# Measures of Pedestrian Behavior at Intersections

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**This research was performed as part of a research project to identify and evaluate intersection improvements for pedestrian safety at urban intersections. Two field studies and a series of field observations were conducted to identify measures and methods that could reliably yield information concerning potentially hazardous pedestrian behavior at intersections. Both operational measures and conflict measures were investigated. Of 16 behavioral measures that were tested at 120 intersections in the original field study, 7 were retained, refined, and tested in the following field study. These measures showed considerable promise in differentiating the high from the low accident intersection of a matched intersection pair (having similar traffic controls and geometrics). The measures that were developed in this task were to be used in the evaluation phase of the project.**

This paper presents the results of a task, which was one of several in a research project (1), to develop and evaluate a set of pedestrian-vehicle measures. Several field studies were conducted to identify measures and methods that could reliably yield information concerning potentially hazardous pedestrian behavior at intersections. The measures investigated were of two general types: operational measures and conflict measures.

Operational measures, such as volume, queue formation, and delay, have long been accepted as useful in establishing the characteristics of pedestrian and vehicle movement. Not nearly so well established, conflict measures have been developed for certain vehicle studies primarily to measure the hazards of traffic zones, such as intersections. Unfortunately, in the specific area of pedestrian countermeasures, conflict measures have not been well established. The relation between such measures and the long-term pedestrian accident history of an intersection has not been demonstrated.

In previous observational studies, a single data collection procedure was usually followed. Mainly, manual observation and hand coding of pedestrian and vehicular activities were used. In some studies the manual tallies of vehicular pedestrian volumes were the major data source; in other studies real-time and time-lapse photography was used to record vehicular and pedestrian behavior. In relatively few studies were pedestrians and drivers interviewed to determine attitudes toward or reasons for their behavior. A notable exception to the reliance on a single procedure and the absence of interview data was the Berger study (2). Consequently, we drew heavily on the methods and findings of that study in developing the measures presented below.

## REQUIRED CHARACTERISTICS OF THE BEHAVIORAL MEASURES

To be useful, a behavior had to possess the following five characteristics:

1. The behavior had to be definable in objective, observable events so that coding would be reliable.
2. The behavior had to occur with sufficient frequency to permit an efficient data collection schedule.
3. The behavior had to have an association with intersection safety or operation (assumed or proven).
4. The behavior had to be sensitive to the differences between intersections. Conflict measures had to, in addition, discriminate on the basis of accident history or vehicle-pedestrian flow. Sensitivity was emphasized for several reasons. Validating the measures would provide considerable guidance in the selection and modification of candidate measures. The selected conflict measures could be used by city engineers to determine warrants for intersection treatment. The acceptance of the countermeasures would depend on proof of their effectiveness. Thus, the behavior used to evaluate the countermeasures must be meaningful and believable to the city traffic engineer.
5. The behavior had to be measurable by currently available and cost-effective techniques.

## APPROACH TO THE DEVELOPMENT OF BEHAVIORAL MEASURES

The initial step was to establish and collect behavioral measures for a set of intersections for which a complete set of accident records was available. Since two inter-

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sections having the same traffic controls and similar geometrics often have different accident records, we concluded that different operational and conflict levels would be associated with the two intersections. Our intent was to determine which behaviors were most often associated with high pedestrian accident intersections.

We identified a set of high pedestrian accident intersections (where three or more accidents had occurred) in Washington, D.C., San Francisco, and Oakland, California, and matched a number of these intersections with low pedestrian accident intersections (where pedestrian accidents were 50 percent or less than those that occurred at the high accident locations). This matching procedure ensured that the evaluation of measures would be conducted within a common situational context, i.e., intersections with similar attributes. This design avoided confounding the results of our sensitivity study with the physical attributes of the intersections.

The field portion of the task was designed to develop measures that would be reliable, be easily applied, have wide application, discriminate between the intersections, and be related to the intersection pedestrian safety record. In addition, the field studies would provide insight into the variety of operational problems at different intersections and their possible remediation.

## FIRST FIELD STUDY

A set of behaviors (Table 1) was generated from the Berger study (2); these behaviors were defined and all measures involved were field tested.

Simultaneously, a listing of the frequency of pedestrian accidents (from 1971 through 1973) by intersection was generated, and all intersections experiencing three or more accidents were designated as potential study sites. Review of the geometric characteristics of these intersections showed that the vast majority had four legs; therefore, only four-legged intersections were considered in the field studies. Sixty of the high accident intersections (45 in Washington, D.C., and 15 in California) were matched with low accident intersections having similar geometrics. In well over 90 percent of the cases, the matched intersections (referred to as a pair) shared a common road and were within several blocks of each other. The following are some characteristics of the 60 pairs:

| Characteristic | Number of Pairs |
|---|---|
| Right angle, two-way, two-way (15 were in California) | 30 |
| Skew, two-way, two-way | 15 |
| Right angle, two-way, one-way | 15 |
| Not signalized | 19 |
| Signalized | 24 |
| Traffic signalized and pedestrian signalized | 17 |

These 60 pairs of intersections served as the test bed for the development of the behavioral measurement procedures. A subset of these site pairs was used in the selection of promising behavioral measures and identification of potential intersection accident causal characteristics.

### Development of Behavioral Measurement Procedures

We decided to attempt to gather the required data by manual tallies and observational procedures because previous studies had proved nonmanual techniques to be costly. For example, Berger (2) found that 3 h were required to reduce a 15.2-m (50-ft) roll of time-lapse film that had required only ½ h to photograph.

A preliminary set of data collection forms was designed for recording the candidate behaviors that had been selected (Table 1). Also, forms were designed for the collection of pedestrian and vehicle volume data.

Approximately 10 people were trained by classroom instruction and by in-the-field practice to use the preliminary forms. During the training sessions, the behavioral definitions were continually refined. Months of effort were devoted to making the measures operative. The measurement procedures were then standardized and the set of data collection forms revised.

A sample of the 60 intersection pairs was selected to determine the reliability of the data collection procedures for each of the measures of interest. The results of this reliability analysis, given in Table 2, indicated that the reliabilities were all high. These results demonstrated the feasibility of using the developed procedures to select the most promising behavior measures.

### Selection of Promising Behavioral Measures

The collection of the behavior measure data represented the major effort of the task. Teams of field investigators visited each site to collect the behavioral and operational data. The procedures that were developed indicated that from one to four field investigators would be needed per intersection (depending on pedestrian volumes).

The data collection schedule was designed to sample the morning peak, off-peak, and afternoon peak traffic. A minimum of 3 h of data were collected at each intersection in a pair by field investigators who traveled back and forth between the two intersections. An additional data collection requirement was that at least 100 pedestrian crossings be observed at a pair and that a minimum of 40 crossings be observed at one of the intersections.

A continuous review of the collected data and field notes indicated that some intersection pairs should be discarded. At some sites, construction was started after the arrival of the field team; at others, the signals at one site in a pair became inoperative. In some cases, differences in geometrics became evident. After careful investigation 38 intersection pairs were selected. These intersections had the following characteristics.

| Characteristic | Number of Pairs |
|---|---|
| Right angle, two-way, two-way (eight were in California) | 21 |
| Skew, two-way, two-way | 6 |
| Right angle, two-way, one-way | 11 |
| Not signalized | 15 |
| Traffic signals | 20 |
| Traffic signals and pedestrian signals | 3 |

Table 3 presents a summary of the data from the 38 selected intersection pairs. The second column in this table gives the percentage of intersection pairs exhibiting 5 percent or more of a particular type of behavior; that is, at least 5 percent of the pedestrians at one of the intersections performed the behavior. Only those intersections where the behavior could occur were included in the calculations. Thus, if an intersection pair did not have signals, it could not have any pedestrians crossing against the signal (CA) and would be excluded from the CA calculations. Fewer than half of the intersection pairs exhibited 5 percent or more of the following behaviors: A, D, RC, VR (pedestrian), VL (pedestrian), SC, VS, VR (vehicle), and VL (vehicle). Because of their infrequent occurrence, these behaviors were eliminated or redefined. The third column of the table indicates the percentage of intersection pairs at which a particular behavior occurred more frequently at the high

Table 1. List of candidate pedestrian behaviors.

| Behavior | Symbol | Definition |
|---|---|---|
| Abort | A | Returning to curb after placing both feet on the roadway or abandoning crossing to cross intersecting street |
| Backup movement | B | Momentarily reversing or hesitating after starting to cross roadway because of the threatening approach of a vehicle |
| Diagonal crossing | D | Crossing intersection diagonally |
| Running in roadway | R | Running in roadway after having entered roadway |
| Running into roadway | RC | Running into roadway from curb |
| Outside crosswalk | OC | Crossing all traffic lanes outside painted crosswalk (not coded for unmarked crosswalks) |
| Crossing against signal[a] | CA | Crossing all traffic lanes against pedestrian or traffic signal |
| Starting during caution signal[a] | SC | Starting to cross roadway during caution phase of signal |
| Starting against signal[a] | SA | Starting to cross roadway against pedestrian or traffic signal although walk or green signal appears before crossing is completed |
| Straight-through vehicle[b] | VS | Being within 6 m of and in path of nonrestricted vehicle proceeding straight through intersection |
| Right-turning vehicles | VR | Being within 6 m of and in path of vehicle turning right into the crosswalk |
| Left-turning vehicles | VL | Being within 6 m of and in path of vehicle turning left into the crosswalk |
| Vehicles moving through crosswalk, then turning right | VT | Being in conflict with vehicles moving through crosswalk and then turning right |
| Vehicle overtaking | VO | Entering roadway and moving in front of stopped or pausing vehicle (not a parked vehicle) into lane of traffic moving in same direction |
| Moving vehicle | MV | Being in traffic lane while vehicle going straight moves through crosswalk |
| Proximity of vehicle | PV | Entering traffic lane while vehicle approaches six car lengths or fewer away |

Note: 1 m = 3.3 ft.
[a]Signalized intersections only. [b]Nonsignalized intersections only.

Table 2. Interrater reliability of sampling of pedestrian behavior.

| Behavior | Mean Correlation Coefficient[a] | Number of Independent Pairs of Coders |
|---|---|---|
| A | 0.9724 | 5 |
| B | 0.8485 | 7 |
| D | 1.0000 | 3 |
| R | 0.8113 | 6 |
| RC | 0.8451 | 5 |
| OC | 0.8599 | 7 |
| CA | 0.8623 | 7 |
| SC | 0.9175 | 4 |
| SA | 0.8872 | 7 |
| VS | —[b] | — |
| VR | 0.8843 | 7 |
| VL | 0.8816 | 4 |
| VT | —[b] | — |
| VO | —[b] | — |
| MV | 0.7508 | 7 |
| PV | —[b] | — |

[a]Each correlation coefficient was based on a sample of 20 cycles. All mean correlation coefficients were statistically significant at the 0.01 level.
[b]Activity occurred too infrequently to calculate a correlation coefficient.

Table 3. Summary of pedestrian behavior recorded at 38 selected intersection pairs.

| | Intersection Pairs (%)[a] | | |
|---|---|---|---|
| Behavior[b] | ≥5% of Pedestrians Exhibited Behavior | Behavior Occurred More Frequently at High Accident Intersection | Percentage of Pedestrians Exhibiting Behavior Was Greater at High Accident Intersection |
| B | 86.8 | 68.4 | 52.6 |
| R | 86.8 | 57.9 | 42.1 |
| RC | 44.7 | 31.6 | 42.1 |
| OC | 54.0 | 37.8 | 37.8 |
| MV | 100.0 | 73.7 | 55.3 |
| VS (pedestrian)[c] | 53.3 | 46.7 | 60.0 |
| VR (pedestrian) | 31.6 | 44.7 | 55.3 |
| VL (pedestrian) | 21.0 | 34.2 | 42.1 |
| PV[c] | 93.3 | 60.0 | 46.7 |
| CA[d] | 82.6 | 56.5 | 34.8 |
| SC[d] | 35.7 | 57.1 | 71.4 |
| SA[d] | 91.3 | 69.6 | 52.2 |
| VS (vehicle)[c] | 0.0 | 53.3 | 60.0 |
| VR (vehicle) | 42.1 | 55.3 | 50.0 |
| VL (vehicle) | 28.9 | 42.1 | 52.6 |

[a]Based on the total number of intersection pairs at which the behavior could occur. Intersection pairs at which behavior occurred with equal frequency or did not occur at all were treated as having occurred less frequently at the high accident intersection.
[b]Behaviors identified by (pedestrian) are based on the number of pedestrians involved in that behavior and those identified by (vehicles) or the number of vehicles involved.
[c]Unsignalized intersections only.
[d]Intersections with traffic or pedestrian signals only.

accident intersection. These data indicate the ability of a behavior to differentiate a high accident location from a low accident location. The fourth column of the table indicates the percentage of intersection pairs at which the percentage of the occurrence of a behavior was higher at the high accident intersection.

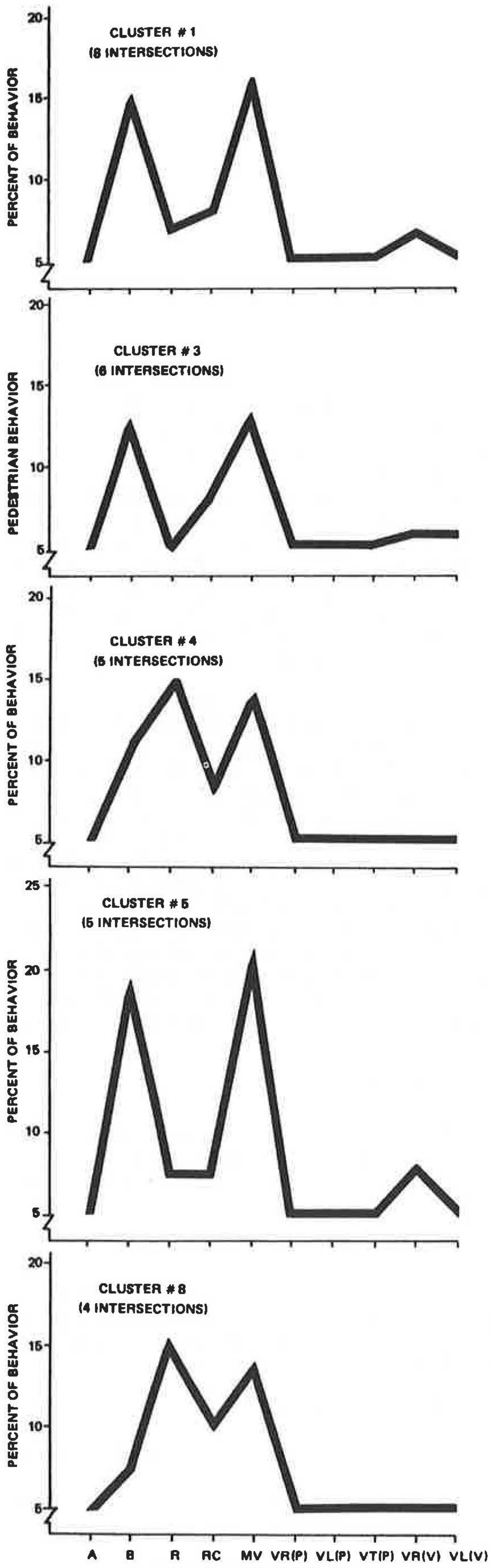
An analysis of these data by the Fisher's distribution free sign test was performed to determine which behaviors significantly differentiated between the high and low members of a pair. This analysis dealt only with the direction of the difference (more frequent at high site equaled a plus, less frequent at low site equaled a minus) and ignored ties. This analysis revealed that the following behaviors occurred more frequently at the high accident sites: B, MV, SA, VR (vehicle), and VL (vehicle).

Although these results appeared to be promising, the high accident sites were noted to have heavier pedestrian volumes. Thus, these differences in frequencies could be attributed to the fact that generally more people were present to exhibit these behaviors. (When we used the percentage of pedestrians exhibiting each behavior as a measure, we found no difference between the percentages at the high and low accident sites.) On the other hand, the differences in the frequency of these behaviors could have been sufficient to contribute to the differences in the accident histories of the intersections.

Based on these results, we decided to further examine the percentage of pedestrians performing each behavior to determine whether a combination of behaviors could be used to differentiate high and low accident intersections. Using a program developed by Yoo, Schmitz, and Berger (3), we classified intersections based on the percentage of pedestrians performing 10 specific behaviors: A, B, R, RC, MV, VR (pedestrian), VL (pedestrian), VS (vehicle), VR (vehicle), and VL (vehicle). These behaviors were selected because they could occur at any of the 38 site pairs. Behavior A, which occurred with extremely low frequency and was therefore omitted from the previous univariate analyses, was included in this analysis since it might interact with other variables. The program compared each intersection with every other intersection. Intersections having similar percentages of pedestrians involved in the same behaviors were clustered together.

Eight clusters of four or more intersections were created; in all, 36 of the 76 intersections were placed into one or more of these clusters. Although seven of the eight clusters contained either all high or all low accident intersections, one cluster contained four low and one high intersections. The success of this classification process was impressive: The program treated each intersection individually and not as a member of a

Figure 1. Profile of low accident intersection clusters.




pair; therefore, signalized and nonsignalized, two-way and one-way, and right angle and skew intersections were all classified by using the same scheme.

The graphs for each of the eight clusters are presented in Figures 1 and 2. A distinctive feature of the low accident clusters (as shown in Figure 1) is that they were bimodal; i.e., the percentage of MV's was equal to the percentage of B's (clusters 1, 3, and 5) or R's (clusters

Figure 2. Profile of high accident intersection clusters.

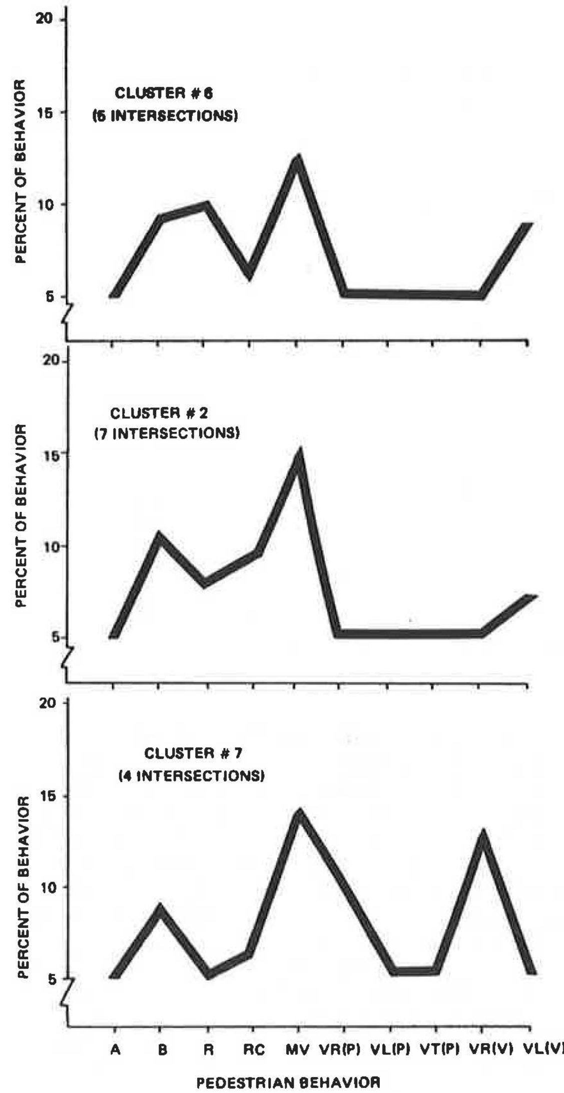



Table 4. Revised list of pedestrian behaviors.

| Candidate Behavior | Symbol | Definition |
|---|---|---|
| Backup movement | B | Momentary reversing or hesitating after starting to cross roadway because of threatening approach of a vehicle |
| Moving vehicle | MV | Being in traffic lane while vehicle going straight moves through crosswalk |
| Turning vehicle | TV | Being within 6 m of and in path of a turning vehicle |
| Vehicle hazard | VH | Entering a traffic lane while an unrestricted vehicle approaches within one block |
| Running vehicle hazard | RVH | Running in a traffic lane in response to a vehicle hazard |
| Running vehicle turning conflict | RTV | Running in a traffic lane in response to a turning vehicle or a potential turning vehicle |

Note: 1 m = 3.3 ft.

**Table 5. Summary of revised pedestrian behaviors recorded at nine intersections.**

| | Signalized Intersections[a] | | | | | | | | | | | | Nonsignalized Intersections[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | |
| Behavior | Frequency | % | Frequency | % | Frequency | % | Frequency | % | Frequency | % | Frequency | % | Frequency | % | Frequency | % | Frequency | % |
| B | + | + | + | + | + | + | | | | | + | + | + | + | | | + | + |
| MV | + | | + | + | + | + | + | + | | | + | | + | + | + | | + | + |
| TV[b] | + | | + | + | | | | | | | + | + | + | + | + | + | | |
| TV (RTV)[c] | + | + | + | + | | | + | + | + | + | | | + | | + | + | | |
| TV[d] | + | + | + | + | | | | | | | + | | + | + | + | + | | |
| RTV[e] | + | | + | + | | | + | + | + | + | | | + | | + | + | | |
| TV + RTV | + | + | + | + | | | | | | + | + | | + | | + | + | | |
| VH | + | | + | | + | + | + | + | | | + | + | + | + | + | | + | + |
| RVH | + | + | + | + | + | + | + | + | + | + | + | + | + | + | | | + | + |
| VH + RVH | + | + | + | | + | + | + | + | | | + | + | + | + | + | | + | + |

[a] + indicates that the high accident site exhibited a greater frequency or percent of the stated behavior.
[b] TV percentage = number of TV's per number of pedestrians.
[c] RTV percentage = number of RTV's per number of pedestrians.
[d] TV percentage = number of TV's per number of vehicles.
[e] RTV percentage = number of RTV's per number of vehicles.

**Table 6. Pedestrian and vehicle volumes at nine intersections.**

| Intersection Number | Type[a] | Pedestrians | Vehicles Turning Left | Vehicles Turning Right | Vehicles Going Straight |
|---|---|---|---|---|---|
| 1 | H | 1125 | 124 | 120 | 1044 |
| | L | 624 | 216 | 76 | 1140 |
| 2 | H | 853 | 104 | 192 | 1168 |
| | L | 269 | 108 | 132 | 960 |
| 3 | H | 138 | 40 | 40 | 452 |
| | L | 156 | 20 | 60 | 368 |
| 4 | H | 139 | 16 | 44 | 408 |
| | L | 130 | 28 | 18 | 700 |
| 5 | H | 149 | 40 | 56 | 1220 |
| | L | 130 | 64 | 64 | 1072 |
| 6 | H | 530 | 100 | 172 | 1144 |
| | L | 365 | 64 | 60 | 906 |
| 7 | H | 154 | 24 | 72 | 236 |
| | L | 76 | 16 | 12 | 144 |
| 8 | H | 123 | 64 | 44 | 304 |
| | L | 94 | 56 | 48 | 328 |
| 9 | H | 120 | 8 | 8 | 228 |
| | L | 72 | 8 | 12 | 168 |

[a] H = high accident intersection; L = low accident intersection.

4 and 8). The clusters containing the high accident locations (Figure 2) had a considerably higher MV percentage than B or R. Although the previous analysis indicated that B's occurred more frequently at the high accident sites, this analysis indicated that the percent of pedestrians displaying B behavior was less. Perhaps high accident locations would have a better accident record if a proportional number of people hesitated for vehicles (B) or ran in response to vehicles (R). Also, of the three high accident clusters, only cluster 6 consisted of nonsignalized intersections. This cluster displayed a higher percentage of R's than cluster 2 or 7. This finding was in keeping with accident data analyzed in another task of the project: A higher percentage of R-behavior pedestrians were hit at nonsignalized intersections than at signalized intersections.

The analysis of the clusters indicated that the following five variables most influenced the differentiating between high and low accident locations: B, R, MV, VR (vehicle), and VL (vehicle).

These results tended to confirm earlier analysis and indicated the predictive value of several of the behavioral measures. (R was added, although SA was excluded from this multivariate analysis since SA could only occur at the 46 signalized sites.)

### Identification of Possible Intersection Accident Causal Characteristics

The final step in the identification of accident causal factors was to perform a detailed site survey in Washington, D.C., of 30 of the 38 intersection pairs. The previously collected data were used to guide the investigation of each site pair. Additional site factors that might account for the differences in accident experience were explored during the activity.

Each site pair was reviewed for pedestrian and traffic volume, the nature of the abutting property, and the type of vehicle regulations in effect. The high accident site did not differ from the low accident site in presence of schools, playgrounds, parking regulations or observance, turn restrictions, vehicle volume, or turning volumes. The sites in a pair all had a road in common, and, therefore, no differences in vehicle volumes were expected.

Several significant differences were, however, uncovered. First, the pedestrian volumes were significantly higher ($p \leq 0.05$) at the high accident intersections. Also, the high accident sites were significantly more commercial or higher in density than the low accident locations. The high accident sites significantly more often had a liquor store abutting on the intersection. The age of the accident-involved pedestrian and the time of day that the accident occurred did not indicate that alcohol was a problem at these locations. Rather, we suspected that the presence of the liquor stores was a general indication of the socioeconomic environment surrounding the intersection. These neighborhoods often had a higher density than the low accident sites and appeared to be less desirable than their low accident counterparts.

## SECOND FIELD STUDY

Because of the promising nature of the behaviors identified in the first field study, we undertook to further refine the data collection methods and the behaviors in a second field study.

### Refinement of Behaviors

Based on the field observations and the subsequent results, a review of the promising behaviors was initiated that stressed the importance of pedestrian safety. Three major questions were asked about each behavior.

1. Does the occurrence of this behavior represent a safety hazard?
2. Are there other behaviors that are not being measured that represent distinctly hazardous situations?
3. Can we improve the procedure by which we measure each behavior?

We concluded that most of the behaviors identified as promising in our previous analyses satisfied question 1.

However, behavior R, by itself, did not appear to be a safety hazard; we would consider this behavior when it occurred in combination with other behaviors.

A consideration of question 2 led to a reevaluation of behavior PV at nonsignalized intersections. Behavior PV seemed to cover an important situation; however, its definition was a source of coding error and was considered too stringent. Therefore, behavior VH was proposed (Table 4) which could be used in combination with behavior R.

Considering question 3 led to the combining of the previous behaviors VR and VL into one behavior, TV, which could also be used in combination with behavior R. A combination of questions 1 and 3 also resulted in the refinement of the definitions of B and MV. A set of revised definitions and symbols (Table 4) led to the revision of the data collection forms, which made it possible to collect over twice as many data per day and greatly simplified the analysis process.

### Pilot Testing

The newly defined behaviors and the revised data collection procedures were pilot tested at nine pairs of intersections. These intersections were randomly selected from those used in the first field study. Three pairs had pedestrian signals, three pairs had traffic signals only, and three pairs had no signals.

A two-person data collection team collected data at each site for a day. The data collection followed the schedule used in the first field study. The data collection procedures met the criteria of efficiency and minimum retraining.

A summary of the results from this pilot study is given in Tables 5 and 6. On the basis of this small sample, MV, VH, and RVH were found to significantly differentiate ($p \leq 0.05$) the high from the low accident intersections in a pair. This differentiation was based on the frequency of the behavior to be higher at the high accident site. Behavior RVH also separated the high from the low sites on the basis of the percentage of that behavior to occur at each site. On the basis of this pilot study, behaviors B, TV, and RTV did not significantly differentiate among the sites, but, based on their performance during the first field study and the trends from this second study, they did show some promise of doing so.

## CONCLUSIONS

The set of behaviors studied appears to address a variety of pedestrian safety problems revealed during a review of the accident data. Behaviors B, VH, RVH focus on the acceptance of small vehicle gaps on the part of pedestrians and the problems of the short time that the pedestrian is visible to the vehicle driver. TV and RTV are a corollary of the turn-merge accident frequently noted at signalized intersections. MV and SA are indications of pedestrian risk taking. In both cases, the pedestrian is in a travel lane exposed to a potential conflict with a vehicle. In behavior SA, the pedestrian anticipates the walk interval (early starter) and possibly presents a target to vehicles speeding to avoid a red stop signal. Behavior MV can occur any time the pedestrian violates the traffic signal or enters the roadway while through vehicles are still moving through the crosswalk area. The two field studies indicate that use of behaviors discussed above shows considerable promise of providing a future tool for differentiating the high and the low accident intersections.

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