Pedestrian Gap-Acceptance

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The object of this research project was to investigate the gap acceptance of pedestrians at an unmarked midblock crossing. Data were collected by means of time-lapse photography and analyzed with the aid of a photo-optical data analyzer. Statistical tests, such as the Kolmogorov-Smirnov test, the chi-square test, and analysis of variance, were utilized to investigate the relationship between size of gap accepted and various factors such as time waited at curbside, volume of traffic, number of persons waiting at curbside, speed of approaching vehicle, and walking speed of the pedestrian. Some conclusions drawn from the results of the tests are that female pedestrians were willing to wait longer at curbside for a suitable gap than were male pedestrians; male pedestrians accepted shorter gaps than did female pedestrians; the minimum acceptable gap in a single stream of traffic was 3 sec or 75 ft; shorter gaps were accepted by groups of pedestrians rather than by individuals; and individual pedestrians crossed the roadway at greater walking speeds than did groups of pedestrians.

•CONSIDER a pedestrian standing at curbside waiting to cross a road on which traffic is flowing. At some instant he decides that an acceptable gap in the traffic stream has presented itself and that it is safe to cross. His decision is usually correct, but occasionally a pedestrian errs in his judgment with the possible result of an injury. The objective of this study was to determine what factors influence the choice a pedestrian makes to accept or reject a given gap in the traffic stream. Throughout this report a gap is defined as the space interval between successive vehicles, expressed either in time or distance. For two-directional traffic flow, a total gap is defined as the sum of the near-stream traffic gap and the far-stream traffic gap.

Although almost 20 percent of the traffic accident fatalities in the United States are those involving pedestrians, research directed at pedestrians has been slight (1, 2, 3). A library search reveals that the amount of available literature relating to the vehicle-vehicle conflict is extensive, but material concerning pedestrian-vehicle conflict is limited, in all but a few cases, to the theoretical study of mathematical models assumed to adequately simulate the problem. However, such agencies as the British Road Research Laboratory have conducted detailed research (4, 5, 6, 7, 8) in England concerning the pedestrian-vehicle conflict. Investigated were such factors as pedestrian risk taken in crossing a street, the willingness of pedestrians to use footbridges or tunnels, and the relative risks of crossing streets at various places and under various conditions.

STUDY DESIGN

Time-lapse photography was used for data collection. This allowed a continuous recording of the exact positions occupied by all vehicles and pedestrians within the camera range at ¾-sec intervals. Color film was used in order to aid in identifying vehicles and pedestrians from frame to frame.

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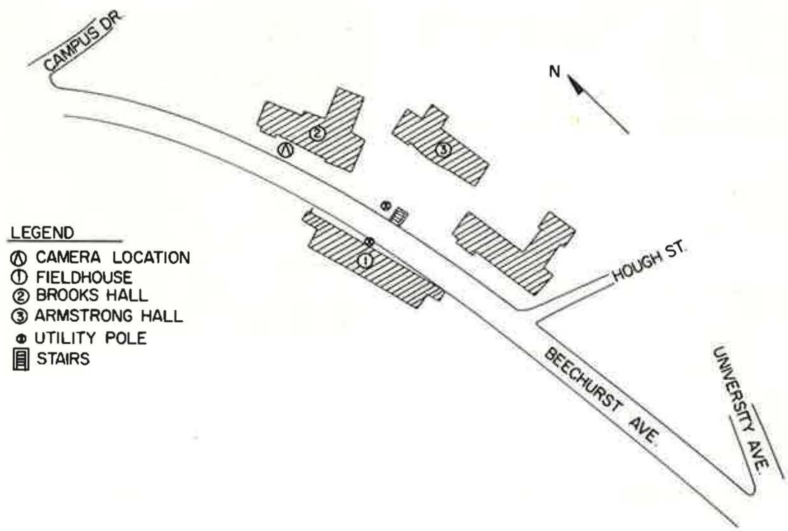

Figure 1. Study site.

An unmarked crossing located in front of the West Virginia University Fieldhouse on Beechurst Avenue was chosen as the study location. In Figure 1, a detailed sketch of the study site is shown. The characteristics of the site that lent themselves to this study are as follows:

1. An uncontrolled midblock crossing (thus reducing the unwanted elements of turning vehicles and traffic signal);
2. Frequent pedestrian crossings at a well-defined point;
3. Free-flowing traffic (frequent gaps of various sizes); and
4. A clear, unobstructed observation point.

In order to ensure a large number of pedestrians, filming was timed to include the changing of physical education classes, and only those periods in which pedestrian-vehicle conflicts appeared were recorded. During periods of no pedestrian activity, the camera was shut off. The camera remained off until a pedestrian approached the crossing area, at which time it was again turned on. This procedure was followed in order to better utilize the available film footage. An attempt was made to film only under similar weather conditions.

Markings were placed at 25-ft intervals at the curbside on both approaches to the crossing in order to define a grid to be used later in film reduction. Using a film segment on which a subject appears as an aid in locating the grid points, a coordinate system was drawn on the projection screen. This grid appeared as a network extending 150 ft on both sides of the crossing point with lines at 25-ft intervals. A sample film segment and the camera setup are shown in Figures 2 and 3.

DATA REDUCTION

A model 224 L & W Photo-Optical Data Analyzer was used to project the film onto the calibrated screen grid and the following information was extracted for each pedestrian observed:

1. Direction of crossing;
2. Pedestrian observation number and sex;
3. Film frame number in which pedestrian first appeared;
4. Group size;
5. Near-side gap accepted in frames;
6. Near-side gap accepted to the nearest 25-ft increment;

7. Far-side gap accepted in frames;
8. Far-side gap accepted to the nearest 25-ft increment;
9. Time waited at curbside in frames;
10. Selected near-side gaps rejected in frames;
11. Selected near-side gaps rejected to the nearest 25-ft increment;
12. Selected far-side gaps rejected in frames;
13. Selected far-side gaps rejected to the nearest 25-ft increment; and
14. Number of frames required for the pedestrian to cross from the near-side curb to the quarter point, centerline, three-quarter point, and far-side curb of the roadway respectively.

Figure 2. Sample film segment.

In addition to the pedestrian data, traffic volumes for each observation period were taken from the film.

DATA ANALYSIS AND RESULTS

Male Versus Female Pedestrians

Of the 740 pedestrians observed during the study, 602 were male and 138 female. An analysis was conducted, using the Kolmogorov-Smirnov two-sample test, to determine if there was a difference between male and female pedestrian crossing characteristics. It was hypothesized that a female would be more cautious, wait for a longer gap, and cross the roadway at a slower speed than would a male pedestrian. The Kolmogorov-Smirnov two-sample test may be used for this comparison because it allows the determination of whether or not two independent samples have been drawn from the same distribution (9). All tests were made at a 5 percent level of significance. From the tests it was concluded that female pedestrians tend to be more cautious and patient than male pedestrians. Females will wait longer at curbside for an adequate gap to occur, and in the process of this waiting, females tend to reject more gaps of equal duration than would males.

Figure 3. Camera setup.

As to the gap finally accepted by a male or female pedestrian, there appears to be some question as to whether or not there is a difference. By the Kolmogorov-Smirnov two-sample test it was determined that no difference exists for the total near-side plus far-side gap accepted (either in seconds or feet) by males and females. The confusion arises when either the near-side or far-side gap is studied alone. From the tests it was concluded that (a) females accept longer near-side gaps in seconds than males, but there is no significant difference for near-side gaps accepted in feet, and (b) females accept longer far-side gaps in feet than males, but there is no significant difference for far-side gaps accepted in seconds.

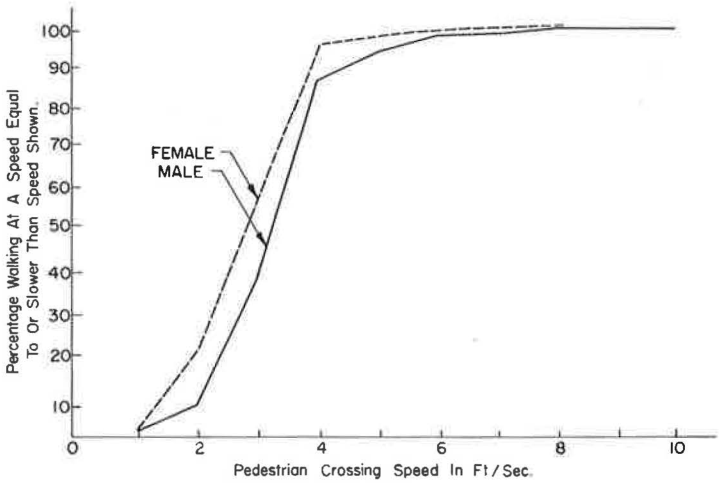

Figure 4. Cumulative overall pedestian crossing speed for males and females.

Finally, the Kolmogorov-Smirnov two-sample test concluded that females cross the roadway at a slower walking speed than do males. This is shown in Figure 4, which graphically compares the walking speed of male and female pedestrians. Table 1 gives the summary of male and female pedestrian crossing characteristics.

Effect of Time Waited at Curbside on Gap Accepted

Figures 5, 6, and 7 show the effect of time waited at curbside on the near-side gap, far-side gap, and total gap finally accepted by the pedestrian. The 1-, 5-, 14-, and 17-sec time-waited curves shown in the graphs were selected for plotting because a large number of observations had been recorded for these increments. The graphs may be interpreted as follows (Fig. 5): (a) 50 percent of the pedestrians who waited 17 sec accepted a gap of 11 sec or less, and (b) 50 percent of the pedestrians who waited 1 sec accepted a gap of 12 sec or less.

TABLE 1

SUMMARY OF MALE VERSUS FEMALE PEDESTRIAN CROSSING CHARACTERISTICS

Hypothesis H_O	Alternative H_O	Test Statistic[a]	Conclusion
Males and females wait the same time at curbside before accepting a gap.	Females wait longer at curbside than do males before accepting a gap.	6.242	Reject H_O
Males and females accept the same near-side gaps in seconds.	Females accept longer near-side gaps in seconds than do males.	7.589	Reject H_O
Males and females accept the same near-side gaps in feet.	Females accept longer near-side gaps in feet than do males.	5.69	Accept H_O
Males and females accept the same far-side gaps in seconds.	Females accept longer far-side gaps in seconds than do males.	2.15	Accept H_O
Males and females accept the same far-side gaps in feet.	Females accept longer far-side gaps in feet than do males.	8.90	Reject H_O
Males and females accept the same total near-side and far-side gaps in seconds.	Females accept longer total near-side and far-side gaps in seconds than do males.	5.633	Accept H_O
Males and females accept the same total near-side and far-side gaps in feet.	Females accept longer total near-side and far-side gaps in feet than do males.	1.408	Accept H_O
Males and females will reject similar near-side gaps in seconds.	Females will reject larger near-side gaps in seconds than will males.	28.949	Reject H_O
Males and females will reject similar near-side gaps in feet.	Females will reject larger near-side gaps in feet than will males.	30.731	Reject H_O
Males and females have the same overall crossing speed.	Males have a greater overall crossing speed than do females.	17.339	Reject H_O

[a]The acceptance region for the test statistic is $-\infty \leq X^2 \leq 5.991$.

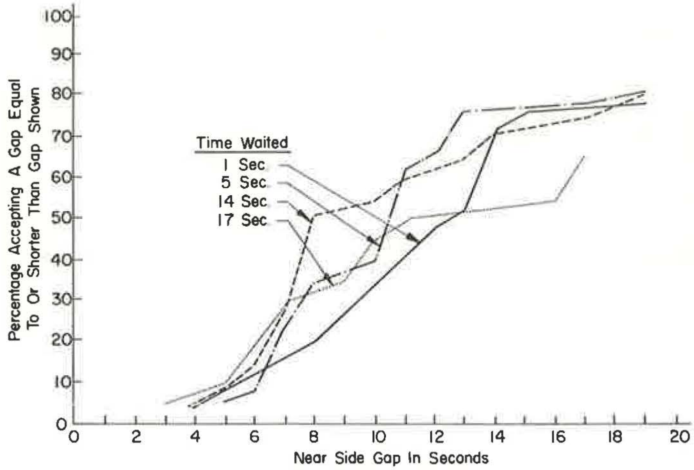

Figure 5. Effect of time waited at curbside on the near-side gap accepted.

From Figures 5, 6, and 7, no consistent conclusion could be drawn as to the effect of time waited on the gap accepted by a pedestrian. Next, these data were subjected to a one-way, fixed-effects analysis of variance test to determine if time waited had a statistically significant effect on the gap chosen (10). In addition, an attempt was made to isolate differences in levels of time waited, such as 1 sec versus 17 sec. The analysis was one-way because only one factor, time waited, was tested as to its effect on the gap chosen. In addition, the model was considered to have fixed effects because the conclusions drawn from this analysis apply only to the 39 intervals of time waited in seconds that were observed at the test site. For the analysis, a level of significance of 5 percent was chosen and the following conclusions were drawn from the test: (a) time waited at curbside has a significant effect on the near-side gap finally accepted in seconds, and (b) time waited at curbside has a significant effect on the total near-side plus far-side gap accepted in seconds.

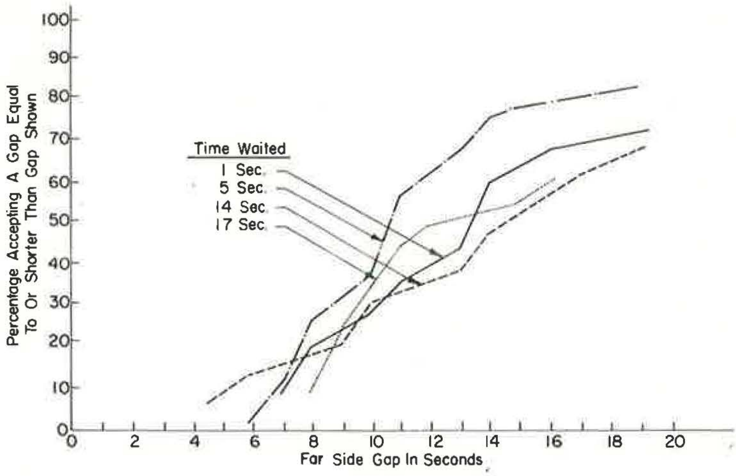

Figure 6. Effect of time waited at curbside on the far-side gap accepted.

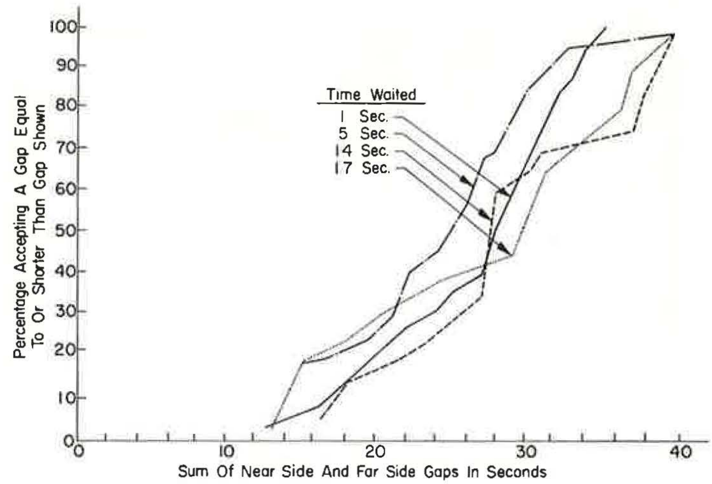

Figure 7. Effect of time waited at curbside on the total gap accepted.

With a significant difference known, an attempt was made to determine the effect of specific changes in the time-waited values. This attempt was unsuccessful because the critical difference in all cases was too large to ascertain statistically.

Thus, it has been shown that, on an overall basis as the time waited increases, the gaps accepted by pedestrians tend to become longer. Individual cases occurred in which pedestrians who waited a long period at curbside actually accepted shorter gaps, but a time-waited value at which this occurred could not be established.

Effect of Group Size on Gap Chosen

To determine statistically if group size had a significant effect on the final gap chosen by the pedestrian, a one-way, fixed-effects analysis of variance test was performed on the data plotted in Figures 8 and 9. In visually comparing the different curves of group size as seen in either Figure 8 or 9, no discernible pattern could be distinguished and

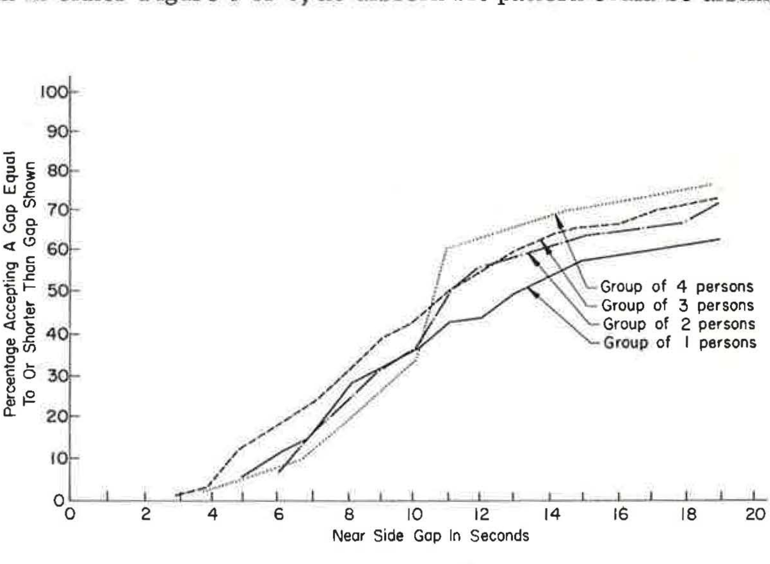

Figure 8. Effect of group size on the near-side gap accepted.

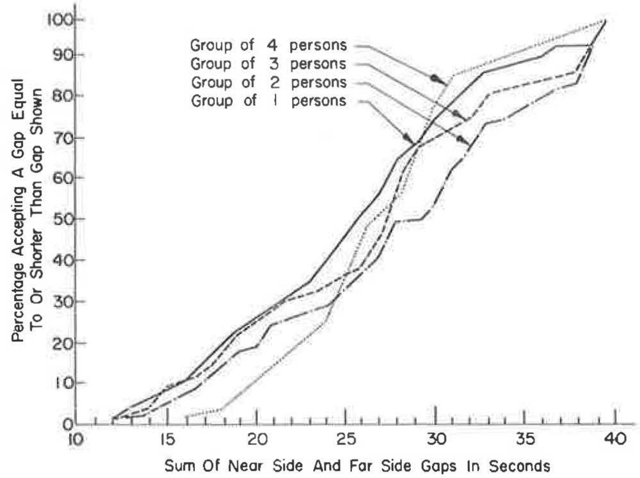

Figure 9. Effect of group size on the total gap accepted.

the only conclusion drawn was that it appeared that group size helps to determine the gap accepted by the pedestrian. Again, as in studying the effect of time waited on the gap eventually chosen by a pedestrian, a level of significance of 5 percent was chosen. The following conclusions were reached: (a) the number of pedestrians waiting at curbside has a significant effect on the near-side gap accepted in seconds by an individual pedestrian within the group, and (b) the number of pedestrians waiting at curbside has a significant effect on the total near-side plus far-side gap accepted in seconds by an individual pedestrian within the group. An attempt was also made to detect where a difference existed between specific group sizes, but this could not be determined from the analysis of variance calculations.

Finally, an attempt was made to pinpoint a difference between specific group sizes by use of the chi-square test and the Kolmogorov-Smirnov two-sample test (previously

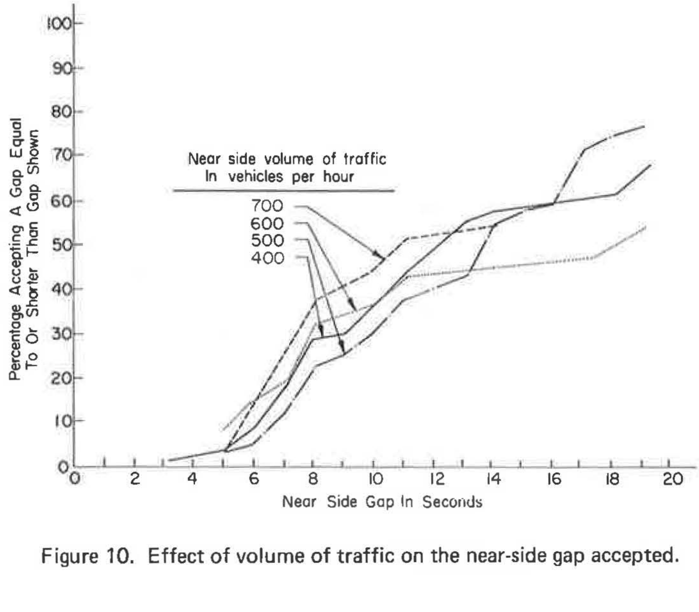

Figure 10. Effect of volume of traffic on the near-side gap accepted.

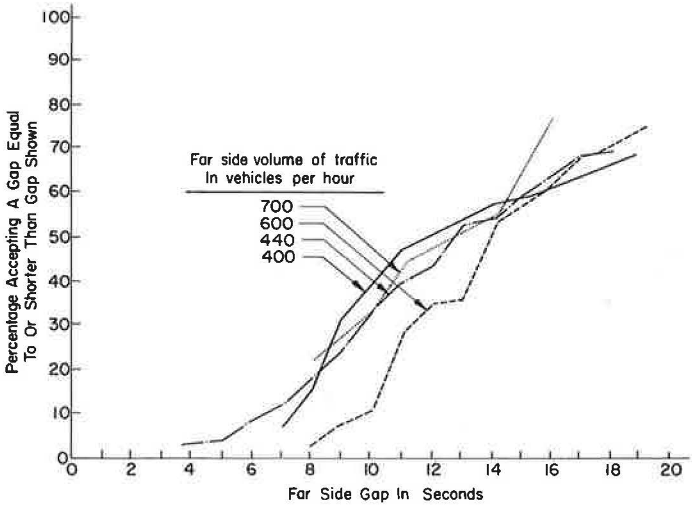

Figure 11. Effect of volume of traffic on the far-side gap accepted.

used in comparing male versus female characteristics). The chi-square test may be used to test whether two samples of data differ in any manner and the Kolmogorov-Smirnov two-sample test determines whether or not two independent samples have been drawn from the same distribution. The chi-square and the Kolmogorov-Smirnov two-sample tests resulted in the following conclusions in comparing a group size of one person first with a group size of three persons and then with a group size of four persons: (a) a group size of three persons tends to accept shorter gaps than a group size of one person, and (b) a group size of four persons tends to accept shorter gaps than a group size of one person.

Effect of Volume of Traffic on Gap Chosen

The effect of traffic volume on the near-side gap accepted and the far-side gap accepted is shown graphically in Figures 10 and 11 respectively. The indicated volumes of traffic plotted were chosen because (a) these values represented a wide range of traffic conditions, and (b) a large amount of film footage was taken during these periods. Several one-way, fixed-effects analysis of variance tests were run on these data. Again, all tests were run at a 5 percent level of significance.

The tests were unable to determine whether or not pedestrians accept shorter gaps as traffic volume increases, as one might hypothesize. Statistically, it was found only that traffic volume does enter into the pedestrian crossing decision. Further research work may tie volume of traffic to the critical gap in the traffic stream discussed later in this paper. When this occurs, volume of traffic can then serve as a warrant for a traffic engineering measure.

Pedestrian Crossing Speed

It appears that the shorter the gap accepted by the pedestrian, the greater is his crossing speed. This conclusion was drawn from the data shown in Figure 12. From the graph it can be observed that 50 percent of the pedestrians who crossed the roadway at 6 ft/sec accepted a near-side gap of 8 sec or less, whereas 50 percent of those crossing the roadway at 3 ft/sec accepted a near-side gap of 13 sec or less. Thus, the pedestrians who crossed the roadway at 6 ft/sec accepted shorter gaps than the pedestrians who crossed the roadway at 3 ft/sec. This relationship of increased pedestrian crossing speed with decreased size of gap accepted is shown in Figure 12. It holds true for a near-side gap of approximately 7 sec or less. At this point the 5

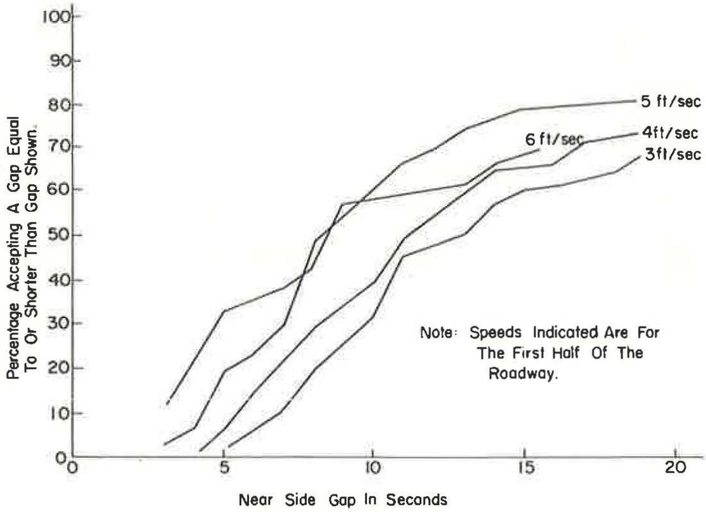

Figure 12. Effect of pedestrian crossing speed on the near-side gap accepted in seconds.

ft/sec and the 6 ft/sec curves cross. An explanation for this may be as follows: If gaps are greater than a certain duration, the gap may be acceptable at a wide variety of crossing speeds. The pedestrian may be in a hurry and run across the street utilizing only a part of the available gap. For example, if a pedestrian selected a 7-sec near-side gap and crossed at 3 ft/sec, he could reach the centerline of the 29-ft roadway in 5 sec, thus leaving a full 2 sec of unused time.

A one-way, fixed-effects analysis of variance test was run to determine whether or not crossing speed had a significant effect on the gap accepted. Using a level of significance of 5 percent, the following conclusions were drawn:

1. Pedestrian crossing speed for the first half of the roadway has a significant effect on the near-side gap in seconds accepted by a pedestrian. In general, as the size of gap accepted decreases, the pedestrian crossing speed for the first half of the roadway increases. However, the change in pedestrian crossing speed required to affect the gap accepted could not be determined.
2. Overall pedestrian crossing speed for the entire roadway width has a significant effect on the total near-side plus far-side gap in seconds accepted by a pedestrian. In general, as the total gap accepted decreases, the overall pedestrian crossing speed increases. However, the change in overall crossing speed required to affect the total gap accepted could not be determined.

Effect of Group Size

The effect of group size on walking speed is shown in Figure 13. Group sizes of one, two, three, and four persons were plotted against pedestrian crossing speed. The curve for a group size of one person is seen to be displaced from the curves of group sizes of two, three, and four persons, but little difference in crossing speed exists between groups of two, three, or four persons. This may be explained by considering that for the individual, the decision to cross is made without judging the movements of other adjacent group members. The individual tends to cross at his own speed and not be influenced by a group "bunching effect" that may tend to slow the individual pedestrian's crossing speed to that of the group.

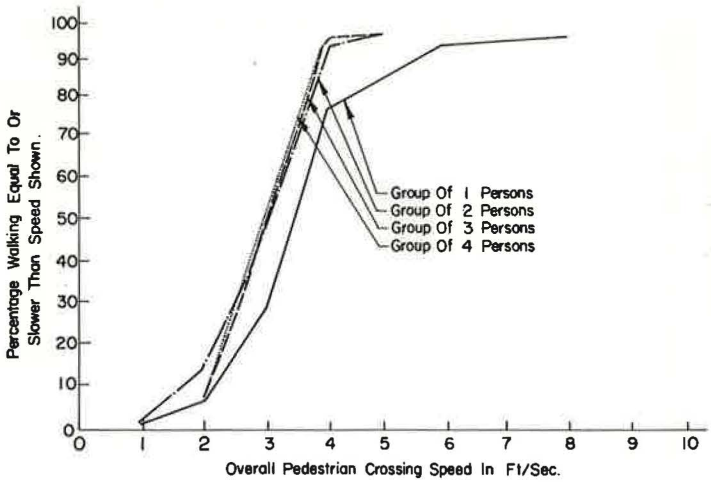

Figure 13. Effect of group size on overall pedestrian crossing speed for the entire roadway width.

Determination of the Limits of a Critical Gap

A minimum acceptable gap may vary from pedestrian to pedestrian, but it is possible to determine a minimum gap acceptable to all pedestrians observed during the study. The following limiting values were determined from the data plotted in Figures 14, 15, and 16:

1. No pedestrian accepted a near-side gap shorter than 3 sec;
2. No pedestrian accepted a near-side gap shorter than 75 ft;
3. No pedestrian accepted a far-side gap shorter than 4 sec;
4. No pedestrian accepted a far-side gap shorter than 75 ft;

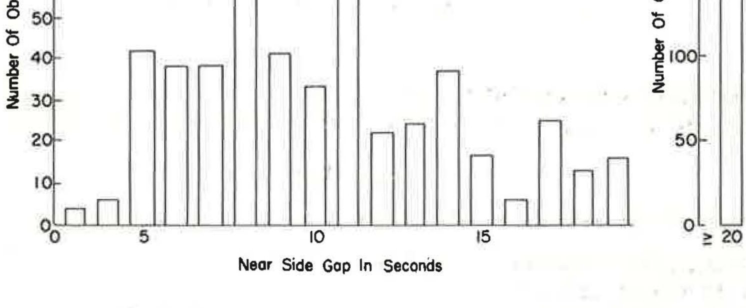

Figure 14. Frequency distribution of near-side gaps accepted.

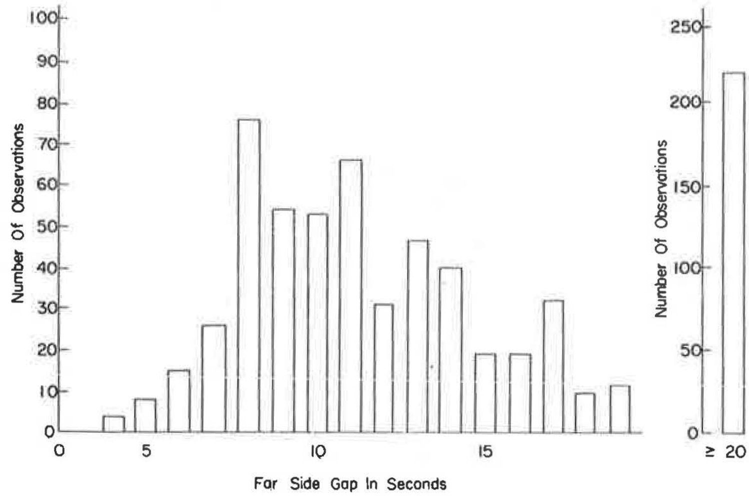

Figure 15. Frequency distribution of far-side gaps accepted.

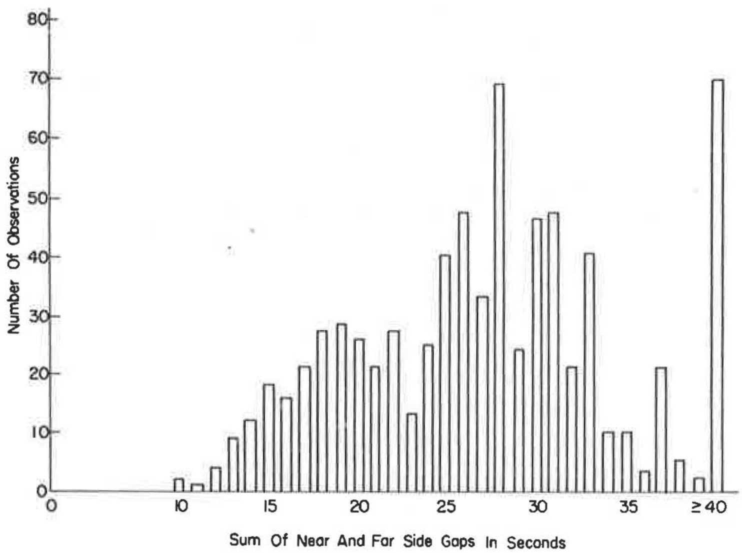

Figure 16. Frequency distribution of total gaps accepted.

5. No pedestrian accepted a total near-side plus far-side gap shorter than 10 sec; and
6. No pedestrian accepted a total near-side plus far-side gap shorter than 200 ft.

SUMMARY

The results of this research may be briefly summarized as follows:

1. Female pedestrians were willing to wait longer at curbside for an adequate gap to occur in the traffic stream.

2. There was no difference in the size of the total gap (near-side plus far-side gap) accepted by male or female pedestrians. However, males accepted shorter near-side

gaps, measured in seconds, than did females, and shorter far-side gaps, measured in feet, than did females. There was no significant difference for near-side gaps measured in feet, nor far-side gaps measured in seconds.

3. Time waited at curbside had a statistically significant effect on both the near-side gap and total gap accepted. In general, the gap size increased as the time waited at curbside increased. However, there were many exceptions.

4. Groups of pedestrians accepted shorter gaps than did individual pedestrians.

5. The effect of traffic volume on gap acceptance could not be statistically verified from the study data. Statistically it was found only that volume of traffic does enter into the pedestrian crossing decision.

6. Pedestrians crossing the roadway at higher walking speeds accepted shorter gaps than those crossing at normal walking speeds.

7. The individual pedestrian crossed the roadway at a greater walking speed than did groups of pedestrians.

8. No pedestrian accepted a near-side gap of less than 3 sec or 75 ft nor a far-side gap of less than 4 sec or 75 ft. No pedestrian accepted a total gap of less than 10 sec or 200 ft.

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