1. The way in which these computed distances fall above and below the direct observation values is an indication that the derived equation is a reasonable one

CONCLUSION

The relationship between speed and the distance required to cross over is the result of an exceedingly complex integration, by drivers, of the psychological factors of motion perception and distance perception with the physical effort of controlling the vehicle. It is impossible to isolate these various factors and only the total effect can be determined

The success of this research upon a reasonably small sample of the driving population leads the writer to conclude that many other design factors for highways could be evaluated with satisfactory reliability by a similar type of statistical attack.

DISCUSSION ON DESIGN DATA FOR CROSSOVER DISTANCES

MR D W. LOUTZENHEISER, *Public Roads Administration*: Doctor Spears has recognized the need of driver behavior observations for use in highway design and has produced a sample, admittedly demonstrative rather than comprehensive, of tangible value. His summary is along academic lines but it appears that the data can readily be converted to a practical, directly usable form While small, his sample is probably the first available on this particular phase. Similar data are contained in the passing studies reported by Mr. Prisk,[1] but are not treated separately

Observed values for crossover distances of vehicle traveling at various speeds are of considerable use in several phases of geometric highway design. They aid in determining lengths for interweaving areas at intersections, such as the distance between directional islands on a rotary, the length of added lane for acceleration or deceleration, or the distance beyond a grade separation at which a ramp turn-off should be located. Since the crossover lengths to be determined for an intersection design are subject to widely variable use by different drivers little is gained from precisely calculated controls The provision of a certain distance to fit a calculated traffic maneuver is no assurance that it will be used precisely as intended; the length can be provided, but there is no way of making drivers use it as the designer wishes. Accordingly, for design use it is more practical to use rounded values, rather than to follow precise empirical formulae

The data shown in Figure 16 (90 percentile value of crossover distance vs speed) can be expressed as a straight line relation in the range of 20 to 60 m.p.h. and yet remain within one per cent of the observed values. The approximate equation $D=70+6V$ (V in m.p h. and D in feet) is thus, for practical use, just as significant as the derived precise quadratic equation. Likewise values for any other percentile may be treated as straight line relations with little error, as shown in Figure 1.

It is a moot question just which percentile value should be used as a design control. The economics of highway design, particularly in intersection areas, generally are such that near-minimum

[1] See pages 366-378, this volume.

rather than near-maximum lengths must be used as controls. Desirably distances longer than near-minimum values should be used, but most designs usually are compromises between desirable values for traffic convenience and minimum values for economic reasons. Unfortunately, the latter is often predominant. The extent and type of traffic to be handled and the funds and areas available for a particular case will jointly determine just what point in the range between minimum and maximum will be used for design control.

Thus a median (50 percentile) or a 30 percentile value, rather than the 90 percentile value assumed by Mr. Spears, is a more logical assumption for design use of this weaving length In some instances it will be necessary to resort to percentile values even lower. But yet there will remain no question as to the adequacy of the resulting design. A crossover distance that, say, a third of all drivers elect to use (as observed in this case) certainly should be sufficient as a minimum for design, representing the smallest reasonable length that can be used by all drivers.

Figure 1 shows Doctor Spears' data over the whole range of percentile values with superimposed approximate straight line relations for speeds between 20 and 60 m p.h. Obviously the relation should be a curve downward to the left to approach zero, but for speeds above 20 m.p.h there is little error in the straight line relations as shown. Note the break at the 40 m.p.h speed in slope of the lines connecting the plotted points. This may be the difference between the metropolitan and rural traffic observed. The 90 percentile data are the same as Figure 16. The 90 percentile distances are about 75 per cent of the maximum for each speed and are three to four times the minimum values. The median distances are about 55 per cent of the maximums and are at least two times the minimums. The 10 percentile distances are about 40 per cent of the maximums and are about 1.5 times the minimums.

In the intersection design policies of the A A.S.H.O. a crossover distance based on a 3-sec. time interval was used as a minimum value. This assumption nearly coincides with the 10 percentile value of Doctor Spears' observations. The minimum or zero percentile values of the chart are equivalent to a time interval varying from about 2.5 sec. at 20 m.p.h. to 1.5 sec. at 60 m.p h.

Doctor Spears indicates summary of only "purely voluntary movements," but unfortunately is unable to give any correlation with density of traffic, pavement widths and the transverse distance in the crossover movements Such additional data would be very helpful in application of the results obtained. His demonstrative type of observations should not be applied in the same manner as data obtained by more precisely measured speeds and distances, but until such are available they are of considerable assistance in design controls.

PROF. R. A. MOYER, *Iowa State College:* In the paper on "Evaluation of Design Data for Crossover Distances" Doctor Spears has determined the crossover distances or lengths along the highway in crossing over from one traffic lane to the next adjacent lane in terms of time observations of actual traffic on various city streets and highways for speeds from 15 to 65 m p h. He reached the conclusion in his paper that the relationship between speed and the crossover distance is the result of an exceedingly complex integration by drivers of the psychological factors of motion perception and distance perception with the physical effort of controlling the vehicle. He contends that it is impossible to isolate these various factors and only the total effect can be determined, presumably by field observations. The speaker does not agree with this conclusion and contends that it is possible to compute these distances on the basis of the natural curved path which the vehicle will normally follow as determined by the frictional factors involved and the rate of change in the acceleration required along the curved path. Field tests at Iowa State College have demonstrated that the natural path of the vehicle in making the are now generally accepted within fairly narrow limits. Extensive observations and tests by the Public Roads Administration and at Iowa State College have indicated that the frictional factor f for design purposes should be approximately equal to 0 15 and that the values for change in the rate of acceleration C should be 2 to 3 ft per sec per sec By

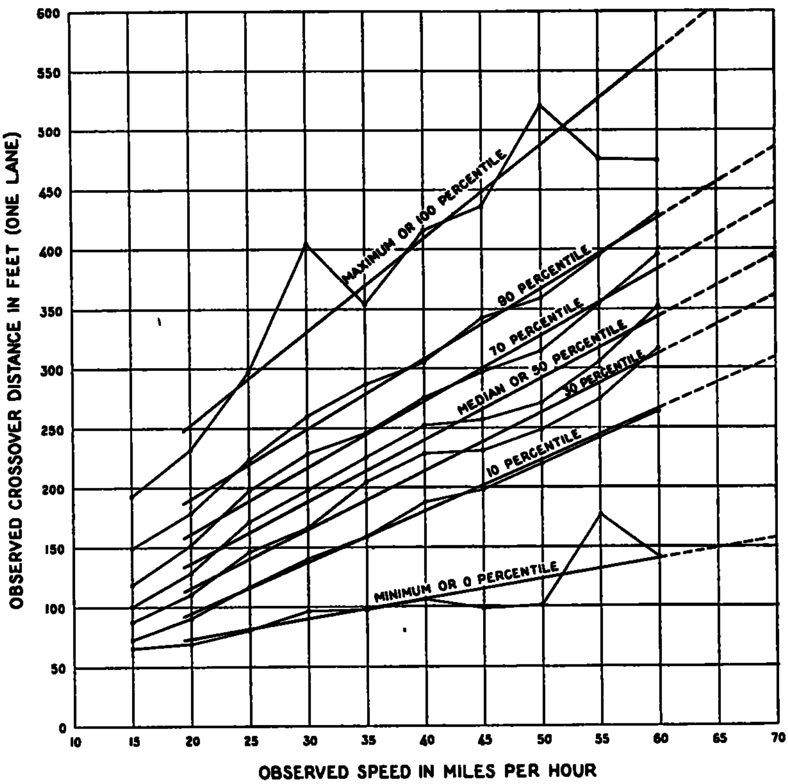

Figure 1

crossover is a series of 4 spiral curves transitional throughout the crossover. Values in the design of curves for the frictional factor (f) and the rate of change of acceleration (C) can be applied in computing the lengths of spirals and crossover distances in much the same way that they are now widely used in the design of any other highway curve. Design values for f and C have been established by field tests and observations and using these design values for f and C in the standard curve formulas to determine the minimum radius and lengths of spiral, the lengths of crossover can be computed for all of the usual design speeds and traffic lane widths Incidentally it should be noted that Doctor Spears did not make corrections for variations in lane widths

Measurements of the type made by Doctor Spears are not new as might be inferred from his paper. Most of the observations along these lines have been made in connection with the determination of safe passing distances and in studies of highway capacity Observations were made by the late Dean Johnson by Dr. Dickinson and by Dr. Greenshields. The latest data along these lines were presented in a paper on "Design of Acceleration and Deceleration Lanes" by Mr. A Mitchell in the March 1941 A S C E. Proceedings He determined the crossover distances by a mathematical analysis using a reverse circular curve as the basis for his computations and verified these values by road tests In a discussion of this paper in the Sept 1941 A.S C E. Proceedings, the writer criticized this method of mathematical analysis because it did not take into account the very important factor of the spiral curve path and the factor C, the change in the rate of acceleration, which is also a measure of the skill of the driver. To support this criticism the writer presented the formulas and tables on the basis of which the minimum crossover distances for various speeds were computed.

In addition to the mathematical analysis, road tests were run to verify the results so obtained. Anyone interested in examining the formulas, tables and charts can do so by referring to the Sept 1941 A.S C E. Proceedings.

It is of interest to note that there is fairly close agreement in the computed values for the various speeds, using an accepted friction value of f=0 14 and a C value (change of rate of acceleration) of 3 ft. per sec.^{3}, and the 90 percentile observed values as determined by Doctor Spears and as given in his Table 1. Thus,

m p h	Length of Crossover: Observed, ft	Length of Crossover: Computed, ft.
20	178	150
30	258	220
40	304	295
50	360	365
60	432	440

The agreement is very good at speeds of 40 m p h. or higher and only at the lower speeds are large differences noted. It is possible that the lane widths and the effect of operation on city streets in metropolitan areas at speeds below 40 m p.h influenced the results to the extent of requiring the longer crossover distances noted above.

The use of the 85 or 90 percentile values in traffic problems involving vehicular and driver behavior has generally been accepted as a sound basis for design purposes. If it can be shown that the values so obtained agree fairly closely with the accepted design factors such as in this case for the friction factors f=0 14 and C=3 ft. per sec.^{3}, the designer has double assurance that he is on safe ground. If, however, construction requirements tempt the designer into using values as low as the 30 percentile values or friction factors above f=0 25 and C values above 4 ft. per sec.^{3}, it should be evident that the design exposes traffic to hazards which are certain to cause accidents or encourage speeds which are unsafe If the designer uses values which are comfortable and acceptable to 90 per cent of the traffic, it may reasonably be assumed that there still is an ample margin of safety to permit safe operation for the remaining 10 per cent of the traffic either by virtue of their greater skill or by their willingness to take greater risks.

Designers have been slow in recognizing the vehicular and driver requirements in solving highway design problems. Too frequently the design has been and still is determined by the construction requirements or construction limitations with the result that the design may soon be obsolete due to changes in vehicle speeds or other traffic factors The data provided by Doctor Spears fill a need in the type of vehicle behavior data which if properly used will provide safer and more permanent type of construction so urgently needed in our highways today. It is hoped that designers will make wider use of vehicular behavior data and of the basic design formulas involving vehicular and driver behavior as brought out in this discussion and in Doctor Spears' paper and that many further studies will be made to supplement our limited knowledge of this subject.

Dr. S. M. Spears, *Author's Closure* The academically precise equation derived in this paper is somewhat unwieldy for practical use and the writer heartily concurs in Mr. Loutzenheiser's suggestion that a simple linear equation is sufficiently accurate for practical usage. The closeness of fit of the data to a straight line is very excellent at both the 90th and 10th percentiles.

In selecting a percentile value for design control the economic factors involved will always point toward the lower percentiles and considerations of maximum safety and convenience will point toward the use of higher values. The writer hesitates to sanction the use of a value as low as the 30th percentile, as suggested by Mr. Loutzenheiser, for there is one element of danger which will always be present, namely, those drivers who begin the crossover maneuver after passing the "tongue" of a crossover lane and thus have less than the full distance available. As an example, if the 30th percentile was adopted for a design speed of 50 m p h. the crossover distance according to the data would be about 260 ft. and if a driver at this speed initiated the crossover movement only 30 ft. past the crossover beginning he would have available only 230 ft. which corresponds to about the 10th percentile. Since a considerable number of late entries could be expected in any traffic stream it seems logical to insist upon one of the higher percentiles in order to assure having available for use a safe crossover distance. Since these distances are for uniform speed a safe crossover can of course be accomplished in a shorter distance if accompanied by deceleration. However, the ideal crossover is without deceleration.

Variations in the lateral placement of vehicles in a lane introduce another variable in any consideration of crossover distances whenever a definite "throw" or transverse distance is used in developing an equation. If the crossover distances were determined for each of the possible variations of lateral placement and transverse distances it would be necessary, for design purposes, either arbitrarily to choose one lateral distance as a base of computations or make a statistical analysis of lateral placement to determine the proper value to be used. The writer chose to combine the variables of lateral placement and crossover distance in one analysis. The observed values therefore do take into account variations in lane widths and lateral placement. Since this investigation was concerned only with contiguous highway lanes the throw or lateral displacement could be reasonably handled in the manner described.

Professor Moyer has mentioned the writer's statement that the relationship between speed and crossover distance is the result of an exceedingly complex integration, by drivers, of the psychological factors of motion perception and distance perception with the physical effort of controlling the vehicle. He criticized the statement that these factors could not be isolated and that only overall effects could be determined Due to the fact that this paper is a part of a more lengthy treatment of psychological factors in highway design, the mention of the impossibility of isolating these factors was wholly from the viewpoint of the psychologist. Professor Moyer's evaluation of a friction factor and a rate of acceleration as affecting crossover distance does take into account physical driving factors and overall psychological factors still without separating the individual psychological factors

The difference between his computed

crossover distances and those of the writer's Table 1 for speeds below 40 m p h can hardly be due to lane width variations since these are included in the writer's analysis It is more likely that these differences are due to the dispersion of the sampled population in the various speed classes. It is noticeable in Table 1 that the standard deviations are somewhat larger for the lower speeds than for the higher, indicating wider distribution in the lower speeds. The higher speed classes show a stronger central tendency. The distribution within the lower speed classes (urban driving) is more nearly a standard probability curve than in the case of the higher speeds which have a sharper peaked distribution curve. This fact would justify a change in friction and curvature factors at this speed in using Professor Moyer's equations. It seems as if at the 40 m p h. level other psychological factors enter which cause a change in driving habits and require the use of different factors of friction and rate of acceleration. Such compensation, properly adjusted, could well result in close correlation between the writer's observed values and those of Professor Moyer over the entire speed range