Lag and Gap Acceptances at Stop-Controlled Intersections

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The purpose of this research study was to investigate the lag and gap acceptances for drivers entering and crossing a major roadway from a stopped position. This driver-behavior evaluation included a determination of a lag-and-gap acceptance distribution for the sidestreet drivers, consideration of community influence on this distribution, and comparisons of time-interval acceptances by drivers making through, left-turn, and right-turn movements.

The study was performed at right-angle intersections formed by two-way, two-lane, urban streets. Four sites, selected in Lafayette and Indianapolis, Ind., were as identical as possible regarding geometry and adjacent land use. The data were collected at these sites by means of a motion picture camera. The technique of probit analysis was employed in the statistical treatment of the observations. In addition, two other methods, one developed by Raff and the other by Bissell, were considered in this evaluation of driver behavior at stop-controlled intersections.

The acceptance distributions were well described by a linear relationship between the probit of acceptance and the logarithm of acceptance time. There were no significant difference between the median lag-acceptance and the median gap-acceptance times at the four intersections. However, significant variations were found between right- and left-turning drivers and between drivers proceeding through the intersection and those making left turns. Right-turning drivers and those crossing the intersection had statistically equal median acceptance times. Community size apparently has some influence on driver performance at intersection approaches controlled by stop signs. A general agreement existed among the three methods of analysis investigated.

•THE INTERSECTION of streets at grade in urban areas is a primary location of traffic accidents and a point of considerable congestion and delay. One-half of all urban traffic accidents and more than three-fourths of all vehicular delays experienced in urban areas occur at these locations (6). The intersection is a critical element because vehicles arriving from different directions converge on this small area. The efficiency and capacity of the entire street system is generally dependent on the characteristics of the intersections in the system. Also, the safety of the individual driver is related to the intersectional characteristics of the street system. The type of traffic control used at intersections influences the frequency and severity of traffic accidents.

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The principle that a majority takes precedence applies in the field of traffic engineering when two traffic streams of unequal volumes come into conflict. The movement with the greater volume is usually less likely to respect the rights of the minor flow. The traffic engineer recognizes this principle when he finds it necessary to stop the minor stream by placing stop signs at the intersection. Whenever a gap in the major flow is equal to or greater than some acceptable value, one or more vehicles in the minor flow merge with or cross the major stream. In selecting acceptable gaps, attention must be focused on the distribution of large openings in the primary traffic stream.

The purpose of this study was to investigate the gap and lag acceptances for drivers entering and crossing a major roadway from a stopped position. A gap is defined as the time interval between the passing of the path of the side-street vehicle by two successive vehicles in a lane of traffic flow on the main street. Gaps are normally measured from front-to-front of the successive vehicles and, thus, include the length of the lead vehicle. On the other hand, a lag is the time interval measured from the arrival of a side-street vehicle at the stop bar of the intersection approach to the crossing of the path of this vehicle by the first main-street vehicle. Lag intervals are measured between the times when the fronts of the vehicles arrive at or cross their respective determination points. This driver-behavior evaluation was subdivided into the following main categories:

1. Determination of lag-and-gap acceptance distribution for side-street traffic regulated by a stop sign;
2. Consideration of community influence on these distributions; and
3. Comparison of driver time-interval acceptance for through, left-turn, and right-turn movements.

For each of these items various statistical tests were employed to evaluate the significance of the findings.

Simulation methods are presently being developed to analyze traffic flow and its characteristics at intersections and at ramps on freeways. However, simulation techniques are dependent on field investigations of traffic-flow performance. The results of driver-behavior studies are required to construct realistic mathematical models which can be used to simulate traffic situations in computer analyses. In addition, time-acceptance distributions provide fundamental information for the development of warrants for traffic-control devices and for the determination of intersection capacities.

PREVIOUS INVESTIGATIONS

Several research projects have been conducted to study the traffic characteristics of at-grade intersections. In these investigations various techniques were used to analyze intersectional flow patterns under different roadway and traffic conditions. In 1944, B. D. Greenshields employed time-motion pictures to study the time intervals accepted by drivers when crossing another traffic stream. Both controlled and uncontrolled intersections were studied, and, in particular, stop sign controlled intersections were included in these investigations. The average minimum acceptable time gap was defined as that value which is accepted by 50 percent of the drivers (3).

A few years later a similar study was made with a 20-pen graphic recorder by M. S. Raff; the concept of a time lag was introduced and evaluated. Instead of Greenshields' definition of an average minimum time gap, Raff developed the critical lag, which is defined as the median time lag; that is, the number of accepted lags shorter than the critical time lag is equal to the number of rejected lags longer than this specific value. In this study the critical lags were not constant but varied from intersection to intersection. Critical lags were influenced by sight obstructions, main-street speeds, main-street width, and the patterns of traffic flow on the side street. However, traffic volumes on the main street did not significantly modify the critical-lag value. Turning movements, which probably affect the amount of delay to the side-street vehicles, received little attention in that study. In comparing the critical lag with the time gap, Raff noted that this gap averaged about 0.2 sec greater than the critical lag (4).

Although most projects were limited to the consideration of vehicular delay and speed-change performance, H. H. Bissell considered vehicular movements through the intersection as through, left turn, and right turn. A 20-pen graphic recorder was used to obtain the necessary data for two intersections within similar urban areas. In the analysis of the data it was determined that the acceptance of lags was not significantly different from the acceptance of gaps. This homogeneity of lags and gaps was demonstrated by the overlapping of the confidence intervals determined for a confidence coefficient of 80 percent. A mathematical formula of the accumulative logarithmic normal distribution for pooled lags and gaps was devised to describe the human judgment for accepting or rejecting the main-street traffic gaps offered to drivers stopped on the side street. Although the lane position (near or far) of the main-street traffic did not influence the gap acceptance for the traffic entering from the side street, the type of entering maneuver produced different gap-acceptance distributions (1).

The studies by Greenshields and Raff were both conducted in New Haven, Conn., and Bissell investigated one intersection in Richmond and another in Oakland, Calif. As a general comparison of the three studies, Greenshields, Raff, and Bissell reported, respectively, a mean gap acceptance of 6.1 sec, a mean lag acceptance of 5.9 sec, and a mean lag-and-gap acceptance of 5.8 sec.

PROCEDURE

To establish the acceptance distributions for lags and gaps, it was necessary to observe driver behavior at selected intersection locations. Statistical estimations and various tests of hypothesis were used, respectively, to develop functional relationships and to appraise the significance of the findings.

Site Selection

The selection of suitable study sites involved the consideration of several factors. To obtain a representative sample of drivers, two at-grade intersections were chosen in each of two cities. Lafayette and Indianapolis, Ind., were selected as typical of small- and medium-sized standard metropolitan areas. These communities permitted a comparison of driving habits as related to city size.

The following limitations were imposed on the selection of study locations to control several roadway and traffic variables which could influence the study results:

1. The four intersections were located in residential sections of an urban area.
2. Commercial roadside development near the intersection, such as service stations, laundries, and ice-cream stands, were not considered objectionable if the rest of the immediate area was residential.
3. To obtain a random sample of gaps in the main traffic stream, the intersections were located at least 0.25 mi from any traffic-control device on the main street.
4. Traffic volumes on the main and side streets were in excess of 250 and 60 vph, respectively. These limits were established to provide for the collection of data within a reasonable period of time. Also, the range of gaps presented to the side-street drivers is a function of the volume on the main street. A wide range of gap and lag sizes was desired in this field investigation.
5. The intersections studied were very similar with regard to their geometry, consisting of two, two-way streets crossing each other at right angles. Sight distance conditions were about equal on all approaches, and the main-street width was approximately the same at all intersections.
6. Posted speed limits on the main and side streets were 30 mph, except for one side street which was posted with a speed limit of 25 mph.

A brief description of each intersection location is given in Table 1.

TABLE I

SUMMARY OF STUDY LOCATIONS

CITY	INTER-SECTION	MAJOR STREET	COMMERCIAL DEVELOPMENT AT INTERSECTION	GRADE AT INTER-SECTION	DEVELOPMENT ALONG STREETS	SIGHT CONDITIONS	POSTED SPEED LIMIT	AVERAGE MAJOR ST. VOLUME	AVERAGE MINOR ST. VOLUME
LAFAYETTE	A	N. 14 ST.	SOME	LEVEL	RESIDENTIAL	ADEQUATE	25 MPH	420 VPH	65 VPH
	B	KOSSUTH ST.	NONE	MOSTLY LEVEL	RESIDENTIAL	ADEQUATE	30 MPH	330 VPH	65 VPH
INDIANA-POLIS	C	N. ILLINOIS ST.	NONE	MOSTLY LEVEL	RESIDENTIAL	ADEQUATE	30 MPH	460 VPH	65 VPH
	D	N. COLLEGE ST.	SOME	LEVEL	RESIDENTIAL	ADEQUATE	30 MPH	590 VPH	65 VPH

Equipment

Time-motion pictures were chosen in this investigation as the best means of securing the necessary data. The camera used was a 16-mm Eastman Cine Kodak Special with a wide-angle lens. A spring motor drove the camera at the rate of 8 frames per sec. Therefore, elapsed time intervals were measured to the nearest 0.125 sec. This degree of precision was considered sufficient to measure lag and gap times. If a vehicle is traveling at 30 mph, approximately 1.0 sec is required for it to pass through an average intersection. About 8 pictures of this vehicle are recorded on the movie film.

Data Collection

Data collection was performed with the same procedure at all study sites. At each intersection the camera was mounted on a tripod at some vantage point located near the side-street approach. The camera was positioned about 30 ft from the main street to view the entire intersection area, and it was relatively inconspicuous to the passing traffic. A typical field installation is shown in Figure 1.

Data were collected on Monday, Wednesday, and Friday in the morning and afternoon off-peak periods. Approximately 5 days were spent at each site to obtain a wide range of traffic-volume levels. Field studies were performed only when the weather was clear and the pavements were dry. The speed of the camera was frequently calibrated with a stopwatch.

The camera was started whenever a side-street vehicle approached the intersection and stopped for the stop sign. After the side-street driver had accepted a time gap, the camera was stopped. The maximum time gap considered in this investigation was 15 sec, and the camera was stopped if the time interval accepted was longer than this limiting value. Only passenger cars and light commercial vehicles with passenger-car operating characteristics were considered in this field investigation.

The developed film was viewed by a time-motion study projector. The projector has a frame counter, and the film can be advanced or reversed one frame at a time. The pictures were projected on a screen with grid lines drawn to define the collision points. The locations of the possible collision points are shown in Figure 2. A stopped vehicle either proceeded straight through the intersection, turned right, or turned left. If a driver went straight through, the path of movement intersected that of vehicles from both the right and the left. When a right turn was made, the movement merged with traffic coming from the left and did not conflict with traffic from the right. On a left turn the path of a main-street vehicle approaching from the left was crossed, and the maneuver merged with the major stream coming from the right.

The frame number in which the vehicle stopped at or crossed the property line of the intersection approach (Fig. 1) was recorded. When the next opposing vehicle crossed the collision point, the frame number was again noted. The difference between these two frame numbers was divided by the camera speed of 8 frames per sec to produce

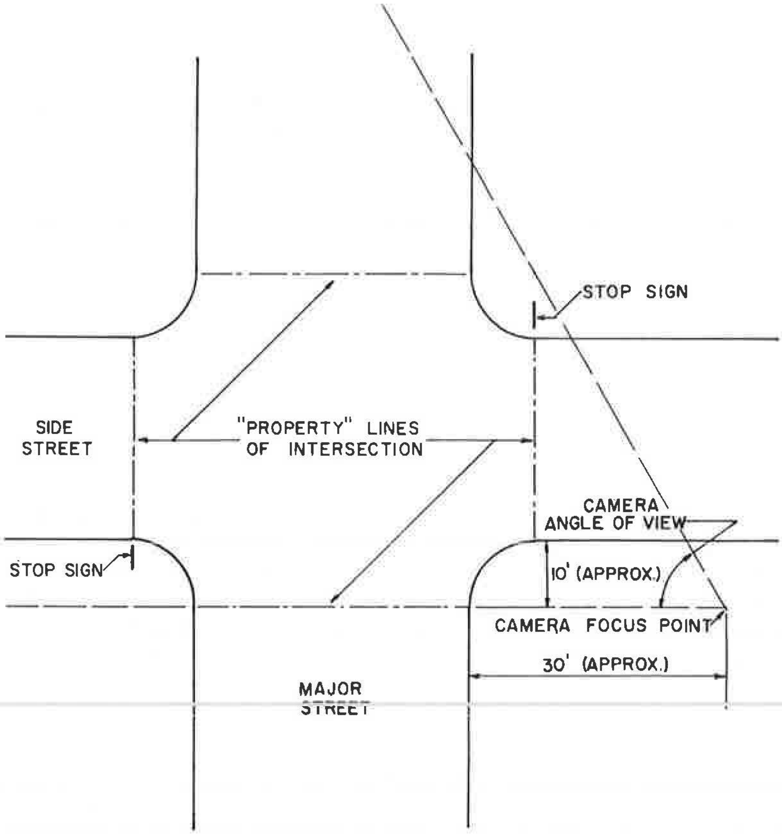

Figure 1. Typical field setup.

the available time lag in seconds. If a driver on the stop-signed street proceeded across the intersection in front of the crossing vehicle, the time interval was considered as accepted. Otherwise, the time opportunity was rejected. A time-gap interval was recorded as the difference in frame numbers, between two successive main-street vehicles passing the collision point, divided by 8 frames per sec.

Data Analysis

The statistical analysis was designed to investigate the significance of the differences in median acceptance times for the following categories:

1. Lag-acceptance time and gap-acceptance time;
2. Acceptance times for right turns, left turns, and through movements; and
3. Acceptance times in one community as compared with those in the other community.

A technique called probit analysis was applied to test these differences statistically. This method is especially applicable in research dealing with "all-or-nothing" responses (2).

The acceptance or rejection of a time gap is an all-or-nothing, or binomial, response, dependent on the size of the gap. The minimum time gap a driver accepts is defined as the tolerance level. The driver is assumed to reject all smaller time gaps and to accept all larger time gaps. This tolerance may be a fixed quantity for a subject, or it may vary with time.

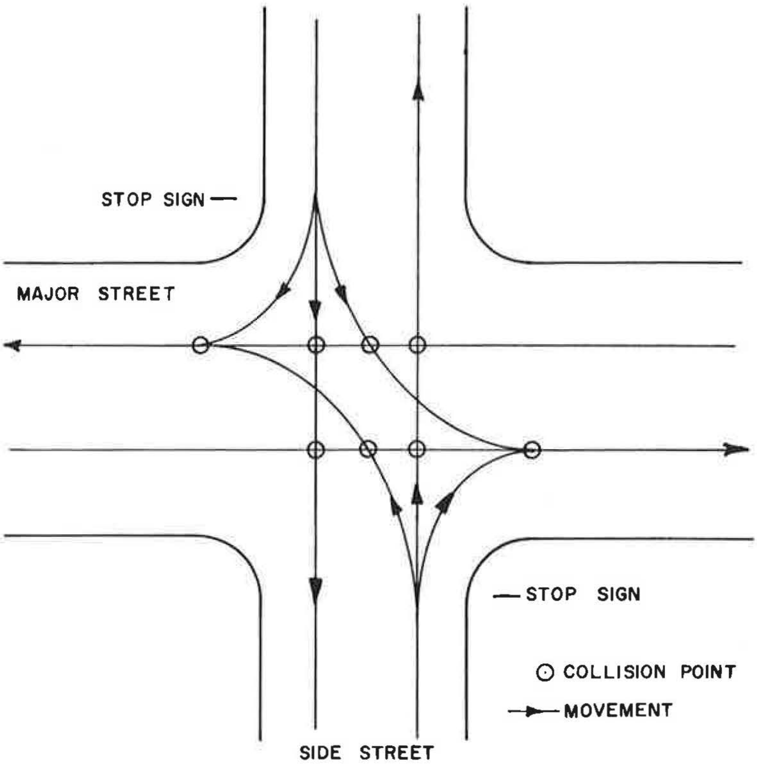

Figure 2. Typical collision points considered for side-street traffic.

A variation in the tolerance value exists from one member to another of the population. Thus, it was necessary to consider the distribution of tolerances over the population studied. The assumption of a normal distribution for the common logarithm of the tolerances suggested the application of the probit transformation. This transformation from percentages or proportions to probits forces the normal sigmoid curve of the untransformed data into a linear relationship.

The probit of the proportion (P) is defined as the abscissa which corresponds to a probability of P in a normal distribution having a mean of 5.0 and a variance of 1.0. A normalizing transformation for the time gap is required so that the transformed measure (x) of the time (t) is normally distributed. The normalizing function was provided by a logarithmic transformation in this investigation of driver acceptance times. The probit of the expected proportion accepting a time gap is related to the time gap by the following linear equation:

$$Y = 5.0 + \frac{1}{\sigma}(X - u)$$

where

Y = probit of the proportion accepting time gap,
X = logarithm of time gap,
u = mean of tolerance distribution, and
σ = standard deviation of tolerance distribution.

By means of the probit transformation the study data were used to obtain an estimate of this equation. The mean and standard deviation of the tolerance distribution were also determined. In particular, median gap- and lag-acceptance times were estimated as the antilogarithm of X when Y = 5.0.

Initially the data were tabulated into groups of 1-sec intervals. These observed data are binomial in nature, and within each time interval driver responses have a binomial distribution. If a driver, selected at random from a population, is exposed to a time interval of t sec, the probability of acceptance is P, and the probability of rejection is Q = 1 - P. The purpose of observing a group of drivers in each interval of the time series was to obtain an estimate of the proportion of drivers accepting this interval.

When experimental data on this relationship between time and acceptance have been obtained, either a graphic or an arithmetic procedure can be used to estimate the slope (b) of the regression line, which is an estimate of the reciprocal of the standard deviation, and the logarithm of the median acceptance time (m) at which Y = 5.0. The arithmetic analysis is necessary when an accurate assessment of the precision of the estimates is desired.

To conduct either type of analysis, the percentage of acceptance observed for each time gap was first calculated and converted to a probit. These probits were then plotted as a function of the logarithm of the time gap, and a straight line was visually fitted to these points. Only the vertical deviations of these points were considered in drawing the line. Very extreme probits outside the range of 2.5 to 7.5 are relatively unimportant and can usually be disregarded. However, these extreme values should be included in the analysis when more drivers are observed in these ranges than in the groups giving intermediate probit values. This regression line is an approximation of the functional relationship between the gap-acceptance probit and the logarithm of gap time. This relation was used to initiate the arithmetic process of estimating a better-fitting regression line. The mathematical basis for the method of estimating the probit regression equation by a process of successive approximations is given by Finney (2).

The statistical comparison of acceptance times is based on the assumption that the variances for the tolerance distributions are equal. This relationship is demonstrated in the probit analysis by the parallelism of the regression lines. If two series of data yield parallel probit regression lines, then a constant difference exists between the time gaps for all corresponding proportions of responding subjects. This constant time difference is determined by computing the antilogarithm of the difference between the common logarithms of the median acceptance times. The various steps followed in estimating the probit regression line are outlined by Finney (2). A test of parallelism for two or more regression lines was performed by comparing the sum of the individual chi-square values for the series with that for the total sums of squares and products.

The methods employed by Raff and Bissell in their analyses were applied to the original data collected in this study to make comparisons with the results obtained by the probit method. Raff determined the critical lag by plotting two cumulative distributions on the same graph. One curve describes the accepted number of lags shorter than a time interval, and the other shows the rejected number of lags longer than this interval. The value of the critical lag was determined as the time at which the two curves intersect (Fig. 3).

Bissell acknowledged the binomial character of the gap-acceptance distribution. The data were plotted on log-probability paper, and a straight line was visually fitted to these points. The lines representing lags and gaps were drawn with equal slope for right turns, left turns, and through movements in each comparison of varying conditions. However, the slopes were different for the various comparisons. A sample graph is shown in Figure 4. The standard deviation was determined directly from this plot by assuming that the mean time gap is the median value of the acceptance time. The standard deviation was then estimated as the difference between the median acceptance value and the time corresponding to an acceptance of 15.9 percent.

RESULTS

Various methods have been developed to determine the time interval an average driver accepts in crossing or merging with a traffic stream from a stopped position.

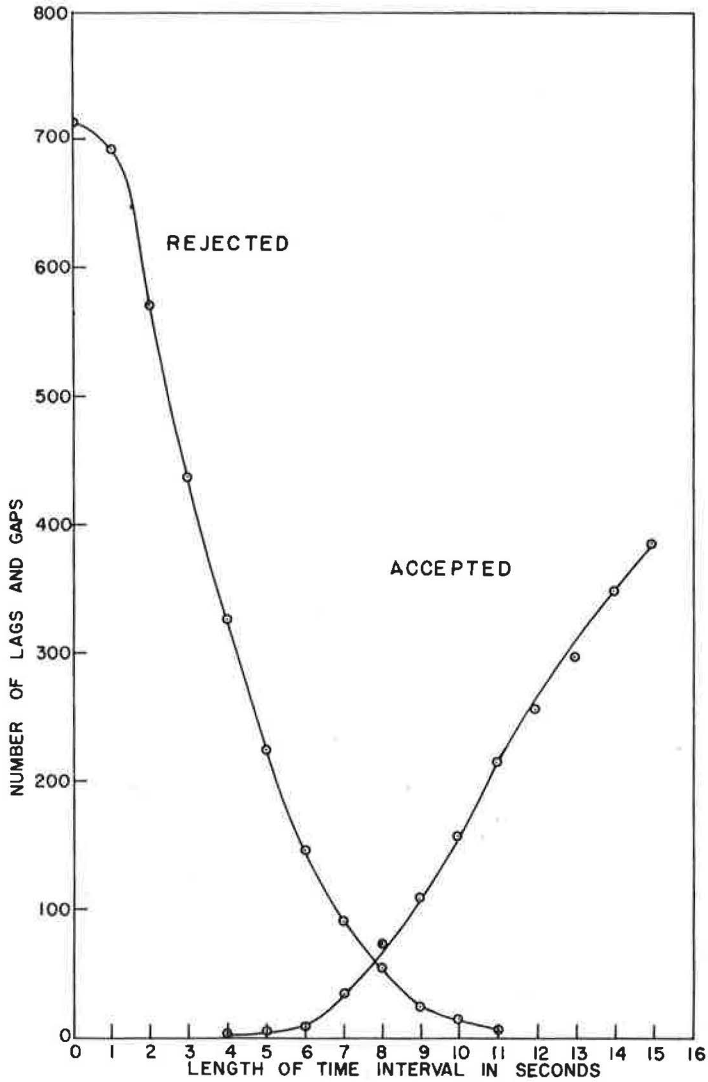

Figure 3. Distribution of accepted and rejected lags and gaps at intersection (A and B) left turns.

Drivers were observed at four different intersections, and the time interval required by each driver to enter or cross the major traffic stream was recorded. The technique of probit analysis was employed in the statistical treatment of these observations. In addition to probit analysis, two other methods, one developed by Raff and the other by Bissell, were considered in this study of driver behavior.

Probit Method

Probit analysis is based on the assumption that a particular transformation of an all-or-nothing response is normally distributed. In the problem of determining lag- and gap-acceptance times, previous studies have indicated that the logarithms of acceptance times are normally distributed. Thus, when the percentages of drivers accepting particular time intervals are converted to probits, a linear relationship exists between the probit of the percent acceptance and the logarithm of acceptance time.

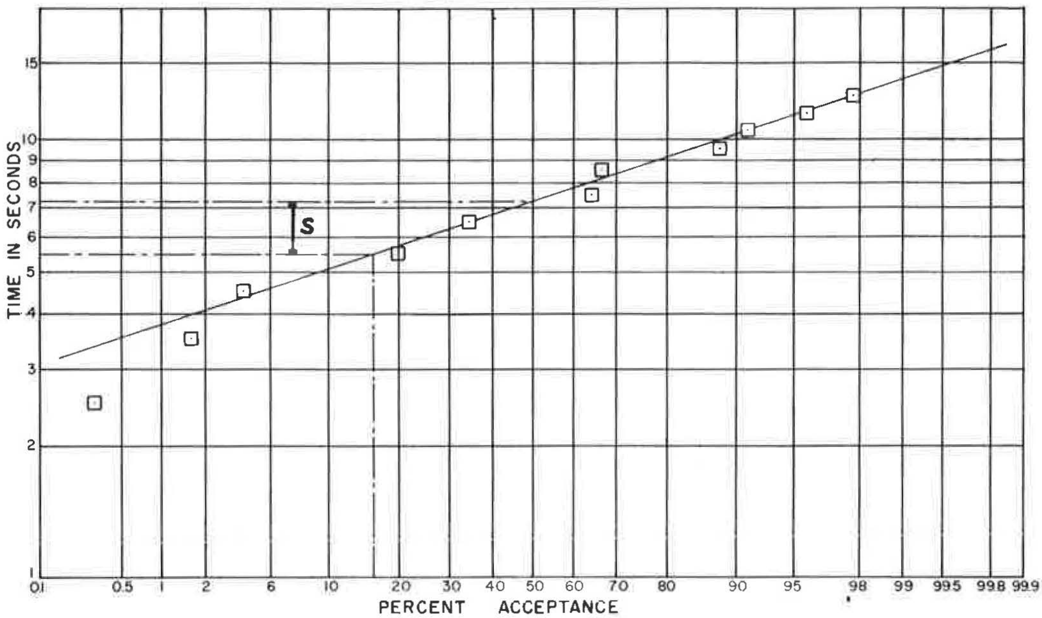

Figure 4. Lag-and-gap distribution for through movements in Lafayette and Indianapolis.

The relationships between lag acceptance and time and between gap acceptance and time are shown in Figures 5 and 6. Similar relations between lag-and-gap acceptance and time intervals for different traffic movements and at the various intersection locations are shown in Figures 7 to 10. Each linear regression represents the best fit of a straight line to the observed data and was used to estimate the median acceptance time. For a 5 percent level of significance the difference in acceptance times was considered as non-significant if the relative acceptance time (R) was equal to or less than 1.10 (2).

In previous studies the precision of the findings was not clearly stated, and no tests were performed to investigate the significance of the results. However, confidence limits for median acceptance time, as well as those for the differences between acceptance times, may be calculated with the probit technique. A test for the goodness of fit of the regression line to the data points measures the precision of the time-value estimates (2).

The differences in acceptance times between lags and gaps were first analyzed in this investigation of driver behavior. By pooling the data from the two intersections in Lafayette, the relative acceptance time was contained in the interval of 1.00 to 1.08 for a confidence coefficient of 95 percent. That is, the median gap-acceptance time is not expected to exceed 1.08 times the median lag-acceptance time for a level of significance of 5 percent. Because the test statistic of 1.08 is less than the critical value of 1.10, the difference between lag acceptances and gap acceptances was not considered significant. The median acceptance times for lags and gaps were, respectively, 7.48 and 7.71 sec. The respective standard errors of estimate were 0.13 and 0.16 sec. The findings for this comparison of lags and gaps are given in Table 2.

For the two intersections in Indianapolis, the relative acceptance time was 1.01 with 95 percent confidence limits of 1.00 and 1.06. With a gap acceptance that was only 1.01 times greater than the lag acceptance, this difference was not large enough to be considered significant. Median acceptance times for lags and gaps together with standard errors and confidence limits are given in Table 3. Because of the small differences that existed between lag acceptances and gap acceptances in both Lafayette and Indianapolis, it was assumed that these lags and gaps came from the same populations in the respective cities.

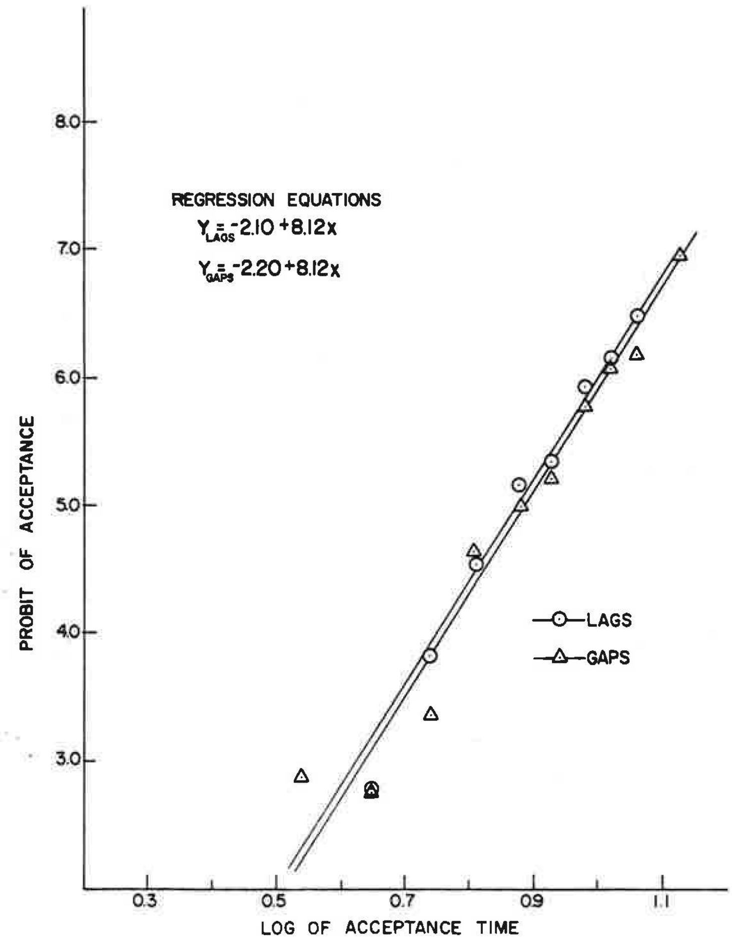

Figure 5. Probit regression lines for estimation of difference of lag acceptance time and gap acceptance time in Lafayette.

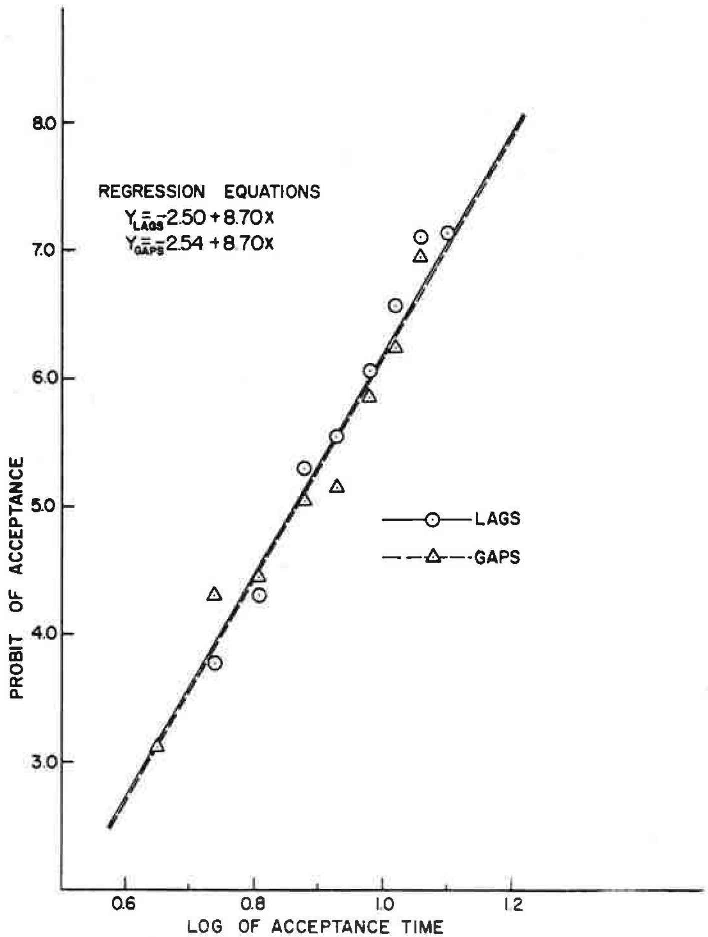

Figure 6. Probit regression lines for estimation of difference in lag acceptance time and gap acceptance time in Indianapolis.

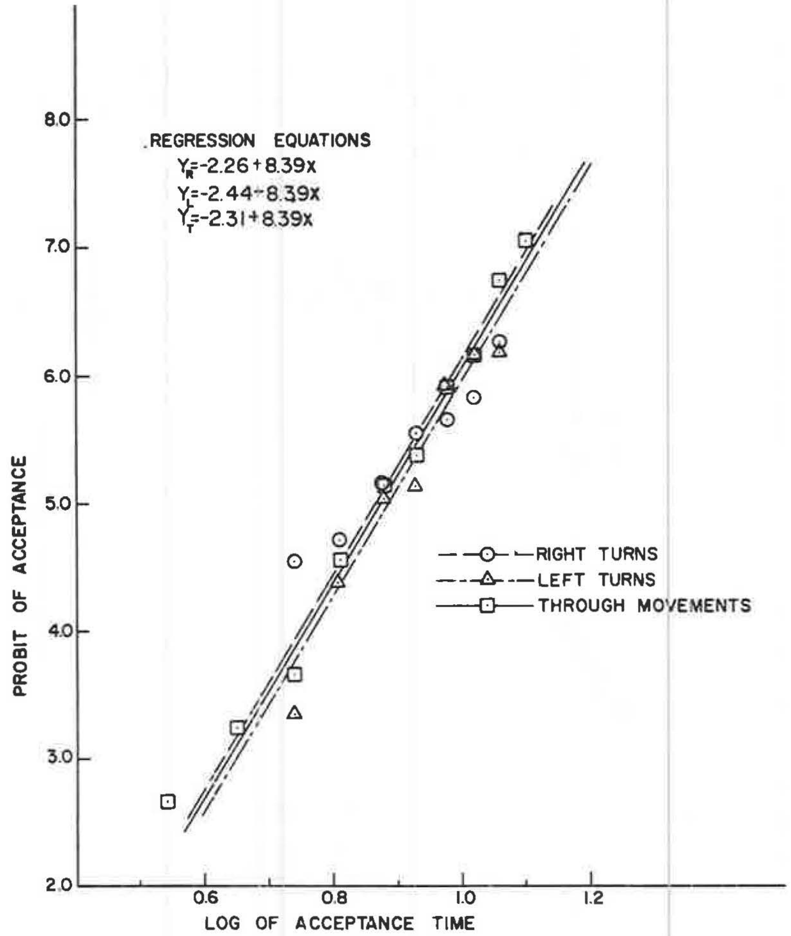

Figure 7. Probit regression lines for estimation of difference in acceptance time for various movements at intersections in Lafayette (lags and gaps pooled).

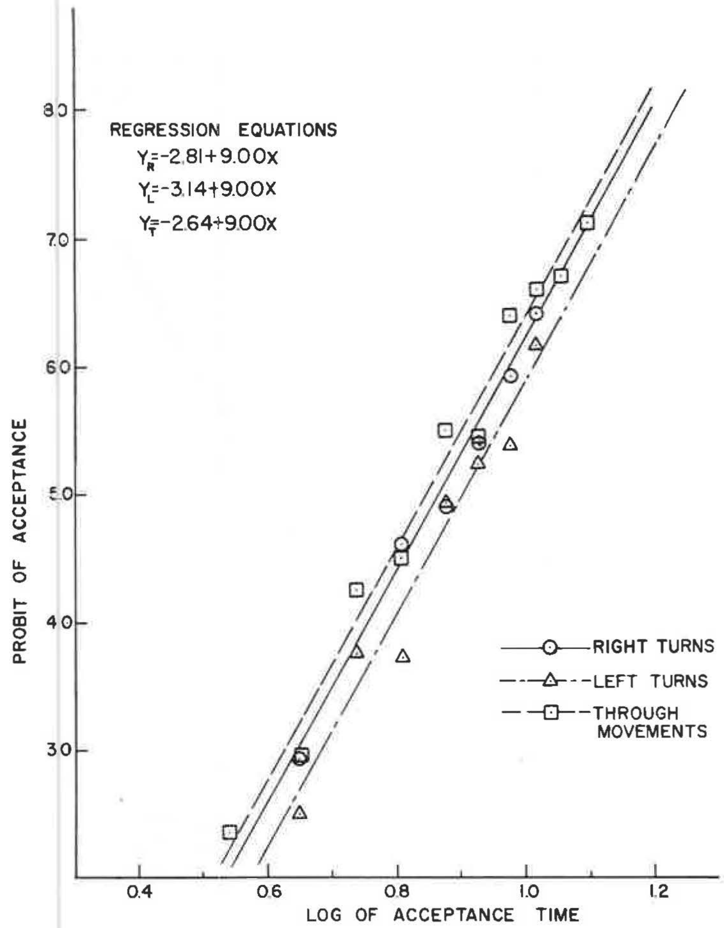

Figure 8. Probit regression lines for estimation of difference in acceptance time for various movements at intersections in Indianapolis (lags and gaps pooled).

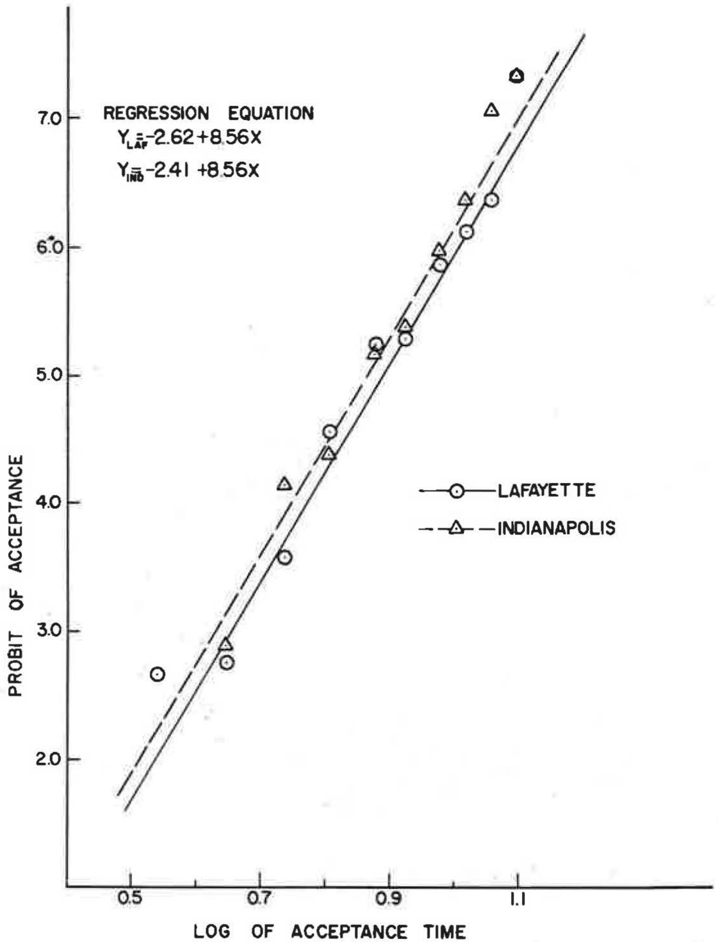

Figure 9. Probit regression lines for estimation of difference in acceptance time for intersections in Lafayette and Indianapolis (lags and gaps pooled, all movements pooled respectively).

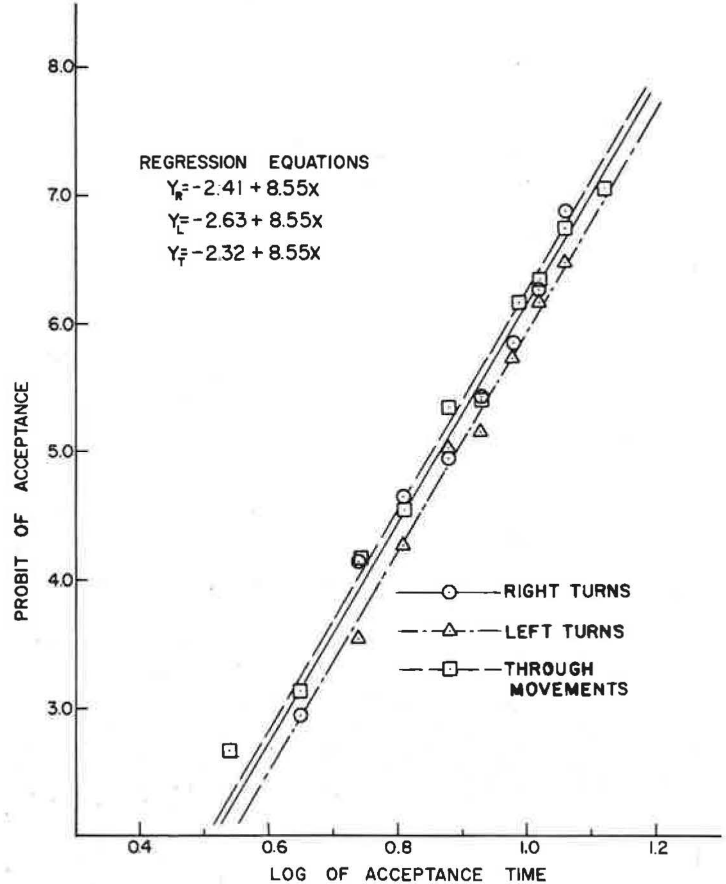

Figure 10. Probit regression lines for estimation of difference in acceptance time for various movements at intersections in Lafayette and Indianapolis (intersections pooled, lags and gaps pooled).

TABLE 2

DIFFERENCE BETWEEN MEDIAN LAG ACCEPTANCE AND MEDIAN GAP ACCEPTANCE AT TWO LAFAYETTE INTERSECTIONS[a]

Summary Statistics	Lags	Gaps
Log of mean acceptance time ($\bar{x}$)	0.893	0.897
Mean probit ($\bar{y}$)	5.15	5.08
Log of median acceptance time (m)	0.874	0.887
Median acceptance time (10^m sec)	7.48	7.71
Standard error of median acceptance time (sec)	0.13	0.16
95 percent confidence limits for median acceptance time (sec)	7.21; 7.75	7.38; 8.04

Test Statistics	Comparison Between Gaps and Lags
Difference in m values (M)	0.013
Relative acceptance time ($R = 10^M$)	1.03
Standard error of relative acceptance time	0.028
95 percent confidence limits for relative acceptance time	1.00; 1.08

[a]Summary of test results.

TABLE 3

DIFFERENCE BETWEEN MEDIAN LAG ACCEPTANCE AND MEDIAN GAP ACCEPTANCE AT TWO INDIANAPOLIS INTERSECTIONS[a]

Summary Statistics	Lags	Gaps
Log of mean acceptance time ($\bar{x}$)	0.898	0.866
Mean probit ($\bar{y}$)	5.31	4.99
Log of median acceptance time (m)	0.862	0.867
Median acceptance time (10^m sec)	7.28	7.36
Standard error of median acceptance time (sec)	0.13	0.13
95 percent confidence limits for median acceptance time (sec)	7.03; 7.53	7.11; 7.61

Test Statistics	Comparison Between Gaps and Lags
Difference in m values (M)	0.005
Relative acceptance time ($R = 10^M$)	1.01
Standard error of relative acceptance time	0.024
95 percent confidence limits for relative acceptance time	1.00; 1.06

[a]Summary of test results.

After the lags and gaps at the intersections in each city were combined, comparisons were performed among the through, left-turn, and right-turn traffic movements. The median acceptance times in Lafayette for right turns, left turns, and through movements were, respectively, 7.33, 7.71, and 7.43 sec. In the comparison between left-turning and right-turning drivers, the relative acceptance time was 1.05 times greater for left turns than for right turns. The 95 percent confidence limits for this relative acceptance time were 1.00 and 1.10.

The relative acceptance times for the comparisons between left turns and through movements and between through movements and right turns were 1.04 and 1.02, respectively. These values were contained in the intervals between 1.00 and 1.08 and between 1.00 and 1.07, respectively, for a 5 percent level of significance. These results are summarized in Table 4 for the various traffic-movement comparisons. According to the criterion that only relative acceptance times greater than 1.10 represent significant differences, the median acceptance times for the various intersectional movements were statistically equal in Lafayette.

Similar comparisons were performed for the data obtained at the two Indianapolis intersections. Significant differences were observed between the lag-and-gap-acceptance times for left turns and right turns and for left turns and through movements. However, the relative difference between right turns and through movements was not significant. The median acceptance times were 7.38, 8.02, and 7.06 sec for

TABLE 4

DIFFERENCE BETWEEN MEDIAN LAG-AND-GAP ACCEPTANCE FOR VARIOUS MOVEMENTS AT TWO LAFAYETTE INTERSECTIONS[a]

Summary Statistics	Side-Street Movements		
	Right	Left	Through
Log of mean acceptance time ($\bar{x}$)	0.905	0.904	0.892
Mean probit ($\bar{y}$)	5.33	5.14	5.17
Log of median acceptance time (m)	0.865	0.887	0.871
Median acceptance time (10^m sec)	7.33	7.71	7.43
Standard error of median acceptance time (sec)	0.22	0.14	0.15
95 percent confidence limits for median acceptance time (sec)	6.91 7.77	7.42; 8.00	7.13; 7.73
Test Statistics	**Comparison Between Movements**		
	Lt to Rt	Lt to Thru	Rt to Thru
Difference in m values (M)	0.022	0.016	0.010
Relative acceptance time ($R = 10^M$)	1.05	1.04	1.02
Standard error of relative acceptance time	0.024	0.028	0.025
95 percent confidence limits for relative acceptance time	1.00 1.10	1.00; 1.08	1.00; 1.07

[a]Summary of test results.

right turns, left turns, and through movements. The upper 95 percent confidence limits for the relative acceptance-time values were 1.18, 1.20, and 1.10, respectively, for the comparisons of left turns to right turns, left turns to through movements, and right turns to through movements (Table 5).

To evaluate the influence of community size on the observed lag-and-gap acceptances, the significance of the difference in the median acceptance values was tested for the combined traffic movements in the two study cities. The median acceptance times were 7.76 sec in Lafayette and 7.36 sec in Indianapolis. The 95 percent confidence limits for the acceptance times (Table 6) were 7.59 and 7.94 sec in Lafayette and 7.18 and 7.54 sec in Indianapolis. The upper 95 percent confidence limit for the relative acceptance time was 1.12. That is, the median lag-and-gap-acceptance time in Lafayette was significantly greater than in Indianapolis for a 5 percent level of significance. Drivers in small-sized cities apparently require larger openings to enter or cross a major traffic flow from a stopped position at an intersection than those operating vehicles in medium-sized communities.

Because the difference in median acceptance times was significant only to a slight degree, the lag-and-gap acceptances were combined for the intersections in Lafayette and Indianapolis. The resulting comparison of lag-and-gap-acceptance times performed between the various movements is given in Table 7. Left-turning drivers have

TABLE 5

DIFFERENCE BETWEEN MEDIAN LAG-AND-GAP ACCEPTANCE FOR VARIOUS MOVEMENTS AT TWO INDIANAPOLIS INTERSECTIONS[a]

Summary Statistics	Side-Street Movements		
	Right	Left	Through
Log of mean acceptance time ($\bar{x}$)	0.871	0.899	0.861
Mean probit ($\bar{y}$)	5.03	4.95	5.11
Log of median acceptance time (m)	0.868	0.904	0.849
Median acceptance time (10^m sec)	7.38	8.02	7.06
Standard error of median acceptance time (sec)	0.16	0.20	0.13
95 percent confidence limits for median acceptance time (sec)	7.06; 7.70	7.64; 8.40	6.82; 7.30
Test Statistics	**Comparison Between Movements**		
	Lt to Rt	Lt to Thru	Rt to Thru
Difference in m values (M)	0.036	0.055	0.019
Relative acceptance time ($R = 10^M$)	1.09	1.13	1.05
Standard error of relative acceptance time	0.039	0.036	0.028
95 percent confidence limits for relative acceptance time	1.00; 1.18	1.06; 1.20	1.00 1.10

[a]Summary of test results.

TABLE 6

MEDIAN LAG-AND-GAP ACCEPTANCE DIFFERENCE, COMBINED MOVEMENTS, BETWEEN LAFAYETTE AND INDIANAPOLIS[a]

Summary Statistics	Lafayette	Indianapolis
Log of mean acceptance time ($\bar{x}$)	0.891	0.876
Mean probit ($\bar{y}$)	5.02	5.09
Log of median acceptance time (m)	0.890	0.867
Median acceptance time (10^m sec)	7.76	7.36
Standard error of median acceptance time (sec)	0.09	0.09
95 percent confidence limits for median acceptance time (sec)	7.59 7.94	7.18 7.54

Test Statistics	Comparison Between Lafayette and Indianapolis
Difference in m values (M)	0.023
Relative acceptance time ($R = 10^M$)	1.05
Standard error of relative acceptance time	0.037
95 percent confidence limits for relative acceptance time	1.00; 1.12

[a]Summary of test results.

1.06 and 1.09 times greater median lag-and-gap-acceptance times, respectively, than those drivers turning right or proceeding straight through the intersection. Significant differences existed between these movements at the 5 percent significance level, because the upper confidence limits for the relative acceptance times were 1.12 for the first comparison and 1.14 for the second comparison. However, right-turning drivers required a median acceptance time that was only 1.03 times greater than that selected by drivers continuing straight through the intersection. The median acceptance times for these two traffic movements were considered statistically equal at the 5 percent level of significance.

Raff Method

The findings obtained by using the Raff method depend largely on the manner in which the curves are fitted to the data points. No test is presently available to check the precision of this visual fitting technique. The resultant values are relatively accurate if the curve closely follows the plotted points. The results of this method are given in Table 8.

In the investigation of median acceptance times for lags and gaps with the combined data for the two intersections in Lafayette, the median value for lags was 7.60 sec and that for gaps was 7.75 sec, or 0.15 sec longer. The median acceptance times for lags and for gaps were found to be equal to 7.35 sec for the two intersections in Indianapolis.

In Lafayette the median lag-and-gap-acceptance time for right turns was 7.55 sec, or 0.05 sec shorter than the corresponding value for through movements. The value for left turns was 7.80 sec, or 0.20 sec greater than for through movements. However, greater differences were evident in Indianapolis for certain traffic movements. The median acceptance times were 7.30 sec for right turns, 7.95 sec for left turns, and 7.10 sec for through movements (Table 8). Drivers moving straight through the intersection had the lowest median acceptance time, although this value was only 0.20

TABLE 7

DIFFERENCE BETWEEN MEDIAN LAG-AND-GAP ACCEPTANCE FOR VARIOUS MOVEMENTS AT FOUR INTERSECTIONS COMBINED IN LAFAYETTE AND INDIANAPOLIS[a]

Summary Statistics	Side-Street Movements		
	Right	Left	Through
Log of mean acceptance time ($\bar{x}$)	0.883	0.908	0.865
Mean probit ($\bar{y}$)	5.14	5.14	5.08
Log of median acceptance time (m)	0.867	0.893	0.856
Mean acceptance time (10^m sec)	7.36	7.82	7.18
Standard error of median acceptance time (sec)	0.14	0.11	0.09
95 percent confidence limits for median acceptance time (sec)	7.10; 7.64	7.60; 8.04	7.00; 7.36
Test Statistics	**Comparison Between Movements**		
	Lt to Rt	Lt to Thru	Rt to Thru
Difference in m values (M)	0.026	0.037	0.011
Relative acceptance time ($R = 10^M$)	1.06	1.09	1.03
Standard error of relative acceptance time	0.026	0.023	0.024
95 percent confidence limits for relative acceptance time	1.02; 1.12	1.05; 1.14	1.00; 1.07

[a]Summary of test results.

TABLE 8

MEDIAN ACCEPTANCE TIMES AT STUDY LOCATIONS—RAFF METHOD

Location	Combined Lags and Gaps (sec)			Combined Movements (sec)	
	Right Turns	Left Turns	Through Movements	Lags	Gaps
Lafayette	7.55	7.80	7.60	7.60	7.75
Indianapolis	7.30	7.95	7.10	7.35	7.35
Lafayette and Indianapolis	7.45	7.85	7.35		

sec shorter than that selected by drivers turning right. The left-turning drivers required a considerably longer median acceptance time.

When data in Lafayette and Indianapolis were grouped together, the median acceptance time for through movements was 7.35 sec, or only 0.10 sec lower than that for right turns. The value of the median lag-and-gap-acceptance time for the left-turning drivers was greater than that for drivers turning right or moving straight through the intersection.

Raff computed values varying from 4.6 to 6.0 sec for the median values of driver lag-acceptance time for the intersections studied in Connecticut (4). These median times are approximately 2.0 to 2.5 sec shorter than those measured in the present investigation. Raff found that 2.0 percent of the drivers accepted a time interval less than 1.0 sec and up to 7.0 percent were observed in the interval between 1.0 and 2.0 sec. This acceptance of extremely short time lags may account for his lower median acceptance times. Lags were measured with the near curb line as the reference point in the Raff study. However, in this study lags were referred to the collision points. The use of the longer approach path in the latter case may partially account for the differences between median acceptance times.

Bissell Method

The results obtained by the Bissell technique are predicated on the accuracy of fitting a straight line to the observed data. Although median values were estimated to the nearest 0.05 sec, precision of this visual fit cannot be described in numerical terms. The lines were drawn parallel to each other so that homogeneity of variance was obtained.

The median acceptance times for lags and for gaps in Lafayette and in Indianapolis had an equal difference of 0.10 sec. These lag-and-gap acceptances were 7.40 and 7.50 sec for Lafayette and 7.20 and 7.30 sec for Indianapolis. The acceptance times determined by the Bissell method are given in Table 9.

Median acceptance times varied only slightly for the two intersections in Lafayette. The single exception was the comparison of through movements and left turns. Drivers performing a left turn required an opening that was, on the average, 0.40 sec longer than that needed by those passing straight through the intersection. Drivers turning right had a median lag-and-gap-acceptance value of 7.30 sec. Left-turning drivers and those proceeding straight through the intersection had median acceptance times of 7.50 and 7.10 sec, respectively.

For the Indianapolis intersections the differences in lag-and-gap-acceptance times for the various movements were found to be greater than the corresponding values in Lafayette. Left-turning drivers had a median lag-and-gap-acceptance time of 7.65

TABLE 9

MEDIAN ACCEPTANCE TIMES AT STUDY LOCATIONS—BISSELL METHOD

Location	Combined Lags and Gaps (sec)			Combined Movements (sec)	
	Right Turns	Left Turns	Through Movements	Lags	Gaps
Lafayette	7.30	7.50	7.10	7.40	7.50
Indianapolis	7.35	7.65	7.05	7.20	7.30
Lafayette and Indianapolis	7.35	7.65	7.10		

TABLE 10

POOLED MEDIAN ACCEPTANCE TIMES IN LAFAYETTE AND INDIANAPOLIS AS DETERMINED BY DIFFERENT METHODS

Method	Combined Lags and Gaps (sec)		
	Right Turns	Left Turns	Through Movements
Probit	7.36	7.82	7.18
Raff	7.45	7.85	7.35
Bissell	7.35	7.65	7.10

sec, which was 0.30 sec longer than that for right-turning drivers and 0.60 sec longer than that for drivers moving straight through the intersection.

Acceptance times for the combined drivers in Lafayette and Indianapolis are also given in Table 9. Right-turning and left-turning drivers had median acceptance times of 7.35 and 7.65 sec, respectively. Drivers moving straight through the intersection had a median lag-and-gap-acceptance time of 7.10 sec.

In his field investigations, Bissell obtained median lag-and-gap-acceptance times for right turns, left turns, and through movements, of 5.25, 6.25, and 5.80 sec, respectively (1). The corresponding values from the combined intersections in the present investigation are 7.35, 7.65, and 7.10 sec. The difference of 2.10 sec between right turns was the greatest variation encountered in the comparison of the two studies.

The discrepancies in these acceptance times are probably due to different populations of drivers. The volumes on the side and main streets were larger in the Bissell investigation, and drivers might have been forced to accept smaller time intervals. However, Raff indicated that main-street traffic volumes have little influence on driver gap-and-lag acceptances. This forced gap acceptance was observed by Bissell during peak hours when side-street drivers forced themselves into the main traffic stream in which adequate gaps were not available. Bissell also noted that many drivers cruised by the stop sign without actually stopping. This fact was particularly true for right-turning drivers and may account for the differences observed in the acceptance times for this turning movement.

Comparison of Analytic Techniques

The corresponding median acceptance-time values as determined by the probit, Raff, and Bissell methods of analysis are compared in Table 10. A reasonable agreement is evident among these three analytic techniques. In general, the lag-and-gap-acceptance times determined by the probit method are smaller than those values obtained by the Raff procedure and larger than those median acceptances estimated by the Bissell method.

CONCLUSIONS

The following conclusions inferred from the findings of this field investigation are valid only for those drivers and vehicles sampled at the study intersections in Lafayette and Indianapolis. However, these locations are representative of right-angle intersections formed by two-way, two-lane urban streets. The traffic flows on the side streets are controlled by stop signs.

1. No drivers accepted any time interval of less than 2.0 sec, and only one driver was observed accepting an interval of less than 3.0 sec.

2. The overall median acceptance times for right-turn, left-turn, and through movements were 7.36, 7.82, and 7.18 sec, respectively.

3. There were no significant differences between the median lag-acceptance and the median gap-acceptance times at the four intersections.

4. In Lafayette the gap-and-lag-acceptance times for the right-turn, left-turn, and through movements were statistically equal.

5. Significant variations were found between right- and left-turning drivers and between drivers proceeding through and those making left turns for the study intersections in Indianapolis. Through-movement and right-turn acceptance times differed only slightly.

6. When the intersections in Lafayette were combined with those in Indianapolis, a difference in acceptance times was found between drivers making left turns and right turns and between those performing through movements and left turns. However, no significant difference existed between right-turning drivers and the drivers moving straight through the intersection.

7. Lag-and-gap acceptances for combined movements in Lafayette and Indianapolis were significantly different. The size of the community apparently has some effect on driver acceptance of time gaps, because this median value increased with decreasing city size.

8. Only two of the median acceptance times as determined by the Raff and Bissell methods were outside the 95 percent confidence limits for the corresponding values obtained by the probit analysis. Thus, a general agreement existed among the results from the three methods investigated.

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