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# Pedestrian Behavior and Bicycle Traffic

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# Contents

# Authors of the Papers in This Record

Bhatacharya, Rathi K., Bradley University, Peoria, IL 61606
Cross, Kenneth D., Anacapa Sciences, Inc., P. O. Drawer Q, Santa Barbara, CA 93102
Cynecki, Michael J., Department of Civil Engineering, Wayne State University, Detroit, MI 48202
Datta, Tapan K., Department of Civil Engineering, Wayne State University, Detroit, MI 48202
Edwards, Jerry L., Barton-Aschman Associates, 1610 South Sixth Street, Minneapolis, MN 55454
Flak, Mark A., Goodell-Grivas, Inc., 17320 West Eight Mile Road, Southfield, MI 48075
Jones, Margaret Hubbard, Institute of Safety and Systems Management, University of Southern California, University Park, Los Angeles, CA 90007
Khasnabis, Snehamay, Department of Civil Engineering, Wayne State University, Detroit, MI 48202
Lehman, Joshua, Traffic and Transportation Division, Seattle Engineering Department, 708 Muni Building, Seattle, WA 98104
Ohrn, Carl E., Barton-Aschman Associates, 1610 South Sixth Street, Minneapolis, MN 55454
Opiela, Kenneth S., GM Transportation Center, General Motors Technical Center, Warren, MI 48090; graduate student at Wayne State University when this research was performed
Randolph, Dennis A., Goodell-Grivas, Inc., 17320 West Eight Mile Road, Southfield, MI 48075
Robinson, Ferrol O., Barton-Aschman Associates, 1610 South Sixth Street, Minneapolis, MN 55454
Sorton, Alex, Traffic Institute, Northwestern University, 555 Clark Street, Evanston, IL 60204
Wheatley, Patricia L., Community Resources Information Services of Santa Barbara County, P. O Box 2478, Santa Barbara, CA 93120; formally with University of California at Santa Barbara
Zegeer, Charles V., Goodell-Grivas, Inc., 17320 West Eight Mile Road, Southfield, MI 48075

# Measuring Pedestrian Behavior

Margaret Hubbard Jones

The lack of a criterion measure of pedestrian performance may, in part, account for the relative neglect of pedestrian safety. The measure developed here is based on observation of pedestrian behavior in normal traffic. Observation is limited to a small number of behaviors that are critical for accident causation in order to reduce the information load on observers. Unambiguous coding rules and intensive training of observers resulted in achievement of very high intercoder reliabilities. The technique was used successfully in an evaluation of a pedestrian safety curriculum for primary grades. At intersections, the behaviors of some 1500 children were coded, and about 750 were coded at midblock crossings. The remarkable finding was the prevalence of dangerous behavior patterns in the school trip, where the probability of an accident is low. Although the measurement technique was developed while observing child pedestrians, it is equally applicable to adults.

The social costs of pedestrian collisions with motor vehicles are immense, contributing almost 20 percent of the fatalities attributable to motor vehicles. Yet pedestrian safety is consistently underplayed in the United States in terms of research, program development, and interest. Although there are many reasons for this, the absence of a reliable and valid criterion of pedestrian performance is an important contributor. This paper describes the development of such a criterion measure. The developmental work was done on children, who are greatly overrepresented in pedestrian fatalities, but the techniques developed are appropriate for pedestrians of any age.

A performance measure should be reliable, valid, feasible, and cost effective if it is to be useful in evaluating behavioral change. The first decision is where to test: Behavior on ranges and in other restricted environments has never been shown to be predictive of behavior in real traffic and, on the face of it, such situations are both too simple and too obtrusive. Even Dueker's technique (1) of eliciting crossing of a real street where there was controlled but real traffic (one automobile) is too simple to permit generalization to other kinds and complexities of situations. The behavior to be measured must therefore (a) be unconstrained, (b) be recorded unobtrusively, and (c) occur in many different situations of normal complexity. That is to say, it must occur in normal walking trips.

Measuring behavior in normal traffic is the best guarantee of validity. The validity sought here is construct validity and it is gained by deriving the behavioral events schedule from the in-depth accident analyses of Snyder and Knoblauch (2) and Knoblauch (3). In a large proportion of cases, the proximal causes of pedestrian accidents are the pedestrian's failure to search and detect and his or her sudden appearance, which implies running into the path of a vehicle and unexpectedness of location or blocking of driver's or pedestrian's view.

The second decision concerns measuring techniques: In theory, these can be instrumented, observational, or some combination of the two. However, the only practical approach involving instrumentation is videotape, which is ultimately coded by trained observers. It has serious disadvantages: It is significantly more expensive and provides much less information about the general traffic circumstances, speed, and distance. It is also more difficult to do unobtrusively in some situations than observation. Its single supposed advantage—potentiality for coding by two observers—is both very expensive and unnecessary, since the observers must be trained to the same high degree of reliability whether or not videotape is used. The method of choice was on-the-spot coding of behavior by highly trained observers. This is both feasible in all situations and most cost effective. The question that usually arises is one of reliability. In three previous studies observers have achieved high interobserver reliabilities (4-6). Standard techniques for increasing reliability are simplification of both the observation itself and the recording of it, avoiding informational overload, and providing extensive training. The remainder of this paper describes the development of the observational technique for pedestrian behavior, the reliability achieved, and, briefly, its use as a criterion of countermeasure effectiveness.

## PARAMETERS OF PEDESTRIAN BEHAVIOR

In order to focus observers' attention and avoid information overload, only those aspects of pedestrian behavior most likely to be causally related to accidents were selected for coding:

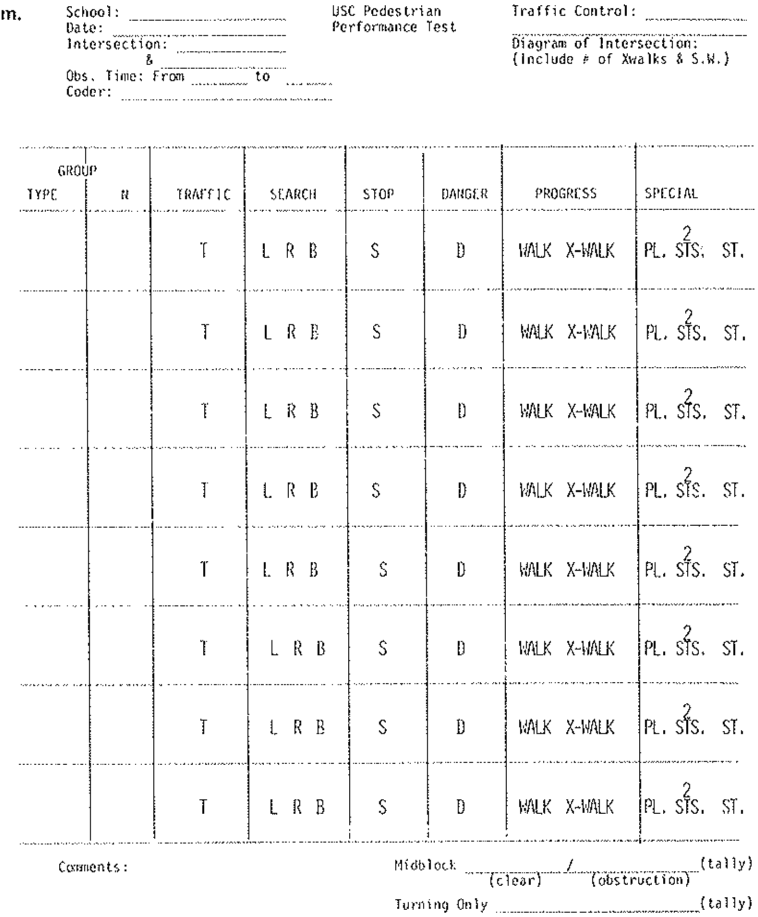
1. Search at the curb,
2. Stopping at the curb,
3. Position within or outside the crosswalk area,
4. Walking versus running,
5. Playing of any sort while crossing,
6. Walking in the street instead of on the sidewalk,
7. Crossing two streets without gaining the curb in between them, and
8. Crossing midblock.

In addition, several situational variables were coded: presence or absence of traffic, size and type of group, and crossing in the presence of an obvious threat to safety. Usually, the behavior of a single individual is coded at any one time. Pedestrians arrive either singly or in groups of various sizes. In the case of groups, a single individual is selected at random before the group is within 3 m (10 ft) of the curb and followed until the far curb is reached. The exception is midblock crossing, where all those crossing are tallied, but only according to whether a visual obstruction was present or not. The reason for identifying group size is that the size of the group is related to its visibility to drivers and possibly also to the responsibility taken by each individual for his or her own safety. Group type permitted the identification of groups of similar age (in this case, children in the primary grades), those that contain an older child, and those that contain an adult. Figure 1 shows the coding form. For each group observed, the symbol was circled if the behavior occurred and slashed if it did not.

## DEVELOPMENT OF THE INSTRUMENT

This instrument was developed as a criterion measure for a pedestrian safety education program for children of the primary grades. To ensure stability of measurement, a large number of observations is necessary. Since this can be obtained for small children only by making observations near elementary schools at times of school trips, observers were stationed near unsignalized intersections a block from the school grounds. Their positions were as unobtrusive as possible—in a

**Figure 1. Coding form.**



School: ____________
Date: ____________
Intersection: ____________
& ____________
Obs. Time: From ______ to ______
Coder: ____________

USC Pedestrian
Performance Test

Traffic Control: ____________

Diagram of Intersection:
(Include # of Xwalks & S.W.)

| GROUP | | | | | | | |
|---|---|---|---|---|---|---|---|
| TYPE | N | TRAFFIC | SEARCH | STOP | DANGER | PROGRESS | SPECIAL |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |
| | | T | L R B | S | D | WALK X-WALK | PL. $\overset{2}{\text{STS}}$. ST. |

Comments:

Midblock ______ / ______ (tally)
(clear) (obstruction)

Turning Only ____________ (tally)

parked car if possible; if not, then away from the corner and as though waiting for someone. The children gave no evidence of awareness of the observers.

During the development of the form, several observers coded together and checked their agreement after each individual pedestrian. Where frequent disagreement occurred, the instructions were clarified and the observers given more training. In some cases some less critical behaviors were eliminated because the observers could not handle the attentional overload. In other cases, some procedural rules helped, for example, check for traffic when the child to be observed was 3 m from the curb. This assured that the action was not submerged in behaviors that required close attention once the pedestrian reached the curb.

Initial training of observers was done by using videotapes of children crossing near schools so that disagreements could be discussed and resolved by reviewing the tapes. However, some aspects of the situation (traffic or danger) were not clear. Training then progressed to the coding of adult behavior (because of convenience of location) and, finally, to coding, in groups of two or more, the behavior of children on school trips, with discussion after each pedestrian was coded. The training required two weeks after the final form was approved, coding for 30 min before school and 20 min after school. As usual, the most difficult behavior to code was search. The coding rules required a definite head movement in the direction of search. Whereas it can be argued that eye movement may sometimes be sufficient if scanning occurs early enough, for children, at least, short-term memory is probably not sufficiently good to make this strategy safe; it is doubtful that it is safe even for adults, except in situations where very few vehicles are in view. Eye movements of more than about 15° engender head movements reflexly, so proper scanning when in the vicinity of the curb would normally involve head movements. It is recognized that search is only part of the process of search and detect, but only search can be observed unobtrusively and in normal situations. Detection is impossible without search; hence, if search is found to be deficient, we can assume that detection is deficient also, though the reverse cannot be argued.

## INTEROBSERVER RELIABILITY

The interobserver reliabilities were based on the coding of the same pedestrians by two observers. In this case there was, of course, no communication between them. Two sets of observations are available: one taken after initial training and just prior to the pretest in a curriculum evaluation study and the other taken about four weeks later, after a few days of refresher training, just prior to the posttest measurements. These data are given in the table below. The statistic used, Cohen's Kappa (7), corrects for chance agreements. A Kappa of 0.60 is satisfactory; hence, these data show high reliability for this technique.

| Coder Pair | Number of Observations | Kappa |
|---|---|---|
| Before pretest | | |
| 2,4 | 89 | 0.92 |
| 3,4 | 268 | 0.74 |
| 1,3 | 108 | 0.80 |
| 1,2 | 212 | 0.74 |

| Coder Pair | Number of Observations | Kappa |
|---|---|---|
| Before posttest | | |
| 2,4 | 69 | 0.76 |
| 1,3 | 147 | 0.74 |
| 2,3 | 90 | 0.89 |
| 1,4 | 139 | 0.80 |
| 1,5 | 317 | 0.82 |
| 3,5 | 149 | 0.82 |
| 4,5 | 154 | 0.77 |

## EVALUATION OF A PEDESTRIAN SAFETY CURRICULUM

The performance measures described were used as the performance criterion in an evaluation study of the California Pedestrian Safety Curriculum. The observations were made of a sample of children at several locations at each of eight schools at two points in time, about four weeks apart. Individuals are not identified. It is assumed that the same children pass a given point each day, with minor exceptions. The sampling occurs when children arrive in groups. Then the observer selects one for coding. The target child is varied from one group to the next for position in the group, size (age), and sex.

The design of this study was a pretest—posttest control group design, stratified by socioeconomic level. Volunteer schools were stratified into high or low socioeconomic status and then eight were randomly assigned to training or control groups. The group from which these schools were selected had been identified as having the most pupils who walk to school. Two observers, assigned to different locations, coded at each school. The observations were made during the two weeks preceding the month-long pedestrian safety training program and during the two weeks following it. Table 1 gives the numbers of pedestrians coded by school and by group for the pretest and posttest. A total of 707 children were observed for the pretest and 870 for the posttest. The discrepancy is attributed to a heat wave that occurred during the pretest; there is no reason to believe that this affected the trained and control groups differently.

Table 2 presents the posttest frequencies of the more critical behaviors. The proportion of children who performed correctly is of greatest interest here. In search (certainly the most critical behavior) only 40 percent of children searched left before they moved into the traffic lane. Back search, to detect potential turning vehicles, was made by a meager 5 percent, and right search was made only about 25 percent of the time. These figures are no different from those obtained in the pretest. Also of prime importance is stopping at the curb before proceeding, since that gives time for detection by both pedestrian and driver. Only 25-30 percent of the children did so. In addition, 20 percent of them stepped into danger. At intersections 30 percent of children ran across the street and 10 percent played as they crossed. Midblock crossings were very frequent—almost half as many as intersection crossings—and the majority of these occurred where vision was obstructed by parked cars. Table 3 shows this analysis.

The proportion of children crossing incautiously is thus appallingly large. Since the school trip probably represents the greatest exposure for young children, it is amazing that more are not hit. Reiss has suggested that the tendency to walk in groups makes them more visible to drivers (8). Somewhat more than 60 percent of our pedestrians walked in groups. Our observation during three studies at elementary school sites during six months of field work was that drivers behave more cautiously in the neighborhoods of schools at the times when children may be expected to be walking there and when they see several groups of children. The fact that the largest number of fatalities to child pedestrians occurs after school hours has led to theorization that children are more distracted then by play and interesting events. However, our data indicate that children's

Table 1. Number of children observed at intersections.

| | Trained Children | | | Control Children | |
|---|---|---|---|---|---|
| School | Pretest | Posttest | School | Pretest | Posttest |
| a | 89 | 80 | e | 176 | 194 |
| b | 147 | 143 | f | 25 | 80 |
| c | 15 | 46 | g | 92 | 151 |
| d | 120 | 102 | h | 43 | 74 |
| Total | 371 | 371 | | 336 | 499 |

Table 2. Analysis of posttest frequencies of pedestrian intersection behaviors for trained and untrained children.

| | Trained Group | | Untrained Group | | |
|---|---|---|---|---|---|
| Behavior | Correct (%) | N | Correct (%) | N | $\chi^{2a}$ |
| Left search | | | | | 0.08 |
| Yes | 40 | 148 | 41 | 204 | |
| No | | 223 | | 295 | |
| Right search | | | | | 0.84 |
| Yes | 26 | 98 | 29 | 146 | |
| No | | 273 | | 353 | |
| Back search | | | | | 0.79 |
| Yes | 6 | 24 | 5 | 25 | |
| No | | 347 | | 474 | |
| Stops at curb | | | | | 4.80[b] |
| Yes | 25 | 93 | 32 | 159 | |
| No | | 278 | | 340 | |
| Steps into danger | | | | | 0.01 |
| Yes | 19 | 72 | 20 | 98 | |
| No | | 299 | | 401 | |
| Walks or runs | | | | | 1.42 |
| Walks | 73 | 271 | 69 | 346 | |
| Runs | | 100 | | 153 | |
| Stays within crosswalk | | | | | 3.33 |
| Yes | 80 | 298 | 85 | 424 | |
| No | | 73 | | 75 | |
| Plays in street | | | | | 0.23 |
| Yes | 9 | 32 | 10 | 48 | |
| No | | 339 | | 451 | |

[a] In all cases df = 1.
[b] $p < 0.05$.

Table 3. Analysis of midblock crossings.

| | Obstructed Crossings | | | Clear Crossings | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | Pretest | Posttest | $\chi^{2a}$ | Pretest | Posttest | $\chi^{2b}$ | Pretest | Posttest | $\chi^{2c}$ |
| Trained | 126 | 164 | | 51 | 44 | | 177 | 208 | |
| Control | 70 | 205 | | 61 | 39 | | 131 | 244 | |
| Total | 196 | 369 | 20.17 | 112 | 83 | 1.34 | 308 | 452 | 9.63 |

[a] df = 1, $p < 0.005$.
[b] df = 1, $p < 0.001$.
[c] df = 1, $p < 0.25$.

traffic behavior is extremely hazardous even under the best of circumstances. This is true even after training in a program that is both more intensive and more focused on critical behaviors than most [see Jones and Fleischer (9) for a full report].

## CONCLUSIONS

Observations of critical pedestrian behavior have been shown to be highly reliable, provided (a) observations are limited to a small number of behavioral events at a time, (b) the behaviors are unambiguously defined, and (c) the observers are highly trained. Although the data reported were obtained on children, adult behavior can be coded as easily. If it is desired to look at other special behaviors, they can be carefully defined and substituted for any of those used here, since adding observational categories will overload the observers and destroy reliability. Training of observers must be continued until the index of agreement (Kappa) reaches a satisfactory level. With these provisos, this method of structured observation can provide the behavioral criterion necessary for the evaluation of pedestrian countermeasures.

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# Use of Pedestrian Conflict Analyses for Hazard Assessment in School Zones

Charles V. Zegeer, Dennis A. Randolph, Mark A. Flak, and Rathi K. Bhatacharya

The purpose of this study was to develop and test a traffic conflicts procedure to assist in the early identification of hazardous school-zone locations. Various pedestrian conflict types and severities were used to collect data and analyze 10 school-zone sites in the Rochester School District. Multivariate linear regression techniques resulted in high correlations between pedestrian conflict levels and site-related traffic and highway variables. A subjective danger index was developed based on various pedestrian conflicts and events. The 10 school-zone locations were priority ranked based on danger index and other conflict measures. A systematic flowchart procedure was used to help select site improvements based on conflict types, safety deficiencies, and corresponding safety improvements. Although pedestrian conflicts were found to be related to known hazardous conditions at the test sites, the relationship between pedestrian conflicts and pedestrian accidents has not been quantified. Further testing of accident-conflict relationships is recommended.

The interaction between pedestrians and motor vehicles results in a serious and costly toll of young lives each year. In the United States, the pedestrian fatality rate for young school children (5-14 years of age) is approximately 5 fatalities/100 000 population. Only the fatality rate for pedestrians over 65 years of age exceeds this rate. In addition, during 1977, there were approximately 1330 pedestrian fatalities among school children in the 5 to 14-year-old age group. An additional 34 000 pedestrians in this age group were injured (1). The school walking trip represents between 10 and 20 percent of the young pedestrian accidents, or 10 000-20 000 accidents annually (2).

Developmental factors have been found to affect a child's safe conduct in traffic. Among the factors are the following:

1. Misunderstanding by children regarding traffic rules and the physics of an automobile,
2. Lack of experience and limited judgment in traffic situations,
3. Restricted visibility due to a child's small size,
4. Limited powers of concentration, and
5. A child's tendency to be playful and impulsive (3,4).

The vehicle and roadway also contribute considerably to the safety problem. One West Virginia study found that the most significant factors of influence on school-zone speeds were the approach speed limit, the distance of school buildings from the roadway edge, traffic volumes, and the length of school zones (5). The control of such vehicle speeds in school zones is often quite difficult. In one study, regulatory school signs with flashers (SCHOOL—25 MPH WHEN FLASHING) were evaluated in terms of speed reduction during flashing periods for 48 school zones. Average speed reductions were only 5.8 km/h (3.6 mph), and motorist compliance with the 40-km/h (25-mph) limit was only 18 percent (6).

Many safety engineers have found that adequate pedestrian accident data are usually not available for proper identification of specific hazardous school locations. Pedestrian accidents are extremely rare events and are virtually impossible to predict based merely on the accident history of a site. An extremely dangerous school zone may go unnoticed for years by school and highway officials if no pedestrian accidents have occurred. In many cases, no improvements will be made at such school-zone locations until a child is killed or severely injured by a motor vehicle. A methodology was needed to assist in the early identification of school locations that have a high potential for pedestrian accidents. Actions can then be made to reduce the chance of such pedestrian accidents. In many cases, the early detection of potential accidents can lead to a simple or low-cost improvement that will greatly improve pedestrian safety near a school.

At the direction of the school board of the Rochester School District, a study was undertaken during 1979 that had as its major objective the improvement of the safety of school trips on highways in the vicinity of local school areas. In order to attain this objective, a comprehensive traffic study was formulated to (a) analyze the existing and potential factors that contribute to the safety of the school trip, (b) identify school-trip safety needs on a districtwide priority basis, (c) recommend short- and long-range improvement programs, (d) develop cost estimates for improvements, and (e) identify possible funding sources to enable implementation of the recommendations.

One of the safety analysis techniques developed and used in the Rochester School study was a pedestrian conflict methodology. By use of this conflict technique, the type and severity of pedestrian hazards was determined by quantitatively recording vehicle and pedestrian actions and interactions in school zones. Three basic assumptions were used for developing a pedestrian conflict procedure for school zones. First of all, an accident that involved a motor vehicle and a child pedestrian is a catastrophic event and should be prevented, if possible, by identifying and correcting locations where such accidents are likely to happen. Second, in the absence of sufficient accident data, the observation of near accidents (potential accidents) and unsafe pedestrian actions can provide useful information concerning locational hazards and the need for safety improvements. Finally, a careful analysis of pedestrian conflict data at selected school zones also requires the use of other appropriate traffic and geometric information to assist in identification of locations and recommendation of appropriate safety improvements.

## TRAFFIC CONFLICT PROCEDURES

Traffic conflicts are considered to be possible measures of accident potential and operational problems at a highway location. A conflict occurs when a driver violates a rule of the road or makes an aggressive movement. Conflict studies may be treated in terms of objective criteria. They allow for the collection of an adequate data sample in as little as a few hours of observation. Operational problems found in this way may be resolved before accidents occur. Conflicts also may be used to make quick evaluations of changes in road design, signing, signalization, and the environment.

In 1967, the first formal procedure was published for identifying and recording traffic conflicts at intersections. The technique was developed by Perkins and Harris of General Motors (GM) Corporation and is commonly referred to as the GM technique (7). In 1969, a procedural manual was written by Perkins to give additional information for the collection of conflict data (8). The GM technique has gained widespread acceptance in recent years, with minor modifications, and is the basis of conflict studies used by several highway agencies, including those of Washington, Virginia, and Ohio (9).

The GM technique identifies five major classes of traffic conflicts: (a) left turn, (b) weave, (c) cross traffic, (d) red-light violation, and (e) rear end. Within these broad categories, 23 specific conflict types are recorded on a standard data form. Three conflict types, defined by GM, are related to pedestrians (8):

1. Single vehicle-pedestrian conflict—A single vehicle slows or weaves to avoid a pedestrian who is crossing the roadway.
2. Pedestrian rear-end conflict—One vehicle closely follows another; the lead vehicle slows or stops to avoid a pedestrian who is crossing the street, and the vehicle following brakes or weaves to avoid the lead vehicle.
3. Weave pedestrian conflict—Two vehicles travel in adjacent lanes; the lead vehicle weaves to avoid an illegal pedestrian, thereby encroaching on the path of the vehicle in the adjacent lane, which causes it to brake or weave.

A conflicts procedure was developed in Kentucky in 1977 that allows for the collection of pedestrian violations and bicycle conflicts (10). All three types of pedestrian conflicts could possibly give an indication of potential accidents between vehicles and pedestrians. The later two conflict types may also provide information on the potential for vehicle-vehicle accidents. The three pedestrian conflict types and the other conflict types described above might be adequate for an overall conflict study at individual intersections; however, they were not considered to be sufficient for an analysis of pedestrian safety in school zones. Greater detail of pedestrian and vehicle actions are needed to better assess the level of pedestrian hazard.

## DEVELOPMENT OF A METHODOLOGY

A preliminary field investigation was made at several school-zone locations in the Rochester School District during peak pedestrian periods. Notes were made as to the events that could signify a pedestrian safety problem. A total of 13 such conflicts and events were defined to be appropriate for further testing:

1. Vehicle slows or stops for pedestrian—A pedestrian crosses the street in front of an approaching vehicle, causing it to slow or stop; brakelights are observed to signify the slowing of the vehicle.
2. Vehicle slows or stops for previous pedestrian conflict—A vehicle following is forced to slow or stop for a lead vehicle that has slowed for a pedestrian.
3. Vehicle weaves for crossing pedestrian—A pedestrian crosses the street, causing an approaching vehicle to weave around him or her.
4. Vehicle brakes or weaves for standing pedestrian—A vehicle brakes or weaves around a pedestrian

who is standing next to the roadway waiting to cross the street.

5. Vehicle brakes or weaves for pedestrian walking on shoulder—A pedestrian walking either with or against traffic causes a vehicle to brake or weave.

6. Vehicle disregards crossing guard—A vehicle, passing through a school zone, disregards a stop indication by the crossing guard by swerving around children or the crossing guard.

7. Turn conflict—A vehicle turns into a driveway or side street and must slow for a crossing pedestrian.

8. Pedestrian runs across street—A pedestrian runs across the street as a car approaches, but the vehicle is not forced to brake or weave.

9. Pedestrian stops in street—A pedestrian maneuvers through traffic and must stop in the median or in the center of roadway to await an adequate gap before completing his or her crossing.

10. Traffic signal violation—A pedestrian crosses against the traffic signal at a signalized intersection.

11. False start across street—A pedestrian starts into the street and, realizing an error in judgment, must retreat to starting point.

12. Jaywalking—A pedestrian crosses the street in violation of appropriate crosswalk locations.

13. Total pedestrian volume crossing street—The number of pedestrians crossing the street within the shcool zone, where they may be exposed to approaching vehicles, is counted.

A standard data form was developed for the recording of these pedestrian conflicts and events, as shown in Figure 1. The first 11 categories of conflicts and events can be assigned a subjective rating based on its nearness to an accident. A routine conflict is a conflict that is judged to be not very close to an accident. A moderate conflict involves a quick maneuver by a vehicle or pedestrian, such as an abrupt vehicle deceleration or swerve, as subjectively rated by the observer. A severe conflict (near-miss accident) is an event where an accident is barely avoided due to a last-second reaction by a driver or pedestrian.

These three severities of pedestrian conflicts were defined to closely correspond to the time-to-accident (TA) or time-to-collision (TC) concept, as developed by Hayward in 1972 (11) and Hyden in 1975 (12). TA or TC is the time required for two vehicles (or a vehicle and a pedestrian) to collide if they continue at their current speeds and direction. A high TA (e.g., above 3 s) represents a small amount of danger since ample time is available to react and avoid a collision. A low TA (below 1 s) indicates that extreme evasion reaction is necessary to avoid a collision (13). In this study, a TA of approximately 1 s or less was termed a severe conflict and a TA of about 1-1.5 s was termed a moderate conflict. Conflicts that have a TA of greater than about 1.5 s were termed routine. Since conflict severities were classified subjectively, variation in TA among observers was estimated to be as high as 0.5 s.

At many school-zone locations, safety problems exist that are related to the school buses and vehicles that load or unload school children. A separate data collection form was developed to record conflicts and events in such situations as follows:

1. School bus passes—a count of the number of school buses that pass through the school zone,

2. School bus stops—a count of the number of school buses that stop in the school zone to load or unload school children,

3. Slow for bus conflict—the number of times that one or more vehicles must slow for a school bus in the school zone,

4. Stop for bus conflict—the number of times that one or more vehicles must stop for a bus in the school zone,

5. Illegal bus passes, same direction—the number of vehicles traveling in the same direction that unlawfully pass a stopped school bus,

6. Illegal bus passes, opposite direction—the number of vehicles traveling in the opposing direction that unlawfully pass the school bus,

7. Slow for loading or unloading vehicles—the number of events where one or more vehicles slows behind a vehicle that is loading or unloading a school child,

8. Stop for loading or unloading vehicles—the number of events where one or more vehicles stops behind a vehicle that is loading or unloading a school child, and

9. Weave for loading or unloading vehicles—the number of events where one or more vehicles weaves around a loading or unloading vehicle.

Figure 1. Data collection form for pedestrian events.

Location ____________ Observer ____________ Date ________ Weather ________

| Time | | Slow or Stop for Ped. | Slow or Stop for Ped. Previous | Weave for Ped. Cross. | Brake or Weave—Ped. Standing | Brake or Weave—Ped. Walking on Shoulder | Vehicle Ignore Crossing Guard | Turn Conflict | Ped. Run Across Street | Ped. Stop In Street | Ped. Traf. Signal Violation | False Start Across Street | Jay-walking | Total Ped. Volume |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | | | | | | | | | | | | | |
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1 = Routine, * = Moderate, ⊛ = Severe

## DATA COLLECTION PROCEDURE

Data were collected at each approach to the school zone by trained observers during times of peak pedestrian activity. For example, if school activity began at 8:00 a.m. and ended at 2:55 p.m., data were collected from about 7:30 to 8:00 a.m. and from 2:50 to 3:30 p.m. Generally, 30-60 min of data per location each day was found to be representative of day-to-day pedestrian volumes and conflicts.

Data were normally collected in 5-min intervals, and a single observer was generally able to handle both forms for one direction of vehicle travel. Two observers are typically used to observe all necessary data during a counting period within the school zone. Care was taken to avoid double counting of pedestrian crossings and other events. The school zone was generally divided into two sections for counting purposes in order to resolve this problem.

Observers were stationed inconspicuously off the roadway edge to permit observation of the entire school zone. For unusually long school zones, where sight distance was limited, additional observers or extra counting periods were required and the school zone was separated into several segments. At least 30-60 min of useful data about pedestrian activity was considered necessary for these sites. Both morning and afternoon counting periods were desired, as well as any other activity times (e.g., lunch and recess) if appropriate.

As a general rule, data collection and analysis efforts represented a relatively small amount of time, amounting to approximately two to four person-hours per location. This will differ, dependent primarily on the pedestrian and vehicle activity, the length of the school zone, the duration of pedestrian activity, and the travel time to the site. Data analysis averaged only about an hour per site and varied, depending on data characteristics.

## CONFLICT SUMMARIES

The 10 locations selected for collection of conflict data were thought to be particularly hazardous, as determined by (a) citizen complaints, (b) vehicle volumes and speeds at the locations, (c) volume of pedestrian street crossings, (d) level of existing pedestrian protection (crosswalks, crossing guards, and pedestrian signal phases), and (e) preliminary field inspections of all locations for possible locational deficiencies (such as sight-distance restrictions).

The 10 school zones are listed in Table 1 and include four elementary school zones, three junior high school zones, and three senior high school zones. Lengths of the school zones ranged from 169 m (550 ft) to 406 m (1320 ft). Data were collected during the spring of 1979 at peak pedestrian times, and the other pertinent information in the table includes the school name, street of the school zone, cross street, dates of data collection, and data collection times.

The number of routine, moderate, and severe conflicts for each event are given in Table 2 for each of the 10 school zones. The data collection times at each site ranged from 15 to 85 min. At most sites, each of the pedestrian activity periods lasted only 10-20 min, and only one to three days of such data were found to be necessary to represent the level of conflicts at a site. For the 10 locations combined, the most common events were the following:

1. Slow or stop for pedestrians—80 routine, 30 moderate;
2. Pedestrians running across the street—85 routine, 14 moderate;
3. Previous conflicts—43 routine, 5 moderate, 1 near miss; and
4. Pedestrian stopping in road—40 routine, 1 moderate.

Of the 1113 pedestrian crossings recorded, 255 were jaywalkers. Five near-miss accidents (severe conflicts) were observed at Reuther Junior High School in 30 min of data collection.

In order to compare numbers on an equivalent time basis, events were summarized by total number per hour per site (Table 3). The greatest number of crossings per hour occurred at Ewell Elementary (397) and at Reuther Junior High (258). Total conflicts per hour were also computed for each category of event and conflict. The most common events (per hour per location) were jaywalking (46.5), running across street (19.5), slow or stop for pedestrian (15.3), and stop in median (8.7). Not all types of conflicts and events were observed during the data collection periods.

Of the 10 school zones selected for this study, only one location (Woodward Elementary) had a problem with the loading and unloading activities of children near the

**Table 1. Characteristics of school-zone test sites.**

| Section Number | School | Street | Cross Street | Section Length (m) | Date | Time |
|---|---|---|---|---|---|---|
| 1 | Reuther Junior High | Auburn | Culbertson-Weaverton | 229 | 5-31-79<br>6-8-79 | 3:50- 4:00 p.m.<br>3:50- 4:10 p.m. |
| 2 | Rochester Senior High | Livernois | Walton toward Willowgrove | 274 | 6-1-79<br>6-8-79 | 2:30- 2:45 p.m.<br>2:25- 2:40 p.m. |
| 3 | Rochester Senior High | Walton | Livernois toward Rockdale | 244 | 6-8-79 | 2:25- 2:40 p.m. |
| 4 | West Junior High | Old Perch | Belle Vernon-Ansal | 174 | 5-31-79<br>6-1-79 | 3:00- 3:20 p.m.<br>3:00- 3:20 p.m. |
| 5 | Woodward Elementary | Pine | Drace-Ferndale | 229 | 6-5-79 | 2:55- 3:25 p.m. |
| 6 | Disco Elementary | 23 Mile | E. Robinwood-W. Robinwood | 168 | 6-7-79<br>6-7-79 | 8:40- 9:05 a.m.<br>3:05- 3:25 p.m. |
| 7 | Ewell Elementary | Shelby | 23 Mile-Van Buren | 174 | 6-6-79<br>6-7-79 | 8:00- 8:30 a.m.<br>3:05- 3:25 p.m. |
| 8 | Ewell Elementary | 23 Mile | Shelby-Mile End | 287 | 6-6-79<br>6-7-79<br>6-7-79 | 8:00- 8:30 a.m.<br>8:00- 8:30 a.m.<br>3:05- 3:25 p.m. |
| 9 | Van Hoosen Junior High | Adams | Mohawk-Potomac | 402 | 5-31-79<br>6-5-79<br>6-8-79 | 2:35- 2:45 p.m.<br>12:15- 1:00 p.m.<br>12:15-12:45 p.m. |
| 10 | Adams Senior High | Tienken | Adams toward Medinah | 317 | 6-8-79 | 12:15-12:45 p.m. |

Note: 1 m = 3.28 ft.

Table 2. Summary of pedestrian conflicts and events by site.

| School | Total Time (min) | Slow or Stop for Pedestrians | | Slow or Stop for Pedestrians, Previous | | | Weave Around Pedestrians | Pedestrians Run Across Street | | Pedestrians Stop in Median or on Centerline | | False Stop Across Street | | Crossing Against Signal or Jaywalking | Total Pedestrian Volume Crossing Street |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | R | M | R | M | N | N | R | M | R | M | R | M | | |
| 1 | 30 | 5 | 8 | 5 | 2 | 1 | 4 | 29 | 2 | 6 | 1 | 6 | | 56 | 129 |
| 2 | 30 | 10 | 19 | | | | | 15 | 11 | 29 | | 2 | | 85 | 85 |
| 3 | 15 | 2 | | | 2 | | | 9 | | 3 | | | | 11 | 11 |
| 4 | 40 | 5 | 1 | 1 | | | | 20 | | 2 | | 5 | | 73 | 102 |
| 5 | 30 | | | | | | | | | | | | | | 77 |
| 6 | 45 | 4 | | 1 | | | | 9 | | | | | | 8 | 43 |
| 7 | 50 | 11 | | 6 | | | | | | | | | | | 331 |
| 8 | 80 | 41 | | 30 | | | | | | | | | | | 299 |
| 9 | 85 | 2 | 2 | | 1 | | | 3 | 1 | | | | 1 | 20 | 34 |
| 10 | 30 | | | | | | | | | | | | | 2 | 2 |
| Total | 435 | 80 | 30 | 43 | 5 | 1 | 4 | 85 | 14 | 40 | 1 | 13 | 1 | 255 | 1113 |

Note: R = routine; M = moderate; N = near miss.

main school entrance. Ten events per hour were observed to involve vehicles unlawfully passing school buses. At the same site, 12 private vehicles per hour were noted loading or unloading children, which resulted in two conflicts per hour.

## Relationships Between Conflicts and Other Variables

An ideal analysis would have been a comparison of the pedestrian conflict measures with pedestrian accidents at the school sites. This would have allowed for the determination of whether pedestrian conflicts are statistically related to pedestrian accidents at the test sites. However, since virtually no pedestrian accident data were available for analysis purposes, this was not possible.

Although such a conflict-accident analysis was not possible, conflict measures were compared with known hazards. For example, past experience suggests that the degree of pedestrian hazard may increase for a combination of variables such as many pedestrian street crossings, a high traffic volume, a low number of acceptable vehicle gaps, and high vehicle speeds. If a pedestrian conflict measure is found to be highly related to combinations of such known pedestrian hazards, then pedestrian conflicts can be considered to be a useful substitute for other subjective measures of pedestrian danger (under certain conditions). However, not all hazardous locations are also high-accident locations; the relationship between pedestrian conflicts and accidents is still unknown and should be tested.

To test the relationship between pedestrian conflicts and various traffic and pedestrian variables, stepwise multiple-regression analyses were used. The dependent variables tested included the following:

1. Total pedestrian conflicts per hour ($C_t$),
2. Routine pedestrian conflicts per hour ($C_r$),
3. Moderate pedestrian conflicts per hour ($C_m$), and
4. Severe pedestrian conflicts per hour ($C_s$).

The independent variables tested included the following:

1. Pedestrian crossing per hour (P),
2. Level of school (elementary, junior high school, and senior high school, using assigned numerical values for the three levels) (S),
3. Traffic volume per hour (V),
4. Number of acceptable vehicle gaps per hour (G),
5. Log (S),
6. Log (P),
7. Log (G),
8. Log (V),
9. Reciprocal of S,
10. Reciprocal of P,
11. Reciprocal of G, and
12. Reciprocal of V.

The analysis consisted of linear plots using the Statistical Package for the Social Sciences (SPSS) computer package. By use of a bivariate analysis technique, total conflicts, routine conflicts, and moderate conflicts were plotted separately against each of the other variables listed above. For total conflicts, the $r^2$ values ranged from 0.03 (plotted against log of V) to 0.52 (plotted

Table 3. Pedestrian conflicts and events per hour.

| Section Number | Slow or Stop for Pedestrians | Slow or Stop for Pedestrians, Previous | Weave for Pedestrians | Pedestrians Run Across Street | Pedestrians Stop in Median or on Centerline | False Start Across Street | Jaywalking Cross Not At Crosswalk | Total Pedestrian Volume Crossing Street |
|---|---|---|---|---|---|---|---|---|
| 1 | 26 | 16 | 8 | 62 | 14 | 12 | 112 | 258 |
| 2 | 58 | | | 52 | 58 | 4 | 170 | 170 |
| 3 | 8 | 8 | | 36 | 12 | | 44 | 44 |
| 4 | 9 | 2 | | 30 | 3 | 8 | 110 | 153 |
| 5 | | | | | | | | 154 |
| 6 | 5 | 1 | | 12 | | | 11 | 57 |
| 7 | 13 | 7 | | | | | | 397 |
| 8 | 31 | 22 | | | | | | 224 |
| 9 | 3 | 1 | | 3 | | 1 | 14 | 24 |
| 10 | | | | | | | 4 | 4 |
| Total | 153 | 57 | 8 | 195 | 87 | 25 | 465 | 1485 |
| Average | 15.3 | 5.7 | 0.8 | 19.5 | 8.7 | 2.5 | 46.5 | 148.5 |

against 1/G). The $r^2$ values for routine conflicts ranged from near 0.00 to 0.40. For moderate conflicts, the best correlation was with 1/G, where the $r^2$ value was 0.79.

The second type of analysis was a multivariate, stepwise regression. In this analysis, the computer program was used to add the independent variables one at a time, in an attempt to explain the variance in the conflict values. Corresponding $r^2$ values were calculated at every level in the process and are shown in the table below.

| Dependent Variable | Independent Variable | Stepwise $r^2$ Value |
|---|---|---|
| Total conflicts per hour | Reciprocal of G | 0.52 |
| | Log of P | 0.64 |
| | Reciprocal of S | 0.82 |
| | Log of V | 0.83 |
| Routine conflicts per hour | Reciprocal of G | 0.40 |
| | Log of P | 0.58 |
| | Log of S | 0.79 |
| | Log of V | 0.83 |
| Moderate conflicts per hour | Reciprocal of G | 0.79 |

For total conflicts, four variables were included in order of importance with a combined $r^2$ of 0.83, as shown above. A best-fit equation was also found for total conflicts by using the reciprocal of G, log (P), reciprocal of S, and log (V).

For moderate conflicts, from 40 percent (using only one variable) to 83 percent (using four variables) of the conflict variation was explained ($r^2$ = 0.40-0.83). The equation for moderate conflicts ($C_m$) was also given as computer output. Very low interrelationships were found between independent variables in each analysis, which supports the validity of including several of the variables in the analysis.

This analysis showed that none of the defined variables alone can be used to accurately explain total or routine pedestrian conflicts. However, the value of vehicle gaps (1/G) correlates well with moderate conflicts ($r^2$ = 0.79). When several of the variables were combined, up to 83 percent of the variation in conflict numbers was explained for the test sites. However, care should be used in interpreting these results, due to the limited number of locations (only 10 sites) in the analysis. Different relationships might be expected if the data base is expanded or if a different data base is used. However, the analysis illustrated that pedestrian conflict measures are related to known site-related hazards for the sites tested.

### Priority Ranking of Locations

A priority ranking of the 10 school-zone sites was desired based on the pedestrian conflicts and events. Thus, a single numerical value, which would include the combined effect of all severities of conflicts and other events, was necessary for each location. A priority ranking of the locations was developed based on an assessment of the danger level (danger index) of each type of event.

By use of a Delphi session, the weighting factors for each type of conflict was subjectively developed and input into the form of a model to be used to describe the danger level at a specific site. The events were grouped into five levels, including the following:

1. Severe conflicts (S),
2. Moderate conflicts (M),
3. Routine conflicts (R),
4. Jaywalkers (J), and
5. Legal street crossings (C).

Weighting factors were developed for the five levels of events based on average weightings assigned by the Delphi participants. A routine conflict was preestablished as having a weight of 1.0 in order to develop a basis for comparison, and weighting factors were individually assigned to the other four events.

The danger index (DI) based on pedestrian conflicts and events was developed as follows:

$$DI = 7.4(S) + 2.8(M) + 1.0(R) + 0.7(J) + 0.2(C) \qquad (1)$$

where

DI = subjective danger index for a school-zone location based on the weighted conflicts and events at the location (in terms of weighted conflicts per hour),
S = hourly number of severe conflicts,
M = hourly number of moderate conflicts,
R = hourly number of routine conflicts,
J = hourly number of jaywalkers, and
C = hourly number of pedestrian crossings.

By using the DI equation, it is evident that a severe conflict is weighted as 7.4 times more serious than a routine conflict. A moderate conflict is 2.8 times more serious than a routine conflict, and jaywalkers and legal crossings are counted as 0.7 and 0.2 times a routine conflict, respectively. This equation allows for inclusion of various types of events to compare the suspected hazard of various locations.

Values of DI were computed for each of the 10 school zones, as given in Table 4. The top priority location was Livernois Avenue at Rochester High School, which had a DI of 399. The next two locations, in priority order, were Reuther Junior High School (DI = 356) and West Junior High School (DI = 141).

The use of subjective rating factors as developed for the DI (in the Delphi session) is not uncommon for high-

Table 4. Data summary for computation of DI and priority ranking.

| Location Number | Conflicts per Hour | | | Jaywalkers per Hour | Volume of Pedestrians, Excluding Jaywalkers | DI | Priority Ranking |
|---|---|---|---|---|---|---|---|
| | Routine | Moderate | Severe | | | | |
| 1 | 102 | 26 | 10 | 112 | 146 | 356.4 | 2 |
| 2 | 112 | 60 | 0 | 170 | 0 | 399.0 | 1 |
| 3 | 56 | 8 | 0 | 44 | 0 | 109.2 | 4 |
| 4 | 50 | 2 | 0 | 110 | 43 | 141.2 | 3 |
| 5 | 0 | 0 | 0 | 0 | 154 | 30.8 | 8 |
| 6 | 18 | 0 | 0 | 11 | 46 | 34.9 | 7 |
| 7 | 20 | 0 | 0 | 0 | 397 | 99.4 | 5 |
| 8 | 53 | 0 | 0 | 0 | 224 | 97.8 | 6 |
| 9 | 4 | 4 | 0 | 14 | 10 | 27.0 | 9 |
| 10 | 0 | 0 | 0 | 4 | 0 | 2.8 | 10 |

way priority ranking formulas. For example, virtually every state highway agency currently uses a methodology known as an adequacy rating (or sufficiency rating) for the priority ranking of highway sections for major reconstruction. Nearly all of these adequacy rating methods include subjective weighting factors for each highway and traffic variable in the formula.

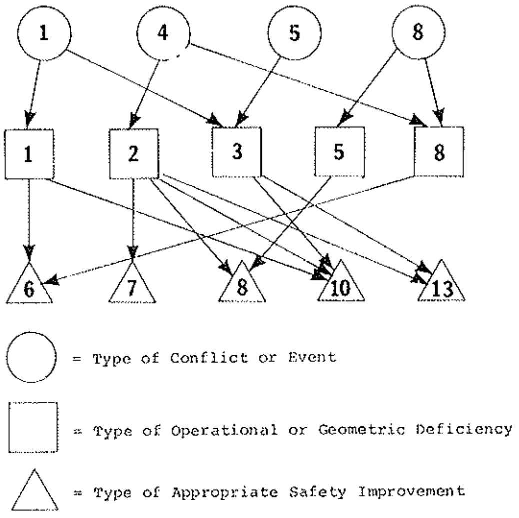
An example of subjective rating factors for priority ranking of hazardous highway was developed by Taylor and Thompson in a research project in 1977 sponsored by the Federal Highway Administration (FHWA) (14). In that study, a hazardousness index method was developed by using 10 different variables, including accident numbers, accident rate, accident severity, traffic conflicts, erratic maneuvers, driver expectancy, information-system deficiency, sight distance, and volume/capacity ratio. For each of the variables, a weighting factor was used, based on the subjective ratings of their importance by numerous highway safety experts in a workshop setting. The ranking of locations was based on the available data variables and their subjective weightings (14).

Care should be taken in the interpretation and use of the DI. Due to the limited available data base, the value of DI cannot be used as a measure of accident potential. Further research is necessary to determine whether there is a significant relationship between pedestrian accidents and the pedestrian DI. The DI value was used only as a priority ranking tool based on pedestrian conflicts and events. A DI value of 300 is not necessarily three times as hazardous as a DI of 100.

A pedestrian conflict study is only one of many engineering studies that should be made at school zones to identify safety problems and to select safety improvements. Other important engineering studies should also be conducted, such as the following:

1. Vehicle volume and gap studies,
2. Sight-distance studies,
3. Vehicle speed studies,
4. Inventory of traffic control devices,
5. Availability of pedestrian facilities,
6. Geometric deficiencies of the roadway, and
7. Other studies.

Figure 2. Flowchart of interrelationships between conflicts, locational deficiencies, and candidate safety improvements.



### Improvement Selection by Using Conflict Data

By using the data collected from the conflicts and events as given in Figure 1, the most appropriate improvements for implementation can be selected. A chart was developed for use in this procedure, as shown in Table 5, which provides a summary list of conflict types, deficiencies, and improvements. The predominant types of conflicts and events should first be recorded for a site. Next, the corresponding geometric or operational deficiencies causing the specific conflict (column two) should be identified. From the list of deficiencies, a list of appropriate safety improvements can be determined.

To illustrate the interrelationships between events, deficiencies, and improvements, a flowchart was constructed, as shown in Figure 2. For example, the four conflict and event types identified were slow or stop for pedestrian (item 1), pedestrian run across street (item 4), pedestrian stop in median (item 5), and jaywalking (item 8). Those four items are each given in circular nodes at the top of the flowchart.

The next step is to identify the deficiencies that correspond to each event at the specific school zone, which requires a knowledge of the study site. Square nodes represent the five deficiency types (items 1, 2, 3, 5, and 8) as listed in Table 5. Conflict type 1 (slow or stop for pedestrian) was caused by high-speed vehicles (deficiency node 1) and inadequate vehicle gaps (deficiency node 3). Arrows are drawn from each predominant conflict type to corresponding deficiencies (square nodes).

Finally, the five selected improvements (items 6, 7, 8, 10, and 13) are given as triangular nodes on the bottom level of the flowchart. Arrows are then drawn from each deficiency to the corresponding safety improvement. For example, deficiency number 2 (high pedestrian volumes) is taken into account with four different improvements (items 7, 8, 10, and 13). Deficiency 8 (vehicles disregarding crossing guard) was addressed only with improvement number 6 (police enforcement).

The example illustrated above represents the location of Livernois Road near Rochester High School. This location was the top-priority location in this study based on the DI. Different interrelationships were also found for other locations. Such a flowchart will help to ensure that locational deficiencies are identified for subsequent selection of appropriate safety improvements.

## CONCLUSIONS AND RECOMMENDATIONS

A pedestrian conflict procedure was developed to assist in the identification of hazardous school zones in the Rochester School District. The following conclusions were reached based on the analysis results. Specific conflicts and events that were observed to occur in 10 school zones under study were defined and tested. Nine other conflicts and events were also defined and tested as related to school buses and other vehicles used to transport children. Severities of all conflicts and events were recorded with respect to nearness to an accident.

Pedestrian conflicts were found to be related to known traffic and pedestrian variables. This indicated that pedestrian conflicts can provide useful information concerning known pedestrian dangers in school zones. A DI formula was developed based on the subjective weightings of five severities of pedestrian events. This formula was used to priority rank the 10 school zones based on suspected degree of hazard. The relationship between the DI and pedestrian accidents could not be

Table 5. Listing of conflicts, locational deficiencies, and candidate safety improvements.

| Conflict or Event | Operational or Geometric Deficiencies | Appropriate Safety Improvements |
|---|---|---|
| 1. Slow or stop for pedestrian<br>2. Slow or stop for pedestrian—previous<br>3. Weave for pedestrian<br>4. Pedestrian run across street<br>5. Pedestrian stop on median<br>6. Intersection crossing against light<br>7. False start across street<br>8. Jaywalking<br>9. Slow for bus<br>10. Stop for bus<br>11. Weave around bus<br>12. Vehicle stop to unload children<br>13. Slow for unloading vehicle—previous<br>14. Weave for unloading vehicle<br>15. Vehicle brakes or weaves for standing pedestrian<br>16. Vehicle brakes or weaves for pedestrian walking on shoulder<br>17. Vehicle disregards crossing guard<br>18. Turn conflict | 1. High vehicle speeds<br>2. High pedestrian crossing volume<br>3. Inadequate vehicle gaps<br>4. Insufficient pedestrian control<br>5. Pedestrian crosswalk needed<br>6. Limited sight distance<br>7. Pedestrian signal phase needed<br>8. Vehicles disregard crossing guard<br>9. Vehicles ignore speed limit<br>10. Random street crossing<br>11. Wide street with insufficient gaps<br>12. Pedestrian crossing from behind parked cars<br>13. Pedestrian disregard of traffic control<br>14. Insufficient parent parking area<br>15. Insufficient bus parking area<br>16. No sidewalk<br>17. No shoulder or sidewalk<br>18. Inoperative pedestrian control<br>19. Worn school signs<br>20. Worn pavement markings<br>21. Unwarranted traffic control devices<br>22. Others | 1. Install regulatory speed limit signing<br>2. Install warning signs<br>3. Paint pavement markings<br>4. Prohibit curb parking<br>5. Construct pedestrian overpass<br>6. Initiate police speed enforcement<br>7. Construct sidewalk railings<br>8. Paint pedestrian crosswalk<br>9. Use crossing guard<br>10. Install pedestrian midblock signal<br>11. Install pedestrian signal phase<br>12. Construct wide median for pedestrian refuge<br>13. Safety education for children<br>14. Initiate driver awareness training<br>15. Construct parking drop-off areas for buses<br>16. Construct parking drop-off areas for vehicles<br>17. Construct sidewalks<br>18. Maintenance control device<br>19. Remove unwarranted signs, markings, and signals<br>20. Additional school bus usage<br>21. Others |

tested due to the unavailability of sufficient accident data.

A flowchart methodology was described to simplify the task of relating observed pedestrian events to corresponding locational deficiencies and appropriate safety improvements. Various other highway and traffic information is also needed to conduct the total analysis.

The refinement and use of this pedestrian conflict methodology deserves further research. In particular, more data are needed at a large sample of school zones to define other types of pedestrian events. The comparison between pedestrian conflicts and pedestrian accidents should also be made to determine whether such a relationship exists.

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# Development of a Conflicts Analysis Technique for Pedestrian Crossings

Michael J. Cynecki

The purpose of the study described in this paper was to develop a pedestrian conflict technique that will be useful in identifying hazardous locations and specific operational deficiencies at pedestrian crossings. A major concern in the development of this conflict technique was flexibility, ease of use, and the ability to develop countermeasures from the collected data. The technique defines 13 principal pedestrian conflicts that may occur and uses different levels of conflict severity. A conflict data form was constructed to assist in the collection of data. The applicability and feasibility of this conflict technique was tested at five crossing locations in which a total of 25 h of data were collected. Although a significant amount of further testing is required to provide conclusive results on the usefulness of this conflict technique, preliminary investigation has indicated that this procedure can yield information that is valuable for the identification of potential safety hazards at pedestrian crossings. The technique may be used to develop countermeasures to reduce or eliminate pedestrian accidents.

Traffic conflicts are a measure of the potential for traffic accidents. A traffic conflict occurs when a driver takes an evasive action to avoid a collision. In the past several years there has been considerable work in analyzing hazardous locations with conflict-analysis techniques, including some attempts to relate the number of traffic conflicts to the number of accidents at a location. This technique has generated much interest in accidents that involve vehicles with vehicles or vehicles with fixed objects; however, little work has been conducted toward the application of traffic conflict techniques to pedestrian accidents.

The purpose of a conflict study is to identify hazardous locations and accident potentials so that these deficiencies may be eliminated before an accident occurs. This is especially important in accidents that involve pedestrians, which often result in an injury or fatality. Although less than 1 percent of all motor vehicle accidents involve pedestrians, approximately 18 percent of all fatality accidents in the United States are pedestrian accidents (1). This indicates that pedestrian accidents are more severe than the average accident. Because of this severity, a conflict technique needs to be developed that will identify hazardous locations and safety deficiencies and assist in the development of countermeasures to reduce or eliminate pedestrian accidents.

The purpose of this study was to develop a conflicts technique for measuring pedestrian accident potentials and to identify operational deficiencies on roadways that pertain to pedestrian safety. The pedestrian conflict technique presented in this paper includes a description of conflict classifications, a data collection procedure, and a form for data collection.

## CHARACTERISTICS OF A CONFLICT STUDY

A conflict procedure should contain certain characteristics to be a useful tool to traffic engineers. These characteristics or attributes include the following (2):

1. Safety-relatedness—Conflicts must be defined in such a way that they are related to a safety problem or an operational hazard. Some driver actions of braking or changing lanes may be unrelated to a collision with a pedestrian. These actions may be a response to a traffic control device or to avoid a pothole. The conflict definitions must also not be too broad. If many types of conflicts are combined into one category, it will be difficult to identify a specific problem at a location from the collected data.
2. Site-relatedness—The conflict definitions that are used must be applicable to the location under investigation. For example, some types of conflicts may occur only at intersections or at locations that have on-street parking. This may call for defining many types of conflicts even though only a few conflict types may occur at a given location.
3. Reliability—A pedestrian conflict procedure should be valid and have a high statistical correlation with pedestrian accidents.
4. Repeatability—The procedure developed must provide consistent results from day to day and from location to location (given similar conditions) or it will be of little use. Another major concern is observer reliability or the consistency of results between observers. This is difficult because of differences in personal concepts of a conflict. Therefore, special training may be required to achieve observer reliability.
5. Practicality—The technique must be easy to use and provide adequate results with a minimum of personpower. One pitfall to avoid is the definition of too many conflicts and assignment of too many sophisticated tasks which may place unrealistic and unachievable demands on human observers.

## FACTORS INVOLVED IN CONFLICT STUDIES

Vehicle-pedestrian conflicts differ from vehicle-vehicle conflicts in several ways. Pedestrian conflicts involve various factors, some of which have little bearing in vehicle conflicts. These differences need to be discussed and analyzed to develop a better understanding of the relationships that are involved and to assist in defining conflict types. Some of these fundamental differences follow:

1. Vehicle-pedestrian accidents are not as numerous as vehicle-vehicle (or vehicle-fixed object) accidents.
2. Accidents are considerably more severe when they involve pedestrians. There is little chance of a property-damage-only (PDO) accident when a pedestrian is struck by a vehicle, and there is a very good chance of a severe injury or fatality, particularly at high-speed locations.
3. Many of the pedestrians involved in accidents are school age, preschool, or elderly. Pedestrians in these age groups may not have adequate knowledge of highway safety, lack responsibility and maturity, or have reduced eyesight and reflexes, which are factors in many pedestrian accidents. On the other hand, motorists must be at least 16 years of age and have good eyesight and health. Although this is not always the case (i.e., drunk drivers), on the average, drivers should have better eyesight and reflexes than children and elderly pedestrians.
4. The operation of a motor vehicle is considerably

more complex and involves many more distractions than does the action of a pedestrian crossing a roadway.

5. Pedestrians are more maneuverable than automobiles in the actions of stopping and changing directions.

6. The speed differential between automobiles and pedestrians is considerable. Automobiles usually travel in speeds that range from 24 to 100 km/h (15 to 60 mph); pedestrian speeds average at about 5 km/h (3 mph).

7. Most pedestrian conflicts occur at right angles when pedestrians are in the action of crossing a roadway. This is not the case with vehicle conflicts.

8. Pedestrians may access a roadway at almost any point. Automobiles normally access a roadway at specified points (i.e., other roadways, driveways, or curbside parking spaces). Therefore, a motorist must be cognizant of pedestrians at every point along a roadway.

9. Sight restrictions may be more prevalent in pedestrian conflicts than in vehicle conflicts. A pedestrian is smaller than a vehicle and can access a roadway from between parked cars and may be shielded from a motorist until he or she is in the roadway (without giving the motorist advance warning).

10. For nighttime conditions, vehicles have headlights, taillights, and running lights that make them more visible to other motorists. Pedestrians are often dressed in dark clothing and are more difficult to detect at night.

11. Pedestrian conflicts and conflict severity can be measured from the movements and reactions of vehicles and pedestrians. When only vehicles are involved, conflicts and conflict severity can usually be measured by watching the movements and reactions of only one vehicle. The example of this is a slow-for-right-turn rear-end conflict. The first vehicle slows for a right turn while the second vehicle brakes or weaves to avoid a collision. The conflict can only be viewed and measured by watching the second vehicle. When pedestrian conflicts occur, a conflict can be viewed from the vehicle's actions (braking or weaving) to avoid a collision or from the pedestrian's actions (stopping, changing directions, or running).

Such items indicate that there is a significant difference between vehicle conflicts and pedestrian conflicts.

The factors that play a part in the number and severity of pedestrian conflicts were investigated. Many of these factors should be noted in the data collection procedure at the site to assist in the identification of hazardous roadway features that should be eliminated. The following list was developed to represent some of these pedestrian conflict factors:

1. Traffic volumes,
2. Percentage of vehicles turning,
3. Right-turn-on-red regulations,
4. Traffic speeds,
5. Vehicle mix (percentage of trucks and buses),
6. Pedestrian volumes,
7. The relationship between pedestrian and vehicle volumes,
8. Time of day and day of week,
9. Season,
10. Weather conditions,
11. Visibility conditions,
12. Sight restriction,
13. On-street parking,
14. Road width and number of lanes,
15. Shoulder widths,
16. Pavement markings,
17. Presence of a left-turn center lane,
18. Medians and pedestrian islands,
19. Roadway surface conditions (i.e., potholes or drainage),
20. Geometrics (grade and horizontal and vertical curvature),
21. The number of vehicle access points,
22. Roadway lighting,
23. One-way versus two-way operation,
24. Location of sidewalks,
25. Crosswalks,
26. Pedestrian warning signs or flashers,
27. Crossing guards,
28. Pedestrian age,
29. Enforcement of vehicle and pedestrian traffic regulations,
30. Pedestrian barriers,
31. Grade separations,
32. Crossing location (intersection or midblock),
33. Number of legs at intersection and angle of intersection,
34. Traffic control devices,
35. Pedestrian phasing at signalized intersections (i.e., WALK-DON'T WALK signs), and
36. School site selection.

Various sources have identified the above factors as contributing factors in increasing or reducing the chance of a pedestrian conflict (3-7). For example, at a signalized intersection where there is a high percentage of vehicles turning, pedestrian crossing is impeded and conflicts involving turning vehicles with crossing pedestrians will result. If right turns on red are allowed at that intersection, the number of conflicts and potential pedestrian hazards will be increased. Wider streets cause longer crossing times for pedestrians, which may increase the chance for a conflict. Other factors (such as roadway geometrics or on-street parking) may cause sight restrictions for motorists or pedestrians; features such as warning signs and pavement markings may forewarn motorists of a crossing location and may assist in reducing conflicts.

The types of conflicts used in this technique are defined in the following section. The conflict definitions are based on the manner in which the pedestrian accesses the roadway (i.e., walking or running into the roadway, walking along the side of the roadway, or walking in a center left-hand turn lane), vehicle turning movements, and vehicle and pedestrian violations of traffic signals.

## Conflict Definitions

### Slow or Weave for Walking Pedestrian

This is a conflict that occurs when a pedestrian accesses a roadway at a normal walking pace (at a right angle to vehicle traffic) and a vehicle weaves or brakes to avoid a collision. This conflict does not include vehicles turning into the path of a pedestrian at intersection locations or violations of a traffic signal by a motorist or pedestrian.

The occurrence of this conflict may, for example, indicate a sight restriction for the motorist or pedestrian. If this is the case, conflicts may be reduced by removing sight obstructions or by improving warnings to motorists of pedestrian access points or crosswalks. However, slow for walking pedestrian is a very general conflict type that may indicate many diverse safety hazards. Walking pedestrian (PW) conflicts may also be caused by inadequate gaps in vehicle traffic, excessive street width, excessive vehicle speeds, or too many pedestrian crossing locations. Thus, recording the type of conflict alone may not indicate a specific operational deficiency. Other data, such as condition diagrams, vehicle and pedestrian volume counts, and gap studies may also be needed to determine the actual locational deficiencies.

When data are being recorded, one conflict should be counted for each pedestrian who conflicts with each vehicle. That is, if two pedestrians are walking across the street and a vehicle brakes to avoid a collision with both pedestrians, then two conflicts are recorded. If a pedestrian causes a conflict with two passing vehicles, then two conflicts are recorded. If, however, a pedestrian causes a vehicle to slow down and this action causes a vehicle-vehicle conflict that does not involve the pedestrian, then only one of these conflict types is counted. The remaining types of pedestrian conflicts are counted in the same manner.

### Slow or Weave for Running Pedestrian

This conflict occurs when a pedestrian accesses a roadway while running (at right angles to vehicle traffic). This conflict is similar to the PW conflict in other respects. A running pedestrian (PR) conflict may indicate the existence of a similar type of problem situation that a PW conflict indicates, except the degree of severity is increased. This type of conflict is also very general in description and the specific locational deficiency should be further identified by collecting additional site-related data.

Because younger children are more apt to run into a roadway without due caution, PR conflict may occur more often at a school crossing or near playgrounds. These conflicts may be reduced by using crossing guards for elementary-school-age children and by fencing off play areas and, if possible, locating schools and play areas away from major roadways. The conflict may also occur at crossings of very wide roadways or may indicate the lack of gaps in traffic large enough to allow crossing. Countermeasures may include the implementation of pedestrian-actuated signals or pedestrian islands.

### Pedestrian Walking or Running in the Roadway with the Flow of Traffic

A conflict of this sort is a result of a vehicle weaving or braking because of a pedestrian walking or running in the roadway or on the shoulder in the direction of vehicle traffic. Such conflicts may indicate the need for sidewalks or wider shoulders to safely accommodate pedestrian traffic.

A with-the-flow-of-traffic (WF) conflict may also occur in areas of on-street parking due to pedestrians accessing parked vehicles. Countermeasures for this problem may include the reduction or the elimination of on-street parking and the widening of parking lanes and shoulders to safely accommodate pedestrians accessing parked vehicles.

### Pedestrian Walking or Running in the Road Against the Flow of Traffic

A pedestrian walking or running in the road against the flow of traffic (AF) is similar to the WF conflict with the exception that the pedestrian is walking or running in the road opposing the direction of traffic.

### Diagonal Pedestrian Crossing

A diagonal pedestrian crossing (PD) conflict occurs when a pedestrian crosses a road at an angle other than 90° to the flow of traffic. This type of crossing can occur at midblock or an intersection. A PD crossing is a hazardous situation because the pedestrian will be in the roadway for a longer time interval and, if the road is a two-way street, the pedestrian will have his or her back to traffic during a portion of the crossing.

This conflict may occur due to the offset of sidewalks accessing a roadway or due to the location of pedestrian traffic generators that are not directly across the street from each other. This problem may be corrected by using better alignment of sidewalks or by implementing pedestrian barriers.

### Pedestrian in Center Lane

This conflict designates the presence of a pedestrian in the center left-hand turn lane or a roadway during the commission of a conflict with a vehicle. This conflict can involve a vehicle in the center lane or the lane adjacent to it. Center lane (CL) conflicts will only be recorded at wide roadways, usually consisting of five lanes or more. This type of conflict will indicate the necessity of additional protection for pedestrians from through and turning traffic. Countermeasures for this problem may include the restriction of vehicle turning movements or pedestrian crossings at the specified location.

### Outside Crosswalk

At locations where crosswalks are marked out, it may be desirable to indicate the number of conflicts that occur outside of the crosswalk. Studying outside crosswalk (OC) conflicts may be useful in investigating the effectiveness of crosswalks in reducing the number of pedestrian access points to a roadway and in identifying the effectiveness of the crosswalk as a safety countermeasure for pedestrians. If a considerable number of OC conflicts are observed, it may be desirable to implement countermeasures to channel the pedestrians to the crosswalk. This may be achieved by using pedestrian barriers, repainting the crosswalk, or relocating the crosswalk. If, however, a sizable number of conflicts occur within the crosswalk, it may indicate that the crosswalk is not providing adequate safety to the pedestrians, and additional protective measures may be required. These measures may include additional warning to motorists, lower speeds, additional police enforcement, pedestrian signals, grade separations, and others.

### Right-Turning Conflicts

Right-turning (VR) conflicts are the result of a vehicle turning right at an intersection or making a right turn into or out of a driveway. For a more involved analysis, this conflict can be subcategorized into two different types: (a) vehicles turning right from the roadway being observed and (b) vehicles turning right onto the roadway of interest. Countermeasures to reduce this conflict may include the restriction of turning movements, special signal phasing to protect pedestrians crossing, or the location of pedestrian crossing points at alternative locations.

### Left-Turning Conflicts

Left-turning (VL) conflicts occur from a vehicle turning left at an intersection or from a vehicle turning left out of or into a driveway. As in VR conflicts, this conflict can also be subcategorized into two separate types: (a) vehicles turning left from the road being observed or (b) vehicles turning left onto the road being observed. Countermeasures for this conflict may include, but not be limited to, prohibition of left turns, special phasing to protect crossing pedestrian, and grade crossing separations.

### Right-Turn-on-Red Conflicts

This conflict occurs when a vehicle initiates a right turn during a red signal phase that conflicts with a crossing pedestrian. The recording of right-turn-on-red (RR) conflicts at signalized intersections is optional, but may yield useful information regarding the safety implications when right-turn-on-red movements are allowed. There may be two types of RR conflicts: (a) right-turn-on-red off of the road under investigation or (b) right-turn-on-red onto the road.

### Signal Change

A signal change (SC) conflict occurs only at signalized pedestrian crossings or at signalized intersections. A conflict of this type occurs when a pedestrian crosses a street with the signal and, before the pedestrian completes the crossing, the signal changes to red and a vehicle brakes, weaves, or hesitates to avoid a collision. This type of conflict may be caused by improper signal timing and may be corrected by using pedestrian islands, improved signal timing, or by the installation of WALK-DON'T WALK signals.

### Pedestrian Violation

A pedestrian violation (PV) designates a conflict that occurs as a result of pedestrian violation of a traffic signal. A pedestrian violation can be either a pedestrian walking against a traffic signal or a pedestrian starting to cross when the pedestrian signal is flashing a DON'T WALK sign. Recording this type of conflict is optional and may be used to indicate pedestrian compliance with traffic signals.

### Vehicle Violation

A vehicle violation (VV) designates a conflict that occurs as a result of a vehicle violation of a traffic control device. The VV can be a failure to stop, failure to yield, running a red light at a traffic signal, or an illegal right turn on red (i.e., where signing prohibits a right turn on red). Recording this type of conflict is optional and may be more appropriate at intersections or signalized locations. It may also be desirable to subclassify these conflicts to identify specific hazardous vehicle actions. Depending on the site and the type of VV observed, these conflicts may be reduced by added enforcement, improving visibility of traffic signs and signals, upgrading traffic control devices, and adding a delayed-red signal phase.

### Summary

Thirteen basic pedestrian conflicts were defined in this section. This does not mean that other types of conflicts do not exist. In some situations, additional conflict definitions may be required to describe specific hazardous movements. It may also be desirable to subclassify a conflict type into two or more specific conflicts to properly understand the problems at a given location.

Since there is a major difference between the activities at intersection and nonintersection locations, some of the defined conflicts will not be applicable to all situations. For example, PW, PR, WF, and AF conflicts may be recorded only at midblock locations; conflict types such as VL, VR, SC, RR, and PV can only occur at intersections.

## Conflict Severity

An important task in this study was to define conflict severity and to determine methods of measuring conflict severity. As previously mentioned, conflict severity can be measured by observing the actions of the pedestrian or vehicle during the occurrence of a conflict. The following is a list of pedestrian actions that can be used to measure conflict severity. These actions are listed by increasing severity, and the subscript p corresponds to the pedestrian action.

1. Hesitation ($H_p$)—Pedestrian hesitates momentarily in travel across a street in response to vehicular traffic,
2. Backup movement ($B_p$)—Pedestrian momentarily reverses direction of travel while in the roadway in response to vehicular traffic,
3. Running movement ($R_p$)—Pedestrian increases speed to avoid a collision with through traffic while in the roadway (similar to an erratic maneuver),
4. Near-miss accident ($N_p$)—A collision is imminent, but is avoided just before impact,
5. PDO accident (P),
6. Injury accident (I), and
7. Fatality (F).

Conflict severity can also be evaluated by observing the action of the vehicle involved in the conflict. Six vehicle actions given below are measures of conflict severity, listed in increasing order of severity. The subscript v indicates a vehicle action.

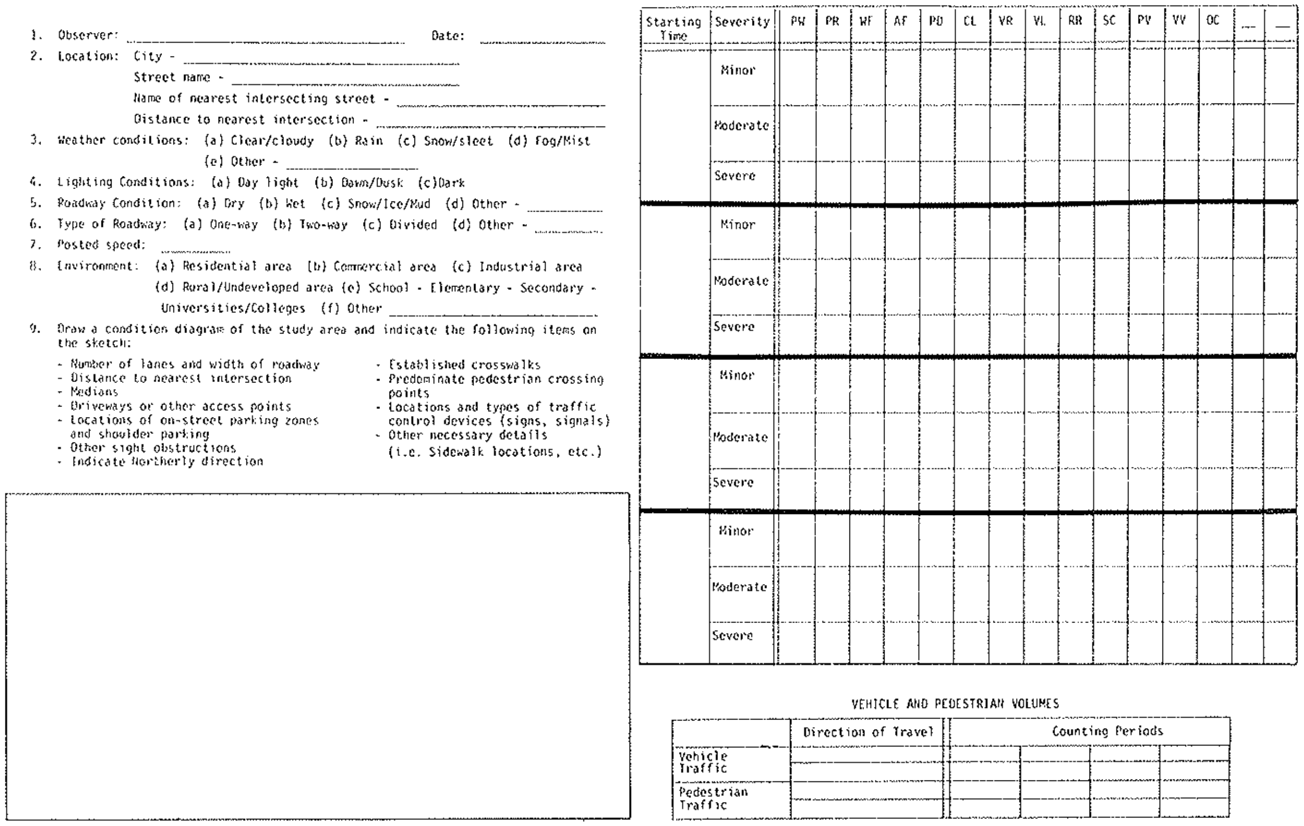
1. Routine conflict ($C_v$)—When a vehicle brakes or weaves routinely to avoid a collision with a pedestrian,
2. Complete stop or erratic maneuvers ($E_v$)—When a vehicle comes to a complete stop or swerves erratically to avoid a collision,
3. Near-miss accidents ($N_v$)—A collision is imminent but is avoided just prior to impact,
4. PDO accident (P)—Property damage only to the vehicle and the pedestrian does not sustain an injury,
5. Injury accident (I), and
6. Fatality accident (F).

The severity of a conflict was determined by observing the actions of the vehicle in this study. This decision was made because it was felt that severity defined by vehicle actions would provide more consistent results and would be easier for the observer to view.

Furthermore, an additional measure of conflict severity was defined, a moving-vehicle action (M). This action occurs when a pedestrian moves across the path of a through or turning vehicle and is approximately 7 m (25 ft) downstream of that moving vehicle but the vehicle takes no evasive action to avoid a collision. The pedestrian is in the moving lanes of traffic when this action occurs. Although the vehicle does not brake or weave in this action, this is still considered a hazardous situation and should be recorded. The hazard is usually indicated by a pedestrian hesitating, backing up, or running to avoid a collision.

Three levels of conflict severity were selected in this conflict procedure to simplify data collection (see Figure 1). The least severe type of conflict (minor conflict) is defined as moving-vehicle conflicts (M) where a hazardous situation exists but no actual weaving or braking takes place. Moderate conflicts are defined as routine

Figure 1. Conflict data form.



1. Observer: ____________________ Date: __________
2. Location: City - ____________________
   Street name - ____________________
   Name of nearest intersecting street - ____________________
   Distance to nearest intersection - ____________________
3. Weather conditions: (a) Clear/cloudy (b) Rain (c) Snow/sleet (d) Fog/Mist
   (e) Other - __________
4. Lighting Conditions: (a) Day light (b) Dawn/Dusk (c)Dark
5. Roadway Condition: (a) Dry (b) Wet (c) Snow/Ice/Mud (d) Other - ________
6. Type of Roadway: (a) One-way (b) Two-way (c) Divided (d) Other - ________
7. Posted speed: ______
8. Environment: (a) Residential area (b) Commercial area (c) Industrial area
   (d) Rural/Undeveloped area (e) School - Elementary - Secondary -
   Universities/Colleges (f) Other ____________________
9. Draw a condition diagram of the study area and indicate the following items on the sketch:
   - Number of lanes and width of roadway
   - Distance to nearest intersection
   - Medians
   - Driveways or other access points
   - Locations of on-street parking zones and shoulder parking
   - Other sight obstructions
   - Indicate Northerly direction
   - Established crosswalks
   - Predominate pedestrian crossing points
   - Locations and types of traffic control devices (signs, signals)
   - Other necessary details (i.e. Sidewalk locations, etc.)

| Starting Time | Severity | PW | PR | WF | AF | PD | CL | VR | VL | RR | SC | PV | VV | OC | ___ | ___ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Minor |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Moderate |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Severe |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Minor |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Moderate |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Severe |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Minor |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Moderate |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Severe |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Minor |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Moderate |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Severe |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

VEHICLE AND PEDESTRIAN VOLUMES

|  | Direction of Travel | Counting Periods |  |  |  |
|---|---|---|---|---|---|
| Vehicle Traffic |  |  |  |  |  |
|  |  |  |  |  |  |
| Pedestrian Traffic |  |  |  |  |  |
|  |  |  |  |  |  |

conflicts ($C_v$) and complete-stop or erratic-maneuver ($E_v$) conflicts. Therefore, a moderate conflict is when a braking or weaving action is taken by a vehicle to avoid a collision with a pedestrian. The third level of conflict severity is a severe conflict, which is defined as a near-miss accident ($N_v$). If an observer witnesses a collision (PDO, injury, or fatality accident), it will be recorded and described separately on the data form.

## DATA COLLECTION PROCEDURE

Conflict studies can be conducted at intersections or at midblock locations, such as school crossings and midblock crossings in the central business district (CBD) or shopping areas and other sites where a hazardous pedestrian problem may exist. The selection of the survey mechanism and sampling procedure for this conflict technique is described below.

### The Survey Team

The survey team consists of two individuals in a single vehicle or on foot along the roadway, at a spot that is inconspicuous, offers clear observation of all pedestrian and vehicle movements, does not disrupt vehicular flow, and does not endanger the safety of the observers. The two must observe the same section of roadway or intersection approach leg at the same time. One individual will be responsible for recording conflicts data while the other is responsible for recording pedestrian and vehicular volumes. The survey team should observe at a distance of 45-90 m (150-300 ft) from the intersection, crosswalk, or point of interest. The observation position should be recorded on the layout sketch and included with the data. Efforts should be made to use the same observation positions in before and after studies.

### Survey Day and Times

Pedestrian conflicts should be counted on a Tuesday, Wednesday, or Thursday for locations where pedestrian and vehicle volumes are constant from day to day. However, at locations where pedestrian volumes vary greatly from one day to the next (i.e., near stadiums and churches), the conflict study should be performed when the problems are most prevalent. Data should be collected for an interval of 2-4 h. The survey may be extended to a longer period of time if the conditions warrant it, such as where insufficient data are available. Where sufficient accident data are available, the survey should be performed when the accident data indicate high hazard time interval. At other locations, the study may be performed when the engineer perceives a problem will exist or when traffic and pedestrian volumes are highest. However, to achieve a full understanding of the potential safety problems at a location, data should be collected during both the peak and off-peak periods.

### Sampling Procedure

The sampling procedure of the General Motors Research (GMR) Traffic Conflicts Technique (7) is recommended. This is the procedure whereby 15-min samples are taken by the survey team for each intersection leg of the roadway under investigation (for intersection locations) or upstream and downstream of the crosswalk or predominant pedestrian crossing point (for midblock locations). At intersection locations, only two intersection approach legs are assigned to a survey team. For example, if the north-south leg of an intersection is the survey assignment, the data on the northbound leg would be counted for exactly 15 min. The survey team would then move to the southbound approach, where an additional 15 min of data would be collected. This would continue throughout the survey period.

### Conflicts Data Form

A data form has been prepared to collect pedestrian conflicts, as shown in Figure 1. This form is designed to assist the observer in recording all of the important operational features of the roadway and the vehicle and pedestrian movements. The data form is divided into four major sections. The first section is designed to identify the conditions that exist at the location under investigation. This information is recorded prior to the study and includes the following: (a) names of the observers, (b) date and location of survey, (c) weather and visibility conditions, (d) classification of roadway, and (e) type of area where the survey is taking place.

In the second section of the data sheet, the observer is provided a space to draw a sketch of the study location, including locations of pedestrian movements, crosswalks, traffic control devices, on-street parking, sight obstructions, and location of the observer. A list of information that may be desirable to record is noted on the data sheet. This information is used with the data from the first section to assist in identifying hazardous roadway features and developing appropriate countermeasures.

The third section of the data form, located on the second page, is where the conflict data are recorded. The starting time of the survey period will be indicated in the first column. Space is provided to record data for four survey periods or one hour. If the survey period is longer than one hour, additional data forms are to be completed and attached to the first form. Conflicts are to be recorded by type and severity. Thirteen types of conflicts are listed at the top of this section and space is provided for two additional types of conflicts. The types of conflicts to be recorded are up to the discretion of the observer. Conflicts are to be recorded by one member of the survey team during the survey period.

The fourth section of the data form is to record pedestrian and vehicle volumes. This section is located on the bottom of the second page of the data form. Pedestrian and traffic volumes are recorded by the second member of the survey team on a counting board (or a separate piece of paper) and are tabulated on the data sheet after each counting period (15 min). The vehicle and traffic volumes are to be recorded by direction when practical. Volume data may be used to indicate conflict rates and will assist in fully describing the operational features of the study location.

Training should be provided to the survey team regarding the proper methods of filling in the data form and recording of conflict data. The observers will also need instruction on distinguishing conflict types and identifying conflict severity. A goal to achieve in the training process is observer reliability or the consistency of results between different observers.

### Data Collection and Analysis

To investigate the feasibility, applicability, and effectiveness of this conflict technique, conflict studies were performed at five pedestrian crossing locations in which a total of 25 h of data were collected. Three of the survey locations were on the campus of Wayne State University, one was in the cultural center of Detroit, Michigan, and the fifth location was in the Detroit CBD.

### Pedestrian Crosswalk at Anthony Wayne Drive

The pedestrian crosswalk investigated at Anthony Wayne Drive is a major crossing point between the parking structure for Wayne State University and the main campus (Figure 2). The crosswalk is located midblock and is designated by pavement markings, overhead flashing warning lights, and advance warning signs. Anthony Wayne Drive is a divided roadway that has four lanes in each direction and a 13-m (20-ft) median. The posted speed is 40 km/h (25 mph), but a sizable portion of motorists exceed the posted speed.

Five hours of data, which included both peak and off-peak periods, was collected at this location. The average pedestrian crossings during the survey period was 300 persons/h and the vehicle traffic was 1150 vehicles/h. An average of 306 conflicts/h were recorded, 77 percent of which were minor (not involving braking or weaving by the vehicle); 23 percent were moderate conflicts; and one near-miss accident occurred. The near-miss accident involved a pedestrian who, while in the middle of the street, stopped to talk to another person at the curb and was almost struck by a speeding vehicle. Although the average pedestrian conflict rate was higher than the average number of crossing pedestrians per hour, this does not mean that every pedestrian was involved in a conflict. On many occasions a single pedestrian was involved in more than one conflict with passing motorists. Conflicts were classified to indicate whether or not they occurred within the crosswalk. The results showed that 59 percent of the conflicts occurred to pedestrians while in the crosswalk and 31 percent occurred outside the crosswalk. Furthermore, 24 percent of the conflicts that occurred within the crosswalk were moderate, but only 20 percent of the conflicts occurring outside of the crosswalk were moderate.

The data collected show that the crosswalk may give the pedestrian a false sense of security, and further precautions should be implemented to reduce vehicle speeds to the posted limit. A reduction in the volume of vehicle traffic on Anthony Wayne Drive is also suggested to improve pedestrian safety. An extensive amount of data is needed from hundreds of other locations to reach a firm conclusion on the level of safety. Therefore, a firm conclusion cannot be made regarding the location until additional data are collected.

### Antoinette Avenue at Cass Avenue

The second crossing investigated was at Antoinette Avenue at the intersection of Cass Avenue in Detroit. Antoinette runs east and west and separates the administration building and computer service center of Wayne State University from the main compus and parking structures (Figure 3). There is a small parking lot on the southeast corner of the intersection opposite the administration building, which is a popular crossing location. The intersection is signalized but does not include special phasing for pedestrians (i.e., WALK-DON'T WALK signs).

Five hours of data were collected to investigate the hazards to pedestrians crossing Antoinette. During this period, crossing pedestrian traffic averaged 200 persons/h. Traffic data also indicated that a high percentage of vehicles turn at this location. An average of 77 conflicts/h were recorded, of which 35 percent were moderate and 65 percent were minor. No severe conflicts were recorded. Approximately 34 percent of the conflicts involved turning vehicles, 10 percent were caused by signal changes during crossings, and 17 percent of

Figure 2. Pedestrian crosswalk at Anthony Wayne Drive.

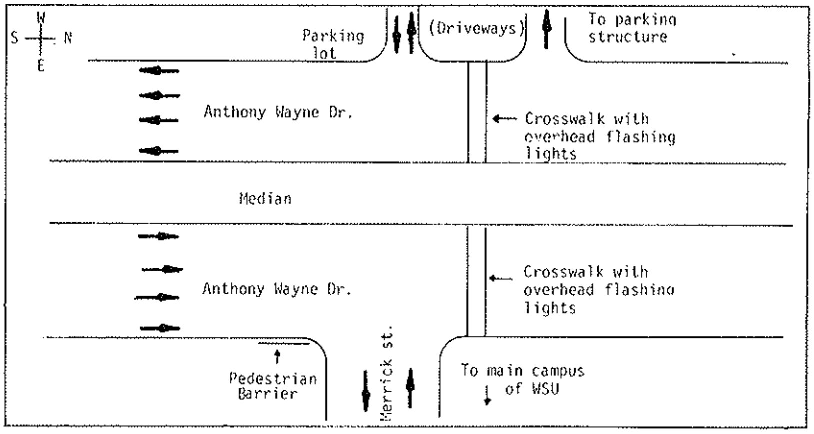
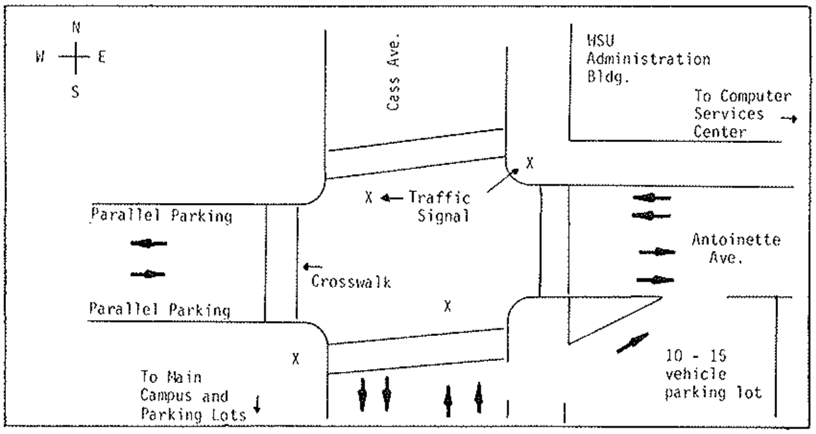


Figure 3. Antoinette Avenue at Cass Avenue.



the conflicts occurred when pedestrians crossed against the signal. An additional 39 percent of the conflicts occurred east of the intersection from pedestrians crossing from the small parking lot to the administration building.

Since many of the conflicts occurred during vehicle turning movements, a countermeasure to reduce some of the turning movements may lead to increased safety. One possible measure will be making Antoinette Avenue a one-way street (westbound) from Woodward Avenue to Cass Avenue. Other studies, such as an analysis of traffic flow patterns in the area, will be needed to analyze the feasibility of restricting turning movements. Another problem was caused by the traffic signal changing during pedestrian crossings. This problem may be corrected by installing WALK-DON'T WALK pedestrian signals at the intersection. An additional improvement at the location may be to prohibit pedestrians from crossing east of the intersection (from the small parking lot) and channel all the crossing pedestrian traffic to the intersection. This may be accomplished by installing a pedestrian barrier. If a countermeasure is employed, a careful investigation must be conducted to study what new problems, if any, will occur. This may be accomplished by comparing before-and-after conflict data to investigate the countermeasure's impact on the number and severity of conflicts.

## Cass Avenue at Antoinette Avenue

To complete the investigation at the intersection of Cass and Antoinette, conflict data were collected for pedestrians crossing Cass Avenue (Figure 3). Approximately 85 pedestrians/h made this crossing, usually on the way to the administration building.

An average of 72 conflicts/h were recorded, of which 53 percent were minor and the remaining 41 percent were moderate in severity. Analysis of the data showed that 74 percent of the conflicts involved turning vehicles, 14 percent occurred during signal changes, and 11 percent of the conflicts were the result of traffic signal violations by pedestrians.

The major problem at this location is the high number of turning vehicles conflicting with crossing pedestrians. Therefore, a restriction to reduce turning movements may be required. The installation of pedestrian signals to reduce signal-change conflicts is also recommended.

## Woodward Avenue at Putnam Avenue and Farnsworth Avenue

The fourth pedestrian crossing investigated was located on Woodward Avenue in the cultural center of Detroit (Figure 4). This site is at a signalized intersection that has pedestrian phasing. The Detroit Public Library and the School Center Building are located on the west side of Woodward Avenue, and the Detroit Institute of Arts, Engineering Society of Detroit, and the Detroit Science Center are located on the east side of Woodward Avenue. Woodward Avenue has three through lanes in each direction, one center lane for left turns, and a lane for parallel parking on each side of the street.

Five hours of data were collected during which an average of 210 pedestrian crossings/h occurred. An average of 66 conflicts/h were recorded, of which 57 percent were minor and the remaining 43 percent were moderate. Vehicle turning movements accounted for 88 percent of the conflicts and pedestrians crossing against

Figure 4. Woodward Avenue at Putnam and Farnsworth Avenues.

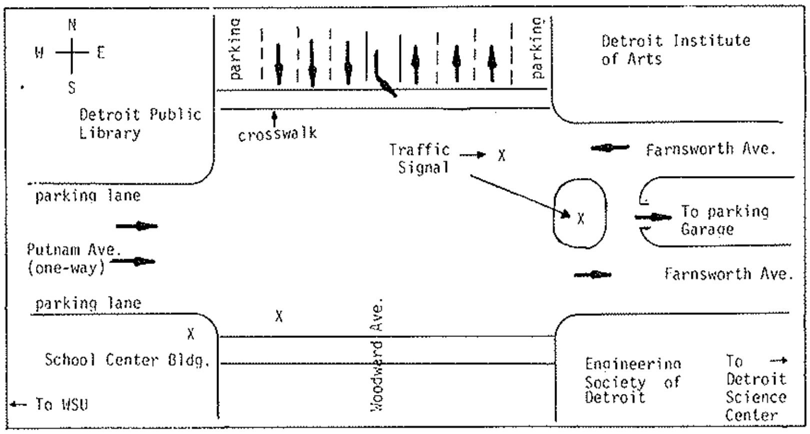
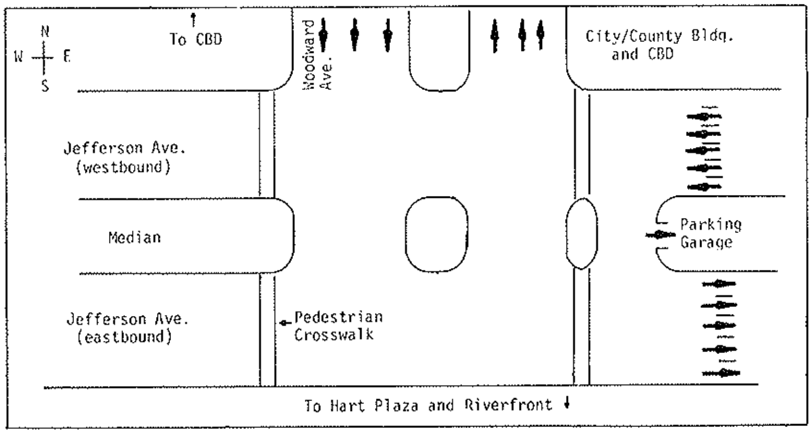


Figure 5. Jefferson at Woodward Avenue.



the signal were responsible for an additional 10 percent of the conflicts. Although Woodward Avenue is approximately 33 m (110 ft) wide, there were only five conflicts caused by signal changes during crossings.

Analysis of the data indicated that the major problem encountered at this location involved vehicle turning movements, especially left turns onto Woodward Avenue conflicting with crossing pedestrians. However, because of the nature of the traffic patterns in the area, turning restrictions are not recommended. A possible safety improvement may include providing protected left-turning phases so that left-turning vehicles will not have to be concerned with through traffic, thus allowing more attention to be given to crossing pedestrians.

### Jefferson Avenue at Woodward Avenue

The fifth pedestrian crossing studied was on Jefferson Avenue in Detroit (Figure 5). Jefferson Avenue is divided by a 10-m (30-ft) median and has five eastbound lanes and six westbound lanes. The CBD of Detroit is located north of Jefferson Avenue, and the Hart Plaza, a riverfront park, is located south of Jefferson.

The study at this location was performed on a Wednesday, during the morning and noon hours. The average vehicle traffic on Jefferson was 1760 vehicles/h and 1437 persons/h crossed Jefferson Avenue during the study. An average of 375 conflicts/h were recorded—60 percent were minor conflicts, 40 percent were moderate, and two near-miss accidents occurred. Both near-miss accidents involved pedestrians who crossed against the light and weaved through the heavy traffic on Jefferson. Vehicle turning movements from Woodward Avenue onto Jefferson Avenue accounted for 56 percent of the conflicts and left-turning movements accounted for an additional 10 percent of the conflicts. Pedestrians caught crossing when the signal changed accounted for 14 percent of the recorded conflicts.

Because of the high vehicle and pedestrian volumes at the intersection and the width of Jefferson Avenue, a grade separation between vehicles and pedestrians may be desirable. This countermeasure may be undesirable, however, because of the cost involved. Since 56 percent of the conflicts involved right-turning movements from Woodward Avenue onto Jefferson Avenue, another countermeasure would be to prohibit crossings on Jefferson Avenue west of the intersection, thus eliminating many of the conflicts that occurred.

## CONCLUSIONS AND RECOMMENDATIONS

Conflict values can be used to rank priority locations based on hazard. Conflict information, along with other data from the site, can be used to identify which countermeasure should be selected. Most importantly, safety deficiencies can be identified when accident data are not available.

The result of the five study locations shows that the conflicts technique presented in this paper can be helpful in indicating safety deficiencies at the pedestrian crossings. This technique was not difficult to use and was applicable to each location investigated. However, further testing is required at additional and more diverse types of pedestrian crossings to determine the full effectiveness of this conflict technique.

This conflict technique may be useful in indicating the relative hazardousness of a pedestrian crossing by a measure such as conflict rate. If this is desired, then a comparison of data from many other locations is required to produce a measure of hazardousness to pedestrians. Once this is accomplished, a few hours of data collection at a site may produce important information on the relative hazardousness of a crossing, as well as safety deficiencies.

Further investigation is needed to determine the amount of data collection required at a site to provide reliable results. Studies are also recommended to investigate the repeatability of results from one day to the next, and comparisons of results from similar locations are desired to further investigate reliability of this technique.

During this study, it was assumed that pedestrian conflicts are a measure of vehicle-pedestrian accident potential. It was not within the scope of this study to determine the exact relationship that exists between conflicts and accidents. However, this relationship should be investigated; this can be accomplished by comparing pedestrian accident histories with conflict data collected at various locations. Investigations can also be conducted to determine which types of pedestrian conflicts are more hazardous. The results of these studies will assist in providing more concise information from this conflict technique regarding hazards to pedestrians at roadway crossings.

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# Causal Factors of Non-Motor-Vehicle-Related Bicycle Accidents

Patricia L. Wheatley and Kenneth D. Cross

The Santa Barbara County Bicycle Safety Project was created in September 1977 and funded through September 1979. The primary area of development in this project involved research into the causal factors of non-motor-vehicle-related bicycle accidents. Many types of accidents fall into this category—bicycles hitting other bicycles, pedestrians, or fixed objects. In addition, bicyclists lose control of their bicycles and fall for many reasons. Although considerable emphasis has been given to bicycle-motor vehicle accidents in the last few years, relatively little attention has been given to the non-motor-vehicle-related bicycle accident. The purpose of the project research has been to provide comprehensive material on the nature and cause of non-motor-vehicle-related bicycle accidents in Santa Barbara County. In addition, the project performed a study on the nature and cause of bicycle-related accidents on separated off-road bicycle facilities in the county. To provide proper perspective on this information, a survey was first taken of the general population of bicyclists in the county.

The Santa Barbara County Bicycle Safety Project was created in September 1977, funded by the California Office of Traffic Safety to the University of California at Santa Barbara. The funding for this project continued through September 1979.

A major emphasis of the Santa Barbara County Bicycle Safety Project, and the topic of this report, was research into the causal factors of non-motor-vehicle-related bicycle accidents. Many accidents fall into this category. For the purposes of this report, all bicycle-related accidents that do not involve a motor vehicle will be referred to as non-motor-vehicle (NMV) accidents.

Bicycle-motor vehicle accident research has received considerable attention over the last few years. On the average, accidents that involve a motor vehicle result in more severe injuries than do NMV accidents. In addition, the study on NMV accidents is difficult because such accidents are rarely reported to any record-keeping agency. In spite of this scarcity of information, it is generally recognized that NMV accidents occur with far greater frequency than do bicycle-motor vehicle accidents. For this reason, the study of NMV accidents was chosen for this project.

Because of the dearth of data on NMV accidents, we decided that a comprehensive survey of the general population of bicyclists might be the only way to obtain information on the full range of NMV accidents.

The purpose of the project research has been to provide comprehensive material on the nature and cause of NMV-related bicycle accidents in Santa Barbara County. In addition, the project performed a study of the nature and cause of bicycle-related accidents on separated off-road bicycle facilities in the county. To provide proper perspective on this information, a survey was first taken of the general population of bicyclists in the county.

Throughout the following narrative, reference will be made to the differences between northern and southern Santa Barbara County. In order to eliminate possible confusion, the following community descriptions are included.

The county of Santa Barbara provides an unusual blend of urban and rural populations. Bounded on the south by the Pacific Ocean, the county lies 148 km (92 miles) northwest of Los Angeles. One-third of the county's area is located in the Los Padres National Forest. A significant portion of the county's 288 000 population resides in the southeastern metropolitan coastal region, including the city of Santa Barbara.

The moderate climate enables continuous outdoor recreation that has increasingly included bicycling. Surveys conducted during the initial research stage of the Santa Barbara County Bicycle Project found that there are 152 528 bicycles and 151 064 bicyclists in Santa Barbara County. Of this number, 96 528 bicyclists live in the southeastern part of the county. A large portion of these bicyclists are adults.

To facilitate the expanded use of bicycles in the southern section of the county, several kilometers of separated bikeways have been and are being built. Santa Barbara County is a pioneer in the area of off-street bikeways.

The coordinating agency, the University of California at Santa Barbara, has a student population of 14 400. The bicycle is the major means of transportation on the university campus. Currently, there are an estimated 10 500 bicycles on campus on any given day. Along with the rise in the bicycling population has been an increase in bicycle accidents. In order to avoid a serious accident problem, a tremendous amount of effort and staff expertise has gone into the development of one of the finest bicycle systems in the nation.

## METHOD

The research plan specified four separate surveys: (a) a random postcard survey of county residents, (b) a questionnaire survey of a large sample of bicyclists who reside in Santa Barbara County, (c) an interview survey of those bicyclists who reside in Santa Barbara County, and (d) an interview survey of those bicyclists who had recently been involved in accidents.

### Postcard Survey

The objective of the postcard survey was to obtain data on a representative sample of county residents to determine the following:

1. Number of bicycles per household,
2. Number of riders per household,
3. Ages and sexes of the riders,
4. Number of bicycles stolen per household, and
5. Type of area (urban or rural) in which the bicyclists reside.

The prime consideration for the selection of the interview sample was to obtain an unbiased, random sample of county residents. The self-addressed, stamped postcard surveys were then mailed to 8 percent of the persons on the list. A total of 7674 postcards were sent to residences as well as to post office boxes and rural delivery routes. The return cards were number coded so that records could be kept of the return rates for each zip code area in the county.

A total of 1874 postcards were returned, reflecting a 24.4 percent return rate. Results of a subsequent tally of age distributions and household sizes were compared with census data to validate the survey results. The survey returns were consistent with census data in nearly every case, provided that the ages and number of persons per household revealed in the survey is consistent with that of the general population.

To further validate the results and to discover any possible biases in the postcard questionnaire, a telephone survey was conducted after all of the postcards had been returned. Telephone numbers were obtained for a sample of those residents who did not respond by using the telephone company's Cross Reference Directory.

The interviewer asked these residents the same questions as those on the postcard survey. Again, no serious biases were discovered.

A computer mask was designed to enter postcard responses. The following information was computed:

1. Number of accidents for males and females by specific age groups;
2. Number of males, females, and total population of each geographic area;
3. Number of urban, rural, and total residents in each geographic area;
4. Number of male and female cyclists and total number of cyclists;
5. Number of urban, rural, and total number of residents in each age group;
6. Total number of bicycles in each geographic area;
7. Average number of bicycles per household in each geographic area;
8. Average number of bicycles per person in each geographic area; and
9. Total number of bicycles stolen in each geographic area.

### Bicycle User Survey

The objective of the bicycle user survey was to obtain population estimates of the riding habits and experiences of Santa Barbara County residents.

A four-page, fold-out survey was designed to include 21 questions, which covered the following areas of interest:

1. Operator characteristics,
2. Rider experience and exposure,
3. Bicycle usage patterns,
4. Bicycle characteristics, and
5. Accident experiences.

The bicycle user survey was taken to elementary, junior high, and senior high schools throughout the county; the University of California; and a two-year college in northern Santa Barbara County. To obtain the adult bicycle-riding populations, surveys were given at the department of motor vehicles in northern and southern Santa Barbara County.

The following is a breakdown of surveys obtained through this effort:

| Age Group | North County | South County | Total |
|---|---|---|---|
| Elementary | 306 | 535 | 841 |
| Junior high school | 185 | 329 | 514 |
| Senior high school | 221 | 266 | 487 |
| College | 68 | 317 | 385 |
| Adults | 56 | 320 | 376 |
| Total | 836 | 1767 | 2603 |

### Telephone Surveys

The objective of the telephone interview was to determine the function failure, environmental, psychological, and contributing factors of the particular types of accidents isolated in the bicycle user survey. Ultimately, the similarities and differences between the types of accidents were determined as a result of this interview survey.

All of the bicycle user surveys were reviewed to isolate those that included accidents that took place during the last 24 months as well as those that resulted in either physical injury or property damage. No surveys were included in the telephone interviews unless prior permission from the victim had been secured (this was determined by the victim's signature on the user survey).

At the same time the telephone surveys were being conducted, a bicycle-use survey was being developed by the Santa Barbara County Transportation Study, which was funded by the Federal Highway Administration and the state of California. The Atascadero Creek and Cabrillo surveys were conducted on new separated bike paths in southern Santa Barbara County. At our request, this research team included on their survey a question that asked for the name and phone number of bicyclists who had accidents on separated bikeways. Through these surveys we were able to add to the numbers of documented adult accident experiences on separated bikeways other than on the university campus. After all telephone interviews were completed, the surveys were grouped into accident types. Similarities and trends were evaluated on the basis of the following:

1. Accident types,
2. Sex of victim,
3. Riding experience,
4. Road type and configuration,
5. Speed of the bicyclist,
6. Type of bicycle used,
7. Condition of the bicycle,
8. Amount of property damage, and
9. Other contributing factors.

A total of 206 accident victims were contacted for telephone interviews; 38 telephone surveys were taken from the Atascadero and Cabrillo bikeway surveys.

## OVERVIEW OF PROJECT

Information from the postcard survey yielded estimates of the proportion of residents of Santa Barbara County who ride a bicycle at least once per year. The percentage of bicyclists who ride was tabulated by age, sex, and census tract. Information concerning the size and distribution of the entire resident population of Santa Barbara County was obtained from a special census conducted in 1975. This special census yielded data on the size of the resident population by age, sex, and census tract. The size of the bicycling distribution for each subpopulation was obtained by multiplying the number of residents in that subpopulation by the estimate of the percentage of residents within that subpopulation who ride bicycles. This procedure yielded estimates of the size of the bicycling population by age, sex, and census tract.

The postcard survey also yielded data on the percentage of bicyclists who have had at least one accident during the past 12 months. This percentage of bicyclists was tabulated by age, sex, and census tract. The number of bicyclists in each subpopulation was multiplied by the estimates of the percentage of that subpopulation who have had an accident during the past 12 months. This task yielded estimates of the size of the accident population by age, sex, and census tract.

One of the main objectives of this study was to identify the types of NMV accidents that occur and the factors that contribute to each type of accident. The detailed data on accident types and contributing factors were obtained during telephone interviews of accident victims whose names and telephone numbers were identified by the bicycle user survey.

Another product of the bicycle user survey was data on the bicycle usage patterns of Santa Barbara County bicyclists. The primary objective in obtaining information on bicycle usage was to obtain quantitative data to use in comparing the relative exposure of the accident population and nonaccident population. The final index of exposure was estimates by bicyclists of the number of kilometers traveled on a bicycle during an average week. Such exposure data are needed to fully interpret the information on accidents.

When attempting to assess the cost-effectiveness of accident countermeasures, it is useful to be able to compare the estimated cost of countermeasure programs with the magnitude of societal loss that results from accidents. Accident cost data were estimated through a consideration of the accident consequences derived from the telephone survey and information on the average cost of generic types of property damage and injuries.

## FINDINGS

### Postcard Survey Results

A total of 1874 postcard questionnaires were returned, which provided information on a total of 4674 residents. To assess the representativeness of the sample of residents who responded to the postcard survey, the age distribution of the respondents to the postcard survey was compared with the age distribution of county residents as measured by a special countywide census taken in 1975. Residents younger than 5 and residents older than 65 years of age were underrepresented in the postcard survey, whereas residents whose ages fall between these two extremes were overrepresented slightly. Although these biases are statistically significant, they are exceedingly small for any mailback survey. Discounting the two extreme age groups, a difference between percentage values for the various age groups never exceeds 1.4 percent and, for most age groups, the difference is less than 1 percent.

The representativeness of the postcard data was also assessed by comparing the postcard data and census data in terms of the average number of residents per household. It was found that these two percentage values differed by less than 0.3 percent. Based on these findings, the biases in the postcard survey are so small that they have little effect on the population estimates of the size and distribution of the bicycling population and the accident population.

Careful study of the census data and the data obtained by the postcard survey indicates that the county could be geographically subdivided into two subpopulations, hereafter referred to as North County and South County. The residents who reside within each of these subpopulations are homogeneous, but the residents residing in North County differ in several important respects from the residents who reside in South County. It was also found that bicycle usage by males differed from bicycle usage by females. For these reasons, the size and distribution of the Santa Barbara bicycling population was derived for four subpopulations: North County males, North County females, South County males, and South County females. The number of bicyclists in each age group was derived by multiplying the number of residents in that age group (as indicated by the 1975 census) by the percentage of residents in that age group who identified themselves as bicyclists on the postcard survey. The results of this analytical procedure are presented in Table 1.

Estimates of the size of the bicycling population in Santa Barbara County are shown in Table 1 by geographical area, sex, and age. The bottom row of Table 1 provides estimates of the size of the bicycling population for all ages combined; the three columns on the right-hand extreme of Table 1 show estimates of the size of the entire bicycling population. The reader's attention is directed to the following findings:

1. It is estimated that there are about 179 000 bicyclists in all of Santa Barbara County.
2. About 59 percent of the bicycling population reside in South County and 41 percent reside in North County. For the entire county, about 53 percent of the bicycling population are males and 47 percent are females. The ratio of male to female bicyclists is higher in North County (55 percent males-45 percent females).
3. For females, the 15 - to 19-year-old group contains the most bicyclists, but the 20- to 24-year-old group is only slightly smaller.

The age distribution was found to be typical of the age distributions reported for many other U.S. communities. That is, the relative number of bicyclists increases rapidly after age 5, reaches a peak between ages 10 and 14, and declines steadily thereafter. The age distribution of bicyclists who reside in South County is considerably different from the age distribution of North County bicyclists. In South County, the relative number of bicyclists is greatest for the group aged 20-24; and the group aged 10-14, which was larger than any other in North County, is the fourth largest age group in South County. The large number of young adult bicyclists in South County is partly the result of the large number of college and university students who reside in the Santa Barbara area and partly the result of different bicycle usage patterns by young adults who are not students. Combining North and South County bicyclists results in an age distribution that indicates that the relative size is nearly the same for the groups aged 10-14, 15-19, and 20-24; it also indicates that the groups aged 5-9 and 25-29 are about the same size.

The relative size of the male and female bicycling population is nearly the same for every age group. The only notable difference is that, in North County, a larger proportion of females between the ages of 25 and 40 are bicyclists.

Examination of the differences between the age distributions of North County and South County bicyclists shows that the trends are the same for male and female bicyclists but are more pronounced for female than male bicyclists. The trend, as discussed above, is that the largest age group in North County is the group aged 10-14, whereas the largest age group in South County is the group aged 20-24. Note that about 18 percent of the male bicyclists and more than 23 percent of the female bicyclists in South County are between the ages of 20 and 24. Figure 1 shows in graphic form the age distribution of North and South County bicyclists with male and female combined.

The respondents to the postcard questionnaire were asked to identify for each bicyclist in the household the number of bicycle accidents experienced in the last 12 months. Bicyclists who had experienced a bicycle accident in the past 12 months were grouped together and will be identified hereafter as the accident group. Bicyclists who had had no accidents in the past 12 months were grouped together and will be referred to hereafter as the nonaccident group.

Table 2 shows the age distributions of the accident group and the nonaccident group for North County and South County separately and combined. Age distributions are not shown by sex because the number of individuals in the North County accident group is too small to enable a comparison to be made between the age distribution of male and female accident victims in North County. Moreover, an examination of the age distributions for the male and female accident victims in South County revealed no major differences. Table 2 shows that the age distribution of the North County accident group is bimodal. That is, a secondary peak is reached for the group aged 5-9 and the primary peak is reached at the group aged 15-19. The age distribution of the South County accident group is quite different. It can be seen that nearly 48 percent of bicyclists in the South County accident group are between the ages of 20 and 24. The group aged 15-19 is the next most frequent, accounting for nearly 15 percent of all bicyclists in the accident group. The group aged 10-14 is the third most frequent, accounting for about 14 percent of the bicyclists in the accident group.

Figures 2 and 3 enable an easy comparison of the age distributions for the accident and nonaccident groups; Figure 2 shows the data for North County and Figure 3 shows the data for South County. Figure 2 shows that bicyclists between the ages of 15 and 24 are grossly overrepresented in the accident group; the overrepresentation is greatest for the group aged 20-24. With only three minor exceptions, all other age groups are underrepresented in the accident group. Figure 3 shows that South County bicyclists between the ages of 10 and 24 are overrepresented in the accident group, and that all other age groups are underrepresented in the accident group. The over-representation is only slight for bicyclists in the groups aged 10-14 and 15-19. However, the over-representation of 20- to 24-year-olds in the accident group is extremely large; bicyclists between the ages of 20 and 24 account for only 17 percent of the bicyclists in the nonaccident group, but they account for nearly 48 percent of the bicyclists in the accident group. It is clear from the above findings that accident countermeasures aimed at 20- to 24-year-old bicyclists have the potential for reducing total accidents by a substantial margin. However, as is true in most other communities, substantial accident-reduction benefits can be expected from effective countermeasures aimed at younger bicyclists.

Table 1. Estimated number of bicyclists in north and south Santa Barbara County.

| | North County | | | | | | South County | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | | | Female | | | Male | | | Female | | | Total Bicyclists | | |
| Age | R | % | B | R | % | B | R | % | B | R | % | B | Male | Female | Combined |
| <5 | 4 373 | 30.2 | 1 321 | 3 963 | 17.1 | 678 | 3 735 | 19.1 | 713 | 3 866 | 24.5 | 947 | 2 034 | 1 625 | 3 659 |
| 5-9 | 5 230 | 92.8 | 4 853 | 4 914 | 92.9 | 4 565 | 5 045 | 92.0 | 4 641 | 5 154 | 85.4 | 4 402 | 9 494 | 8 967 | 18 461 |
| 10-14 | 6 665 | 98.1 | 6 538 | 6 014 | 91.8 | 5 521 | 6 102 | 99.2 | 6 053 | 6 348 | 98.3 | 6 240 | 12 591 | 11 761 | 24 352 |
| 15-19 | 6 565 | 86.3 | 5 666 | 5 620 | 81.1 | 4 558 | 8 476 | 87.9 | 7 450 | 9 224 | 91.2 | 8 412 | 13 116 | 12 970 | 26 086 |
| 20-24 | 6 985 | 71.7 | 5 008 | 4 342 | 72.2 | 3 135 | 10 589 | 87.3 | 9 244 | 10 605 | 89.8 | 9 523 | 14 252 | 12 658 | 26 910 |
| 25-29 | 4 875 | 68.5 | 3 339 | 4 058 | 73.7 | 2 991 | 8 157 | 87.7 | 7 154 | 7 465 | 85.7 | 6 398 | 10 493 | 9 389 | 19 882 |
| 30-34 | 3 783 | 61.9 | 2 342 | 4 064 | 56.9 | 2 312 | 5 467 | 70.7 | 3 865 | 5 375 | 69.7 | 3 746 | 6 207 | 6 058 | 12 265 |
| 35-39 | 3 887 | 55.1 | 2 142 | 3 827 | 73.0 | 2 794 | 4 170 | 67.8 | 2 827 | 4 366 | 67.7 | 2 956 | 4 969 | 5 750 | 10 719 |
| 40-44 | 3 715 | 60.7 | 2 255 | 3 483 | 54.5 | 1 898 | 4 001 | 71.6 | 2 865 | 4 055 | 49.4 | 2 003 | 5 120 | 3 901 | 9 021 |
| 45-49 | 3 269 | 63.6 | 2 079 | 3 154 | 49.1 | 1 549 | 3 917 | 61.8 | 2 421 | 4 170 | 57.6 | 2 402 | 4 500 | 3 951 | 8 451 |
| 50-54 | 3 074 | 56.4 | 1 734 | 3 098 | 33.3 | 1 032 | 4 112 | 40.3 | 1 657 | 4 624 | 47.1 | 2 178 | 3 391 | 3 210 | 6 601 |
| 55-59 | 2 476 | 36.4 | 901 | 2 296 | 20.0 | 459 | 3 442 | 52.9 | 1 821 | 3 831 | 30.9 | 1 184 | 2 722 | 1 643 | 4 365 |
| 60-64 | 1 876 | 36.4 | 684 | 1 972 | 27.6 | 544 | 3 006 | 37.9 | 1 139 | 3 791 | 17.8 | 675 | 1 823 | 1 219 | 3 042 |
| 65-69 | 1 641 | 27.3 | 448 | 1 580 | 0.1 | 2 | 2 818 | 30.4 | 857 | 4 071 | 14.6 | 594 | 1 305 | 596 | 1 901 |
| 70-74 | 1 075 | 55.6 | 598 | 1 065 | 75.0 | 799 | 2 174 | 27.9 | 607 | 3 073 | 4.0 | 123 | 1 205 | 922 | 2 127 |
| ≥75 | 1 213 | 50.0 | 607 | 1 676 | 11.1 | 186 | 2 942 | 3.0 | 88 | 5 389 | 0.1 | 5 | 695 | 191 | 886 |
| Total | 60 704 | 66.7 | 40 515 | 55 126 | 59.9 | 33 023 | 78 153 | 68.3 | 53 402 | 85 407 | 60.6 | 57 788 | 93 917 | 84 811 | 178 728 |

Notes: R = number of residents (from 1975 to census data); % = percentage of residents who ride a bicycle (from 1978 postcard survey); and B = estimated number of bicyclists (R x %).

Figure 1. Age distribution of Santa Barbara County bicyclists.

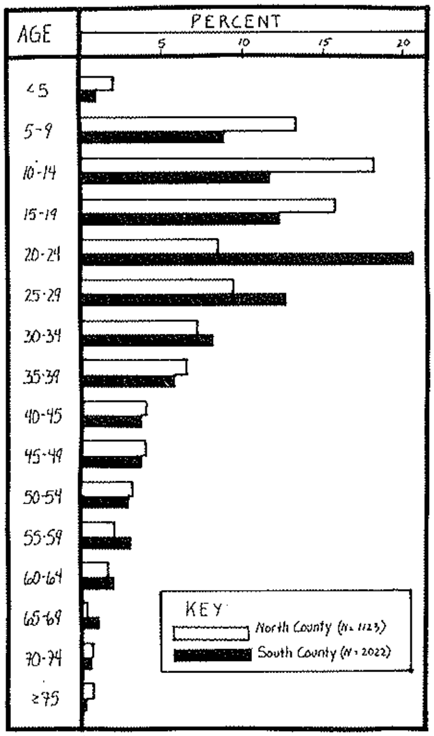


Table 3 gives estimates of the total number of persons in North County and South County who have had at least one accident during the last 12-month period. Estimates were derived for each age group by multiplying the total number of bicyclists in that age group who have reported having an accident during the last 12-month period by census group. Again, the data used to derive these estimates were obtained from the postcard survey and from a special census taken in 1975.

The data in Table 3 reveal several important findings. First, the incidence of NMV accidents in South County is about four times as great as that in North County. A relatively small amount of this difference is attributable to the larger bicycling population in South County than that in North County. Note in Table 3 that the estimated number of bicyclists in North County is 74 000 whereas the estimated number of bicyclists in South County is approximately 105 000. Thus, if the accident rate were the same in North and South County, the number of accidents in South County would be only about 25 percent greater than the number of accidents in North County. It is clear from these results that the accident rate in South County is considerably greater than that in North County. The extent of this difference is made clear by comparing columns 3 and 6 in Table 3. These proportions can be interpreted as accident rates for the corresponding age group. For instance, the number associated with the 10-14 year age group in North County indicates that about 1.46 NMV accidents/100 bicyclists can be expected to occur each year. The largest accident rate for both North County and South County is associated with the group aged 20-24. However, it can be seen that South County bicyclists in this age group experience more than 18 accidents/100 bicyclists, whereas North County bicyclists in this age group experience about 6 accidents/100 bicyclists. The accident rate is higher in South County for 10 of the 16 age groups, and the rate is essentially the same for the remaining six age groups.

Items were included on the postcard questionnaire to obtain information about the number of bicycles in use in Santa Barbara County and the number of bicycles that are stolen each year. The findings are summarized in the table below. The data are shown for urban areas, rural areas, and for urban and rural areas combined.

| Item | Urban | Rural | Combined |
|---|---|---|---|
| Total bicycles | 2954.00 | 397.00 | 3351.00 |
| Mean bicycles per household | 1.90 | 2.16 | 1.93 |
| Mean bicycles per resident | 0.71 | 0.76 | 0.71 |
| Mean bicycles per bicyclist | 1.05 | 1.23 | 1.07 |
| Total bicycles stolen, past 12 months | 221.00 | 18.00 | 239.00 |
| Bicycles stolen per 1000 in use | 74.8 | 45.3 | 71.3 |
| Bicycles stolen per 1000 households | 142.2 | 97.3 | 137.5 |

## DESCRIPTION OF TYPES OF ACCIDENT AND CONTRIBUTING FACTORS

The accident types and the factors that contribute to

Table 2. Age distributions of the accident and nonaccident groups.

| | Accident Group | | | | | | Nonaccident Group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North County | | South County | | Total | | North County | | South County | | Total | |
| Age | No. | Percent | No. | Percent | No. | Percent | No. | Percent | No. | Percent | No. | Percent |
| <5 | 1 | 3.3 | 0 | | 1 | 0.5 | 11 | 0.9 | 17 | 0.9 | 28 | 0.9 |
| 5-9 | 5 | 16.7 | 13 | 8.1 | 18 | 9.4 | 226 | 19.4 | 165 | 8.7 | 391 | 12.8 |
| 10-14 | 3 | 10.0 | 22 | 13.8 | 25 | 13.1 | 202 | 17.3 | 221 | 11.7 | 423 | 13.8 |
| 15-19 | 7 | 23.4 | 24 | 14.9 | 31 | 16.2 | 169 | 14.6 | 242 | 12.8 | 411 | 13.4 |
| 20-24 | 6 | 20.0 | 77 | 47.9 | 83 | 43.5 | 88 | 7.5 | 342 | 18.0 | 430 | 14.0 |
| 25-29 | 1 | 3.3 | 10 | 6.2 | 11 | 5.8 | 110 | 9.4 | 257 | 13.5 | 367 | 12.0 |
| 30-34 | 1 | 3.3 | 6 | 3.7 | 7 | 3.7 | 83 | 7.1 | 168 | 8.8 | 251 | 8.2 |
| 35-39 | 2 | 6.7 | 2 | 1.2 | 4 | 2.1 | 72 | 6.2 | 124 | 6.5 | 196 | 6.4 |
| 40-44 | 1 | 3.3 | 2 | 1.2 | 3 | 1.6 | 57 | 4.9 | 93 | 4.9 | 150 | 4.9 |
| 45-49 | 2 | 6.7 | 2 | 1.2 | 4 | 2.1 | 53 | 4.5 | 76 | 4.0 | 129 | 4.2 |
| 50-54 | 0 | | 1 | 0.6 | 1 | 0.5 | 34 | 2.9 | 61 | 3.2 | 95 | 3.1 |
| 55-59 | 0 | | 1 | 0.6 | 1 | 0.5 | 23 | 2.0 | 60 | 3.2 | 83 | 2.7 |
| 60-64 | 0 | | 1 | 0.6 | 1 | 0.5 | 21 | 1.8 | 37 | 1.9 | 58 | 1.9 |
| 65-69 | 0 | | 0 | | 0 | | 8 | 0.7 | 20 | 1.1 | 28 | 0.9 |
| 70-74 | 0 | | 0 | | 0 | | 5 | 0.4 | 14 | 0.7 | 19 | 0.6 |
| ≥75 | 1 | 3.3 | 0 | | 1 | 0.5 | 5 | 0.4 | 2 | 0.1 | 7 | 0.2 |
| Total | 30 | | 161 | | 191 | | 1167 | | 1899 | | 3066 | |

Figure 2. Comparison of age distribution of North County accident and nonaccident groups.

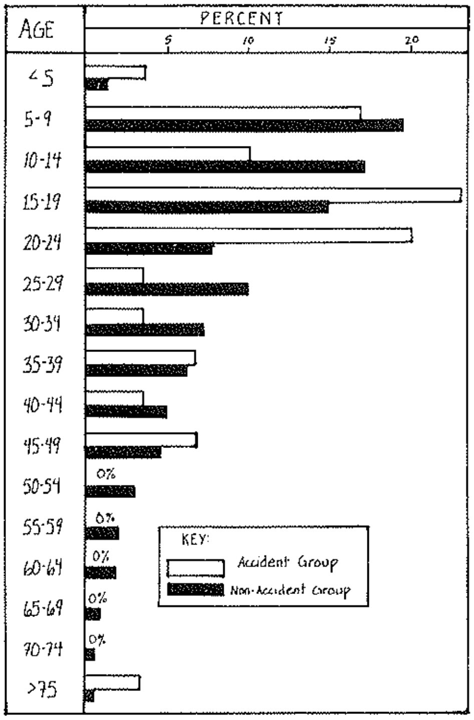
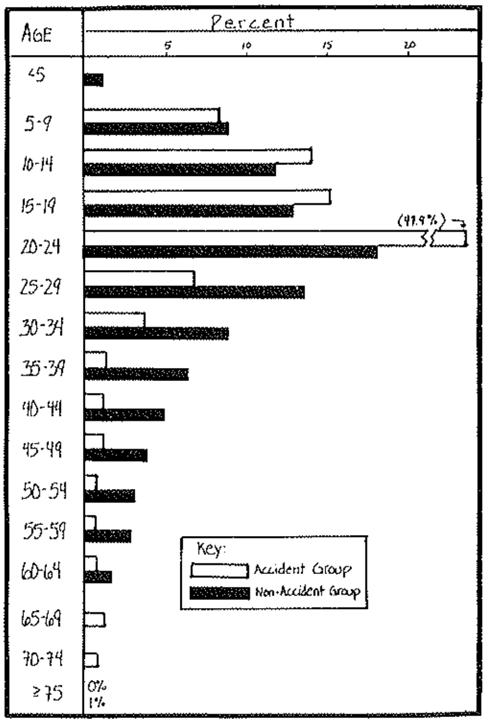


Figure 3. Comparison of age distribution of South County accident and nonaccident groups.



accidents were defined from a study of the data compiled from the telephone interviews with the accident victims. Eight of the 206 accident cases investigated proved to be bicycle-motor vehicle accidents, so the following results are based on interviews with 198 bicyclists who recently were involved in NMV accidents. The information obtained for each case was studied by three members of the project staff. Each staff member made independent judgments about the factor that precipitated the accident and the one or more factors that contributed to the accident. Differences in judgments about precipitating factors and contributing factors were resolved through discussion.

An attempt was made to contact virtually every bicyclist in the user survey who reported having had a recent NMV accident. Many bicyclists, especially young adults, could not be located because of an address change. For this reason and others, the sample of bicyclists interviewed cannot be considered representative of the total accident population in Santa Barbara County. To correct for the biases in the telephone survey data, the age distribution of the sample of bicyclists in the telephone survey was multiplied by weighting factors such that the age distribution for the telephone survey matched the age distribution of the accident population in Santa Barbara County, as revealed by the postcard survey. This age distribution is shown in Table 2 and discussed above. The weighting factors

Table 3. Estimates of the total number of persons in North County and South County who have had at least one accident during the last 12-month period.

| | North County Bicyclists | | | South County Bicyclists | | |
|---|---|---|---|---|---|---|
| Age | Number | Had Accident (%) | Estimated Number of Accidents | Number | Had Accident (%) | Estimated Number of Accidents |
| <5 | 1 999 | 8.33 | 167 | 1 660 | 0.00 | 0 |
| 5-9 | 9 418 | 2.16 | 203 | 9 043 | 7.30 | 818 |
| 10-14 | 12 059 | 1.46 | 176 | 12 293 | 9.05 | 1112 |
| 15-19 | 10 224 | 3.98 | 407 | 15 862 | 9.02 | 1431 |
| 20-24 | 8 143 | 6.38 | 520 | 18 767 | 18.38 | 3449 |
| 25-29 | 6 330 | 0.90 | 57 | 13 552 | 3.75 | 468 |
| 30-34 | 4 654 | 1.19 | 55 | 7 611 | 3.45 | 263 |
| 35-39 | 4 933 | 2.70 | 133 | 5 783 | 1.59 | 92 |
| 40-44 | 4 153 | 1.72 | 71 | 4 868 | 2.11 | 103 |
| 45-49 | 3 628 | 3.64 | 132 | 4 823 | 2.56 | 123 |
| 50-54 | 2 766 | | 0 | 3 835 | 1.61 | 62 |
| 55-59 | 1 360 | | 0 | 3 005 | 1.64 | 49 |
| 60-64 | 1 228 | | 0 | 1 814 | 2.63 | 48 |
| 65-69 | 450 | | 0 | 1 451 | | 0 |
| 70-74 | 1 397 | | 0 | 730 | | 0 |
| ≥75 | 793 | 16.67 | 132 | 93 | | 0 |
| Total | 73 535 | | 2053 | 105 190 | | 8018 |

used for each of the age groups is shown in the following table:

| Bicyclist's Age | Weighting Factor |
|---|---|
| <5 | 1.00 |
| 5-9 | 4.60 |
| 10-14 | 2.30 |
| 15-19 | 1.18 |
| 20-24 | 7.13 |
| 25-29 | 2.32 |
| 30-34 | 7.40 |
| >35 | 1.00 |

As the accident types are discussed in the following pages, two percentage values are given for each type of accident. One percentage value indicates the proportion of accidents in the unweighted sample that is accounted for by that accident type. The other percentage value indicates the percentage of accidents in the weighted sample that is accounted for by that accident. When percentage values for the weighted and unweighted sample are approximately the same, it can be concluded that that accident type is relatively independent of bicyclists' age; or, stated differently, accidents of that type are experienced by bicyclists of different ages.

## Class A Accidents—Collision or Near Collision With a Moving Object

All of the accidents included in class A involved the collision of a bicyclist with another moving object or a bicyclist falling or colliding with a fixed object while attempting to avoid a collision with a moving object. Class A accidents were subdivided into the four accident types listed in the table below. Class A accidents accounted for slightly more than 28 percent of the NMV accidents in the weighted sample.

| Accident Description | Sample (%) | Weighted Sample (%) |
|---|---|---|
| Type 1—Collision or near collision with another bicycle | 19.1 | 21.2 |
| Type 2—Collision or near collision with animal | 1.5 | 1.5 |
| Type 3—Collision or near collision with pedestrian | 1.0 | 4.6 |
| Type 4—Fell or struck fixed object when evading collision with motor vehicle | 2.0 | 1.0 |
| Total class A (N = 47) | 23.6 | 28.3 |

### Type 1: Collison with Another Bicycle

The table above shows that accident type 1 accounts for slightly more than 21 percent of the NMV accidents in the weighted sample. (Hereafter all percentage values cited in the text refer to the weighted sample.) Type 1 accidents can be divided into five distinctly different subtypes, based on the factor that precipitated the accidents. The subtypes are listed below along with the percentage of all type 1 accidents that were accounted for by that subtype.

Subtype 1—misjudged the intentions of the other bicyclist—63 percent;

Subtype 2—obstructed view of another bicyclist—13 percent;

Subtype 3—distracted, not looking in direction of other bicyclist—8 percent;

Subtype 4—misjudged the space required to overtake and pass—8 percent; and

Subtype 5—game playing or stunting—8 percent.

All of the accidents classified into subtype 1 involved a bicyclist who observed the other bicycle soon enough to avoid the accident, but failed to do so because he or she misjudged the intentions of the other bicyclist. Subtype 1 accidents most commonly involved two or more bicyclists who were riding together, either abreast or in tandem. The accidents occurred when one of the bicyclists unexpectedly turned, slowed speed, failed to turn, or failed to slow. An unexpected turn was the most common type of misjudgment.

A smaller, but nevertheless important, number of subtype 1 accidents involved bicyclists who were not riding together but were approaching one another on either an orthogonal path or a parallel path. In most of these cases, both bicyclists misjudged the intentions of the other.

All subtype 2 accidents occurred when one bicyclist's view of the other was obstructed until the bicycles were in such close proximity that the accident could not be avoided. In all cases, the bicycles approached one another on orthogonal paths. The objects that obstructed the bicyclist's view were vegetation or parked motor vehicles.

All the bicyclists in subtype 3 were distracted and, therefore, were not searching in the direction of the other bicyclist. All subtype 4 accidents resulted from a bicyclist's misjudgment about the space required to overtake and pass another bicyclist. That is, one bicyclist attempted to overtake and pass another bicyclist at a point where there was insufficient space to do so safely. All subtype 5 accidents occurred when two or more bicyclists were game playing or stunting.

### Type 2: Collision or Near Collision with Animal

Nearly every book on bicycle riding warns of the hazards associated with animals chasing bicyclists or unexpectedly dashing into the bicyclist's path. The table shows that collisions or near collisions with animals accounted for only 1.5 percent of the NMV accidents in the weighted sample. The low incidence of this type of accident may be due to the fact that most, and perhaps all, communities in Santa Barbara have leash laws for dogs. It would be interesting to compare the incidence of this accident type in Santa Barbara County with the incidence in one or more communities that do not have a leash law.

### Type 3: Collision or Near Collision with Pedestrian

A collision or near collision with a pedestrian accounted for only 1 percent of the accidents in the unweighted sample but accounted for nearly 5 percent of the accidents in the weighted sample. This difference is due to the fact that this accident type more often involves older riders than younger riders. The incidence of bicycle-pedestrian accidents in the telephone survey was too small to make a definitive statement about how and why they occur. However, information obtained from bicyclists who were riding on one of the two main separated bicycle paths in Santa Barbara indicates that the incidence of bicycle-pedestrian accidents increases dramatically when separated bike paths are used by pedestrians and bicyclists. It was found that 3.8 percent of the bicyclists interviewed on the bike paths had recently been involved in an accident with a pedestrian on one of the two main paths in the city of Santa Barbara. The data indicate that bicycle-pedestrian accidents most frequently occur when the pedestrian turns unexpectedly as he or she is being overtaken from the rear by a bicyclist. This type accident is particularly common when the pedestrian is roller skating or riding on a skateboard.

In summary, the telephone survey indicated that bicycle-pedestrian accidents are not as frequent as other types of accidents on the public streets. However, the evidence from the bike path surveys indicates that bicycle-pedestrian accidents may increase dramatically when bicyclists and pedestrians are permitted to use the same separated bike path. Other support for this contention comes from data on the incidence of bicycle-pedestrian accidents on college and university campuses.

### Type 4: Fell or Struck Fixed Object When Evading Collision with Motor Vehicle

Many bicycle enthusiasts claim that numerous accidents occur when bicyclists fall or strike fixed objects as a result of their attempt to avoid a collision with a motor vehicle. This claim is not supported by the data compiled during this study. As is shown in the table, type 4 accidents accounted for only 1 percent of the NMV accidents in the weighted sample. It is possibly that the incidence of type 4 accidents may be far greater in other communities within Santa Barbara County. However, we hypothesized that the bicycle enthusiasts' claim that this type of accident occurs frequently is based on the incidence of near accidents rather than the incidence of actual accidents.

## Class B Accidents: Fell or Collided with Stationary Object After Losing Control of Bicycle

As its title implies, all class B accidents occurred when the bicyclist lost control of the bicycle and fell or collided with a fixed object. The accident types and subtypes within class B are differentiated in terms of the factors that led to the loss of control. As is shown in the table below, class B accidents accounted for 61 percent of the accidents in the weighted sample.

| Accident Description | Sample (%) | Weighted Sample (%) |
|---|---|---|
| Type 5—Lost control because of irregular road surface | 22.6 | 22.6 |
| Type 6—Lost control when performing stunts | 6.5 | 3.6 |
| Type 7—Lost control due to vehicle handling deficiency | 13.6 | 12.6 |
| Type 8—Lost control when carrying object in hands | 3.0 | 1.4 |
| Type 9—Lost control because object caught in moving part of vehicle | 11.1 | 13.8 |
| Type 10—Lost control because of other bicycle failure or defect | 8.0 | 7.1 |
| Total class B (N = 129) | 64.8 | 61.1 |

### Type 5: Lost Control Because of Irregular Road Surface

The data indicate that nearly 23 percent of all NMV accidents involve a bicyclist who lost control of the bicycle because of an irregularity in the road surface on which he or she was riding. Type 5 accidents can be further divided into subtypes based on the type of road surface irregularity that led to the loss of control. The type 5 subtypes are listed below along with an indication of the proportion of all type 5 accidents accounted for by each subtype.

Subtype 1—wet pavement—12 percent;
Subtype 2—sand, gravel, or dirt on paved surface—30 percent;
Subtype 3—tire hit large rock or other debris—20 percent;
Subtype 4—crack, bump, or hole in paved surface—30 percent;
Subtype 5—sewer grate—2 percent;
Subtype 6—rut or bump in unpaved surface—5 percent; and
Subtype 7—railroad track—2 percent.

Speed was judged to be a contributing factor in 49 percent of all type 5 accidents. In about one-half of the cases in which speed was judged to be a contributing factor, the bicyclist was riding down a hill. The effect of speed manifested itself by reducing the amount of time the bicyclist had available to respond to the irregularity of the road surface, increased the bicycle's sensitivity to road surface irregularities, or both. In 37 percent of the type 5 accidents, the bicyclist observed the irregularity of the road surface soon enough to have slowed speed or steered around the irregularity. In these cases, the bicyclist's failure to change speed or path was due to misjudgment of the effect of the irregularity on the bicycle's performance. In short, the bicyclist failed to perceive the irregularity as an accident hazard. In the remaining cases, the bicyclist failed to observe the road surface irregularity until it was too late to initiate effective evasive action. As indicated above, the bicyclist's failure to observe the irregularity soon enough to respond was often due, in part, to the bicycle's high speed.

### Type 6: Lost Control When Performing Stunts

Three-quarters of type 6 accidents occurred when a young bicyclist was riding over a jump. It is interesting to note that in every one of these cases, the bicyclist was riding a Motocross bicycle. In the remaining cases, the bicyclist was attempting a wheelie, riding a serpentine course, or riding over a curb. These three accident subtypes accounted for about 25 percent of type 6 accidents and occurred with about equal frequency.

### Type 7: Lost Control Due to Bicycle-Handling Deficiency

The preceding table shows that more than 12 percent of the NMV accidents in the weighted sample resulted directly from a deficiency in the bicyclist's vehicle-handling skill. As the term is used here, vehicle-handling skill deficiency refers to an inadequate level of skill to safely perform the maneuver that the bicyclist was attempting just prior to the accident. That is, a bicyclist may have a bicycle-handling skill deficiency even though his or her bicycle-handling skills are far better than those of the average bicyclist. Type 7 accidents can be divided into subtypes based on the maneuver that the bicyclist was attempting when the accident occurred. The accident subtypes are listed below along with an indication of the percentage of type 7 accidents accounted for by each subtype.

Subtype 1—high-speed braking—24 percent;
Subtype 2—high-speed turning—16 percent;
Subtype 3—high-speed steering—28 percent;
Subtype 4—normal-speed braking—8 percent;
Subtype 5—normal-speed turning—8 percent; and
Subtype 6—normal-speed steering—16 percent.

Bicyclists involved in subtypes 1 through 3 were at least as skilled as the average bicyclist in the age group. Conversely, bicyclists involved in subtypes 4 through 6 were judged to have far less bicycle-handling skills than the average bicyclist of the same age. Some of the type 7 accidents involved an irregularity in the roadway surface, such as wet pavement or gravel. However, it was judged that the accident was precipitated by the skill deficiency rather than by the roadway surface irregularity.

### Type 8: Lost Control When Carrying Object in Hands

Type 8 accidents occurred relatively infrequently, accounting for only 1.4 percent of the accidents in the weighted sample. One-half of these accidents resulted from the bicyclist's inability to slow or stop by manipulating caliper brakes with only one hand. The other type 8 accidents resulted from a bicyclist's inability to steer and maintain balance when carrying an object in one hand. The incidence of type 8 accidents is surprisingly low in light of the number of bicyclists who are seen riding 10-speed bicycles and have only one hand available for steering and braking.

### Type 9: Lost Control Because Object Caught in Moving Part of Bicycle

Type 9 accidents accounted for nearly 14 percent of the accidents in the weighted sample. Type 9 accidents can be divided into subtypes based on the object that became lodged in a moving part of the bicycle. The subtypes of accident type 9 are as follows:

Subtype 1—pant leg caught between chain and sprocket—32 percent;
Subtype 2—passenger's hand or foot caught in spokes—23 percent;
Subtype 3—object hanging from handlebars lodged in front wheel or spokes—27 percent;
Subtype 4—chain lodged between spokes and frame—5 percent; and
Subtype 5—miscellaneous—13 percent.

### Type 10: Loss of Control Because of Bicycle Defect or Failure

Subtypes 4 and 5 of accident type 9 involved a bicycle failure. They were classified in accident type 9 because the failure resulted in an object being lodged in a moving part of the bicycle. It can be argued that these accidents should be classified in type 10 rather than type 9. Type 10 accidents can be divided into subtypes based on the part of the bicycle that was defective or that failed. This classification resulted in the identification of seven subtypes, each of which occurred with about equal frequency.

Subtype 1—defective brakes,
Subtype 2—loose handlebars,
Subtype 3—wet brakes,
Subtype 4—bicycle frame broke,
Subtype 5—gears slipped,
Subtype 6—chain broke, and
Subtype 7—front wheel was loose.

High speed was a factor in 41 percent of all type 10 accidents. That is, it was judged that the bicycle failure would not have resulted in a loss of control if the bicyclist had been riding at a reasonable speed.

## Class C: Bicyclist Collided with Stationary Object with Subsequent Loss of Control

The table below shows that class C accidents accounted for only 10.4 percent of those in the weighted sample.

| Accident Description | Sample (%) | Weighted Sample (%) |
|---|---|---|
| Type 11—Bicyclist's view of object was obstructed | 1.0 | 1.3 |
| Type 12—Degraded visibility | 1.5 | 0.4 |
| Type 13—Bicyclist not searching ahead | 9.1 | 8.7 |
| Total class C (N = 22) | 11.6 | 10.4 |

Type 11 and type 12 accidents resulted from the bicyclist's view of the object being obstructed (1.3 percent) or obscured (0.4 percent) by degraded visibility conditions. These results indicate that few NMV accidents result from a bicyclist's inability to observe a fixed object until an accident is imminent. The distinguishing characteristic of type 13 accidents is that the bicyclist failed to observe the object struck because he or she was not searching in the direction he or she was traveling. Eighty percent of type 13 accidents involved the collision of a bicyclist with the rear of a parked motor vehicle. In over one-half of these accidents, the bicyclist was interacting with a riding companion who was riding abreast or behind the bicyclist. In the remaining cases, the bicyclist was communicating with a passenger, searching to the rear for overtaking traffic, or throwing a newspaper. These three accident subtypes occur with about equal frequency.

## RELATIONSHIP BETWEEN ACCIDENT LIKELIHOOD AND EXPOSURE

The bicyclists who completed the questionnaire in the user survey were asked to indicate the number of kilometers per week they travel on school trips, trips to and from work, trips to visit friends and relatives, shopping and errand trips, trips traveling to a specific place of recreation, and recreational trips that have no specific destination. There was no expectation that these items would yield precise information on the absolute number of kilometers per week ridden for each of these purposes. However, it was reasoned that such items would yield data in which the bias is constant for bicyclists in the same age group and, therefore, would enable a comparison to be made of the relative exposure of bicyclists in the accident group and those in the nonaccident group.

A computer program was written to compute for each bicyclist in the user survey the estimated distance traveled for all trip purposes combined. The computer program then divided the bicyclists into age groups and, for each age group, divided the bicyclists into an accident group and a nonaccident group. The distribution of kilometers traveled per week was studied in the median and interquartile range for each population; the subpopulation was computed.

Our findings indicate that the 25th centile bicyclist rides about 5.6 km per week (3.5 miles per week), the 50th centile bicyclist rides about 14.3 km (8.9 miles) per week, and the 75th centile bicyclist rides slightly more than 25 km (16 miles) in an average week. The trends are completely consistent with the hypothesis that accident likelihood increases with exposure, as measured by the number of kilometers traveled per week. For every age group, the accident group reported traveling more kilometers per week than the bicyclists of the same age in the nonaccident group. Similarly, the kilometers traveled per week, like the incidence of NMV accidents, increases consistently to the 20- to 24-year-old group. Unfortunately, there was an insufficient number of older bicyclists to determine whether exposure, like accident frequency, decreases with age beyond age 24.

## CONSEQUENCES OF NMV ACCIDENTS

In order to estimate the cost of the total societal losses from NMV accidents, the following procedure was used. Cost were divided into four major areas:

1. Doctor, dentist, and hospital costs;
2. Cost of bicycle damage;
3. Cost of other property damage, such as damaged clothing and books; and
4. Cost of days lost from school or work as a result of the NMV accident.

Although the bicyclists were questioned about the number of days in which they were partially disabled or suffered pain and discomfort, no attempt was made to estimate the cost of partial disability or pain and suffering. The method used to estimate the dollar loss associated with each of the four categories is as follows.

### Medical Costs

Most of the estimates of medical costs were derived from cost data contained in a recent report on the cost of motor vehicle accidents (1). Note that the cost estimates quoted in Faigin's report are consistently low because of the inflated cost of medical care that has occurred since the report was published; however, no more accurate cost estimates could be located. Thus, the following costs were assumed for medical care:

1. Emergency-room treatment—$85,
2. Hospital care—$100 per day, and
3. Doctor's care—$20 per visit.

When surgery or dental work was needed, the cost estimates used were those reported by the accident victim.

### Bicycle and Other Property Damage

At the time of the telephone surveys, few persons were aware of the dollar cost of damage to their bicycle. In numerous cases, the person simply failed to repair the damage, or the bicyclist or a parent repaired the damage as well as possible. In order to obtain information with which to estimate the cost of bicycle damage, local expert bicycle repairpersons were surveyed to obtain their estimates of the cost of parts and labor to repair various types of damage.

For property damage other than that sustained by the bicycle, the cost estimates used in the analyses were those provided by the bicyclist.

### Cost of Days Lost from Work or School

The cost of a day missed from work was assumed to be $65. This value was computed by Faigin in 1976 (1) and is undoubtedly higher today. The cost of a day lost from school was assumed to be $5. This value was suggested by Cross in 1978 (2) in a discussion of the cost of bicycle-motor-vehicle accidents.

### Average Costs and Total Losses

By using the cost estimates described above, it was determined that the average cost of a NMV accident was $106. In an earlier part of this section, it was estimated that 2053 North County bicyclists and 8018 South County bicyclists had at least one NMV accident during the past 12 months. Thus, the annual cost of NMV accidents is estimated to be about $218 000 in North County and about $850 000 in South County or about $1 070 000 for the county as a whole.

These cost estimates must be considered highly conservative in that they make no allowance for pain and suffering. Although emotional trauma represents a real and important societal loss, no satisfactory technique has been established for placing a monetary value on such a loss. In addition, no consideration has been given for the time lost by friends or relatives who care for an injured bicyclist. Moreover, the cost estimates cited above were based on the number of bicyclists who had one or more accidents during the past 12 months. Since some bicyclists have more than one bicycle accident during any 12-month period, the cost estimates cited above should be multiplied by the ratio of total accidents divided by total accident victims. Finally, the cost estimates must be considered conservative because the assumed costs of medical care and days lost from work or school are based on 1975 dollars rather than 1979 dollars.

## CONCLUSION

The annual societal cost of NMV accidents has been conservatively estimated at $1 070 000 for Santa Barbara County. This is the first time a documented estimate of cost has been made to confirm the magnitude of this problem. With this documentation of cost, the need has been established for a remedy.

Whenever a decision is being made concerning the development of safety education programs, a balance between societal cost and societal benefit must be made. The cost of education can only be justified if the potential societal benefits outweigh the costs. We think that a societal loss of this magnitude justifies extensive educational development.

Never before have Americans been as energy conscious as they have in recent times. Bicycle use has become a logical alternative to fuel-consumptive vehicles. Consequently, more bicycles are now on the road than ever before. With this increased bicycle use has come a desperate need for bicycle safety education. In the current political climate, individual states as well as the federal government are placing high priority on the development of facilities that will encourage bicycle use for transportation. Without balancing education with this acceleration, we could be creating a tremendous safety problem while striving to save energy.

By using research projects that have defined major accident causes, it will be possible to direct meaningful safety education to adults as well as children.

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# Determination of the Characteristics of Bicycle Traffic at Urban Intersections

Kenneth S. Opiela, Snehamay Khasnabis, and Tapan K. Datta

A study of bicycle traffic at urban intersections was conducted to determine the characteristics representative of this mode. The study was undertaken to address information deficiencies recognized during efforts to develop a multimodal-intersection-simulation model. The study focused on the arrival patterns, approach speeds, and crossing gap-acceptance characteristics of bicycle traffic. Traffic data were collected from a number of intersection locations operating under multimodal demand, which included motor vehicle, pedestrian, and bicycle modes. A video recording procedure was used to record and subsequently retrieve information relative to the various events of interest. Statistical analysis of the data was conducted to establish the characteristics of bicycle traffic arrivals, approach speeds, and crossing gap acceptance. The analysis of arrival data revealed that a negative exponential distribution represented a reasonable model for low-to-medium volumes of bicycles. Other arrival models were noted to be applicable in some cases, but the negative expontential was preferred because of its universality and simplicity. Approach speeds were noted to range from 3.4 to 39.6 km/h (2.1 to 24.6 mph), with the distribution of speeds corresponding to a normal curve. Analyses of bicycle speeds on different facilities and the impact of bicycle lane traffic on automobile speeds were performed. Last, an analysis of crossing gap acceptance revealed that the distribution of accepted gaps corresponds to a log normal function. The results of the study are presented and the applicability of the findings discussed. Recommendations are made for improving the procedures used and conducting further investigations.

The sale and use of bicycles for both utilitarian and recreational travel has grown since the mid 1960s (1-3). Transportation professionals, in recognition of this trend, had begun to give serious attention to the bicycle mode by the mid 1970s. Many programs were initiated to plan, design, and implement facilities for bicycle travel (4-7).

The task of integrating bicycle facilities into the urban transportation system is not an easy one. Difficulties arise from the competing needs of other modes; the lack of agreement relative to the type, placement, and control of such facilities; and the limited understanding of the characteristics of bicycle traffic. The latter aspect, in particular, has prevented transportation professionals from applying various analytic or simulation techniques to determine the impacts of alternative intersection designs and control strategies. Consequently, few quantitative data exist for evaluation of the impacts of bicycle facility implementation. It is quite clear that an impending need exists for more information and a better understanding of the characteristics of bicycle traffic and its impact on intersection performance.

Some analysis has been undertaken by Jilla to measure the effect of shared use of roadways (8). He found that automobile traffic speeds are reduced and that vehicles are laterally displaced in the presence of bicycles. Loop and Layton conducted similar studies to determine the effects on speeds and lateral displacement (9). They noted only small decreases in automobile speeds but observed that the reductions were influenced by the width of the roadway and the volume of traffic. In each case, observations were made at nonintersection locations. Chao, Matthias, and Anderson have conducted studies of the behavior of bicyclists at signalized intersections (10). Their study focused primarily on signal-observance behavior for different types of controls and did not attempt to define the characteristics of bicycle traffic. Ferrara's work represents the only effort aimed at quantitatively evaluating intersection performance where both motor vehicles and bicycles compete for the use of the road (11). A limited amount of field data was collected and a simulation analysis of alternate options for intersection control was conducted. His analysis, however, fails to consider the effects of pedestrians, delay of one cyclist on another, and unbalanced intersection flow. Further, his study was based on data collected in California, an environment largely conducive to the use of the bicycle. Other studies of bicycle traffic have been undertaken in Europe but, for the most part, the results of these studies have not been available to engineers in this country. Further, the European experience may not be relevant in this country since the role of the bicycle as a means of urban transportation is significantly different, implying that bicycle traffic characteristics may not be similar. The need exists for further investigations into the nature of bicycle traffic characteristics.

The need for additional information relative to the characteristics of bicycle traffic was recognized during efforts to develop an intersection simulation model capable of representing multimodal demand situations. Multimodal demand occurs when significant volumes of bicycle, motor vehicle, and pedestrian traffic use common intersection space. The inherent differences in the performance characteristics of these modes influence the operation of an intersection. Simulation techniques were determined to offer the best means to assess the impacts of multimodal demand on intersection operation. The existing information relative to the characteristics of bicycle traffic was, however, found to be inadequate for simulation purposes. The collection, reduction, and analysis of field data became a necessary prerequisite for this study. The objective of this paper is (a) to describe the methodology employed to obtain and analyze bicycle characteristics data, (b) to present the conclusions drawn from the data analysis, and (c) to discuss the applicability of the information.

## DATA COLLECTION

The data collection effort for this study involved the identification of data needs, the selection of candidate locations, and the development of a data collection procedure.

### Data Requirements

The initial step in this study involved the establishment of data requirements. The primary focus of the effort was oriented to obtaining operations data pertaining to bicycle arrivals, speeds, and gap acceptance. It was necessary to determine data requirements to ensure that all relevant information would be collected and that it be done in an efficient and accurate manner.

The lack of sufficient information that defined the characteristics of bicycle traffic at intersections necessitated efforts to obtain bicycle operations data. The operations data determined to be necessary for this study included the following:

1. Traffic arrivals—Traffic arrivals data indicate both the volume and the time distribution of the traffic demand. Changes in volumes or the pattern of arrivals influence the operation of urban intersections.
2. Approach speeds—The approach speed of traffic influences stopping distances, clearance intervals, and turning radii at intersections. It is necessary to determine approach speeds for each mode for accurate replication of intersection operation.
3. Gap acceptance—Gap-acceptance events describe the behavior of individual traffic entities in accepting or rejecting gaps in the traffic stream. The length of gap accepted by an individual traffic entity will reflect the aggressiveness of the driver, the capabilities of the vehicle, and the length of wait.

### Selection of Candidate Sites

Data collection was made difficult by the fact that relatively few locations exist where sufficient volumes of multimodal traffic (specifically bicycle traffic) can be found. Help was sought from local officials, bicycle advocates, police departments, and others to generate a list of potential candidate locations. Most of the candidate locations were visited for a field evaluation of traffic and environmental conditions. Candidate locations for data collection were selected from this list on the basis of the following criteria:

1. Sufficient volumes of motor vehicle, pedestrian, and bicycle traffic must exist;
2. Bicycle traffic must be largely utilitarian travel (it has been suggested that trip purpose significantly influences characteristics such as speed, risk taking, and route selection);
3. An acceptable vantage point exists near the intersection to allow discrete observation of traffic operations and thus avoid modification of behavior; and
4. The location must represent a typical urban intersection.

Approximately 40 intersection locations were investigated in the preliminary search. Of these, 15 were found to meet the above criteria and were used for data collection. The locations at which data were collected for this study are described in Table 1. The table summarizes the environmental features of each location.

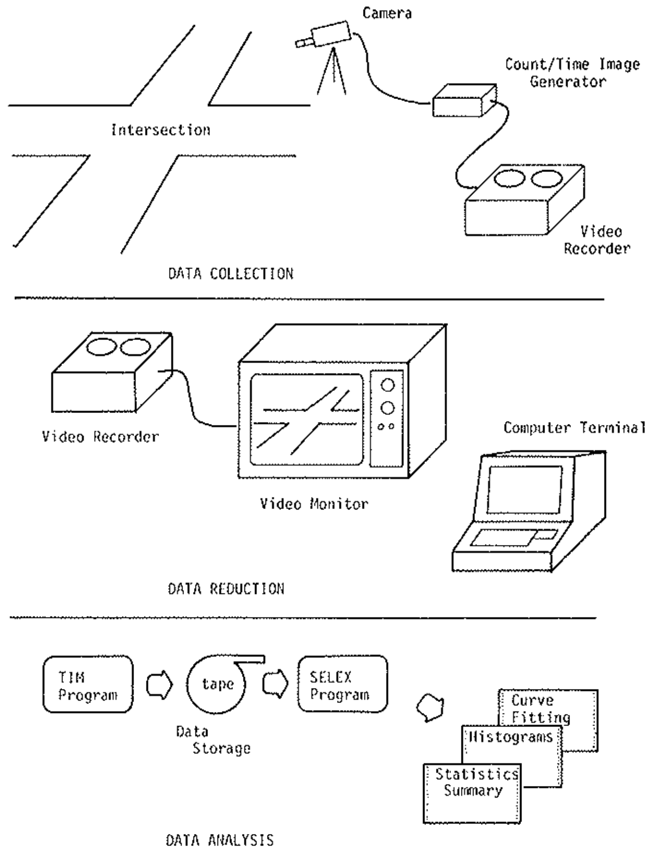
Note from the locations of the intersections that in all cases the data were collected in the proximity of college campuses. The proximity to campuses introduces

Table 1. Description of data collection locations.

| Site |  |  |  |  |  |
|---|---|---|---|---|---|
| No. | Location | Area | Control | Type[a] | Volume[b] Level |
| 1 | Shaw Lane and Farm Lane, East Lansing | Campus | Signal | FOL | Medium |
| 2 | Shaw Lane and Case Road, East Lansing | Campus | Priority | FOL | Medium |
| 3 | MAC and Albert, East Lansing | Urban | Signal | Skew | Medium |
| 4 | Bogue and Shaw Path, East Lansing | Campus | Priority | FOL | Medium |
| 5 | State and Washington, Ann Arbor | Urban | Signal | FOL | Medium |
| 6 | East University and Hill, Ann Arbor | Suburban | All stop | FOL | Medium |
| 7 | South University and Forest, Ann Arbor | Urban | Signal | FOL | Medium |
| 8 | Thompson and Madison, Ann Arbor | Campus | All stop | FOL | Medium |
| 9 | Cedar and Michigan, Lansing | Urban | Signal | FOL | Heavy |
| 10 | Farm Lane and Wilson, East Lansing | Campus | Priority | FOL | Medium |
| 11 | South University and Church, Ann Arbor | Suburban | All stop | FOL | Light |
| 12 | Massachusetts and Memorial, Cambridge | Urban | Priority | FOL | Heavy |
| 13 | Thompson and Jefferson, Ann Arbor | Campus | Priority | FOL | Light |
| 14 | Cass and Antoninette, Detroit | Urban | Signal | FOL | Medium |
| 15 | Albert and Charles, East Lansing | Urban | All stop | FOL | Light |

[a] FOL = four legged, orthogonal intersection.
[b] Estimated motor vehicle traffic demand levels.

Figure 1. Schematic of data collection, reduction, and analysis procedures.



a bias to the young adult age group; however, they represented the only locations where significant volumes of utilitarian bicycle traffic could be found. The locations included priority (one street given priority over the other), all-stop, and signalized intersections. In all cases, with the exception of location 3, the intersections had four orthogonal legs. Location 3 had four legs, but was skewed (nonorthogonal). The motor vehicle traffic volumes were generally estimated to be light to medium. Location 9 had heavy motor vehicle volumes, but very low nonmotorized volumes. Location 12 was noted to have high motor vehicle and nonmotorized traffic moving in parallel directions but only limited conflicting movements. The area type designation indicates whether the location was characterized by high-density land use (urban), medium density (suburban), or an institutional density (campus).

The bicycle facilities at the candidate locations included bicycle lanes on the roadway and separate bike paths. In many cases no special bicycle facilities existed and the cyclists used the sidewalk or the street. Some of the candidate location provided more than one type of facility. In such cases, observations of bicycle traffic were categorized by type of facility.

## Data Collection Methodology

A data collection procedure was developed to obtain the necessary traffic operations data from the candidate intersection locations. Initially, a manual procedure was devised, but such a procedure required several observers in the field to obtain all the necessary data. Furthermore, the collected data required recording for computerized analysis. These limitations rendered manual techniques impractical and an alternate method was sought. Time-lapse photography was determined to provide an effective means to obtain the data needed. This method required only one observer in the field and allowed films of intersection operation to be replayed repeatedly until all pertinent data were obtained. A monochromatic, time-lapse video recording system was procured. The system consisted of a video camera and a portable video recorder with a time-lapse feature that allowed filming at regular speed (real time) or at one-fifth speed. The elapsed time was superimposed on the films during recording by using a video time image generator. The time image generator was incremented once each 0.1 s, which allowed precise isolation of event times from the resulting films. The time-lapse system was rounded out by a variety of camera mounting and power equipment to allow considerable latitude in the selection of vantage points for data collection. That the entire system could be readily carried by a single person enhanced this latitude.

The video tapes resulting from filming intersection operations were reviewed on a video monitor. The speed at which films could be reviewed was a function of the filming speed. Many films were shot in the time-lapse mode to allow up to 2.5 h of actual time to be recorded on each 12.7-cm (5-in) reel of video tape. The tapes were replayed at time-lapse speed for real-time observation of the intersection or at regular speed for quick scans of the film. Films recorded at regular speed were viewed in slow motion by playing the tapes back at time-lapse speed. The recorder allowed the film to be stopped at any point to isolate an individual video field for detailed analysis or data recording. The schematic diagram shown in Figure 1 depicts the equipment and procedures used in data collection, reduction, and analysis.

## DATA REDUCTION

The data reduction phase of the project involved extracting time information about events from the video recordings, converting the data into a computer-readable form, and conducting statistical analysis of the data. In order to accomplish these tasks, it was necessary to develop procedures for data reduction and to design and implement computer software to facilitate data reduction.

### Procedures

The reduction of data from the video tapes required numerous passes over each tape to obtain data for all the events of interest. It was found that, for manual data extraction, the tapes had to be run at their slowest speed and stopped frequently to record data. This method allowed accurate recording of event times, but it was extremely slow. An alternate method was devised in which the internal computer clock was used to mark the times of certain events. The program developed for this purpose recorded the current elapsed time value in milliseconds at each impulse input by the observer at the computer terminal. The event times corresponding to those on the video recording were produced through association of elapsed time to the initial video timer image input to the program. Subsequent statistical analysis of the resulting list of event times allowed the development of statistical models for bicycle traffic characteristics. The use of the computer program provided two important advantages: (a) it greatly reduced data reduction time and (b) data were stored directly on the computer, which facilitated later analysis of means, variances, and other distribution parameters.

The specific procedures used to reduce the collected data from the video tapes are described below.

#### Speeds

The speeds of traffic entities were determined by noting the time required to traverse a known distance, which is defined by a set of fixed objects (i.e., the width of roadway or the distance between lamp posts). The time required to traverse the section was obtained by noting the entry and exit clock images superimposed on the video recording. The speed was computed by dividing the reference distance by the elapsed time for each entity. Conversion factors were used as necessary to output the speed values in units of meters per second or kilometers per hour. A special version of the program allowed stratified speed analysis. An index value designating one of two groups was input to categorize the data and thus allow consideration of external influences on speed (i.e., speed of bicycle traffic when motor vehicles are in an adjacent lane).

#### Arrival Times

The arrival distributions for bicycle entities were obtained by noting the time image recorded corresponding to the occurrence of an entity at some preselected point. The interarrival times were calculated as the difference between successive times, starting from the beginning of the sampling period. The distribution of interarrival times over a specified period of time (usually 15 min) was subsequently represented by a probability function. A special variation of this procedure was designed to consider group arrivals.

#### Gap Acceptance

The simulation of cyclists crossing at intersections required that a function describing the gap-acceptance behavior be determined. An accepted gap was equal to the difference in time from when the queuing point was left to when the crossing was completed. A rejected gap was measured as to the time headway between mainstream traffic entities during which a crossing was not attempted. Data were recorded such that the arrival time of an entity wanting to cross was indexed with a value of 1. The length of the rejected gap was equal to the difference between the bicycle arrival at the queuing point and the passage of a mainstream traffic entity or the time between successive mainstream entities. Rejected gaps were indexed with a value of 0. If the gap was accepted, an index of 2 was used, and the crossing time was recorded. These indices served to identify the various event times obtained in collecting the gap data and thus facilitate the reduction of these data.

### Program

The reduction of data into quantitative measures was facilitated by the development of a computer program. The program was capable of reading the data sets generated from the procedures described above and conducting statistical analysis of arrival, speed, and gap-acceptance data. The program was designed to read a data set and execute one or more data reduction operations specified by the user. For example, a set of speed data may be analyzed to determine traffic speeds in one analysis, and a second pass may be used to perform an analysis of the arrival pattern of the traffic observed. Inputs to this program included program control cards, location and sample identification information, conversion factors, and the raw field data.

The program produces several outputs. These include the following:

1. Statistical summaries of totals, means, standard deviations, maximums, and minimums;
2. Histograms of data distribution; and
3. Measures of the degree of fit of data to theoretical probability functions.

Outputs from this program were used for data analysis.

## DATA ANALYSIS

The arrival, speed, and gap-acceptance data collected for bicycle traffic were subjected to a rigorous statistical analysis. The results of the analysis for each type data are presented in the following sections.

### Arrival Data

Arrival data collected for bicycle traffic were analyzed to determine the levels of traffic demand and the characteristic patterns of this demand. Bicycle arrivals were observed (video recording) upstream of intersections. The locations were selected to be several hundred meters away from intersections to eliminate any influence on the arrival patterns. Bicycle arrival data were recorded at six intersection locations for thirty-eight 15-min sampling periods. The interarrival times for 570 bicyclists were recorded during these observations. The arrival data obtained in these 38 sampling periods are presented in Table 2. Note that volumes ranged from a high of 160 bicycles/h to a low of 16 bicycles/h. The product of the volume and the mean interarrival time did not always equal 1 h. This deviation

Table 2. Summary of bicycle arrival data.

| Count Number | Location | Volume (bicycles/h) | Mean Interarrival Time (s) | SD | Ratio[a] | Maximum | Minimum |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 56 | 55.81 | 42.35 | 0.76 | 154.00 | 2.20 |
| 2 | 1 | 36 | 99.40 | 76.49 | 0.77 | 206.10 | 13.30 |
| 3 | 1 | 104 | 31.58 | 33.08 | 1.05 | 111.80 | 0.50 |
| 4 | 1 | 16 | 198.57 | 165.78 | 0.83 | 348.60 | 15.90 |
| 5 | 12 | 100 | 32.88 | 32.44 | 0.99 | 120.00 | 1.00 |
| 6 | 12 | 132 | 26.73 | 26.10 | 0.98 | 106.00 | 1.00 |
| 7 | 11 | 36 | 99.67 | 165.86 | 1.66 | 514.00 | 4.00 |
| 8 | 11 | 40 | 86.00 | 134.25 | 1.56 | 459.00 | 3.00 |
| 9 | 11 | 92 | 37.57 | 37.90 | 1.01 | 123.00 | 1.00 |
| 10 | 11 | 48 | 71.16 | 70.59 | 0.99 | 220.98 | 3.00 |
| 11 | 11 | 80 | 44.90 | 73.81 | 1.64 | 309.00 | 1.00 |
| 12 | 5 | 16 | 193.50 | 120.77 | 0.62 | 349.20 | 66.00 |
| 13 | 5 | 24 | 142.83 | 190.76 | 1.34 | 447.00 | 15.00 |
| 14 | 5 | 32 | 107.10 | 88.11 | 0.82 | 213.00 | 1.80 |
| 15 | 5 | 24 | 101.67 | 45.03 | 0.44 | 148.00 | 51.00 |
| 16 | 5 | 48 | 67.08 | 76.28 | 1.14 | 241.00 | 6.00 |
| 17 | 5 | 52 | 52.00 | 81.27 | 1.56 | 309.00 | 0.0 |
| 18 | 5 | 44 | 61.80 | 90.13 | 1.46 | 292.80 | 0.0 |
| 19 | 5 | 48 | 68.83 | 74.34 | 1.08 | 270.00 | 2.00 |
| 20 | 5 | 36 | 45.00 | 31.26 | 0.69 | 104.40 | 4.80 |
| 21 | 5 | 72 | 49.89 | 54.63 | 1.10 | 184.98 | 2.04 |
| 22 | 5 | 52 | 56.31 | 45.62 | 0.81 | 159.00 | 3.00 |
| 23 | 5 | 36 | 99.67 | 84.63 | 0.85 | 240.00 | 1.00 |
| 24 | 5 | 48 | 74.00 | 53.20 | 0.72 | 148.20 | 1.00 |
| 25 | 5 | 40 | 85.20 | 70.64 | 0.83 | 223.00 | 3.00 |
| 26 | 4 | 48 | 71.80 | 67.71 | 0.94 | 194.90 | 4.80 |
| 27 | 4 | 36 | 95.40 | 91.97 | 0.96 | 284.70 | 2.40 |
| 28 | 4 | 16 | 191.02 | 157.91 | 0.83 | 404.80 | 50.60 |
| 29 | 4 | 48 | 71.95 | 68.92 | 0.96 | 201.20 | 1.00 |
| 30 | 4 | 28 | 85.79 | 134.30 | 1.57 | 371.10 | 8.60 |
| 31 | 4 | 32 | 93.48 | 94.35 | 1.01 | 286.70 | 10.30 |
| 32 | 4 | 24 | 91.48 | 86.15 | 0.94 | 248.10 | 7.30 |
| 33 | 4 | 160 | 21.76 | 30.34 | 1.39 | 128.60 | 0.20 |
| 34 | 4 | 108 | 31.92 | 45.35 | 1.42 | 201.40 | 0.60 |
| 35 | 4 | 96 | 41.31 | 41.78 | 1.01 | 183.30 | 0.10 |
| 36 | 4 | 140 | 24.11 | 30.48 | 1.26 | 171.80 | 1.20 |
| 37 | 4 | 100 | 35.92 | 30.74 | 0.86 | 116.20 | 2.00 |
| 38 | 4 | 132 | 29.41 | 33.54 | 1.14 | 172.40 | 0.90 |

[a] Ratio is computed by dividing the standard deviation by the mean interarrival time.

Table 3. Chi-square comparisons of observed and theoretical arrival distributions.

| Location | Negative Exponential | Shifted Negative Exponential | Gamma | Erlang[a] | Log Normal[b] | Uniform |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| Computed | 2.16[c] | 2.33[c] | 2.96[c] | 2.16[c] | 1.10[c] | |
| Critical | 6.25 | 4.60 | 4.60 | 4.60 | 4.60 | |
| 12 | | | | | | |
| Computed | 4.00[c] | 4.03[c] | 4.60[c] | 1.39[c] | 1.69[c] | 2.65[c] |
| Critical | 6.25 | 4.60 | 4.60 | 4.60 | 4.60 | 4.60 |
| 12 | | | | | | |
| Computed | 3.01[c] | 5.66[c] | 3.74[c] | 8.69 | 3.86[c] | |
| Critical | 7.78 | 6.25 | 6.25 | 6.25 | 4.60 | |
| 4 | | | | | | |
| Computed | 7.55[c] | 18.29 | 9.46[c] | 48.48 | 26.95 | |
| Critical | 15.99 | 14.68 | 14.68 | 15.99 | 14.68 | |
| 4 | | | | | | |
| Computed | 9.71[c] | 16.49 | 7.12[c] | 9.71 | 17.78 | 73.93 |
| Critical | 17.21 | 12.02 | 10.64 | 12.02 | 10.64 | 9.24 |

[a] Corresponding k-values = 1, 2, 2, 2, 1.
[b] Corresponding alpha values = 0.9, 1.0, 1.2, 1.1, 0.8.
[c] No significant difference between observed and theoretical distributions.

resulted from the use of an asychronous counting procedure, which allowed the occurrence of long gaps at the beginning or end of the sampling periods.

The distribution of bicycle arrivals was analyzed by using the curve-fitting feature of the data reduction program. The program computed the theoretical frequencies corresponding to parameters estimated from the data for negative exponential, shifted negative exponential, gamma, Erlang, log normal, and uniform distributions. The corresponding observed frequencies were compared to the theoretical distributions by using a chi-square test for 16 intervals. Comparisons were made for various interval sizes and the number of intervals was collapsed as necessary to ensure that a minimum of five observations existed in each interval.

The results of the chi-square analysis performed for five of the larger samples are provided in Table 3. The larger samples provided a sufficient number of degrees of freedom to permit meaningful interpretation of the comparisons. In Table 3 the chi-square results are given for the comparisons to the theoretical curves. The critical value of the chi-square (at the 10 percent level) that corresponds to each comparison is provided below the computed value. For each comparison, the appropriate number of degrees of freedom was determined.

In all cases, the negative exponential and gamma distributions were found to provide an acceptable representation of the actual arrival distribution. Other theoretical distributions were noted to provide a reasonable approximation for some of the samples, but these distributions were not generally applicable for all cases.

It was concluded that the pattern of bicycle arrivals corresponded to a random process that could be represented by a negative exponential distribution. This conclusion was based on the results that indicated an acceptable fit to real data and the use of this distribution in previous traffic studies. The gamma distribution was not chosen for two reasons. First, it represents a more complex model, which requires two parameters instead of one, and second, the low values of alpha estimated for generating the function (i.e., 0.60-1.20) imply that the data possess a high degree of randomness. The use of the negative exponential distribution was consistent with Ferrara's approach and superior in that it is a simpler model. The negative exponential distribution may, however, slightly underpredict the number of short headways while slightly overpredicting higher headway values.

### Speed Data

Intersection approach speeds for bicycle traffic were determined from the data collected for 486 bicycle entities. The approach speeds of bicycle traffic were observed upstream of seven intersection locations. The locations were selected to be sufficiently distant from the intersections to minimize the effect of traffic controls on approach speeds. Table 4 provides a summary of the average, maximum, and minimum speeds observed in the various sampling periods. Note that the average speed of bicycle traffic was 20.8 km/h (12.9 mph). The overall speeds ranged from a high of 39.6 km/h to a low of 3.4 km/h (24.6-2.1 mph). The standard deviation of bicycle speeds was found to be 4.2 km/h (2.6 mph).

The effect of facility type on bicycle speeds was analyzed to determine if a significant influence existed. The speed data were classified by bicycle lane, bike path, sidewalk, and no-special-facility categories. The results of the stratification are shown below (1 km/h = 0.62 mph).

| Facility | Sampling Periods | Observed Speeds (km/h) | | |
|---|---|---|---|---|
| | | Mean | Maximum | Minimum |
| Bike path | 14 | 20.26 | 39.18 | 4.38 |
| Bicycle lane | 4 | 24.99 | 40.88 | 4.07 |
| Sidewalk | 5 | 18.51 | 30.15 | 3.39 |
| No facility | 5 | 19.07 | 36.91 | 8.06 |
| Overall | 28 | 20.71 | | |

The mean speeds on bicycle lanes were the highest at 24.9 km/h (15.5 mph) followed by an average of 20.3 km/h (12.6 mph) for bike paths. The higher speeds may be attributed to the separation of bicycle traffic from other modes. The bicycle lane was believed to have the highest average speeds because it offered the largest amount of maneuvering space, particularly where automobile volumes are low. Bicycle speeds averaged 19.0 km/h (11.8 mph) on roadways where no special facilities were provided. The lowest mean speeds were observed for bicycles on sidewalks [18.5 km/h (11.5 mph)]. The lower speeds may be the result of greater cautiousness on the part of the bicyclists in pedestrian traffic. These findings were not considered to be conclusive since the data for bicycle lane, sidewalk, and no-facility situations were limited. Furthermore, differences in the conditions of each location may have contributed to variations in the observed speeds.

The distributions of bicycle speeds were analyzed and the normal distribution was found to provide a close approximation to the data collected. The data shown in Figure 2 indicate normality by displaying the characteristic bell-shaped curve for the observed frequencies. The curve was derived from plotting 159 speed observations for bicycles.

The influence of bicycle traffic in bicycle lanes on automobile traffic on a two-lane, one-way roadway was reviewed. Table 5 shows the mean automobile speeds determined from a limited sample of 262 automobiles. The mean automobile speeds with bicycles present [43.94 km/h (27.30 mph)] exceeded those without bicycles present [46.48 km/h (28.88 mph)] by an average of 2.6 km/h (1.6 mph), indicating no major influence. The results tend to support the findings of Loop and Layton (9), but they must be viewed cautiously, since the sample sizes were small. The effect on automobile speeds for vehicles in the curb lane revealed no significant difference between the bicycle and no-bicycle conditions. The speed of traffic in the left lane displayed a more noticeable, yet small, difference. These differences would suggest that only a small interaction effect exists between automobile and bicycle traffic.

### Gap-Acceptance Data

A total of 260 bicycle crossings of two lanes of one-way motor vehicle traffic [7.3 m (24 ft) wide] were recorded to determine the gap-acceptance characteristics of the bicyclist. The length of each rejected and accepted gap was recorded and the data were analyzed by using the data reduction program. It was determined that the average accepted gap was 3.9 s. The minimum accepted gap was noted to be 1.1 s. Table 6 provides a summary of the gap data obtained in 14 sampling periods. The average rejected gap was 2.6 s in length and the maximum rejected gap was 8.1 s. Many cyclists accepted much shorter gaps by not stopping prior to initiating the crossing maneuver. When traffic conditions required a stop, the accepted gap tended to be longer in duration. No effort was made to separate rolling and stopped-start crossings and quantify the difference.

The frequency of accepted and rejected gaps of given lengths are plotted in Figure 3. The critical gap, as represented by the intersection of the gap-acceptance and gap-rejection curves shown in Figure 3, was noted to be 3.2 s. The frequency distribution of the gap-acceptance data is shown in Figure 4. The slightly skewed shape of the curve depicted in the figure indicates that the data correspond to a log normal distribution. The same data were plotted on a log-probability graph, as shown in Figure 5. The straight-line relationship apparent for the data supports the hypothesis that the bicycle gap-acceptance function is log normal. This finding differs from the linear gap-acceptance function postulated by Ferrara (11).

## CONCLUSIONS AND RECOMMENDATIONS

The analysis of field data collected at urban intersections operating under multimodal traffic demand resulted in useful information relative to the characteristics of bicycle traffic. The specific conclusions drawn from the study included the following.

Insufficient information exists relative to the characteristics of bicycle traffic at urban intersections. Past studies, with the exception of Ferrara's work (11), have not quantitatively addressed the intersection problem. Video recording techniques can be used to obtain operations data for bicycle traffic analysis. The use of a time image generator to superimpose an elapsed time value on the recordings allowed accurate isolation of event times. The development of computer software for data reduction and analysis facilitates the use of such a system.

An analysis of bicycle interarrival times indicated that a random arrival pattern characterized the situations observed. A negative exponential distribution was determined to best represent the arrival pattern for low to medium traffic volumes. Other distributions, such as the gamma, log normal, Erlang, shifted negative exponential, and uniform, were compared to the field data, but they did not provide an adequate fit for all of the cases compared.

Table 4. Summary of observed bicycle speeds.

| Count Number | Location | Facility Type | Total (N) | Speed (km/h) Mean | Speed (km/h) Maximum | Speed (km/h) Minimum |
|---|---|---|---|---|---|---|
| 1 | 2 | Path | 4 | 29.57 | 37.97 | 18.25 |
| 2 | 2 | Path | 13 | 33.89 | 43.14 | 21.82 |
| 3 | 2 | Path | 15 | 32.82 | 43.33 | 22.20 |
| 4 | 2 | Path | 32 | 31.91 | 58.08 | 20.19 |
| 5 | 1 | Lane | 14 | 30.92 | 41.13 | 17.22 |
| 6 | 1 | Lane | 9 | 30.27 | 42.59 | 20.11 |
| 7 | 1 | Lane | 26 | 27.56 | 45.25 | 5.99 |
| 8 | 1 | Path | 12 | 29.57 | 42.59 | 21.95 |
| 9 | 1 | Path | 9 | 22.75 | 28.96 | 17.23 |
| 10 | 4 | Side | 4 | 27.92 | 37.97 | 23.36 |
| 11 | 4 | Side | 12 | 27.26 | 36.20 | 20.11 |
| 12 | 4 | Side | 7 | 26.53 | 36.20 | 18.10 |
| 13 | 1 | Path | 8 | 31.70 | 40.22 | 26.82 |
| 14 | 1 | Path | 6 | 31.99 | 36.20 | 27.85 |
| 15 | 1 | Path | 40 | 28.85 | 46.26 | 9.61 |
| 16 | 1 | Path | 27 | 25.44 | 37.01 | 8.70 |
| 17 | 1 | Path | 24 | 26.76 | 38.95 | 6.44 |
| 18 | 1 | Path | 35 | 27.56 | 38.95 | 16.81 |
| 19 | 1 | Path | 25 | 28.13 | 35.24 | 18.50 |
| 20 | 1 | Path | 33 | 28.13 | 37.01 | 18.97 |
| 21 | 11 | None | 15 | 22.27 | 33.13 | 12.23 |
| 22 | 11 | None | 11 | 21.50 | 27.47 | 18.02 |
| 23 | 2 | Side | 30 | 29.93 | 44.34 | 21.77 |
| 24 | 2 | Lane | 21 | 41.17 | 48.27 | 27.58 |
| 25 | 5 | Side | 7 | 24.46 | 36.06 | 5.00 |
| 26 | 5 | None | 8 | 33.61 | 40.31 | 25.50 |
| 27 | 5 | None | 17 | 35.66 | 54.29 | 22.86 |
| 28 | 3 | None | 22 | 27.13 | 50.01 | 11.86 |

Note: 1 km/h = 0.62 mph.

Figure 2. Frequency distribution of observed bicycle speeds.

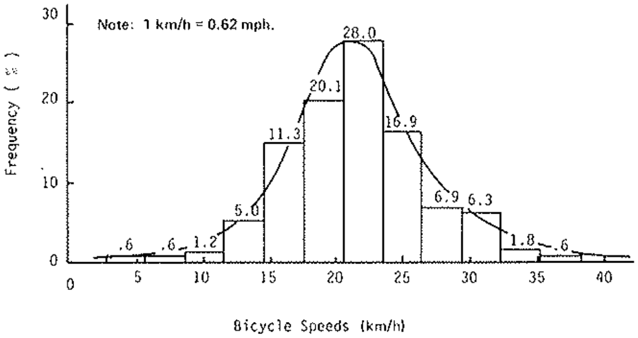


Table 5. Effects of bicycle-lane traffic on automobile speeds.

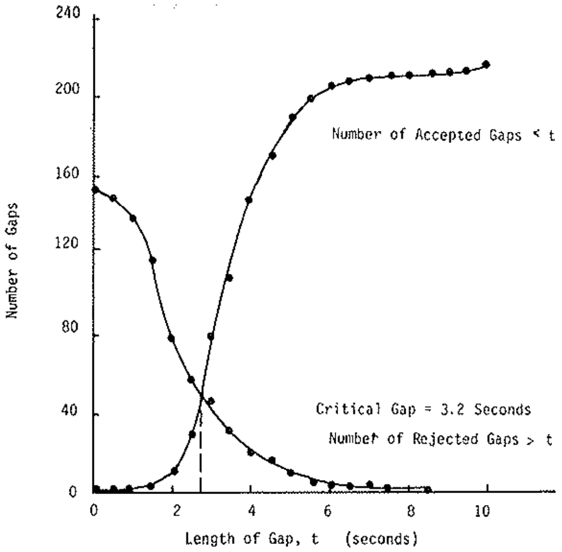
| Lane | Bicycles Present, Location 1 Speed (km/h) | Bicycles Present, Location 1 No. of Automobiles | No Bicycles, Location 2 Speed (km/h) | No Bicycles, Location 2 No. of Automobiles | Overall Speed (km/h) | Overall No. of Automobiles |
|---|---|---|---|---|---|---|
| Curb | 48.37 | 4 | 46.66 | 36 | 46.82 | 40 |
| | 47.00 | 2 | 45.36 | 61 | 45.41 | 63 |
| | 40.53 | 8 | 43.72 | 32 | 43.07 | 40 |
| Left | 43.48 | 5 | 48.99 | 31 | 48.22 | 36 |
| | 38.79 | 2 | 47.85 | 36 | 47.35 | 38 |
| | 45.45 | 10 | 46.23 | 35 | 46.05 | 45 |
| Overall | 43.92 | 31 | 46.47 | 231 | 47.26 | 262 |

Note: 1 km/h = 0.62 mph.

Table 6. Summary of gap acceptance and rejection data.

| Count | Location | Rejected Gaps Total | Rejected Gaps Average (s) | Rejected Gaps Maximum (s) | Accepted Gaps Total | Accepted Gaps Average (s) | Accepted Gaps Minimum (s) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 14 | 2.42 | 8.10 | 32 | 3.60 | 2.40 |
| 2 | 1 | 5 | 2.92 | 4.60 | 10 | 4.64 | 2.30 |
| 3 | 2 | 4 | 3.85 | 6.80 | 9 | 4.43 | 2.50 |
| 4 | 2 | 12 | 3.13 | 6.90 | 16 | 3.81 | 2.80 |
| 5 | 2 | 14 | 2.69 | 6.40 | 21 | 3.74 | 2.30 |
| 6 | 2 | 14 | 2.39 | 4.60 | 18 | 3.28 | 2.00 |
| 7 | 2 | 7 | 1.66 | 3.50 | 14 | 3.36 | 1.50 |
| 8 | 2 | 14 | 2.26 | 5.30 | 17 | 3.16 | 2.30 |
| 9 | 2 | 15 | 2.05 | 3.70 | 29 | 3.59 | 1.10 |
| 10 | 2 | 25 | 2.65 | 5.30 | 13 | 4.34 | 2.50 |
| 11 | 2 | 13 | 2.28 | 5.20 | 15 | 4.75 | 2.70 |
| 12 | 2 | 8 | 2.40 | 3.80 | 24 | 4.09 | 1.80 |
| 13 | 2 | 8 | 2.69 | 3.90 | 18 | 4.07 | 3.10 |
| 14 | 2 | 7 | 3.16 | 5.90 | 24 | 3.97 | 1.80 |

Figure 3. Frequency distribution of accepted and rejected gaps.



Bicycle approach speeds were studied, and a mean approach speed of 20.8 km/h (12.9 mph) was noted. The frequency distribution of speed data indicated a normal distribution. A limited study of the average approach speeds on bicycle lanes, bike paths, streets without special bicycle facilities, and sidewalks revealed a difference in speed levels. Bicycle lanes were noted to have the highest average speeds; sidewalks had the lowest. These results were not considered conclusive since the sample was small and no attempts were made to isolate the influences of the environment in which the data were collected.

A limited analysis of the effect of the presence of bicycle traffic (in bicycle lanes) on automobile traffic revealed that only small reductions in speed occurred. This finding, although based on a small sample, tends to support the conclusions of earlier research.

Bicycle crossing gap acceptance was analyzed, and it was determined that the distribution of accepted gaps corresponded to a log normal function. It was noted that accepted gap size was related to whether the crossing was initiated from a rolling or standing start.

The findings of this study serve to increase the understanding of the characteristics of bicycle traffic at urban intersections. The information presented here provides some of the inputs necessary to conduct simulation analysis of urban intersections that service bicycle traffic. The information may also serve as the basis for the application of other analytical models, such as delay and queuing models for the analysis of the impacts of various intersection control strategies. For example, the arrival and gap-acceptance functions derived in this study can be used in a queuing model to determine the expected waiting time, or the amount of space required to accommodate bicyclists making left turns. The queuing model results could be used to measure the effectiveness of alternative intersection design treatments. The bi-

Figure 4. Frequency distribution of accepted gaps.

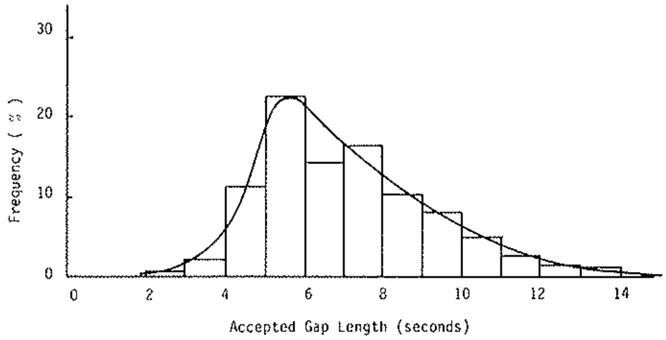
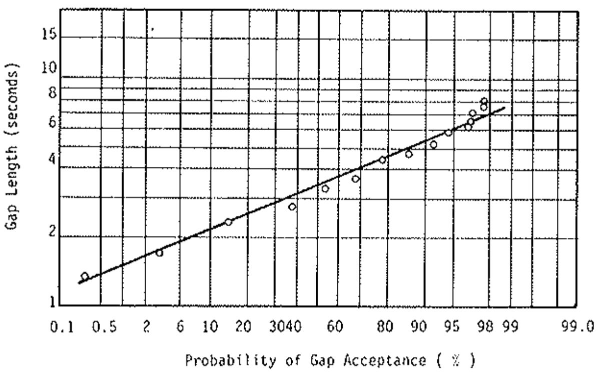


Figure 5. Log probability plot of accepted gaps.



cycle characteristics data could also serve to define the intersection crossing time for the design of signal clearance intervals or the design of the curvature for bicycle facilities at intersections. The use of bicycle traffic characteristics data derived from the observation of actual conditions can improve the design and operation of urban intersections that serve multimodal traffic.

Further studies will be necessary to verify the conclusions reached here and to extend the information about bicycle traffic characteristics to other areas and traffic situations. Several recommendations for future efforts include the following:

1. Since the data obtained for this study were collected in the proximity of college campuses, it is highly likely that it is biased to the young adult age group. It is therefore necessary to obtain similar information for situations where the bicycle traffic consists of other age groups.
2. Data collection can be enhanced through the use of multiple camera arrangements or the provision of mobile vantage points to allow better viewing of the intersection under study.
3. Further studies are necessary to identify the characteristics of nonutilitarian bicycle traffic, the influence of location, and the behavior of bicyclists under high-volume situations.
4. Studies (possibly before-and-after studies) are necessary to assess the influence of facility type on the characteristics of bicycle traffic.

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# Discussion

Alex Sorton and Joshua Lehman

The methodologies developed by Opiela, Khasnabis, and Datta are extremely valuable for urban transportation planners and researchers who are concerned with and responsible for intersection design and operation. The applicability of their work, however, is limited by the failure to properly develop the groundwork on which it has been based. Intersections, the focus of their paper, simply have not been explored in adequate detail.

A prime criterion for their selection of intersections is, "The location must represent a typical urban intersection." It could be argued at length as to whether such a typical urban intersection exists, and, if so, what its configuration and characteristics might be.

The authors mention that 15 of an original array of 40 have been selected and describe the characteristics of these intersections in Table 1. Yet some essential parameters are missing, so it becomes difficult to gage how typical these locations may be, and more difficult still to extrapolate the Michigan examples to locations elsewhere. For examples, are the roadways two- or four-lane? What is the roadway width? How are the intersection legs channelized? Does a bicycle facility exit the intersection in the same form that it entered? Could more precise measures of volume level be provided?

It would be most helpful to include a diagram of each location, so that the reader might better visualize the conditions from which the observations are made and on which the conclusions are drawn. Details of this sort are necessary if we are to better understand bicyclist behavior, in general, and the specifics of gap acceptance, queuing arrangements, and the like.

The impression conveyed in the paper is that gap acceptance is for varying conditions but, in actuality, only two locations were examined. According to Table 6, only locations 1 and 2 were observed, and both are in East Lansing campus situations. Yet reference to Table 4 indicates that location 1 is a lane and a path, and that location 2 is a path, a lane, and a sidewalk. It is our contention that gap acceptance will vary with each condition, and thus values should not be aggregated, as in Table 6. Values should be established for each type of bicycle facility.

Further, there is mention of "bicycle crossing of two lanes of motor vehicle traffic [7.3 m (24 ft) wide]." But crossing two lanes of one-way traffic is simply not the same as crossing one lane each of traffic moving in opposite directions. The data are useful for specific situations but can be taken no further.

Other questions that might have been asked are: Do the bicyclists cross at the same location as pedestrians? Do they cross from a path to a street or from a lane to a lane? Better sense could be made of the results had we been provided with more essential details.

These details also color any conclusions that might be drawn about the effects of bicycles on motor vehicular speeds. Information as to the widths of the roadway, motor vehicle lanes, and bicycle lanes is necessary before better sense can be made as to bicycle speeds. The paper states that bicycle speeds were highest on the bicycle lanes [mean 24.9 km/h (15.5 mph)], whereas on streets without bicycle lanes, bicycle speeds were lower, 19.0 km/h (11.8 mph) average. We need to know what the lane widths were in each situation. We would hypothesize that bicycle speeds are higher in wider motor vehicle curb lanes. Information as to vehicular volumes is also desirable, as the number, and type, of motor vehicles have a definite effect on bicycle speeds.

Another behavioral question is raised by the fact that all the data were collected in the proximity of college campuses. The authors acknowledge that this "proximity to campuses introduces a bias to the young adult age group." Other biases may also be introduced. The motor vehicle operators with whom the bicyclists interact may more likely be college students as well, so age selectivity and personal familiarity with bicycle operation might be considered as further influential factors.

In sum, the paper has much general value, yet more needs to be made explicit. The investigative techniques appear to be useful, and much thought has been given to how to best compile and analyze data. Yet the heart of the matter—the urban intersections themselves—are inadequately analyzed and categorized.

One observation in the introductory literature review illustrates the need to be discrete. The authors cite Ferrara's work on intersection behavior in California, "an environment", we are told, "largely conducive to the use of the bicycle." But there are a multitude of "Californias", northern and southern, coastal and interior, bicycle oriented and automobile oriented. Similarly, there are many kinds of intersections. We need stricter guidelines and fewer generalizations before better sense is to be made of bicycle traffic at urban intersections.

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# Strategies for Increasing Levels of Walking and Bicycling for Utilitarian Purposes

Ferrol O. Robinson, Jerry L. Edwards, and Carl E. Ohrn

This paper reports the results of an extensive survey of motorized and nonmotorized travel. The survey was conducted in connection with a study to (a) identify problems associated with walking and bicycling, (b) identify a wide range of incentives to promote the use of walking and bicycling for utilitarian trip purposes, and (c) establish the cost-effectiveness of the incentives identified. This paper limits itself to an analysis of the survey results as they relate to the topics of (a) trip and trip-maker characteristics, (b) mode choice and mode preference, and (c) changes in preference for alternative modes of travel in response to the implementation of selected scenarios. The scenarios tested were (a) provision of bicycle and pedestrian facilities, (b) fee on automobile use during peak periods, (c) compact land-use setting with provision of pedestrian and bicycle facilities, and (d) increases in fuel prices. The survey responses indicate that a compact land-use arrangement, combined with the provision of pedestrian and bicycle facilities, has the greatest potential for creating a shift from the automobile to walking and bicycling. Bicycle and pedestrian facilities alone follow in importance. A fee on automobile use during peak periods has the effect of reducing automobile use; however, one-third to one-half of the trips diverted go to transit rather than to nonmotorized modes. Finally, doubling the price of fuel appears to be the least effective of the strategies analyzed for increasing walking and bicycling.

The importance of walking and bicycling for utilitarian travel has long been recognized in many countries (1, 2). However, only in the past several years has interest grown in nonmotorized modes in the United States. This interest has been generated, to a large extent, by economic, social, and environmental concerns related to the negative effects of widespread use of the automobile. At present, however, the general public, as well as public officials, are skeptical about the feasibility of nonmotorized modes as means of transportation and the advisability of investing public dollars to encourage their use. It is important, therefore, to determine as clearly as possible the extent to which a mode shift from the automobile to nonmotorized modes can be achieved if we invest public money in a variety of strategies.

This paper explores the potential of various strategies for increasing the demand for nonmotorized travel. Estimates of changes in modal share are developed

Table 1. Summary of survey contacts.

| City | Not at Home | No Qualified Respondent at Home | Refusals | Placements | Total |
|---|---|---|---|---|---|
| Austin | 1739 | 88 | 180 | 1380 | 3 387 |
| Columbus | 1650 | 195 | 246 | 1380 | 3 471 |
| Denver | 2742 | 294 | 609 | 1380 | 5 025 |
| Huntington Beach | 947 | 231 | 277 | 1380 | 2 835 |
| Philadelphia | 1066 | 99 | 208 | 1380 | 2 753 |
| Total | 8144 | 907 | 1520 | 6900 | 17 471 |

Table 2. Summary of survey placements.

| City | Not Returned | Unused Returns | Processed | Total |
|---|---|---|---|---|
| Austin | 441 | 139 | 800 | 1380 |
| Columbus | 490 | 90 | 800 | 1380 |
| Denver | 418 | 162 | 800 | 1380 |
| Huntington Beach | 510 | 70 | 800 | 1380 |
| Philadelphia | 673 | 41 | 666 | 1380 |
| Total | 2532 | 502 | 3866 | 6900 |

based on respondents' ranking of alternative modes after the introduction of each scenario or strategy. Current mode choice and its relation to current modal preference and to trip and trip-maker characteristics are analyzed.

## SURVEY DESCRIPTION

To accomplish the objectives of the study, a self-administered attitudinal and market research survey was designed. A number of guidelines and constraints were established at the outset to ensure that the survey effort would focus on the types of trips and population groups that exhibit the greatest potential for use of nonmotorized modes. The following decisions affect the results of the survey and should be kept in mind while examining the results presented here:

1. The study examines users of all major transportation modes (automobile, transit, bicycle, and walk); however, special attention is given to automobile users because they represent the largest share of utilitarian trip making. Thus, strategies aimed at increasing nonmotorized travel must take into account the needs of automobile users.
2. The surveys focus on utilitarian trips, specifically work, shopping, personal business, and college-level school trips rather than recreation trips.
3. Given the limited cargo-carrying capacity of nonmotorized modes, major shopping trips, involving heavy or large cargo, were excluded.
4. Emphasis is placed on home-based trips since the decision to bicycle or to walk rather than to take the car is made at the home end.
5. The survey was administered to persons 16 years and older. Younger persons are currently significant users of nonmotorized modes for school and shopping trips and are not viewed as having significant potential for a mode shift away from automobile.
6. Given the dominance of short trip length in nonmotorized travel, rating and ranking of modes was constrained to work trips that were within 4.8 km (3 miles) for walking and 9.6 km (6 miles) for bicycling and to shopping and personal business trips that were within 3.2 km (2 miles) and 6.4 km (4 miles) for walking and bicycling, respectively.

### Survey Methodology

The survey instruments were designed to be self-administered. All questionnaires were hand-delivered by trained field interviewers to households preselected randomly within the selected geographic areas. This method of delivery, sometimes referred to as the drop-off, pick-up technique, has the advantage of giving the field worker the opportunity to explain the purpose of the study, to review the survey form, to answer questions, and, in general, to engage the cooperation of the potential respondent to the survey.

When the questionnaire was dropped off, the interviewer agreed with the respondent on a date (usually within three to four days) when the questionnaire would be ready for pickup. To increase the rate of return, a reminder postcard was mailed to each participating household on the day following placement. On returning to the household on the day specified for pickup, if the respondent was not at home or had not completed the questionnaire, a second attempt was made to collect the form. If at this point no contact was made, a preaddressed, postage-prepaid envelope was left with instructions that the questionnaire be returned by mail. Contacts were made during the day as well as during evening hours, and approximately one-half of the questionnaires were placed with male members of the household and one-half with females 16 years of age or older.

Tables 1 and 2 summarize the returns. A total of 17 471 households were contacted in the five geographic areas, and 6900 questionnaires were placed with potential respondents. Of the surveys placed, 4368 or 63.3 percent were returned, and 3866 were finally processed.

Given the length of the survey questionnaire (16-18 pages), the return rate of 63.3 percent is quite acceptable when compared with surveys of similar length (3). Several factors are seen as contributing to this result. First, the drop-off, pick-up technique has been found to elicit a greater rate of return than a mail survey. Second, the forms were attractive, printed clearly, identified with each city's letterhead, and accompanied by an introductory letter signed by a city official. Finally, the reminder postcard, second visit, and preaddressed and stamped return envelope are all seen as contributing factors to the rate of return obtained.

### Geographic Areas Surveyed

Five geographic areas that represent various regions within the United States were surveyed. Within each area, specific sites [10-15 km$^2$ (4-6 miles$^2$) in size] were selected according to the set of criteria described below for each site.

### Austin

Two residential sites connected with the University of Texas campus were surveyed. One site corresponds to the residential area located north and west of campus, characterized by renter-occupied apartments and single-family homes. This site is located within 1.6 km (1 mile) of the central business district (CBD) and contains bicycle lanes and an extensive sidewalk network. The area contains many shopping opportunities and the university itself is a major employer. The second site is composed of university student housing, and it is located within 10 km (6 miles) of the campus.

### Columbus, Indiana

Columbus represents a small city site. The area surveyed included most of the contiguous built-up section of the city. The area is characterized by single-family, owner-occupied housing, major industrial plants, CBD, and strip commercial area. There are sidewalks in about one-half of the area and very few bicycle paths and lanes.

### Denver

A central city site was selected in Denver. The site is located southeast of the CBD and within 8 km (5 miles) of it. The area is made up mainly of single-family homes and small apartments. There are sidewalks throughout the area as well as an extensive system of bicycle paths and lanes.

### Huntington Beach, California

This area represents a suburban site and is 19 km (12 miles) away from the nearest center, Long Beach. The 7.8-km$^2$ (3-mile$^2$) site selected in Huntington Beach is located west of the city and is characterized by single-family housing, nearby schools, a light-industry district, and a community shopping center.

### Philadelphia

Two neighborhoods, located within 1.6 km of the CBD, were selected to represent fringe sites. Society Hill and Rittenhouse are characterized by rowhouses and high-rise apartments, large concentrations of employment and commercial activity nearby, extensive pedestrian facilities and walking activity, and limited bicycle facilities.

The areas surveyed were selected because they offered specific features that were considered beneficial to the purposes of the study. The most important characteristic included their location near a variety of walking and bicycling opportunities for work, school, shopping, and personal business trips; the socioeconomic characteristics of residents; and the mixture of housing types and densities. In general, all areas had sidewalks, but only three of the sites had extensive systems of bicycling facilities.

The five sites represent a spectrum of urban environments, which ranged from a small city to an inner city neighborhood of a major metropolitan area. This intentional factor allows the potential transfer of data to a large segment of areas by identifying areas and population groups that exhibit similar characteristics.

## SURVEY RESULTS

The remainder of this paper will examine the results of the survey as they relate to current mode choices, their relationship to characteristics of the trip and the trip maker, and a comparison between mode choice and modal preference. Finally, changes in modal preference in response to hypothetical scenarios designed to act either as disincentives to automobile use or as incentives to nonmotorized use are analyzed.

### Trip-Maker Characteristics

A summary of socioeconomic characteristics of respondents is presented in Table 3. Table 3 reveals an overrepresentation of females for shopping and personal business trips, particularly in Columbus and Philadelphia. Overall, the distribution of both automobile and walk trips between women and men is even (49 percent of women, 51 percent of men). On the other hand, two-thirds of the bicycle trips and one-third of bus trips were made by men.

Table 3 shows that the university area in Austin exhibits the lowest age profile. In terms of mode choice, there is a significant difference between the age of bicyclists and the age of users of other modes. Even excluding school trips, the average age for bicyclists on work and shopping-personal business trips is 32 and 29 years, respectively, versus 37 and 40 years for automobile.

The most common occupations encountered were professional-technical, blue collar, and housewife. Confirming the above finding about bicycle use by women, only 6 percent of bicycle trips are taken by housewives (versus 19 percent of automobile trips).

There appears to be a relationship between housing density and choice of mode. Survey responses reveal that 88 percent of automobile trips originate from low-density housing (single family, duplex, and townhouse), and only 12 percent originate from high-density housing (walk-up, low-rise and high-rise apartments). On the other hand, 56 percent of walk trips originate from low-density housing and 44 percent are from high-density units.

Automobile ownership is lower in the two cities that reported the highest use of nonmotorized modes. Philadelphia reported the lowest number of automobiles and the lowest use of the automobile for both the work and shopping-personal business trip purposes. This result is consistent with the relation found nationwide between automobile ownership and vehicle trips made (4). The relation between the number of automobiles owned and mode chosen is not significantly different between Columbus, Denver, and Huntington Beach. At an aggregate level, bicycle ownership is not an explanatory variable for choice of mode for either work or shopping-personal business trips. Huntington Beach reported the highest number of bicycles per household (2.2 bicycles compared to an average 1.5 for all cities); however, its choice of the bicycle was similar to that in other cities, excluding Austin. Bicycle ownership is average in Austin, but it reports the highest share of bicycle trips.

### Trip Characteristics

Survey responses show that whenever three or more additional stops are made for the purpose of shopping-personal business, the choice of automobile is roughly twice as frequent as the choice of nonmotorized modes. Exceptions to this pattern are found in Philadelphia and Austin. In Philadelphia, more than 16 percent of shopping and personal business trips that include three or more additional stops were made by nonmotorized modes compared to 8 percent by automobile. These findings tend to support the contention that multiple stops do not exclude use of nonmotorized vehicles.

Although there is no significant difference among cities in the number of persons that accompany the traveler, there is a difference between modes regarding this characteristic. In fact, 28 percent of the automobile users in all communities had two or more additional persons in the vehicle when making shopping-personal business trips. Only 20 percent of those persons reporting nonmotorized trips for this purpose had two or more additional persons accompanying them.

People choose the period from 9:00 a.m. to 2:00 p.m. for making shopping-personal business trips regardless of mode. However, the situation in Austin is different. In Austin, the most frequent time for making such trips is between 2:00 and 6:00 p.m. This is true for both automobile users and those who walk. This most likely reflects the fact that students shop after class. By 6:00 p.m., nearly 91 percent of those who walk have made their trips, whereas 85 percent of automobile trips have been completed.

Distance is clearly a factor in the choice of mode, as can be seen from Table 4. In all cities, more than 90 percent of nonautomobile trips were 3.2 km (2 miles) or less in length. Only 18.3 percent of automobile trips are accomplished within a distance of 0.8 km (0.5 mile) whereas 63 percent are made within a distance of 3.2 km (2 miles) (assumed maximum distance for walking trips for shopping). Approximately 80 percent of automobile trips for shopping-personal business are 6.4 km (4 miles) or less (which is the assumed maximum distance for bicycling). This suggests a significant potential for future competition between automobile modes and nonmotorized modes within these trip distances.

## Mode Choice and Preference

To determine how users evaluate the transportation services available to them, respondents were asked to rank their preferences for the existing modes. Table 5 shows the percentage of respondents who chose each mode as well as the percentage that ranked each mode as their most preferred. Examination of this table shows several patterns emerging. Preference is a good indicator of choice, as shown by the fact that 72 percent of respondents would prefer automobile for their trip to work and 75 percent actually do choose automobile. By using similar survey techniques, Koppelman, Hauser, and Tybout have reached similar conclusions regarding the relation between mode preference and choice (5); however, not everyone chooses the preferred mode. For example, overall 14 percent of respondents identified walk as their first preference, yet only 11 percent actually used it. In fact, in areas of high automobile use (Columbus, Denver, and Huntington Beach) a lower number of respondents indicate automobile as their preferred mode than actually choose it. In areas of low automobile use or, conversely, of high transit and walking activity (Austin and Philadelphia), a higher number of people show automobile as their preferred mode than actually choose it. On the

Table 3. Socioeconomic profile of respondents.

| City | Trip Purpose | Male (%) | Female (%) | Age | | Automobiles per Household | Bicycles per Household | Average Income ($) | Occupation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Average | Mode | | | | Most Frequent | % | Next Most Frequent | % |
| Austin | School | 50.7 | 49.3 | 24.0 | 21-25 | 1.7 | 1.3 | 14 842 | - | | - | |
| | Shopping or personal business (PB) | 50.2 | 49.8 | 28.7 | 16-25 | 1.6 | 1.5 | 14 555 | Student | 29.8 | Professional-Technical | 29.3 |
| Columbus | Work | 55.0 | 45.0 | 38.2 | 36-50 | 1.9 | 1.6 | 19 270 | Blue collar | 31.3 | Professional-Technical | 26 |
| | Shopping or PB | 41.8 | 58.2 | 44.2 | 26-35 | 1.8 | 1.6 | 17 400 | Housewife | 22 | Professional-Technical | 16.5 |
| Denver | Work | 50.0 | 50.0 | 35.3 | 26-35 | 1.9 | 1.6 | 21 275 | Professional-Technical | 49 | Blue Collar | 17.8 |
| | Shopping or PB | 48.8 | 50.9 | 45.1 | 26-35 | 1.8 | 1.3 | 18 060 | Professional-Technical | 28.5 | Housewife | 15.5 |
| Huntington Beach | Work | 50.0 | 50.0 | 37.7 | 36-50 | 2.4 | 2.2 | 27 370 | Professional-Technical | 41.9 | Secretarial-Clerk | 18.3 |
| | Shopping or PB | 48.0 | 52.0 | 40.4 | 36-50 | 2.3 | 2.2 | 25 220 | Housewife | 27.0 | Professional-Technical | 26.3 |
| Philadelphia | Work | 51.7 | 48.3 | 37.7 | 26-35 | 1.0 | 1.0 | 31 975 | Professional-Technical | 64.1 | Managerial | 15.7 |
| | Shopping or PB | 42.7 | 57.0 | 40.3 | 26-35 | 0.9 | 1.1 | 29 970 | Professional-Technical | 46.3 | Managerial | 11.7 |
| Total | School | 50.7 | 49.3 | 24.0 | 21-25 | 1.7 | 1.3 | 14 842 | - | | - | |
| | Work | 51.7 | 48.3 | 37.2 | 26-35 | 1.8 | 1.6 | 24 720 | Professional-Technical | 44.6 | Blue Collar | 17.6 |
| | Shopping or PB | 46.5 | 53.4 | 39.7 | 26-35 | 1.7 | 1.5 | 20 590 | Professional-Technical | 28.6 | Housewife | 15.9 |

Table 4. Cumulative percentages for distribution of trips by distance for shopping and personal business trips.

| City | Mode | Distance | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0-0.40 km | 0.41-0.80 km | 0.81-1.60 km | 1.61-3.20 km | 3.21-6.40 km | 6.41-9.60 km | 9.61-16.00 km | 16.00 + km |
| Austin | Automobile | 4.7 | 18.7 | 40.0 | 57.4 | 82.5 | 91.4 | 98.0 | 100.0 |
| | Nonautomobile | 16.5 | 61.7 | 81.7 | 93.0 | 95.6 | 98.2 | 99.1 | 100.0 |
| Columbus | Automobile | 3.4 | 19.4 | 46.4 | 71.9 | 91.7 | 95.1 | 95.7 | 100.0 |
| | Nonautomobile | 15.2 | 72.8 | 94.0 | 97.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Denver | Automobile | 1.7 | 11.8 | 28.2 | 50.0 | 75.5 | 90.6 | 96.3 | 100.0 |
| | Nonautomobile | 26.7 | 73.3 | 80.0 | 93.3 | 96.6 | 98.3 | 100.0 | 100.0 |
| Huntington Beach | Automobile | 5.8 | 22.8 | 46.5 | 71.1 | 88.9 | 92.8 | 94.7 | 100.0 |
| | Nonautomobile | 40.0 | 73.3 | 83.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Philadelphia | Automobile | 0.0 | 15.7 | 35.2 | 50.9 | 62.7 | 74.5 | 84.3 | 100.0 |
| | Nonautomobile | 32.4 | 70.1 | 89.4 | 98.6 | 100.0 | 100.0 | 100.0 | 100.0 |

Note: 1 km = 0.6 mile.

Table 5. Summary percentages of modes chosen and preferred modes.

| | | Automobile | | Walk | | Transit | | Bicycle | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Purpose | Chosen | Preferred | Chosen | Preferred | Chosen | Preferred | Chosen | Preferred | Other[a] Chosen | No Response |
| Austin | School[b] | 18 | 26 | 36 | 28 | 28 | 19 | 15 | 25 | 3 | 2 |
| | Shopping-PB | 64 | 62 | 23 | 19 | 6 | 5 | 6 | 14 | 1 | |
| Columbus | Work | 91 | 86 | 4 | 6 | 1 | 2 | 1 | 4 | 3 | 2 |
| | Shopping-PB | 87 | 86 | 7 | 5 | 2 | 2 | 1 | 4 | 3 | 3 |
| Denver | Work | 80 | 74 | 4 | 6 | 10 | 8 | 4 | 10 | 2 | 2 |
| | Shopping-PB | 74 | 73 | 13 | 11 | 10 | 8 | 2 | 6 | 1 | 2 |
| Huntington Beach | Work | 92 | 89 | 2 | 3 | 1 | 4 | 1 | 4 | 3 | |
| | Shopping-PB | 90 | 90 | 6 | 5 | 1 | 1 | 2 | 4 | 1 | |
| Philadelphia | Work | 29 | 34 | 35 | 44 | 26 | 10 | 4 | 9 | 6 | 3 |
| | Shopping-PB | 16 | 24 | 63 | 60 | 13 | 8 | 2 | 7 | 6 | 1 |
| Total | Work | 75 | 72 | 11 | 14 | 9 | 6 | 3 | 7 | 2 | 1 |
| | Shopping-PB | 68 | 69 | 21 | 18 | 6 | 5 | 3 | 7 | 2 | 1 |
| | School | 18 | 26 | 36 | 28 | 28 | 19 | 15 | 25 | 3 | 2 |

[a] Respondents were asked to rank preference for the four modes indicated.
[b] Survey of school trips was done in Austin only.

other hand, fewer respondents show walk and transit as their preferred modes than are currently using them. Of all modes, bicycle is the only one for which preference is consistently greater than choice. This is true regardless of the current level of bicycle use or the purpose of the trip.

These above findings indicate that, as a result of mode availability and individual circumstances, a certain number of captive users are associated with each mode. Policymakers could benefit from the knowledge of the conditions that would bring people's use of bicycle for utilitarian trips more in line with their indicated preference for bicycling. Later phases of the project will attempt to respond to this need.

## TESTING OF SELECTED STRATEGIES

In keeping with the fundamental objective of the study, a set of scenarios was developed that is considered to contain many of the important factors that can explain potential shifts to nonmotorized modes. Because of questionnaire length and time constraints, the strategies tested in the survey were limited to the following:

1. Provision of improved pedestrian facilities (sidewalks, pathways, and ancillary facilities);
2. Provision of improved bicycle facilities (bikeways, bicycle lanes, and ancillary bicycle facilities);
3. Implementation of pricing mechanism to discourage vehicular traffic in the downtown areas during peak periods (congestion fee; availability of flexible work hours was also tested concurrently with the congestion-fee strategy);
4. Encouragement of self-contained development where trip generators are in relatively close proximity to each other (compact land use; also tested with this strategy were lowering of speed limits and reduction of parking-space availability); and
5. Increases in fuel prices (fuel price increases were tested alone as well as in combination with the above strategies).

The major strategies tested were presented in the form of stretcher scenarios. The technique of stretcher scenarios, described by Urban and Hauser (6), involves brief descriptions of hypothetical scenarios that span the range of new transportation alternatives. By use of consumer preference responses to the stretcher scenarios, it is possible to interpolate consumer preferences to alternative future conditions that lie between current conditions and the stretchers, rather than merely extrapolating from current conditions.

After each of the strategies listed above was described, respondents were asked to rank their order of preference for the four modes examined. The changes in preference can be interpreted as the result of people's rearrangement of their perceptions of the attributes of the various modes in response to the innovations. Therefore, a common finding in attitudinal studies is that stated intentions or preferences do not always agree with subsequent behavior (7). In fact, stated preferences have tended to overestimate actual mode shifts (8). Therefore, the responses should be interpreted as indicative of the relative shifts that might be accomplished when comparing alternate strategies. The absolute value of the resulting shift to nonmotorized modes not only represents extreme values attainable only under the hypothetical conditions described in the statement, but may also include an overestimate of actual shifts due to the inability of respondents to predict future behavior accurately. Subsequent development of perception and preference models are likely to provide a truer measure of the magnitude of modal shifts that can realistically be expected to occur.

Each scenario will be described next, followed by an analysis of its effect on modal preference, where effects are measured in terms of the degree of change from current preferences.

### Compact Land-Use Scenario

The description of this concept statement read as follows:

#### Living Nearer to Travel Destinations

Many planners maintain that the use of automobiles has greatly increased the levels of air pollution, energy consumption, traffic congestion, and costly street and highway expenditures. It has been suggested that, in order to reduce these problems, people must live nearer to their places of employment, shopping, school, and recreation.

Some communities have been designed with this compact land-use arrangement in mind. Their layout is such that most shopping and personal business trips can be accommodated within a six-block [0.5 mile (0.8 km)] distance and most work trips are within 2 miles [3.2 km] of home.

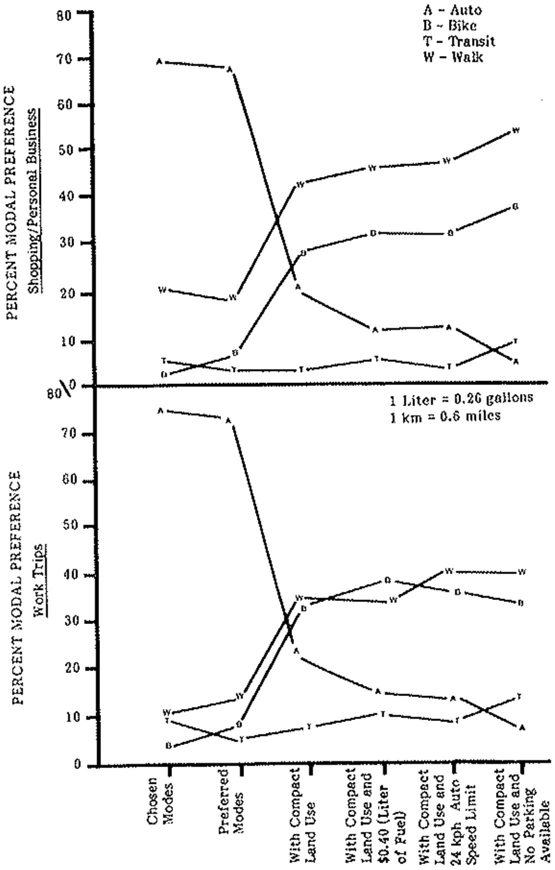
Suppose you live or moved to one such community. Suppose further that special bicycle paths and pedestrian pathways are provided so that it is possible to walk or bicycle to all shopping and personal business destinations without having to cross streets that carry heavy motor vehicle traffic; bicycle storing and lock-up facilities are provided in large numbers, free of charge, throughout the area; convenient bus service is available; and there are no special restrictions on the use of automobiles.

Table 6. Effect of strategies on modal preference, expressed as percentages of those choosing each mode.

| Mode | Current Performance | | With Improved Pedestrian Facilities | | With Improved Bicycle Facilities | | With Congestion Fee of $2.00 | | With Compact Land Use | | With Increase in Fuel Price of $0.40/L | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Work | Shopping-PB | Work | Shopping-PB | Work | Shopping-PB | Work | Shopping-PB | Work | Shopping-PB | Work | Shopping-PB |
| Automobile | 72 | 69 | 52 | 51 | 56 | 56 | 42 | 32 | 23 | 20 | 47 | 36 |
| Walk | 14 | 18 | 30 | 33 | 17 | 17 | 18 | 28 | 34 | 45 | 16 | 25 |
| Bicycle | 7 | 7 | 10 | 10 | 18 | 21 | 16 | 19 | 33 | 29 | 14 | 13 |
| Transit | 6 | 6 | 5 | 3 | 5 | 4 | 21 | 17 | 7 | 4 | 12 | 19 |

Note: 1 L = 0.26 gal.

Figure 1. Effect of compact land use plus fuel price increases and restricted speed and parking.



This statement contains two main elements that explain why such a scenario is responsible for the highest shifts from the automobile to walking and bicycling (see Table 6). These two elements are (a) acceptable distances for walking and bicycling and (b) walking and bicycling facilities separated from motorized traffic.

As can be seen from Figure 1 and Table 6, the number of respondents who select automobile as their preferred mode is reduced significantly (although not shown, the shift is particularly dramatic for Denver, Columbus, and Huntington Beach; even in Philadelphia, where automobile usage is relatively low, the shift in preference from automobile to nonmotorized modes is appreciable).

Although these results might seem unrealistic at first glance, it should be noted that, at present, the neighborhoods surveyed in Philadelphia (both of which exhibit short walk distance to the employment center and extensive sidewalk networks) show a significant amount of walking activity. In these neighborhoods, approximately 40 percent of respondents to the work survey, and 65 percent of the respondents to the shopping-personal business survey, walked to their destination. The 1970 census shows that 44 percent of those who work in Center City live within 9.6 km (6 miles) of City Hall, 30 percent live within 6.4 km (4 miles), and 14 percent live within 3.2 km (2 miles). A survey conducted in 1973 indicated that, assuming bicycle lanes and bicycle parking were available, 38 percent of bicycle owners and 17 percent of nonowners would commute to work (9). This result is consistent with our survey, which shows approximately a 30 percent preference level for bicycle under the compact land-use scenario that includes bicycle paths and lanes as well as parking facilities. The importance of bicycle facilities for attracting utilitarian trips, when provided in connection with specific compact land uses, such as university campuses and CBDs, has been recognized and documented (10-12).

Whether changes in land-use distribution can be accomplished in areas such as Huntington Beach in order to increase nonmotorized level of use significantly is a matter for further analysis. It appears, however, that residents of the area perceive such arrangements as conducive to reducing dependence on the automobile. It is interesting to note that in response to the direction to indicate their agreement or disagreement with the statement, "I would like to live in this type of community," in reference to the compact land-use concept statement, approximately 70 percent of all persons surveyed either agreed or strongly agreed with the above statement.

The effect on mode shift of combining an increase in fuel price [$0.40/L ($1.50/gal)] with the compact land-use scheme is only marginal (see Figure 1). Most of the shift is accomplished with the land-use concept and only an additional 5-10 percent of the respondents indicate that they would shift their preference from automobile to nonmotorized modes with the juxtaposition of the increase in gasoline prices. The superposition of a speed limit of 24 km/h (15 mph) on the compact land-use concept has no detectable effect on mode shift. This is probably because, under such a land-use arrangement, respondents might reason that trips are quite short and, thus, attaining high speeds becomes unnecessary. Restricting the availability of parking in the land-use arrangement concept causes approximately a 10 percent shift in the number of respondents that select automobile as their first preference. This shift is taken up by the remaining modes.

## Improvement of Bicycle Facilities Scenario

The following concept statement related to improvements in bicycle facilities was included in the survey questionnaire:

Figure 2. Effect of improved bicycle facilities plus increased fuel prices.

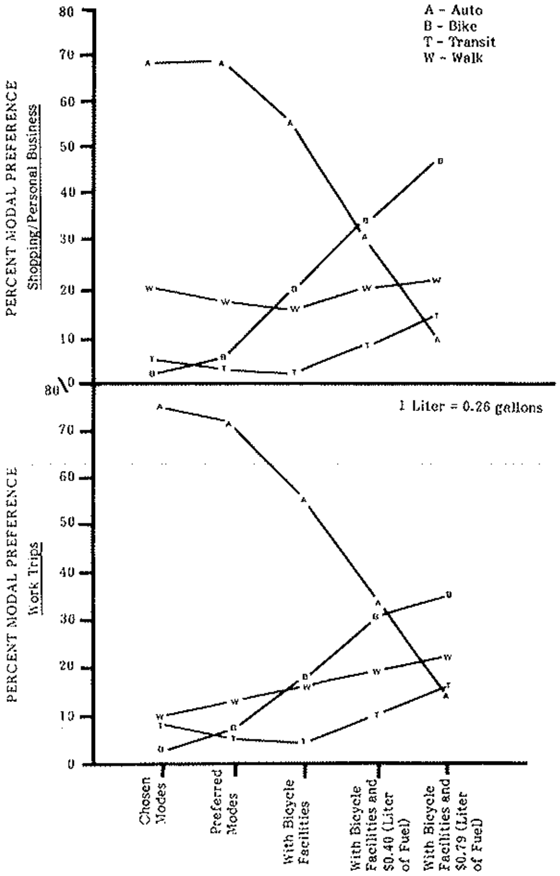
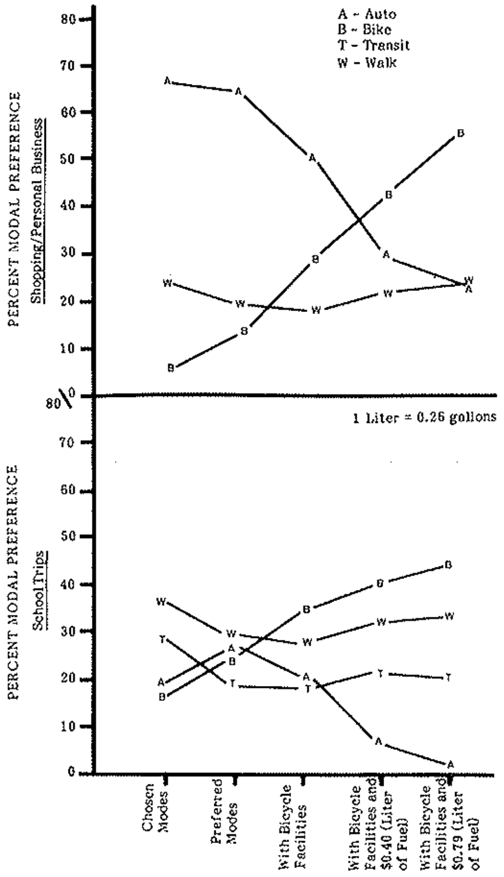


Figure 3. Effect of improved bicycle facilities plus increased fuel prices—Austin.



Bicycle-Related Facility Improvements

Suppose the city introduces several improvements to bicycle-related facilities designed to increase the comfort and safety of cyclists. The improvements consist of (a) providing bicycle paths, (b) reserving street lanes for bicycle use, (c) improving road surfaces, (d) installing secure bicycle lock-up facilities in many areas, and (e) providing better lighting.

On most local streets, a yellow stripe is painted near the right-hand side of the road marking a lane reserved strictly for bicycle use. Separate bicycle paths are built adjacent to all major roadways. These bicycle paths are separated from automobile traffic by a metal guardrail or a grass median. All these paths and street lanes are smoothly paved for better riding. In addition, high-intensity lights are added along the bikeways to provide excellent visibility at night. A large number of secure bike lock-up facilities are provided and, in high-activity areas, these consist of enclosed storage lockers manned by a full-time attendant. Finally, convenient locker, shower, and changing facilities are made freely available.

Respondents were then directed to indicate their ranked preference for the four major modes (automobile, bicycle, transit, and walk). Results are plotted in Figure 2. The current mode split (chosen mode) as well as the preferred modes are also plotted for reference purposes.

On the basis of the concept statement given above, 15-20 percent of the respondents shifted their preferred mode from automobile to bicycle. The pattern of decreased automobile use and increased bicycle use is consistent, generally, among the areas surveyed. However, Austin, which currently exhibits a relatively high level of bicycle use, appears to have the greatest potential for increased shift to the bicycle (see Figure 3). This is clearly a result of the proximity of the university for school trips, the availability of shopping-personal business opportunities nearby, and a familiarity of current bicycle use. The element of social acceptability appears to play an important role in the propensity for increased bicycle use. The relationship between high bicycle use for utilitarian purposes and the availability of bicycle paths and lanes has been documented previously (1, 13).

To determine the simultaneous effect of bicycle facility improvement and fuel price increase, survey participants were asked to repeat the ranking of modes with bicycle facilities in place, but assuming also that the price of fuel doubled to $0.40/L and $0.80/L ($1.50/gal and $3.00/gal). The additional burden placed on automobile use by the added fuel cost has the effect of reducing the number of respondents that select automobile as their preferred mode. At the $0.40/L price level, approximately 25 percent of the respondents to the shopping-personal business survey shifted their preference from automobile to other modes (15 percent shifted their preference to bicycle, and the other 10 percent selected walk and transit). On the work-trip survey, 20 percent of the respondents shifted their preference to other modes (13 percent to bicycle and 7 percent to walk and transit). Almost identical results are obtained when the fuel price increases to $0.80/L as were obtained above for work trips.

## Improvement of Pedestrian Facilities Scenario

The survey contained the following stretcher scenario related to the improvement of pedestrian facilities:

Suppose the city introduces several improvements to pedestrian-related facilities designed to increase the comfort and safety of pedestrians. The improvements consist of (a) providing pedestrian pathways, (b) improving sidewalks, (c) providing better lighting, and (d) making traffic signals more pedestrian-oriented.

Separate pedestrianways or walkways are built adjacent to all major roadways. These pathways are separated from automobile traffic by trees or grass median. At all busy street crossings, pedestrians will be able to change traffic lights in their favor. All existing sidewalks are repaired to make walking easier. High-intensity lights are added along the pathways to provide excellent visibility at night. Finally, the walkways are enhanced by the presence of water fountains, shade trees, benches, and pedestrian-oriented stands with flowers, newspapers, and refreshments.

Respondents were directed to proceed with the questions related to this statement only if their most recent trip destination was within the distance limit for walking—3.2 km (2 miles) for shopping-personal business, and 4.8 km (3 miles) for work. The respondents were then asked to rank the four major modes, assuming that the improved pedestrian facilities were in place. The results are plotted in Figure 4 and summarized in Table 6. On the average, 15-20 percent of those now using automobile indicate that they will switch to walking if the pedestrian facilities are in place.

While differences exist, it is interesting to note the similarity and consistency of response found among the different areas and trip purposes surveyed. In the areas surrounding the University of Texas and in Philadelphia, where there is a significant amount of walking at present, the effect of providing the improved facilities for walking is to shift an additional 15-20 percent of the automobile users to walking (this is illustrated in Figure 5 for the Philadelphia sites). In contrast, results in Huntington Beach show that only about 5 percent of the automobile trips will shift to walking. As indicated earlier, there is heavy dependency on the automobile in Huntington Beach because of the suburban nature of that area, which no doubt explains in part the low propensity for walking found there. This finding is similar to that encountered for the bicycle facilities scenario: The greater the current level of walking, the greater is the potential for increased walking. The corollary is that the greater the level of automobile use, the greater will be the tendency for continued automobile use. A peculiar finding is that a slight diversion of automobile trips to bicycling is observed (on the order of 5 percent), although no specific mention is made of bicycles in the pedestrian-facilities concept statement. Apparently some respondents are assuming that the pedestrian paths and ancillary facilities will be available to bicyclists.

In general, the simultaneous provision of pedestrian facilities and fuel price increases have the effect of shifting additional trips from automobile to all other modes, but particularly to nonmotorized modes. Over all areas surveyed, about 20 percent of respondents to the work-trip survey shift from automobile when fuel price is \$0.40/L, and an additional 20 percent shift at \$0.80/L. The shopping-personal business survey shows a shift of 25 percent at \$0.40/L and 15 percent at \$0.80/L. These reductions in automobile use are somewhat higher than when fuel pricing alone is tested. The increased fuel price in areas where walking is currently at a high level has a negligible effect on the amount of walking that is already taking place. Instead,

Figure 4. Effect of improved pedestrian facilities plus increased fuel prices.

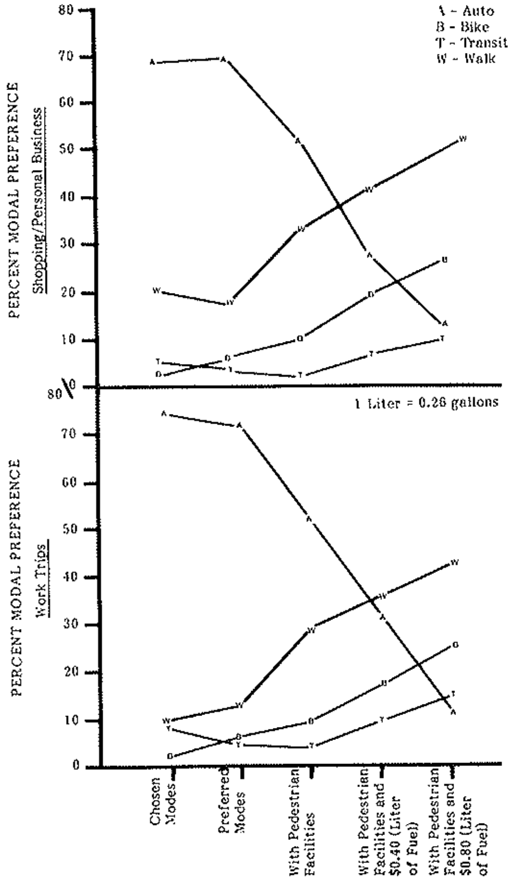
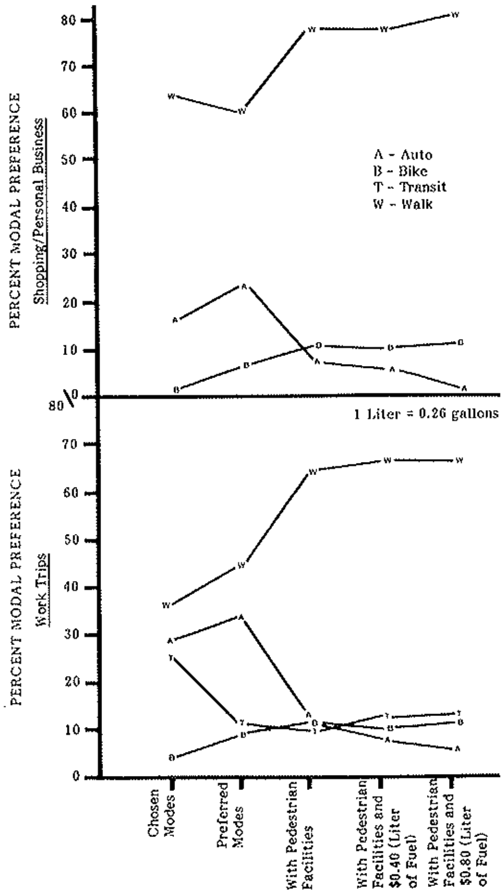


Figure 5. Effect of improved pedestrian facilities plus increased fuel prices—Philadelphia.



the reduction in automobile usage is taken up by increased bicycle and transit usage.

### Automobile Congestion-Fee Scenario

In order to test the effect of implementing policies that can act as disincentives to automobile use and thus cause shifts to nonmotorized use, the following concept statement was included in the survey questionnaire:

> Automobile Congestion Fee
>
> It is decided that, in order to reduce congestion and lower fuel usage, a fee of $1 will be assessed to the owners of automobiles operating during the morning (7:00-9:00 a.m.) and evening (4:00-6:00 p.m.) rush hours. This means that you would be charged up to a $2.00/day if you operate a motor vehicle during these peak travel periods. Billing would be made on a monthly basis using an automated billing process.

As with the preceding concept statement, respondents were directed to rank the modes in order of preference. The resulting modal distribution is plotted in Figure 6 and summarized in Table 6.

The congestion-fee strategy has the potential for effecting significant shifts away from automobile. A congestion fee of $2.00/day causes a reduction of 35 percent in the number of respondents who select automobile as their preferred alternative. Walk and bicycle take up most of this shift for the shopping-personal business trips; for the work trips, transit takes up half of the shift and the nonmotorized modes account for the other half. The pattern of decrease in automobile usage due to the congestion fee of $2.00/day is fairly predictable from area to area except for work-trips responses in Huntington Beach. Although about 30 percent of the respondents indicate a shift to another mode, automobile still remains the number-one preference for 60 percent of the respondents. When the congestion fee is increased to $4.00/day, an additional 10 percent shift in the number of respondents occurs in all areas surveyed.

When, in addition to the congestion fee of $2.00/day, an increase in the price of fuel to $0.40/L is introduced in the concept statement, the effect on mode shift from automobile to other modes is almost negligible. This somewhat unexpected result might be explained by the already fairly low level of automobile use when the increase in the fuel price is introduced. In order to give respondents an option to avoid the congestion fee assessed during peak hours by either arriving early to work and leaving early or arriving later and leaving later, they were asked to indicate their ranked modal preferences under a flexible-hours scheme. The results (as can be seen in Figure 6) indicate that respondents who had shifted from automobile to other modes in response to the congestion fee revert to using their automobiles for their work trips. As a result, the percentage of respondents to the work-trip survey who use their automobile increases from 40 percent when the congestion fee of $2.00 is in effect to 60 percent when flexible work hours are introduced. It is interesting to note that transit, which picks up much of the shift away from automobile, becomes less attractive when flextime is introduced. This points out that, when developing policies to increase nonmotorized use, care should be taken to avoid running counter to the positive aspects of existing policies or practices.

It is important to note that the application of an automobile fee during peak periods is only one method among many that can accomplish similar results. Other measures might involve the institution of parking restriction, tolls, even-odd license plates for every-other-day access, or license stickers (14). The latter has been successfully put into operation in Singapore (15). Under this scheme, a special sticker that costs approximately $2.00/day must be displayed during the morning rush hours within a cordoned area of downtown.

### Fuel Price Increase

To determine the effect that gasoline price increases might have on shifts in modal preference, the following directions were included in the survey: "Assume that on your next trip to work all travel conditions remained the same as at present except that the price of gasoline increased to one of the price levels indicated below." Respondents were then directed to rank the specified modes (walk, automobile, bicycle or transit) from most to least preferred for each of the following price levels: $0.26, $0.40, $0.80, and $1.05 or more per liter ($1.00, $1.50, $3.00, and $4.00 or more per gallon). The results are plotted in Figure 7.

Given current income levels, the survey indicates decreased automobile use in response to increases in fuel price, both for work and shopping-personal business trips. This is true even in areas where automobile use is currently low (Austin school trips and Philadelphia work and shopping-personal business trips), although in these areas the decrease in automobile use is much less pronounced. The decrease in automobile use for work trips is lower than that for shopping-personal business trips. This was to be expected, and it indicates that a higher priority is placed on work than on nonwork, discretionary trip making. Fuel price increases have practically no effect on the distribution of trips by mode in the Philadelphia areas surveyed. Even at the very highest price level tested [$1.05 or more/L ($4.00 or more/gal)] automobile work trips in the Huntington Beach precincts still attract more than 35 percent of the trips. For shopping-personal business trips, the percentage is reduced to about 20 percent. Observe that automobile use decreases fairly rapidly as fuel price increases up to $0.53/L ($2.00/gal). After that point, the rate of decrease slows down considerably. The nonmotorized modes, on the other hand, show fairly rapid gains up to the $0.53/L price level and then taper off quite rapidly, which suggests a plateau. Further increases in the gasoline price beyond this level translate into diminishing gains for nonmotorized modes.

A great deal of caution must be exercised when examining the above results. In addition to the uncertainties associated with translating perceptions into preferences, the additional question of timing is critical when discussing demand changes in response to fuel price increases. Whereas respondents generally react to a doubling in the price of fuel by assuming that such an increase occurs instantaneously, in reality, price increases take place over a period of time, thus giving the consumer time to adjust to the small incremental increases. For this reason, elasticities of demand estimated from the above modal preferences are certain to be considerably greater than would occur under actual conditions.

## CONCLUSIONS

A summary of the most important findings is given below. Table 6 provides a comparative view of the effect on modal preference of the various strategies tested. Current preference is a good indicator of current mode choice. In general, however, indicated preference levels tend to underestimate choice of auto-

Figure 6. Effect of congestion fee plus increased fuel prices.

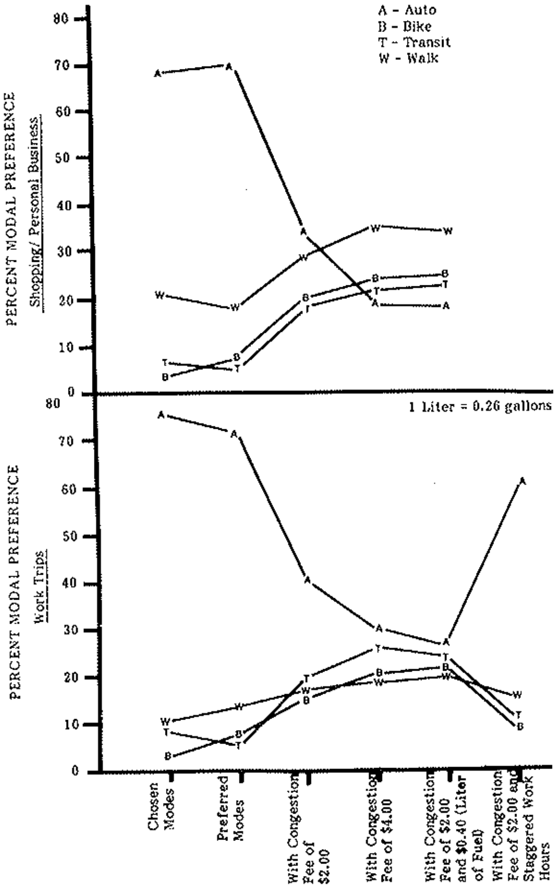
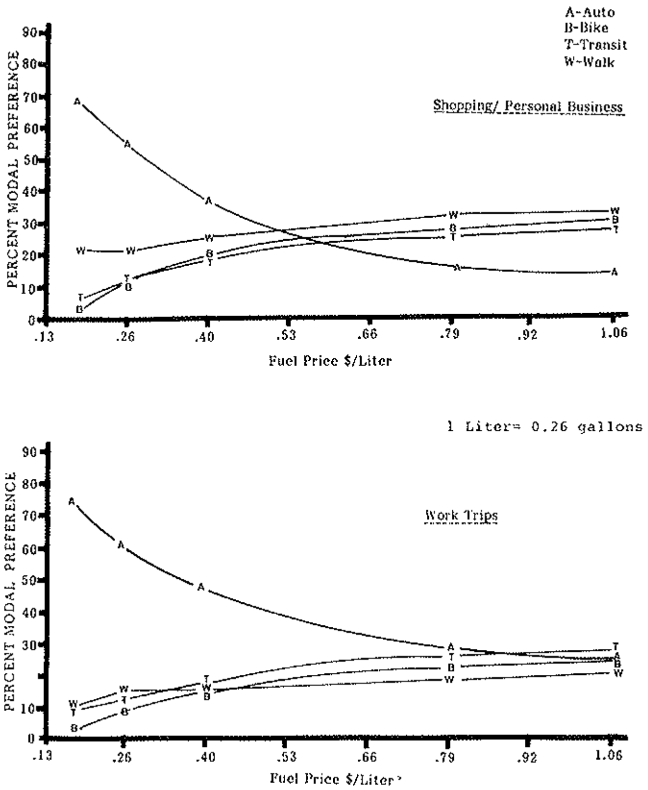


Figure 7. Mode choice versus fuel price.



mobile, transit, and walk, and overestimate actual bicycling. The following ordering shows the hierarchy of strategies, based on their potential for effecting shifts from the automobile:

1. Compact land use,
2. Congestion fee,
3. Fuel price increases,
4. Pedestrian facilities, and
5. Bicycle facilities.

The hierarchy of strategies tested for their ability to increase walking or bicycling is as follows:

1. Compact land use;
2. Pedestrian or bicycle facilities, respectively;
3. Congestion fee;
4. Fuel price increase; and
5. Bicycle or pedestrian facilities, respectively.

The concept of a compact land-use distribution (which includes walk and bicycle facilities, with work, shopping, and other opportunities within walking and bicycling distance) produces the greatest shift in preference from automobile to walking and bicycling. The relative importance of this strategy underscores the realization that the most effective way of promoting use of nonmotorized modes may not always be responsive to policy actions. This is not to say, for instance, that new economic forces such as that brought about by a limited gasoline supply, might not be able to influence how people choose their places of residence in relation to their places of employment. In such a case, gasoline supply or its cost could be set by policy.

Separate facilities play an important role in people's preference for nonmotorized modes, second only to that of compact land use. The significance of facilities is further emphasized by the fact that the compact land-use scenario contains not only the very important element of short trip distance, but also the element of separate facilities for nonmotorized travel. Thus, facilities can play a prominent role in increasing nonmotorized travel, particularly if they are provided in the context of compact land-use configurations, such as college campuses, residential areas near CBDs, and areas where shopping opportunities are within walking or bicycling distance of medium- to high-density residential areas.

Pricing, either through congestion fees or increases in fuel prices, has the potential for causing significant shifts from the automobile. However, transit absorbs a large portion of the shift, thus reducing the potential nonmotorized share. An increase in the price of fuel to $0.40/L is somewhat less effective in causing shifts from the automobile than is the application of a congestion fee of $2.00/day. It does have the effect, however, of increasing consumers' preference for transit, especially for shopping and personal business trips.

Current level of nonmotorized use appears to be related to the potential increases in walking and bicycling. Both the Austin precincts, with their relatively high current share of bicycle use, and the precincts in Philadelphia, with their high level of walking, exhibit the highest shifts toward bicycling and walking, respectively, with the introduction of facilities.

With the exception of the compact land-use scenario, the application of any strategy, by itself, causes a maximum shift of approximately 20 percent to either walking or bicycling. Given the hypothetical and somewhat unrealistic nature of the scenarios, this value can be taken to represent the upper-limit diversion from automobile to walking and bicycling (for noncompact land-use settings).

Different strategies affect modal preference differently, depending on the purpose of the trip. There is little or no difference in the preference level between the trip purposes tested under the improved pedestrian and bicycle facilities strategies. Significant differences do exist between the levels of preference for work trips and strategies. For example, work trips, which are taken usually during rush periods, are less affected by both strategies than are shopping-personal business trips. This is to be expected since the latter can be more easily scheduled for off-peak periods. In the case of the fuel pricing strategy, shopping-personal business trips can be consolidated, which thus reduces the impact of the price increase.

Current preferences are good indicators of current mode choice, but no assurances can be made at this point about the reliability of future preferences for predicting future choice. The modified preferences result from changes in the perception of the mode attributes as a result of the scenarios introduced. Whether this modified perception will lead to changes in behavior as reflected by actual shifts to other transportation modes is the subject of perception and preference modeling work just completed. Those results will be publicized at a later date.

## ACKNOWLEDGMENT

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