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# Urban Accident Patterns

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# FOREWORD

The papers in this RECORD cover a number of different subject areas. Two of the papers deal with urban accident patterns, and 3 are related to pedestrian facilities.

King and Goldblatt discuss the relationship of accident patterns to type of intersection control. Many different measures of effectiveness that describe changes in accident patterns were computed and analyzed. Hypothesis testing revealed that, although there was a definite shift in the distribution of accident types, there was no evidence that signalization by itself would lead to a significant decrease in net accident-related disutility especially for traffic signals not warranted by traffic volume.

Cooper describes a Canadian study on the effects of increased enforcement levels on driver behavior and safety at urban intersections. The results of the study indicated that visible police presence at an urban intersection can significantly reduce the incidence of traffic violations. This effect, however, appeared to be restricted to the time of actual police presence and disappeared almost immediately after the police left. The most significant improvements for reducing violations occurred when 1 police officer was visible for 1 h/day. Further increases in effort did not produce an appreciable improvement.

Stone and Surti's paper presents a model for performing feasibility studies of pedestrian mall proposals. The model is based on the systems approach to solving large-scale decision problems. To demonstrate the application of the model, the authors compare 2 alternative mall configurations: a pedestrian-only mall and a pedestrian mall with an exclusive bus lane. The case study was the proposed 16th Street Mall for Denver's central business district.

Austin, Kassen, and Vanstrum report on a study of driver perception of pedestrian conspicuousness under the standard headlight system. The degree of visual protection necessary for pedestrians under night driving conditions is explored. The performance of various reflective surfaces illuminated by the present standard headlight system is compared to the brightness and area requirements found for each level of visibility and conspicuousness.

Demetsky and Perfater examined pedestrian attitudes and behavior in suburban environments. Nine case studies were made to determine the role of walking as an exclusive mode of travel. The sites examined accounted for 3 major types of pedestrian facilities: overpasses, tunnels, and at-grade crossings. Locations where new pedestrian facilities are anticipated also were studied. Various pedestrian characteristics were found to be related to walking activity. Acceptable walking distances up to about 0.25 mile (0.4 km) were given for adults; distances up to 1 mile (1.6 km) offered little impedance for children.

# RELATIONSHIP OF ACCIDENT PATTERNS TO TYPE OF INTERSECTION CONTROL

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The change in accident patterns accompanying a change in intersection control was investigated. The investigation included a review of previously made studies, an analysis of before and after accident data, and a detailed statistical analysis of a large, specially assembled, nationwide accident data base. Analysis of variance and regression techniques were used to show that the relationship of accident patterns to type of control must be represented by a complex model and that a simple-signal—no-signal division cannot explain changes in accident patterns. A large number of different measures of effectiveness that describe changes in accident patterns were computed and analyzed. Hypothesis testing revealed that, although there was a definite shift in the distribution of accident types, there was no evidence that signalization, by itself, would lead to a significant decrease in net accident-related disutility, especially for traffic signals not warranted by traffic volume. No conclusive evidence was found to justify a general reduction of minimum volume requirements for rural conditions or high-accident locations.

•THE CURRENT Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (1) specifies an accident experience warrant that implies that (a) certain types of intersection accidents exist whose probability of occurrence is significantly lower when a signal control traffic and (b) installation of a traffic signal will provide net benefits in the form of lower frequency of accidents. Previously made accident studies were reviewed to determine the validity of these implied assumptions. This review was supplemented with a set of analyses of a large data base. These interrelated studies were designed to reveal any statistically valid relationship that exists between type of intersection control and any of a number of descriptions of accident histories for a given intersection (2).

Many approaches are possible in any study of intersection safety. The most common approach consists of before and after studies at individual intersections where a control change has been made. The data collection and analysis aspects of this method have been well documented (3). The main drawback of this method is its lack of generalizability. Even though significant changes can be detected by comparing before and after data, they may not apply to all intersections of similar configuration and traffic demand. Another approach consists of collecting accident data at a large number of locations covering a wide range of traffic-flow characteristics, land uses, and geometric conditions and various types of intersection control. By using appropriate statistical techniques, one can assess the separate influence of each of these factors.

In this study, a nationwide sampling of intersection accident records was undertaken. We decided to concentrate the main effort on evaluating differences in the distribution of accidents by type and severity because many previous studies indicated that the installation of traffic signals alone did not lead to a decrease in accident rate.

Publication of this paper sponsored by Committee on Traffic Control Devices.

# PREVIOUS STUDIES

Because accidents often serve as the justification or impetus for traffic engineering improvements, research on accident patterns has received considerable attention in the past. An excellent description of research through 1970, which can be found elsewhere (4), will be summarized in this paper together with an analysis of several more recent studies.

## 2-Way Control

A number of past studies indicated that accident rates at 2-way stop intersections tended to increase as cross-street volumes increased and to decrease as main-street volumes increased (4). Right-angle accidents predominated; they accounted for as much as 59 percent of the total.

## 4-Way Control

Many past studies indicated that 4-way stop control led to a decrease in accident rates if entering volumes, particularly major-street volumes, were below the current warrant levels that require installation of traffic signals. The proportion of right-angle collisions for 4-way stop control was markedly lower than the proportion for 2-way stop controls. This reduction of accident rates also was noted by Heany (5). An overall reduction of 87 percent in the number of accidents was recorded at 57 intersections, none of which met traffic-signal warrants. This reduction appeared to be independent of volume splits.

Intersections controlled by flashing beacons, which have the same legal effect as stop-sign control, generally are characterized as having lower accident levels than intersections controlled by signs. Cribbins and Walton (6) noted statistically significant changes in accident rates after installation of flashing beacons at low-volume, high-speed, rural intersections. They noted, however, no significant change in distribution of accidents by type.

## Traffic Signals

The conclusion of many studies dealing with the effect of signalization on accident patterns can best be illustrated by the following (4):

> In summary, the effect of installing traffic signals cannot be described specifically. Under certain circumstances, the signal may reduce accidents; however, the widespread examples of higher rates after installation under certain circumstances should alert the engineer to the possibility of a worse accident experience. Factors that are generally favorable for an improved accident experience after the installation of traffic signals include high traffic volume, existing high accident frequencies, and complex five-and-six-leg intersections.
>
> Regarding the effect of accident type and severity, traffic signals tend to reduce right-angle accidents and increase rear-end and turning accidents. Accident severity, or the percent of injury accidents, does not appear to increase with signalization.

A before and after study of 33 new traffic installations in Michigan showed that, although total accidents increased by 8 percent, right-angle and sideswipe accidents were reduced by 45 percent and 60 percent respectively. However, an 84 percent increase in the number of rear-end accidents and a 236 percent increase in left-turn accidents were noted.

Data on 28 newly signalized intersections in Concord, California, showed a reduction in total accidents. However, a decrease in right-angle accidents and an increase in rear-end accidents occurred after signal installation.

The sample used in the Concord, California, study consisted of 15 actuated, 1 semi-actuated, and 12 fixed time controls. Applying Michaels' method (3) to these data shows that

1. The change in total accidents was not significant,
2. The decrease in right-angle accidents was significant (conservative test), and
3. The increase in rear-end accidents was significant (liberal test).

A chi-square test for a 2 x 2 contingency table (7) shows that there was no significant difference between fixed time and actuated signals for rear-end accidents but that a significantly larger reduction ($p = 0.10$) in right-angle accidents was experienced by the traffic-actuated group.

The Virginia Department of Highways (now the Virginia Department of Highways and Transportation) furnished accident data for 30 intersections. The data collection period for both before and after studies was either 1 or 2 years totaling 50 intersection years of data. Table 1 gives a summary of the results of the study. In the before study property damage for accidents totaled $205,655; in the after study it totaled $221,718. This represents a +7.8 percent change.

Because of the completeness of the data furnished many additional statistical tests, including t-tests on both the overall before and after means and the mean of the individual differences, could be performed (8). These tests showed that

1. The increase in mean number of accidents for all intersections was not significant.
2. Sixteen intersections showed higher total accidents in the after period, 4 were unchanged, and 10 were lower.
3. The mean increase for individual intersections was 3.27, which was significant ($p = 0.10$).
4. The decrease in total persons killed and injured was not significant.
5. The increase in the average dollar value of property damage was not significant.
6. The increase in the average number of rear-end accidents was highly significant ($p = 0.005$).
7. The decrease in the average number of right-angle collisions was significant ($p = 0.01$).

The data, as furnished, did not include a classification for abutting land use. It did, however, include speed limits for major streets. Using these as the criterion, we divided the data set into 2 subsets; 40 miles/h (64 km/h) was the dividing line. A set of 2 x 2 contingency tables that resulted from this partition was constructed by using the same variables as those given in Table 1. Using the standard chi-square test for contingency tables one can show that none of these tables show significance at the $p = 0.10$ level. On the basis of this data set, the urban-rural classification does not statistically influence the pattern of changes in accident rates.

The data set also was partitioned on the basis of minimum right-angle accidents per year in the before period according to a MUTCD accident warrant. The resulting 2 x 2 contingency table is as follows:

| Right-Angle Accidents | Total Accidents: Before | Total Accidents: After |
| --- | --- | --- |
| More than 5 | 269 | 264 |
| Less than 5 | 142 | 245 |

The difference between these 2 categories was significant at the $p = 0.01$ level. This indicates that when the number of right-angle accidents at an unsignalized intersection is low, then the installation of a signal could increase the total number of accidents.

Young (9) stratified according to certain warrants the before and after accident experience at 31 newly signalized intersections. The results are given in Table 2.

A number of studies indicate that both absolute reductions in accident rates and changes in distribution of accidents by type could be achieved by traffic signal modernization (4). This is especially the case if the modernization tended to increase the visibility of signals or decrease the total number of vehicles stopped. This is further supported by Lewis (10) who showed that enhancement of signal target value and visibility had substantially the same effect on the relative occurrence of rear-end and right-angle accidents as did new signalizations in the Michigan, Virginia, and Concord, California studies.

The difficulty inherent in drawing unequivocal conclusions concerning the effect of signalization from accident studies was shown by Thorpe (11) and Andreassend (12). Using essentially identical data bases (accidents in Melbourne, Australia), Thorpe (11) found that signalized and unsignalized intersections had the same accident rates and Andreassend (12) found that the effect of signalization caused a highly significant 32 percent reduction in total accidents. Thorpe (11) used a comparison technique, and Andreassend (12) made a before and after study.

## DATA COLLECTION AND REDUCTION

### Data Collection

Data were collected at intersections by using a comprehensive data form distributed to a number of traffic engineers. Accident data were received from the jurisdictions given in Table 3. Over 300 data sets from 300 intersections were received. Detailed and comprehensive data for each location were received, but computer storage constraints limited final analysis to 250 data sets.

### Data Reduction

The data, as received, were examined and entered in computer storage. A computer program that could read the data, make diagnostic checks, and assign the intersection to a data cell was written. Each cell was defined by the following 5 variables:

1. Geographic area
   a. Northeast
   b. North central
   c. South
   d. West
2. Type of area
   a. Central business district (CBD)
   b. Outskirts of CBD
   c. Rural
3. Major-street volume
   a. Light
   b. Medium
   c. Heavy
4. Split between volume on major and minor approaches
   a. Even ($0.5 \leqslant$ major/total volume $< 0.6$)
   b. Uneven ($0.6 \leqslant$ major/total volume $< 1.0$)
5. Control
   a. 2-way stop

b. 4-way stop
c. Signal

Each cell contained the following information:

1. Number of intersections and their serial numbers
2. Number of intersection months of exposure
3. Number of accidents
4. Distribution of accidents by type and percentage:
   a. Rear end
   b. Right angle
   c. Left turn
   d. Pedestrian
   e. All other
5. Number and percentage of accidents with fatalities, injuries, and property damage

## CHOICE OF MEASURES OF EFFECTIVENESS

Because no judgment could be inferred about how a change in accident patterns would make itself felt and because no general agreement exists on any 1 measure of effectiveness (MOE), a number of MOEs were considered. Ten of these were computed and analyzed in parallel.

1. Accident evaluation index (13) is a function representing the effect of type of accident, accident severity, and abutting land use.
2. Injury and fatality ratio is the number of accidents producing fatalities and injuries divided by total accidents.
3. Rear-end ratio is the ratio of rear-end collisions to total accidents.
4. Severity index (13) is a weighted index based on accident severity.
5. Right-angle ratio is the ratio of right-angle collisions to total accidents.
6. Normalized accident total is total accidents normalized for months of exposure.
7. Volume accident rate is total accidents divided by peak-hour entering volume and multiplied by 100.
8. Accident disutility is the product of the accident evaluation index and accident rate and can be construed as an index of net economic loss because accidents are normalized for traffic-flow levels.
9. Right-angle accidents is the average number of right-angle accidents per year. This is 1 of the criteria of the existing accident warrant.
10. Right-angle accident rate is the average volume rate of right-angle accidents and is the product of the number of right-angle accidents times accident rate.

## DATA ANALYSIS

Statistical test performance on the data included analysis of variance, multiple linear regression and hypothesis testing. Because the data analysis was started before the entire data base was assembled, it was performed on 2 distinct data sets (2).

The data could not fill all of the possible 216 data cells because data from the Northeast and data representative of 4-way stop control were scarce. So a reduced design using only 4 variables was adopted. This design could store data in 24 cells; 23 of these were filled. The only cell missing data represented the combination of CBD, heavy-flow, even-split, and 2-way stop data.

### Analysis of Variance

The initial data set was then subjected to a number of analysis of variance tests using the IBM analysis of variance program (ANOVA). Separate analyses were made for each

**Table 1. Virginia accident study.**

| Classification | Number of Accidents Before | After | Change (percent) | Significance[a] |
|---|---|---|---|---|
| Severity of accident | | | | |
| Fatality | 9 | 3 | -66.7 | —[b] |
| Injury | 218 | 179 | -17.9 | —[b] |
| Type of accident | | | | |
| Rear end | 89 | 250 | +180.9 | C |
| Right angle | 255 | 168 | -34.1 | C |
| Turning movement | 31 | 36 | +16.1 | N |
| Pedestrian | 3 | 7 | +133.3 | N |
| Head on | 3 | 3 | — | — |
| Miscellaneous | 30 | 45 | +50.0 | C |
| Surface condition | | | | |
| Wet | 78 | 132 | +69.2 | C |
| Dry | 333 | 377 | +13.2 | L |
| Visibility | | | | |
| Night | 125 | 149 | +19.2 | L |
| Day | 286 | 360 | +25.9 | C |

[a]Significance in accordance with Michaels' method (3). [b]Not applicable.

**Table 2. Cincinnati accident study.**

| Warrant (14) | Number Meeting Warrant | Accident Comparison Increase | Decrease |
|---|---|---|---|
| Volume | 5 | — | 5 |
| Interruption | 7 | — | 7 |
| Pedestrian | 2 | — | 2 |
| Accident | 4 | — | 4 |
| Progression | 2 | 1 | 1 |
| Combined | 1 | 1 | — |
| None | 15 | 7 | 8 |

**Table 3. Jurisdictions providing accident data.**

| States | Cities | Counties |
|---|---|---|
| Colorado | Atlanta | Nassau, New York |
| Illinois | Baltimore | Sacramento, California |
| Maryland | Canton, Ohio | |
| Massachusetts | Chicago | |
| New York | Dallas | |
| Oklahoma | Fort Lauderdale | |
| Pennsylvania | Fort Worth | |
| Washington | Kansas City | |
| West Virginia | Los Angeles | |
| | Milwaukee | |

**Table 4. Results of ANOVA.**

| Effect | Accident Evaluation Index | Injury and Fatality Ratio | Rear-End Ratio | Severity Index | Right-Angle Ratio |
|---|---|---|---|---|---|
| A | 0.05 | | | | 0.10 |
| V | | | 0.10 | | |
| AV | | | | | |
| S | 0.10 | | | | 0.05 |
| AS | | | | | 0.10 |
| VS | | | | | |
| AVS | | | | | |
| C | 0.10 | | 0.10 | | 0.01 |
| AC | | | | | 0.05 |
| VC | | | | | |
| AVC | | | | | |
| SC | | | | | |
| ASC | | | | | |
| VSC | | | | | |

Note: A = area. V = volume. S = split. C = control.

**Table 5. Independent variables for regression analysis.**

| Symbol | Definition | Explanation |
|---|---|---|
| $x_1$ | Total volume | Variable consisting of the sum over the number of approaches of volume per lane |
| $x_2$ | Split | Variable representing major-minor critical approach lane split |
| $x_3$ | Urban | Binary (0, 1) if the intersection is (rural, urban) |
| $x_4$ | CBD | Binary (0, 1) if the intersection is (non-CBD, CBD) |
| $x_5$ | Conflict | Variable representing total potential conflicts at the intersection |
| $x_6$ | Left-turn conflict | Variable representing total left-turn conflict potential |
| $x_7$ | Approach sight distance | 1 if the intersection has 2 or more approaches with fair sight distance or 1 or more approaches with poor sight distance; 0 otherwise |
| $x_8$ | Grade | Binary (0, 1) if any approaches are (level, not level) |
| $x_9$ | Log volume | Log of $x_1$ |
| $x_{10}$ | Multiphase | Binary (0, 1) if signal control (is, is not) 2 phase; this variable is forced out of the stop equations |
| $x_{11}$ | One-way | Binary (0, 1) if 1 or more approaches (are not, are) 1-way |
| $x_{12}$ | Daylight | Variable representing percentage of all accidents occurring during daylight hours |
| $x_{13}$ | Major volume | Variable representing major street volume |
| $x_{14}$ | Square of major volume | Square of $x_{13}$ |
| $x_{15}$ | Major street split | Variable representing the major street directional split |

of 5 variables previously described.

ANOVA was run for a full factorial design with 4 main effects—1 at 3 levels and 3 at 2 levels—resulting in a total of 24 degrees of freedom. The 4-way interaction was equated to the residual sum of squares and used for the computation of the F-ratios. The grand mean was used to fill the 1 empty cell. Table 4 shows the level of significance for each source. Blank entries indicate that the effect for a specific MOE was not significant at a confidence level of $p = 0.10$.

The injury and fatality ratio and severity index were not significantly affected by any of the 4 effects or their interactions. Examination of the detailed output reveals that, although none of the main effects were significant at the $p = 0.10$ level, the interactions, including some of the higher ones, appeared to play a larger role in explaining variance than did the main effects. So changes in accident severity are not caused simply but rather appear to be the result of a more complex process.

Rear-end and right-angle ratios showed the relative predominance of certain types of accidents. The importance of rear-end collisions was marginally significant as a function of volume and control. Interaction of volume and control, however, was not significant. The volume variable used in this analysis was normalized for number of lanes, and the high-low division was based on the heaviest approach lane. Higher levels of significance prevailed for right-angle ratio. Changes in this MOE can be related to changes in the type of intersection control and, marginally, to changes in area. This was the only MOE that indicated the possibility of a significant relationship with 1 of the interactions. The area-control interaction was significant at the $p = 0.05$ level. Split and area-split interaction may be marginally significant. The right-angle collision percentage thus is related strongly to type of control and also may be related to area and split and some of their interactions.

Area was significantly related to change in the accident evaluation index. Control and split were marginally significant. In interpreting these results, one must remember that urban and rural area differences were built into the accident evaluation index, so significant changes should be expected.

## Regression Analysis

Considering the computed parameters as dependent variables, we performed a series of stepwise linear regression analyses. The 4-13-65 version of the stepwise regression (BMDO2R) program of the Health Sciences Computing Facility at the University of California, Los Angeles, was used. Because the influence of type of control was of prime importance to this project, 2 separate sets of analyses were performed on 2-way stop intersection data, and 2 sets were performed on signalized intersection data. We intended that the overall analysis would consider the significant independent variables remaining in each equation after the last step, the relative size of their coefficients, and the coefficients of multiple regression for each equation. The set of dependent variables consisted of the first 6 MOEs and the logarithm of 1 of these. Table 5 gives the definitions of the independent variables. Table 6 gives the independent variables and the coefficient of multiple regression (R) for each of the final equations. Also given for each of the independent variables is the significance level that rejects the hypothesis that the coefficient of that variable is zero. If no value is shown, the hypothesis cannot be rejected at the 0.90 level.

Initial results showed that values of R were low. Even the relatively high value for the stop-control accident evaluation index ($R = 0.763$, $R^2 = 0.582$) is deceiving because urban-rural differences were built into this index. $x_3$ contributed 0.402 to the total $R^2$.

For the data base used, the general indication is that a simple linear regression model, even one with many independent variables, would not furnish an adequate model of the accident experience associated with a given type of intersection control. Many additional potential independent variables would have to be considered, and a more complex, probably nonlinear, regression model would have to be constructed before an appreciably large fraction of the total variance could be accounted for. Although the computed value of R was invariably lower for signal control than for stop-sign control for the analyses completed, the accident pattern at signal-controlled intersections requires a much more complex model for explanation. Although no firm conclusions can be drawn from this part of the study, there is a strong indication that the signal no-signal difference alone does not adequately explain changes in accident pattern.

## Hypothesis Testing

A series of statistical tests was performed to determine whether differences in accident patterns for defined subgroups were significant. To relate this analysis to the proposed traffic-signal warrants, we included only those data for intersection configurations for which traffic-signal warrants had been developed (2). The reduced data set consisted of 168 intersections. These were partitioned into rural or urban classifications according to whether approach speeds exceeded 40 mph (64 km/h). The sample contained 51 rural and 117 urban intersections.

Tables 7, 8, and 9 give the mean and variance for each of the MOEs for the total sample and its urban and rural components. The ratio of mean to standard deviation, as a measure of spread of the distribution, is also given. An F-test was performed on the variances to determine whether the sample of signalized intersections and the sample of stop-sign-controlled intersections could have come from the same population. If this test showed that the hypothesis of equal variance could not be rejected, a t-test was performed to test for equality of means.

The inferences that can be drawn from this analysis are as follows:

1. The 2 aggregate populations studied, one that was signal controlled and one that was stop-sign controlled, were significantly different for 9 out of 10 MOEs considered.
2. The exception, accident rate, was not significantly affected by type of control.
3. For the urban subpopulation, 7 out of 10 MOEs exhibited significantly different populations for the 2 types of control.
4. Two MOEs, accident disutility and right-angle accident rate, were only marginally significantly different.
5. The remaining MOE, injury and fatality ratio, was not significantly affected by type of control.
6. For the rural subpopulation, 9 out of 10 MOEs exhibited significantly different populations for the 2 types of control.
7. The exception, accident disutility, was not significantly affected by type of control.

It is important to note that for accident disutility, which is a detailed measure of accident frequency, type, and severity that is normalized for volume, no significant difference existed between control types for urban and rural subpopulations.

We decided to partition the data set according to whether an intersection satisfied the proposed volume and peaking warrants. This resulted in a set of 2 x 2 contingency tables that contained aggregate, urban, and rural data. A sample of this table is as follows:

| | Signals | |
|---|---|---|
| Intersection | Warranted | Not Warranted |
| Signalized | MOE | MOE |
| Not signalized | MOE | MOE |

For each of these contingency tables, statistical tests were performed to determine significant differences that could be attributed to either warrant adherence or type of

**Table 6. Results of regression analysis.**

| Dependent Variable | Control | $\bar{x}$ | R | Level of Significance $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{15}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Accident evaluation index | Signal | 1.45 | 0.573 | | | 0.95 | | | | | 0.95 | | 0.95 | | 0.90 | | | |
| | Stop sign | 1.77 | 0.763 | 0.95 | | 0.95 | | 0.90 | 0.95 | | 0.90 | 0.95 | —[a] | 0.95 | | | | 0.90 |
| Injury and fatality accidents | Signal | 0.319 | 0.403 | | | 0.95 | | | | 0.95 | 0.95 | | | 0.95 | | | 0.95 | |
| | Stop sign | 0.366 | 0.528 | | | | | | | 0.90 | 0.90 | | —[a] | | 0.90 | | | |
| Rear-end ratio | Signal | 0.327 | 0.444 | | | | | | | | | | 0.95 | | | 0.90 | | 0.90 |
| | Stop sign | 0.134 | 0.634 | | | | 0.95 | | | 0.95 | 0.95 | | —[a] | 0.90 | | | | |
| Severity index | Signal | 2.63 | 0.362 | 0.90 | | 0.95 | | | | | | 0.90 | | | 0.90 | | | |
| | Stop sign | 6.44 | 0.389 | | | | | | | | 0.90 | | —[a] | 0.90 | | | | |
| Right-angle ratio | Signal | 0.233 | 0.392 | 0.95 | | 0.95 | | | 0.95 | | | 0.90 | | 0.90 | 0.95 | | —[a] | |
| | Stop sign | 0.500 | —[b] | | | | | | | | | | | | | | | |
| Log of accident evaluation index | Signal | 2.85 | 0.627 | | | | —[a] | | | | 0.95 | | 0.95 | | | | | —[a] |
| | Stop sign | 2.94 | —[b] | | | | | | | | | | | | | | | |
| Total accidents | Signal | 16.78 | 0.390 | | | | | | | 0.95 | 0.90 | | 0.90 | | —[a] | | | |
| | Stop sign | 8.87 | —[b] | | | | | | | | | | | | | | | |

[a]Variable not in final equation. [b]Analysis not made.

**Table 7. Mean and variance of measures of effectiveness, all data.**

| Measure of Effectiveness | Signal Control[a] $\bar{x}$ | s | $\bar{x}$/s | Stop-Sign Control[b] $\bar{x}$ | s | $\bar{x}$/s | Significance of Difference $\bar{x}$ | $s^2$ |
|---|---|---|---|---|---|---|---|---|
| Accident evaluation index | 1.477 | 0.336 | 4.4 | 1.823 | 0.398 | 4.6 | — | 0.10 |
| Injury and fatality ratio | 0.324 | 0.220 | 1.5 | 0.405 | 0.294 | 1.4 | — | 0.01 |
| Rear-end ratio | 0.322 | 0.201 | 1.6 | 0.142 | 0.149 | 0.95 | — | 0.01 |
| Severity index | 2.682 | 1.926 | 1.4 | 7.162 | 14.968 | 0.48 | — | 0.01 |
| Right-angle ratio | 0.237 | 0.197 | 1.2 | 0.525 | 0.287 | 1.8 | — | 0.01 |
| Normalized accident total | 12.538 | 8.470 | 1.5 | 5.620 | 4.940 | 1.1 | — | 0.01 |
| Volume accident rate | 6.117 | 4.444 | 1.4 | 5.112 | 4.440 | 1.2 | —[c] | —[c] |
| Accident disutility | 9.136 | 7.196 | 1.3 | 9.524 | 9.355 | 1.0 | — | 0.05 |
| Right-angle accidents | 2.783 | 2.641 | 1.1 | 2.897 | 3.209 | 0.90 | — | 0.10 |
| Right-angle accident rate | 1.425 | 1.458 | 0.98 | 2.938 | 3.303 | 0.89 | — | 0.01 |

[a]117 in sample. [b]51 in sample. [c]Not significant.

**Table 8. Mean and variance of measures of effectiveness, urban data.**

| Measure of Effectiveness | Signal Control[a] $\bar{x}$ | s | $\bar{x}$/s | Stop-Sign Control[b] $\bar{x}$ | s | $\bar{x}$/s | Significance of Difference $\bar{x}$ | $s^2$ |
|---|---|---|---|---|---|---|---|---|
| Accident evaluation index | 1.399 | 0.324 | 4.3 | 1.570 | 0.434 | 3.6 | — | 0.05 |
| Injury and fatality ratio | 0.316 | 0.256 | 1.2 | 0.296 | 0.244 | 1.2 | —[c] | —[c] |
| Rear-end ratio | 0.321 | 0.212 | 1.5 | 0.175 | 0.124 | 1.4 | — | 0.01 |
| Severity index | 2.37 | 4.84 | 0.49 | 5.230 | 7.682 | 0.68 | — | 0.05 |
| Right-angle ratio | 0.240 | 0.191 | 1.3 | 0.456 | 0.198 | 2.3 | 0.01 | —[c] |
| Normalized accident total | 11.58 | 7.045 | 1.6 | 4.747 | 2.572 | 1.8 | — | 0.01 |
| Volume accident rate | 5.28 | 3.422 | 1.5 | 3.786 | 2.380 | 1.6 | — | 0.05 |
| Accident disutility | 7.247 | 4.549 | 1.6 | 5.639 | 3.408 | 1.7 | 0.10 | 0.10 |
| Right-angle accidents | 2.765 | 8.483 | 0.31 | 2.119 | 1.290 | 1.6 | — | 0.01 |
| Right-angle accident rate | 1.306 | 1.319 | 0.99 | 1.811 | 1.426 | 1.3 | 0.10 | —[c] |

[a]110 in sample. [b]24 in sample. [c]Not significant.

**Table 9. Mean and variance of measures of effectiveness, rural data.**

| Measure of Effectiveness | Signal Control[a] $\bar{x}$ | s | $\bar{x}$/s | Stop-Sign Control[b] $\bar{x}$ | s | $\bar{x}$/s | Significance of Difference $\bar{x}$ | $s^2$ |
|---|---|---|---|---|---|---|---|---|
| Accident evaluation index | 1.756 | 0.153 | 11.4 | 2.029 | 0.173 | 11.7 | 0.01 | —[c] |
| Injury and fatality ratio | 0.354 | 0.190 | 1.9 | 0.487 | 0.292 | 1.7 | — | 0.05 |
| Rear-end ratio | 0.332 | 0.193 | 1.7 | 0.114 | 0.144 | 0.79 | 0.01 | 0.10 |
| Severity index | 3.827 | 3.210 | 1.2 | 8.655 | 17.461 | 0.50 | — | 0.01 |
| Right-angle ratio | 0.224 | 0.215 | 1.5 | 0.580 | 0.302 | 1.9 | — | 0.05 |
| Normalized accident total | 16.043 | 10.782 | 1.5 | 6.40 | 5.763 | 1.1 | — | 0.01 |
| Volume accident rate | 9.288 | 5.804 | 1.6 | 6.21 | 5.368 | 1.2 | 0.025 | —[c] |
| Accident disutility | 16.112 | 9.526 | 1.7 | 12.74 | 11.341 | 1.1 | —[c] | —[c] |
| Right-angle accidents | 2.846 | 2.267 | 1.3 | 3.55 | 4.04 | 0.89 | — | 0.01 |
| Right-angle accident rate | 1.855 | 1.684 | 1.1 | 3.86 | 4.07 | 0.95 | — | 0.01 |

[a]30 in sample. [b]28 in sample. [c]Not significant.

control. The Kolmogorov-Smirnov test (7) and the t-test for differences between independent samples with unequal variances were used (8). On the basis of these tests, a number of inferences can be drawn.

1. The accident evaluation index was significantly higher for the unsignalized case regardless of whether signals were warranted for both aggregate and urban conditions. This MOE was significantly higher for rural conditions when signals were not warranted. This may be attributed to the high speeds prevalent at rural locations that have low volumes (volumes below warrant levels).
2. The injury and fatality ratio was not significant for rural conditions. For urban as well as aggregate locations, the significantly higher value of the MOE appears to reflect the relatively high incidence of pedestrian accidents at high volumes (signals warranted).
3. The rear-end ratio was universally significantly higher at signalized locations than at stop-sign-controlled intersections regardless of whether the signals were warranted. There also was a slightly significant increase at rural locations where signals were warranted but not installed.
4. The severity index for the aggregate and for the rural cases was significantly higher for locations where signals were warranted but not installed. For the urban case, significance was noted for cases with both high volume (signals installed and warranted) and very low volume (signals neither installed nor warranted).
5. The right-angle ratio was significantly higher in the absence of signals for all land use conditions.
6. The number of accidents was significantly related to either of the 2 indicators (signals and warrant adherence) of higher volumes.
7. The accident rate was significantly higher at locations where unwarranted signals had been installed. The effect was more pronounced for rural than for urban conditions.
8. Accident disutility was significantly higher for locations where unwarranted signals had been installed. The effect was more pronounced for rural conditions.
9. Right-angle accidents for aggregate and urban locations showed a higher value for locations where warranted signals had been installed. This probably reflected higher traffic volume at these locations. For rural conditions there was a marginally significant higher value for locations where warranted signals had not been installed.
10. The right-angle accident rate for the urban case was insensitive to any of the conditions tested. For the aggregate and the rural case, it was higher for locations where either warranted signals had not been installed or where unwarranted signals had been installed.

For the purposes of this study, 2 conditions are of interest: those where signals were warranted but were not installed and those where signals were unwarranted but were installed. These conditions represent, in statistical terms, the consequences of making errors of the first and second types in the development and application of signal warrants. The significant effect of these 2 conditions on each of the 10 MOEs is given in Table 10.

## CONCLUSIONS

Examination of the results of the accident analysis program in conjunction with the results of past research leads to a number of tentative conclusions.

1. Signalization leads to a reduction in right-angle accidents and an increase in rear-end accidents.
2. Signalized intersections may have higher accident rates, but this is usually offset by less disutility per accident, which leads to no significant change in total accident-related disutility.
3. There appears to be no clear-cut evidence that the installation of signals will

**Table 10. Summary of hypothesis testing.**

| | Significance | | | |
|---|---|---|---|---|
| | Signals Warranted But Not Installed | | Signals Not Warranted But Installed | |
| Measure of Effectiveness | Urban | Rural | Urban | Rural |
| Accident evaluation index | Higher | Higher | Lower | Lower |
| Injury and fatality ratio | None | None | None | None |
| Rear-end ratio | Lower | Lower | Marginally higher | Marginally higher |
| Severity index | None | Higher | Lower | Marginally lower |
| Right-angle ratio | Higher | Higher | Lower | Lower |
| Normalized accident total | Lower | Lower | Higher | Marginally higher |
| Volume accident rate | None | None | Marginally higher | Higher |
| Accident disutility | None | None | Marginally higher | Marginally higher |
| Right-angle accidents | None | Marginally higher | None | None |
| Right-angle accident rate | None | Marginally higher | None | None |

reduce the adverse effects of accidents. This appears to hold especially for those cases where signals would not be warranted.

4. As far as accident patterns are concerned, there is no clear-cut justification for lowering numerical warrant minimums for rural conditions. In fact, the effect of unwarranted signals is more adverse for rural conditions.

5. The number of right-angle accidents appears to be an insensitive indication of any expected improvement in accident patterns as the result of signalization. The right-angle ratio seems to be better suited to that purpose.

6. The installation of flashing beacons to supplement stop-sign control generally appears to have a favorable effect on accident patterns.

## ACKNOWLEDGMENT

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## REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1971.
2. E. G. Lieberman, G. F. King, and R. B. Goldblatt. Traffic Signal Warrants. NCHRP Project 3-20, Draft Final Rept., Dec. 1973.
3. R. M. Michaels. Two Simple Techniques for Determining the Significance of Accident-Reducing Measures. Traffic Engineering, Vol. 36, No. 12, Sept. 1966.
4. P. C. Box and Associates. Intersections. In Traffic Control and Roadway Elements—Their Relationship to Highway Safety, Highway Users Federation for Safety and Mobility, 1970.
5. J. J. Heany. Four-Way Stop: A Highly Effective Safety Device. Philadelphia Bureau of Traffic Engineering, 1970.
6. P. D. Cribbins and C. M. Walton. Traffic Signals and Overhead Flashers at Rural Intersections: Their Effectiveness in Reducing Accidents. Highway Research Record 325, 1970, pp. 1-14.
7. S. Siegel. Non Parametric Statistics for the Behavioral Sciences. McGraw-Hill Book Co., New York, 1956.
8. E. L. Crow, F. A. Davis, and M. W. Marfield. Statistics Manual. Dover Publications, Inc., New York, 1960.
9. T. E. Young. New Traffic Signals, Their Effect on Street Utilization. HRB Special Rept. 93, 1967, pp. 84-95.

10. R. G. Lewis, Jr. Progress Report, 1967-1968. Chattanooga Traffic Engineering Department.
11. J. C. Thorpe. Accident Rates at Signalized Intersections. Proc., 4th Conference of Australian Road Research Board, Vol. 4, Part 1, 1968, pp. 995-1004.
12. D. C. Andreassend. Another Look at Traffic Signals and Accidents. Proc., 5th Conference of Australian Road Research Board, Vol. 5, Part 3, 1970, pp. 304-318.
13. P. Abramson. An Accident Evaluation Analysis. Highway Research Record 486, 1974, pp. 33-41.
14. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1961.

# EFFECTS OF INCREASED ENFORCEMENT AT URBAN INTERSECTIONS ON DRIVER BEHAVIOR AND SAFETY

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The study described in this paper was initiated in 1972 in an attempt to define the nature and magnitude of the effects on driver behavior and safety resulting from increased levels of enforcement of traffic laws. A major purpose of the study was to investigate the increased benefits to be obtained from higher enforcement levels to determine how police can be cost effectively employed. The results of the study indicated that visible police presence at an urban intersection can significantly reduce the incidence of traffic violations. This effect appeared to be restricted to the time of actual police presence; it disappeared almost immediately after the police left. Traffic conflicts were recorded as representing a measure of safety, but, although their effects were similar to those on violations, results were not judged significant. Based on effectiveness in reducing violations the most significant improvement occurred in employing a single policeman for a period of 1 h/day. Further increases in effort did not produce appreciable further improvement.

•ALTHOUGH the effects of enforcement practices on driver behavior have not been exhaustively researched, the literature contains many references to studies in this field. Most of the studies relate to speed control (4, 6). Unfortunately, many of the studies lacked adequate design or control, but an overall pattern of behavior can be deduced from them. In general, the evidence points to the ability of visible enforcement symbols, which are related in the driver's mind to punishment, to produce a temporary modification of driver behavior within a restricted distance or time frame.

In terms of safety benefits resulting from long-term application of enforcement practices, the situation also is not clear-cut. A number of studies have reported accident reductions over periods ranging from a few weeks to several years, but there is disagreement on the significance and nature of the effects achieved (6). Where accident reductions were reported, there was no real consistency about the relative effects of enforcement on severe and minor accidents except that in most cases a significant distinction between them was noted.

Very few of the past studies were oriented specifically toward assisting police forces in evaluating their enforcement programs and providing them with information that could be employed to increase their effectiveness. So, during the fall of 1972, the Road Safety Branch of the Canada Ministry of Transport conducted a research study to investigate the effects of increased enforcement on driver performance and safety to make recommendations on more efficient use of the police force.

## DESIGN OF THE STUDY

The investigation was designed and conducted with the cooperation of the Toronto police force. Wherever possible, the major characteristics of the study were kept consistent with existing enforcement methods and practices.

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Police motorcycle officers were employed as the basic enforcement symbol; the number of officers stationed at an intersection at any given time was limited to a maximum of 2. The police were instructed to be highly visible at all times and to maintain their normal function of issuing warnings or tickets to offending drivers.

The 2 independent variables chosen for study were duration of enforcement (3 levels) and magnitude of effort (1 or 2 officers per location).

Seven intersections were chosen for observation in Toronto. Six were study locations, and 1 was a control location (Figure 1). Each study location received a different combination of duration and magnitude of enforcement. Each was signalized to make it easier to define vehicle maneuvers and violations, and each was chosen on the basis of similar characteristics including geometric design, traffic volume, number and type of traffic control devices, pedestrian flow, and environmental factors such as abutting land use. In addition, each intersection was studied in terms of the ratio of repeating (daily commuters) to nonrepeating drivers because it was considered that learned behavior might be involved. This ratio was the basis of the selection of the 7 locations. Levels of existing enforcement were noted and, in all cases, were found to be relatively inconsequential when compared with the higher levels contemplated for the study.

To select time durations for enforcement activity, we constructed a statistical model that considered various combinations of sampling schemes and traffic compositions. Analysis of this model led to the selection of time periods of 60, 120, and 180 min/day to represent a cost-benefit optimum based on efficiency of driver exposure to enforcement at the point where added returns became marginal. Through this same analysis, we determined that there should be 20 days of increased enforcement (4 weeks minus weekends). The study thus consisted of 2 weeks of base data collection under prestudy conditions, 4 weeks of increased enforcement levels, and 2 weeks when levels were reduced to their original state.

Enforcement schedules for each intersection were set up through consultation with the police. These schedules were designed to ensure that the total daily time spent at each intersection remained constant; the period of enforcement was changed systematically, however, so that all hours of major traffic flow were covered. Care was taken to ensure that police personnel were rotated among the various locations. Table 1 gives the enforcement schedule.

## CONDUCT OF THE STUDY

To assess the possible effects of enforcement on driver behavior, we selected number and type of traffic violations as the dependent variables. We decided to record violations in the following categories: turns to or from the wrong lane, prohibited turns, failure to signal turns, and infractions at traffic signals. We based our decision on a previous Canada Ministry of Transport study in which violations at intersections were investigated and on an analysis of past accident records at the 7 study locations.

We also decided to record the number of traffic conflicts at each intersection. Conflicts have been researched widely in recent years and have been shown to be significantly related to traffic accidents. By considering conflicts, we eliminated the necessity for a long-term investigation because the frequency of conflicts is several thousand times that of accidents. A conflict was defined as any abnormal deceleration, lane change, or to avoid collision. Weave, left-turn, right-turn, cross-traffic and rear-end conflict categories were considered (Figure 2).

During the study a record of all violations, conflicts, and violations that directly resulted in conflicts was kept and summarized at hourly intervals. Traffic volumes also were monitored closely both as an exposure statistic that considered all traffic movements and as a check to ensure that prestudy travel patterns established by a preliminary license plate survey were not changing. A number of permanent, traffic-counting stations in the area proved useful in providing day-to-day traffic volume fluctuations.

The observers used in the study for counting traffic volumes, violations, and conflicts were given a comprehensive training course and some field practice to ensure

Figure 1. Study area and locations.

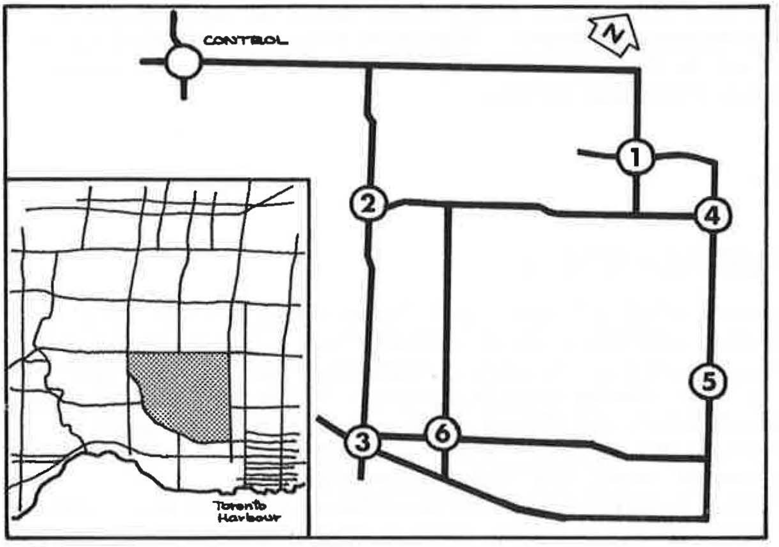
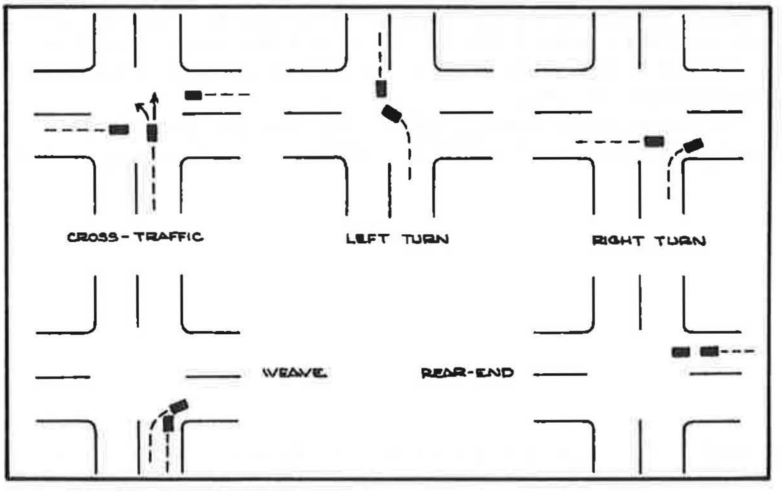



Table 1. Enforcement schedule.

| Study Location | Number of Officers | Enforcement Duration (min/day) |
|---|---|---|
| 1 | 1 | 60 |
| 2 | 1 | 120 |
| 3 | 1 | 180 |
| 4 | 2 | 60 |
| 5 | 2 | 120 |
| 6 | 2 | 180 |

Figure 2. Traffic conflict categories.



that they were familiar with the new concepts, especially that of conflicts, that were involved. Four observers were stationed at each intersection (1 for each approach) and all data were recorded on separate forms. Observers were supervised closely in the field and were rotated among the intersection approaches to minimize the effects of any systematic counting or recording errors.

## RESULTS OF THE STUDY

### Effects of Enforcement on Violation Behavior

Figure 3 shows the variation in total violations counted over the study period at 1 of the locations. Volume fluctuations over the same period are shown above the violation plot.

To discover what, if any, effect was produced by increased exposure to the enforcement symbol, we analyzed the results by through route at each intersection. This analysis indicated that those routes having the highest proportion of repeating drivers displayed the greatest reduction in violations during the enforcement phase. These routes were used in the data analysis to quantify the enforcement effects.

Because there was evidence from the literature that enforcement may have different effects on different classes of accident severity, the data collected were used to assess the probability of the arising of accidents and conflicts as a direct result of traffic violations. Details of this analysis can be found elsewhere (10). It was found that the violations monitored during the study could be classed as either hazardous or nonhazardous. Those of the latter type were turns to the wrong lane, prohibited turns, and failure to signal turns. Turns from the wrong lane and traffic signal infractions were shown to have a higher-than-chance probability of resulting in conflicts or accidents.

The number of violations occurring each day then were separated into these 2 groups and replotted so that possible reductions could be assessed in this new form. Figure 4 shows an example of this that is typical of the results obtained for all the locations because hazardous violations, when considered alone, were considerably less affected by increased enforcement than were total violations. Hence it can be surmised that, in this study at least, enforcement may have a more salutary effect on the less critical violations.

Although fewer violations occurred during the enforcement period, these decreases had to be tested for significance. An attempt to quantify in some manner the overall effects of the different levels of enforcement also had to be undertaken. This was difficult because a considerable variation occurred from day to day throughout the study. The effects of this natural fluctuation had to be separated from the changes occurring as a result of the introduction of enforcement.

To test for significance, we constructed a series of the differences among daily totals that covered the period of increased enforcement. This series can be represented by the following:

$$\Delta_{i1} = Y_{i+1} - Y_i$$

$$\Delta_{i2} = Y_{i+2} - Y_i$$

$$\Delta_{i3} = Y_{i+3} - Y_i$$

and so on where $Y_i$ = total number of violations occurring at an intersection on day i.

To test the null hypothesis that enforcement had no effect on violation rates, we calculated the limits of this series for each location and compared them with the values of differences between days before and after introducing enforcement by using a 95 percent level of confidence. Details of this test are discussed elsewhere (10). As we ex-

Figure 3. Typical pattern of violation occurrences.

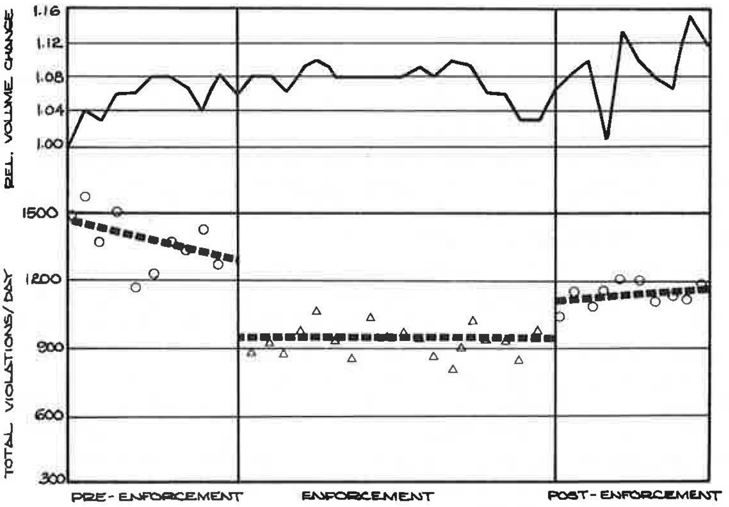



Figure 4. Effect of enforcement on hazardous violations.

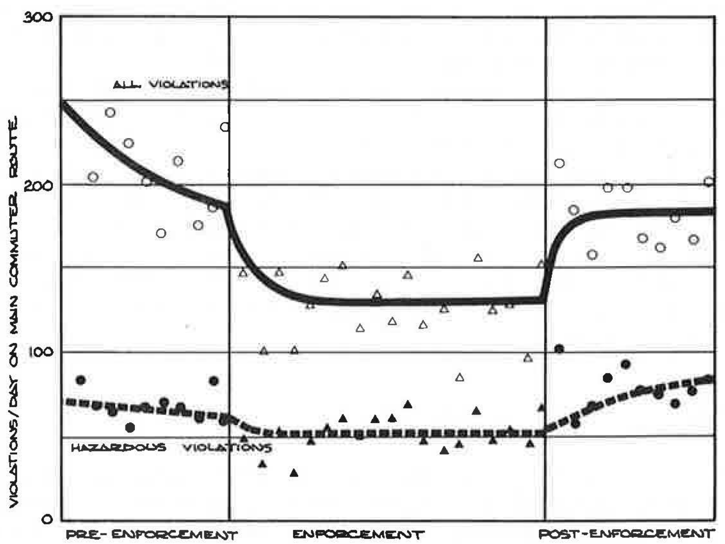
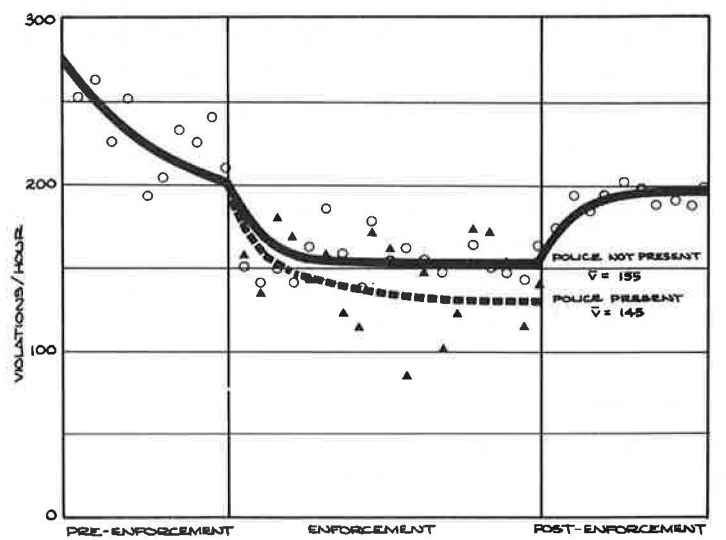



Figure 5. Effect of police presence on violation rate.



pected, the control location showed no change but of the 6 other study locations (where there was at least visual evidence of decreases) only 3 gave results that could be judged significant at the 0.05 level.

Similar tests also were run on the number of violations occurring after the extra enforcement was removed. Most locations showed an increase over the enforcement period but only 3 of the 6 proved significant. These 3 were, however, the same locations that had shown a significant decrease during enforcement.

Perhaps the most interesting observation concerns the nature of the decreases and subsequent increases in violation behavior. The changes appeared immediately on institution and relaxation of the enforcement effort and showed little or no transitional characteristics that would be typical of a learning process. This suggested that the phenomenon was an instinctive and immediate reaction to a visual symbol with no thought of long-term implications. To verify this we made a further separation within the data. Violations occurring during actual police presence were separated from violations occurring on the same day but when the police were absent. The figures were adjusted to a common base for comparison and plotted as shown in Figure 5. These plots show that the level of violation reduction was greater during actual police presence than when they were not there. Thus the hypothesis presented on the nature of driver reaction is strengthened. These differences were tested for significance by means of a t-test for paired samples. At half of the locations the difference between violation behavior with and without police presence was significant.

Although there appeared to be no descernible pattern in effects on different classes of violations, those of a hazardous nature were more often below average than above average in violation reduction.

To quantify those reductions that proved significant, we used regression analysis to fit curves to each of the 3 phases of the study. Best fit relationships were selected from among linear, polynomial, and power curves; the maximums and minimums were compared to establish the value of the reductions. Figure 6 shows these values as a function of level of police enforcement and indicates that, although an initial low-order level may produce significant improvement in driver behavior, subsequent increases may be of little additional value.

### Effects of Enforcement on Safety

A serious problem was encountered in the attempt to relate enforcement increases to changes in recorded conflicts. Despite the training provided, observers took longer to attain a stable counting performance than the amount of time alloted. Thus, as shown in Figure 7, the initial tendency to drastically overcount during the first week of data collection produced a sharply decreasing trend that extended across the base-enforcement interface and had the effect of masking any possible decreases that would have been due to the police efforts. This occurred with violations but not to the same extent. We used the same procedure to test for significance as was employed with the violation data, and the results were, in most cases, negative. Two locations were marginal and possibly could be considered significant but this would be a presumption. In terms of conflict reduction during police presence versus conflict reduction when police were absent, the results were uniformly negative both visually and statistically. But when the data were reduced in this format, the graphs of conflict rates showed definite reductions and subsequent increases similar to those found in the case of violations (Figure 8).

A major influencing factor in considering the results of the conflict investigation is that numbers of conflicts, when compared to violations, are uniformly low and thus are greatly affected by extraneous factors such as counting variability.

## CONCLUSIONS

The study indicated that increased enforcement may bring about a reduction in the number of violations committed by motorists. It also indicated that this reduction occurs

Figure 6. Effect of varying enforcement level on violation rate.

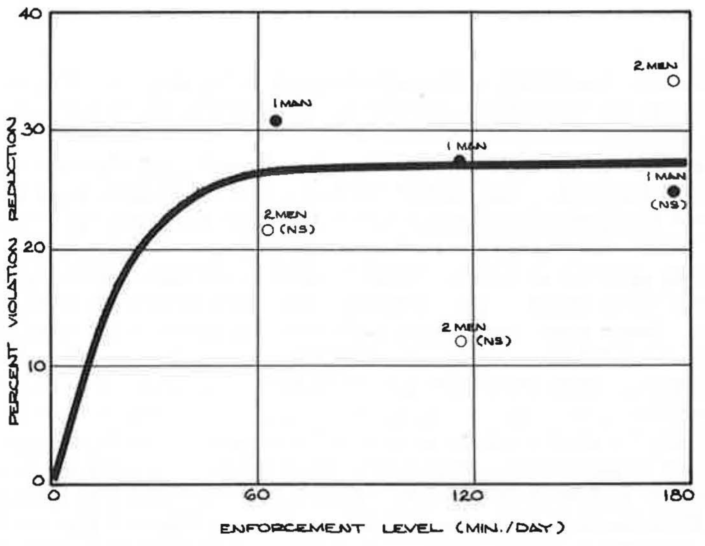



Figure 7. Typical pattern of conflict occurrences.

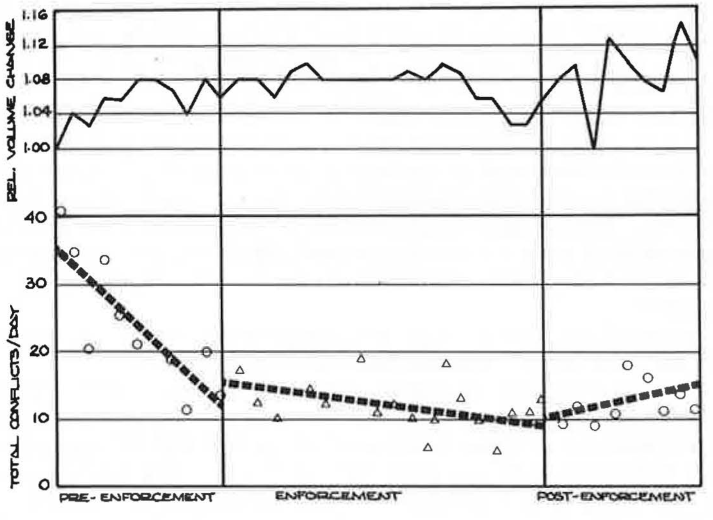
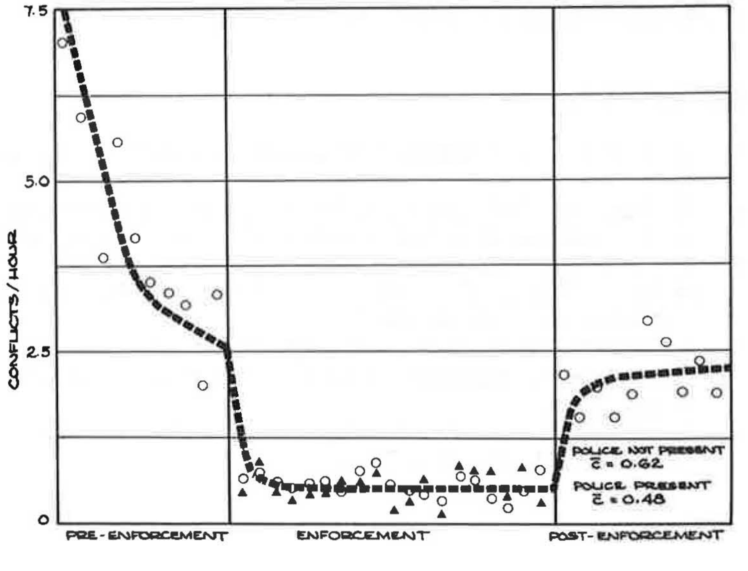



Figure 8. Effect of police presence on conflict rate.



almost immediately after enforcement is increased. The reduction seems to be related more to an instinctive reaction to visual evidence of enforcement than to a typical learning process.

Driver behavior tends to revert to its original characteristic after increased enforcement ends. The nature of this subsequent rise suggests that drivers quickly observe the lack of police presence and relapse to preenforcement violation behavior.

These conclusions are reinforced by the fact that adherence to traffic laws was higher during periods of police presence than when police were absent even though the program was still in effect. The intersections were not covered by police at the same times each day. Therefore, many motorists who did not commit violations while under police observation did so when their commuting schedule did not coincide with the enforcement schedule. This effect did not change significantly over the entire enforcement period. Therefore, no evidence of learning behavior could be found. In apparent contradiction to this, greater reductions generally occurred on the approach legs representing the higher proportion of repeaters. This might be explained by drivers' greater familiarity with the intersection and thus heightened sensitivity to change.

Enforcement did not uniformly influence driver behavior for all types of violations. The violations most affected were those that tend to be less hazardous possibly because the more severe or hazardous classes of violations are not as likely to be premeditated. For instance, a decision to run a red light or speed up to catch an amber signal may be a spur-of-the-moment decision influenced more by factors other than police presence. On the other hand, not signalling turns seems to be a characteristic of some motorists who, when they observe the police, realize the legal requirement and decide to use their indicator to be on the safe side.

The significant information that was obtained on the relative effects of different levels of enforcement on violation rates indicated that the returns to be expected in employing a saturation program may be marginal when compared to more modest procedures. Assigning 1 policeman to an intersection for 1 h/day produced a significant improvement over a no-enforcement situation, but increasing this coverage to 2 policemen for 3 h/day reduced violation occurrence only slightly above the first level of increase.

Although the conflict data did not produce significant results, trends in the data support the conclusions reached on violation behavior.

A number of factors undoubtedly combined to reduce the efficiency and enthusiasm of the traffic observers. Among these were adverse weather conditions and boredom. To a major extent these are unavoidable and will be encountered during any such study. What this does point up, however, is the problem associated with using human observers who are subject to psychological influences and performance decrements from a variety of uncontrollable factors. A study specifically designed to identify and quantify such effects might provide useful findings that could be applied to the results of many investigations involving human observation.

## REFERENCES

1. P. J. Cooper. Predicting Intersection Accidents. Canada Ministry of Transport, 1973.
2. K. Hanawa. Relationship Between Accident Involvement Rate and Patrol Density. Rept., National Research Institute of Police Science, Vol. 13, No. 1, Tokyo, 1972.
3. A. D. Little. The State of the Art of Traffic Safety: A Critical Review and Analysis of the Technical Information on Factors Affecting Traffic Safety. Automobile Manufacturers Association, 1966.
4. T. Murata and M. Kobuyaski. Effects of Police Enforcement in Terms of Vehicle Speed. Rept., National Research Institute of Police Science, Vol. 13, No. 1, Tokyo, 1972.
5. R. Myrick and L. E. Schiesinger. Driver Improvement or System Improvement? Traffic Quarterly, Vol. 18, 1964.

6. The Effects of Enforcement of Legislation on Driver Behaviour and Traffic Accidents. Organization for Economic Cooperation and Development, Research Group S6, Paris, Interim Rept., 1973.
7. J. Slavin. Problems of Law Enforcement. Proc., 13th Annual Canadian Highway Safety Council Conference, Quebec City, May 1967.
8. Expert Group on Safety. The Road Accident Situation in Australia—A National Review. Canberra Act Australian Government Publishing Service, 1972, pp. 20-24.
9. The Police in Traffic Safety Work. Department of Traffic Safety, Institute of Transport Economy, Oslo, Norway, Research on Traffic Safety Information Leaflet 1, March 1973.
10. P. J. Cooper. Effectiveness of Traffic Law Enforcement. Canada Ministry of Transport, Aug. 1974.

# FEASIBILITY-STUDY MODEL FOR PEDESTRIAN MALLS

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A model for performing feasibility studies of pedestrian mall proposals is presented and demonstrated by application of the model to a case study. The model is based on the systems approach to solving large-scale decision problems. It is designed to determine which, if any, of a set of possible mall configurations is most feasible based on the results of a comprehensive cost-benefit analysis. A direct benefit-to-cost ratio is calculated for each of the alternatives, which is based on only those direct costs and benefits (increased sales tax and property tax) that can be converted into dollars. If this direct benefit-to-cost ratio is greater than unity for any proposed alternative, then the model has provisions to modify this direct ratio based on the indirect factors that will affect the desirability of the project. The method that is presented is designed to evaluate factors such as noise, pollution, and effect on public transit. First, a summary of available background information on these factors and their relationship to malls is provided. Second, the evaluation problem is presented in a concise format that allows the decision maker to easily evaluate the indirect costs and benefits. This technique assigns a weighting factor to the various indirect costs and benefits and modifies the direct dollar costs and benefits as a result of these weighting factors. The case study was chosen to demonstrate the feasibility-study model with a real-world decision problem—the proposed 16th Street mall for the central business district of Denver. Two alternative mall configurations are compared according to the authors' value systems.

•STIMULATED, perhaps, by the success of the Nicollet Mall in Minneapolis, several civic and business leaders in Denver developed a preliminary plan to construct a pedestrian mall on 1 or 2 of the primary business throughfares in the Denver central business district (CBD). These leaders formed Downtown Denver, Inc., and, in conjunction with the Denver Planning Office, they proposed that a pedestrian mall with an exclusive transit way be built on 16th Street and perhaps on 17th Street (1). 16th Street runs 1 way southeast and contains most of the major retail stores in the CBD. It connects the Skyline Urban Renewal Project with the Civic Center, which includes the State Capital. Seventeenth Street parallels 16th Street and runs 1 way northwest. It has a completely different character than 16th Street and contains most of the major office and financial buildings in the CBD. An overall design concept for the mall and preliminary cost estimates were prepared (2).

## ALTERNATIVE CONFIGURATIONS

The study should determine not only whether a proposed project is feasible but also which proposed alternative configuration is optimal. These alternative configurations

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should be synthesized by the project's planners and be subjected to a cost-benefit study to make the optimality decision.

For this study, only 2 alternative configurations were considered: a pedestrian-only mall with cross-street traffic (option 1) and a pedestrian-plus-transit mall with cross-street traffic (option 2). Option 1 would allow mall access to emergency vehicles and perhaps very small people-mover or moving sidewalk systems. Option 2 would allow mall access to buses on an exclusive right-of-way similar to that of the Nicollet Mall in Minneapolis, Minnesota. The time limitations of this study did not permit detailed construction cost estimates to be prepared for each of these alternatives. Thus the calculated construction costs were considered to apply to both options 1 and 2. The difference in other costs between the 2 options were treated separately.

The direct quantifiable benefits of the 2 options also were considered equal because of a lack of reliable data available on the performance of existing pedestrian malls.

## MAJOR ASSUMPTIONS

A 25-year planning period was used for making forecasts of operating and maintenance costs and retail sales. The following includes the major assumptions that were made:

1. Retail sales will increase at a decreasing rate for a total of 5 years after project completion, and
2. Retail sales will not increase after 5 years but will remain at a constant higher level than would occur without the mall for the remaining 20 years of the planning period.

Direct costs were included in the evaluation for all items that incur some sort of cost from the public sector. Direct benefits were calculated based on increased property tax revenues and increased sales tax revenues. All other costs and benefits were considered indirect and were treated by a separate methodology either because they were not readily quantifiable into dollar amounts or because there was a lack of data on which to base predictions of the dollar amounts of the indirect costs and benefits. The direct costs that were considered in the case study are as follows:

1. Construction,
2. Demolition,
3. Paving,
4. Architectural treatments such as landscaping, curbs, gutters, and drainage,
5. Irrigation,
6. Fixtures such as lights, kiosks, and benches,
7. Traffic control device improvements,
8. Design fees and legal fees,
9. Utility improvements,
10. Indirect traffic control improvements and street construction,
11. Side-street and alley improvements,
12. Cost growth and uncertainty,
13. Operation and maintenance,
14. Disruption of traffic flow, and
15. Disruption of bus routes.

The indirect costs that were considered are as follows:

1. Parking problems,
2. Disruption during construction phase, and
3. Disruption of mail and goods delivery.

The direct benefits that were considered were

1. Tax revenues from increased retail sales and
2. Increased land values and resultant property tax revenues.

The indirect benefit that were considered were

1. Open space and aesthetic improvements,
2. Lower noise levels,
3. Lower localized pollution levels,
4. De-emphasis of automobile,
5. Emphasis on public transportation,
6. Social gathering and interaction place,
7. Increased safety,
8. Greater future construction activity, and
9. Uncertainty of mall's revenue generating ability.

## DIRECT COSTS

### Construction

The construction costs of the mall will be about $280,000/block in 1974 dollars, which, for a 9-block length, will be $2.52 million (2, p. 60).

### Design Fees and Legal Fees

The fee for such a large-scale project often can reach 10 percent of the direct construction costs, which would give a total design and legal fee of about $250,000.

### Utility Improvements

At present, no utility upgrading is planned for the 16th Street mall. However, it would perhaps be reasonable to include $250,000 for an estimate to include unforeseeable problems.

### Traffic Control Device Improvements

For the traffic rerouting scheme shown in Figure 1, approximately 43 intersections will be changed because a reversal in direction is needed on 13th, 14th, and 15th Streets and part of 16th Street. The Department of Public Works of the city and county of Denver has estimated that the cost to retime the signal controllers, remount signs and signals, purchase new signs, change pavement markings, and complete all other necessary changes would be about $10,000/intersection, or $430,000. When this is added to the total of $100,000 required for modifications to the signals and signs on the 10 intersections on the mall itself, the total will reach $530,000. Other changes that may be made at the time the rerouting is completed include the following:

| Change | Cost (dollars) |
|---|---|
| Improvements to Colfax Avenue between Bannock Street and Broadway | 100,000 |
| Widening of 18th Street between Broadway and Lincoln Street | 20,000 |
| Rerouting of Speer Boulevard northbound between Lawrence and Wazee Streets | 350,000 |
| Other miscellaneous changes to 15th and Delaware Streets | 175,000 |
| Total | 645,000 |

Total direct and indirect costs for traffic control improvement is $1.175 million.

## Side-Street and Alley Improvements

The plan for 16th Street does not provide for alley and side-street improvements, but the analysis could be expanded to include such cost considerations. Such improvements could be used to link the mall directly to other parts of the downtown area and might include improved lighting and pavement and pedestrian canopies. About $200,000 could be spent for alley and side-street improvements for certain key locations on a demonstration and trial basis (2).

## Operation and Maintenance

Total cost for mall maintenance and operation has been estimated to be $135,000 for the first year and $82,000 for each additional year. If a 25-year life is assumed and a 6 percent/year inflation factor is used, then the present worth of the operation and maintenance of the mall over a 25-year period, starting in 1974, would be $1.164 million (3, p. 691, Table 7).

## Disruption of Traffic Flow

Because 16th Street will be closed, drivers who usually use 16th Street will have to choose an alternate route. Let us attempt to determine the value of the time lost to drivers because of this rerouting according to the following assumptions:

1. Each driver will lose 0.5 min/trip.
2. Total number of people affected per day will be equal to the present weekday vehicular traffic on 16th Street.
3. Time lost will be significant on weekdays only (260 days/year).
4. Value of time lost in 1974 dollars will be $2/h.

The traffic counts conducted by the Joint Regional Planning Program in 1971 showed that a weekday average of about 16,100 vehicles/day travel on 16th Street in the mall area. The value of time lost then would be $34,900/year in 1974 dollars. Over a 25-year period, if we use the uniform series, present worth factor for i = 6 percent, and p = 24 years as we did before, then this would total $472,900.

## Disruption of Bus Routes

The Denver Regional Transportation District (DRTD) was contacted to determine how many buses traverse 16th Street during weekday rush hour. Rerouting will cause a slight delay for the buses. DRTD indicated that 207 buses were scheduled to go to the CBD between 7 and 8:30 a.m. on weekdays and 222 buses were scheduled between 4:30 and 6 p.m. DRTD also indicated that about 85 percent of these buses travel on 16th and 17th Streets. Let us assume that half of this 85 percent travel on 16th Street. This means that 182 buses will be affected per day. If we assume 0.5 min of delay/bus and that bus occupancy averages 10 people, total number of days per year is 260, and value of time lost is $2/h, then the total value of time lost per year would be $473,000. Over a 25-year period, this would total $6.41 million. This is a tremendously large figure and is probably somewhat unrealistic because planned bus system improvements, such as exclusive bus lanes in the CBD, may alleviate these time delays. Let us assume therefore that all of the bus system improvements will be completed within a year after the mall is completed. The value of time lost then would be $473,000. This cost applies only for option 1.

### Total Direct Cost of Mall

When mall operating and maintenance costs for a 25-year period are included, total direct cost of the mall would be $7.6 million for option 1 and $7.1 million for option 2 ( Table 1).

## DIRECT BENEFITS

### Retail Sales Estimate

The 1967 census of manufactures showed that the entire Denver CBD retail sales total for 1967 was $168 million. If we raise this value to 1974 dollars and make no allowance for overall net growth or decline, it would be $237.6 million. The 16th Street Commercial Center does not, however, constitute all of this sales volume. A simple method of estimating the percentage of the total of the CBD retail sales volume that can be allocated to 16th Street has been devised based on the ratio of the retail sales floor space of 16th Street to that of the total CBD.

One source showed that the retail sales floor space for the CBD is 2.543 million $ft^2$ (0.229 million $m^2$). A survey by the Denver Planning Office of the establishments on 16th Street showed that a total of 2.025 million $ft^2$ (0.182 million $m^2$) of floor space is devoted to retail sales (including eating and drinking establishments) between Lawrence Street and Cheyenne Place on 16th Street. Thus 16th Street retail floor space occupies 79.6 percent of the entire CBD retail floor space. Multiplying the 1974 estimated total of $237.6 million in retail sales for the CBD by this factor results in an estimate of $189.1 million in retail sales for 1974 on 16th Street between Lawrence Street and Cheyenne Place. Of course, this estimate may not be altogether accurate. It represents the best information available at this time. However, retailers are unwilling to provide any information that may divulge their sales figures to their competitors. Other possible sources of such information such as state revenue officials, the Denver Chamber of Commerce, the Denver Planning Office and the Denver Regional Council of Governments were consulted, and no information was received. Certainly if a mall feasibility analysis is to be seriously considered these data must be made available.

### Prediction of Increase in Retail Sales

The best method for predicting increases in retail sales for a new mall appears to be one that bases the estimate on the results that have been obtained in other cities where malls have been constructed. Again, however, reliable data are not available. The data given in Table 2 summarize the results that have been reported in other cities. Unfortunately, the techniques that were used to obtain these data were not explained. Most of the sources report that the data are "spotty," but that, generally retail sales have risen from 4 to 40 percent in the first year after the mall opening (4, p. 24).

In Table 2, the figures for retail sales percentage increase represent the lowest value that was found in the literature or an average value if it was available. From the data given in Table 2, it appears reasonable to predict that the 16th Street Mall would produce a 15 percent increase in retail sales for at least the first year. Table 3 gives retail sales predictions (in 1974 dollars) based on the following assumptions:

1. Base-line yearly sales figure will be $189.1 million for 1974;
2. Mall will be completed in 1976;
3. Value of the dollar will increase at 6 percent/year;
4. Retail sales, except those due to the mall, will show no net growth;
5. Mall will cause a 15 percent increase in sales in the first year, and after 5 years this will decrease to zero and hold constant; and
6. Fifty percent of sales tax revenues will be diverted from locations outside Denver, and 50 percent will come from within Denver.

Figure 1. Possible revised traffic routing for 16th Street Mall.

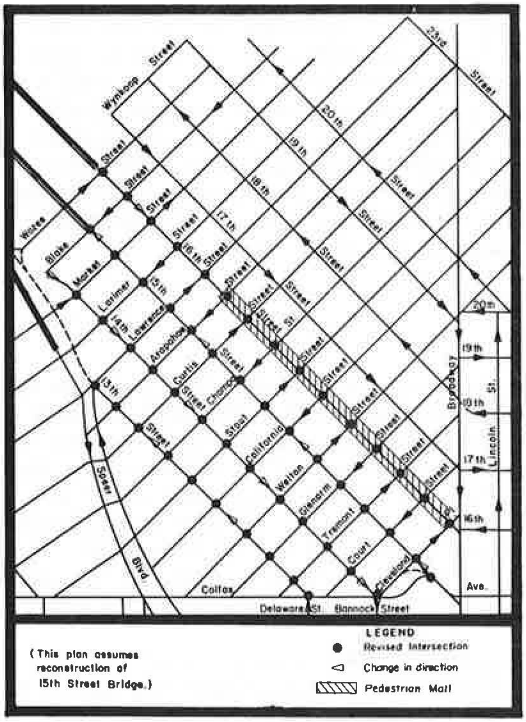


Table 1. Estimate of total direct costs.

| Item | Cost (dollars) |
|---|---|
| Construction | 2,520,000 |
| Design and legal fees | 250,000 |
| Utility improvements | 250,000 |
| Traffic control device improvements | 530,000 |
| Other traffic control improvements and street construction | 645,000 |
| Side-street and alley improvements | 200,000 |
| Cost growth and uncertainty allowance[a] | 1,095,000 |
| Operating and maintenance costs[b] | 1,164,000 |
| Disruption of traffic flow | 472,000 |
| Disruption of bus routes[c] | 473,000 |
| Total for option 1 | 7,599,000 |
| Total for option 2 | 7,126,000 |

[a]Based on approximately 25 percent of $4,395,000, which is the subtotal of the first six items.
[b]For 25-year period i = 6 percent: $135,000 first year and $82,000 each successive year.
[c]For option 1 only.

Table 2. Characteristics of selected U.S. malls.

| Location | Cost/Linear Foot (dollars) | Cost (thousands of dollars) | Percent Increase in Retail Sales |
|---|---|---|---|
| Fresno, California | 1,010 | 1,841 | 14 |
| Springfield, Illinois | – | – | 14 |
| Kalamazoo, Michigan | 108 | 120 | 15 |
| Knoxville, Tennessee | 712 | 313 | 20 |
| Pomona, California | 213 | 640 | 20 |
| Atchison, Kansas | 333 | 300 | 11 |
| Danville, Illinois | – | 112 | 7 |
| Jackson, Michigan | 97 | 75 | 30 |
| Providence, Rhode Island | 543 | 530 | 5 |
| Santa Monica, California | 391 | 703 | 5 |
| Miami, Florida | 200 | 600 | 10 |
| Eugene, Oregon | 1,587 | 1,800 | 16 |
| Minneapolis, Minnesota (7) | 1,460 | 3,874 | 13 |
| Louisville, Kentucky (8) | 615 | 1,500 | 15 |
| Denver, Colorado[a] | 850[b] | 2,520 | – |

Note: 1 ft = 0.305 m.
[a]Proposed.
[b]Uses construction costs as estimated for this report for a mall length of 2,970 ft (103 m) (9 blocks).

Table 3. Estimate of increased sales tax revenues.

| Year | Retail Sales Without Mall (millions of dollars) | Retail Sales With Mall (millions of dollars) | Percent Increase Over Previous Year |
|---|---|---|---|
| 1976 | 189 | 218 | 15 |
| 1977 | 189 | 245 | 12 |
| 1978 | 189 | 262 | 9 |
| 1979 | 189 | 278 | 6 |
| 1980 | 189 | 286 | 3 |
| 1981 to 2000 | 3,780[a] | 5,720[b] | 0 |
| Total | 4,725 | 7,009 | |

[a]$189 million/year. [b]$286 million/year.

Increased sales due to the mall will be $2,284 million, increased city sales tax (at 3 percent) will be $7.1 million, and direct benefits due to increased sales tax revenues (half of the total) will be $3.6 million. The increased sales base that results in 1980 also provides a greater sales volume on each of the 20 remaining years of the mall's possible 25-year lifetime by $97 million/year, if we assume that the sales level will remain constant after 1980. Unfortunately, we do not have enough long-term data on malls to determine whether the gains in sales that occur early in the life of the mall will hold constant later or whether they will taper off. These gains may be permanent because, historically, malls have proved to be a stimulus for new construction and investment in the area after they have been in operation for some time.

## Property Tax Revenues

The Assessment Division of the city and county of Denver was contacted to estimate the assessed value of the retail establishments on the proposed mall. The 1973 property tax records were used to determine total property tax revenues received by the city and county of Denver from all of the owners of property with frontage on 16th Street on the 9-block length of the proposed mall. Table 4 gives the assessed value and property taxes by block according to the 1973 mill levy of $73.301 per $1,000 assessed valuation.

The total 1973 property tax revenues from these businesses was $2.190 million. Let us assume that the mall will increase the property values of these businesses in a fashion based on the following results for malls in 3 other U.S. cities (4):

1. Kalamazoo, Michigan, reported a 30 percent increase in property values;
2. Knoxville, Tennessee, reported a 27 to 75 percent increase in property values; and
3. Pomona, California, reported a 20 percent increase in property tax revenues.

From these results it appears reasonable to assume that assessed value and, consequently, property tax revenues will increase by at least 20 percent. The planning period again will be 25 years. We will assume that

1. Property tax revenues will increase at an annual rate of 4 percent/year for 5 years and then will hold constant for the remainder of the 25-year period.
2. Net assessed values will stay constant except for increases due to the mall.
3. Mill levies will be $73.301 per $1,000 assessed value.

A summary of the situation is given in Table 5. Increased property tax revenues will be approximately $11 million.

## Total Direct Benefits

Total direct benefits of the mall is the sum of the increase in sales tax and property tax revenues attributable to the mall. This estimate for both options 1 and 2 is $14.4 million.

## Direct Benefit-to-Cost Ratio

At this point in the study, calculating a benefit-to-cost ratio for direct costs and benefits is possible. If at this point the benefit-to-cost ratio is less than unity, the proposal should be deemed unfeasible. If the ratio is greater than 1, then one should evaluate the effects of the indirect costs and benefits on the direct benefit-to-cost ratio. For option 1, the direct benefit-to-cost ratio is $14.4 million/$7.6 million or 1.9. For option 2, the direct benefit-to-cost ratio is $14.4 million/$7.1 million or 2.0.

## COST-BENEFIT ANALYSIS

After calculating a benefit-to-cost ratio for the direct quantifiable costs and benefits, one must determine the effect on the benefit-to-cost ratio of those factors that are not readily quantifiable. The technique presented here involves presenting the decision maker with the following:

1. Relevant background information that shows, if possible, the results of experience gained in other cities with malls,
2. Evaluation in the form of a decision tableau that the decision maker uses to assign a weighting factor for each of the cost and benefit areas and for each of the alternative configurations, and
3. Benefit-to-cost ratio adjustment that takes into account the results of the weighting factor assignment.

### Indirect Costs

#### Parking Problems

A study of parking availability in the Denver CBD (5) indicated that "in relationship to the proposed 16th Street mall the existing supply of parking appears to be adequate as to both amount and location." So for this study no cost impact for parking will be shown.

#### Disruption During Construction Phase

Little comment on this problem has been made in the literature. Consequently, even though one might anticipate a certain decrease in retail sales and an increase in congestion during construction, this effect will have to be estimated by assigning a weighting factor because of the lack of available data.

#### Disruption of Mail and Goods Delivery

Preliminary plans for the Denver mall call for the use of existing cross streets and alleys for goods delivery. This is similar to the method used on the Nicollet Mall where there have been no serious problems with store deliveries. The possibility of problems occurring especially during the early stages of the mall's operation should not be overlooked, however. Therefore, weighting factors should be included to allow for this contingency, and the factor for option 2 will be somewhat lower than that for option 1 because the transit way may be used for mail delivery.

### Indirect Benefits

#### Open Space and Aesthetic Improvements

This factor is clearly a function of mall design. Its relative importance will be determined by the decision maker's value system in assigning a weighting factor. Architectural renderings of the mall help in making this evaluation.

#### Lower Noise Levels

An interesting experiment in this area was conducted during the summer of 1970 with

**Table 4. 1973 assesed value and property taxes on 16th Street by block.**

| Block | Assessed Value (thousands of dollars) | | Property Taxes (thousands of dollars) | |
|---|---|---|---|---|
| | Southwest Side | Northeast Side | Southwest Side | Northeast Side |
| Curtis | 2,452.6 | 6,487.0 | 179.8 | 475.5 |
| Champa | 331.4 | 501.4 | 24.3 | 36.8 |
| Stout | 645.2 | 821.8 | 47.3 | 60.2 |
| California | 2,060.7 | 726.0 | 151.1 | 53.2 |
| Welton | 753.3 | 957.2 | 55.2 | 70.2 |
| Glenarm | 592.9 | 474.2 | 43.5 | 34.8 |
| Tremont | 670.7 | 1,395.6 | 49.2 | 102.3 |
| Court | 3,753.2 | 980.2 | 275.1 | 71.8 |
| Cleveland | 5,534.0 | 738.0 | 405.6 | 54.1 |

**Table 5. Estimate of increased property tax revenues.**

| Year | Property Taxes Without Mall (millions of dollars) | Property Taxes With Mall (millions of dollars) | Percent Increase Over Previous Year |
|---|---|---|---|
| 1976 | 2.19 | 2.28 | 4 |
| 1977 | 2.19 | 2.37 | 4 |
| 1978 | 2.19 | 2.46 | 4 |
| 1979 | 2.19 | 2.56 | 4 |
| 1980 | 2.19 | 2.66 | 4 |
| 1981 to 2000 | 43.80[a] | 53.20[b] | 0 |
| Total | 54.75 | 65.53 | |

[a]$2.19 million/year. [b]$2.66 million/year.

**Table 6. Indirect cost evaluation.**

| Cost Area | Weighting Factor[a] | |
|---|---|---|
| | Option 1 | Option 2 |
| Parking problems | 0 | 0 |
| Disruption during construction | 10 | 10 |
| Disruption of mail and goods delivery | 10 | 5 |
| Total | 20 | 15 |

[a]This factor can range from zero to 100. One hundred is equivalent to all direct quantifiable costs that will result from the mall.

**Table 7. Indirect benefit evaluation.**

| Benefit Area | Weighting Factor[a] | |
|---|---|---|
| | Option 1 | Option 2 |
| Open space and aesthetic improvements | 10 | 5 |
| Lower noise levels | 10 | 5 |
| Lower localized pollution | 10 | 5 |
| De-emphasis of automobile | 5 | 5 |
| Social gathering and interaction place | 5 | 3 |
| Emphasis on public transportation | 5 | 10 |
| Increased safety | 10 | 7 |
| Greater future business activity | 10 | 10 |
| Uncertainty of mall's revenue generating ability | -25 | -25 |
| Total | 40 | 25 |

[a]This factor can range from zero to 100. One hundred is equivalent to all direct quantifiable costs that will result from the mall.

the temporary closing of New York City's Fifth Avenue to vehicular traffic. Noise levels dropped from 78 decibels to 58 decibels, which is extremely significant (6). There is no reason to assume a similar decrease would not occur in an urban mall such as the proposed 16th Street mall. Option 1 would decrease noise levels more than option 2.

### Lower Localized Pollution Levels

The Fifth Avenue closure produced impressive results in decreasing the level of carbon monoxide along the avenue. The reduction was from 30 parts per million to 5 parts per million. Equally impressive results were recorded in Tokyo, Japan, and Marseilles, France. Exclusion of vehicles reduces street-level concentrations of pollutants, especially carbon monoxide, but does little to improve the city-wide pollution problem. Thus the value of this local pollution reduction effect is difficult to determine directly and a weighting factor is used. Option 1 would serve to reduce pollutants along the mall better than option 2. This should be reflected in the weighting factors.

### Emphasis on Public Transportation

Option 2 probably would emphasize public transportation more than option 1, and this should be reflected in the weighting factors.

### De-emphasis of Automobile

This is an indirect benefit of vehicle-free zones because they may tend to orient people's thinking toward finding alternatives to the automobile for shopping.

### Social Gathering and Interaction Place

Malls in other cities have served to bring people together for community-related purposes such as art festivals, fund-raising drives, and musical presentations. The value of this aspect of the mall will be estimated by the decision maker by what weighting factor is assigned. Option 1 probably would be of more value than option 2 in serving as a public gathering place.

### Increased Safety

The improvement in safety that will result from the mall can be quantified in terms of a dollar cost reduction to society.

Unfortunately, neither the Police Department nor the Traffic Engineering Department was able to provide any accident statistics for 16th Street in the proposed mall area. The street is a heavily traveled 1-way thoroughfare with an average daily traffic volume of nearly 20,000 vehicles at the southern end of the proposed mall and an average daily traffic volume of about 13,500 vehicles at the northern end. One-way cross streets are spaced at $\frac{1}{16}$-mile (0.88-km) intervals. One can assume that several accidents must occur each year along the 9-block length of the proposed mall. If the mall is constructed, however, it is reasonable to assume that those accidents that occur at the intersections will be eliminated. Because of the lack of data on accidents on 16th Street, we recommend that safety be treated as an indirect benefit for this example. Of course, pedestrian safety also should be considered, and one would expect that option 1 should have a slightly higher weighting factor for safety than option 2.

Greater Future Construction Activity

Several cities have noted a significant increase in business activity after malls have been in operation. Business activity can take the form of lower vacancy rates, increased investment, new construction, and higher rental rates. The Minneapolis Nicollet Mall has apparently generated more than $250 million in new construction, according to the Denver Planning Office. As more data become available from other malls, this factor can be moved from the indirect to the direct benefit category. For this study, using the weighting factor method for evaluation will suffice.

Uncertainty of Mall's Revenue Generating Ability

The direct benefits of the mall depend on predictions of increased retail sales and increased land values. Although these predictions are based on data reported by cities with malls in operation, these predictions are, to a certain degree, uncertain because of the assumptions that must be made. This uncertainty will be considered as a "negative benefit" and will be assigned a negative value in the benefit evaluation table.

## Evaluation of Indirect Costs and Benefits

After the decision maker has received a presentation of the supporting information, he or she can complete the weighting factor assignment by using a form similar to Tables 6 and 7, the evaluation tables. In Tables 6 and 7, the weighting factors given are ours and are included only for illustration. This approach is conceptually and mathematically simple and is based on the value system of the decision maker.

Adjusted Costs

The procedure for determining adjusted costs is as follows:

$$C_j = \text{direct costs} + \text{indirect costs}$$

$$= \text{direct costs} + (\text{direct costs} \times \text{sum of weighting factors in decimal form})$$

where $C_j$ = adjusted costs for option j. According to the data in Table 6, the following applies for options 1 and 2:

$$C_1 = \$7.60 \text{ million} + (\$7.60 \text{ million} \times 0.20)$$

$$= \$9.12 \text{ million}$$

$$C_2 = \$7.13 \text{ million} + (\$7.13 \text{ million} \times 0.15)$$

$$= \$8.20 \text{ million}$$

Adjusted Benefits

The procedure for determining adjusted benefits is as follows:

$B_j$ = direct costs + indirect costs

= direct costs + (direct benefits × sum of weighting factors in decimal form)

where $B_j$ = adjusted benefits for option $j$. According to the data in Table 7, the following applies for options 1 and 2:

$B_1$ = \$14.4 million + (\$14.4 million × 0.40)

= \$20.2 million

$B_2$ = \$14.4 million + ( \$14.4 million × 0.25)

= \$18.0 million

Overall Benefit-to-Cost Ratio

Any alternative with a benefit-to-cost ratio less than 1 should not be considered feasible. Of those feasible alternatives, the one with the largest benefit-to-cost ratio should be selected for implementation.

$R_j = B_j \div C_j$

where $R_j$ = benefit-to-cost ratio for option j. For our case study of option 1

$B_1$ = \$20.2 million

$C_1$ = \$9.1 million

$R_1$ = 2.2

and option 2

$B_2$ = \$18.0 million

$C_2$ = \$8.2 million

$R_2$ = 2.2

Thus for this case study both options appear to be feasible. That the benefit-to-cost ratios were the same is to be expected because the direct benefits for the 2 alternative configurations were considered equal. This was done because no other information was available on which to base the estimates.

## RECOMMENDATIONS

The model presented herein is only as meaningful as the information on which the feasibility study was based. There is a pressing need to accumulate a large amount of data on the costs and benefits of malls currently in operation. And this necessitates the release of certain information, such as retail sales data, that is not generally released by private enterprise. If such data could be obtained, then this model would be more than just an exercise in making learned assumptions; it could be a helpful tool.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Downtown Denver Pedestrian Transit Mall Proposals. Denver Planning Office and Downtown Denver, Inc., Jan. 1973.
2. Planning and Preliminary Design, 16th Street Mall. C. F. Murphy Associates and Johnson, Johnson and Roy, Inc., Denver, Feb. 1974.
3. Norman N. Barish. Economic Analysis for Engineering and Managerial Decision-Making. McGraw-Hill Book Co., New York, 1962.
4. Building Downtown Malls. Downtown Research and Development Center, Downtown Idea Exchange, New York.
5. Parking Availability Within the Denver Central Business District and Peripheral Areas and Implications for the 16th Street Mall. Central Area Development Group, Denver, July 1973.
6. Vehicle-Free Zones in City Centers. In Housing and Urban Development International Brief 16, U.S. Government Printing Office No. 2300-0194, June 1972.
7. Nicollet Mall Civic Cooperation to Preserve Downtown's Vitality. Planner's Note-Book, American Institute of Planners, Vol. 1, No. 6, Sept. 1971.
8. Revival Time for Louisville. Business Week, Sept. 8, 1973, p. 52.

# DRIVER PERCEPTION OF PEDESTRIAN CONSPICUOUSNESS UNDER STANDARD HEADLIGHT ILLUMINATION

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A driver must perceive objects in the roadway early to avoid accidents. Pedestrians are the most vulnerable of all roadway users, and they must completely avoid accidents to escape injury or death. How conspicuous pedestrians should be at night is explored in this study. Brightness and area are related to subjective driver interpretations of pedestrian conspicuousness. The performance of various reflective surfaces illuminated by the present standard headlight system is compared to the brightness and area requirements found for each level of conspicuousness. The area available for pedestrian visibility enhancement is determined by silhouette area analysis. Applicable reflective treatments are proposed as safety countermeasures, and other potential contributing factors are discussed.

•THE PEDESTRIAN accident problem and the need for more effective countermeasures to reduce pedestrian injuries and fatalities are well documented. In 1973 there were 10,500 pedestrian fatalities, accounting for nearly 20 percent of the total highway death figure (1). A breakdown of statistics into daytime and night categories is quite revealing. During the daytime periods in 1973 there were 4,800 pedestrian fatalities or about 46 percent of the total, and at night there were 5,700 fatalities or 54 percent of the total. One could conclude from this that night is slightly more dangerous than day. However, if one further analyzes these figures based on exposure to risk, a different picture emerges. In 1973 the number of vehicle miles driven at night was only 44 percent of that driven in the daytime. Therefore, if one surmises that an accident involving a pedestrian and a motor vehicle resulting in a pedestrian fatality is strictly a function of vehicle travel, then only 2,112 fatalities should have occurred at night. The actual total is 2.7 times greater than this. If one takes pedestrian exposure into account, a still higher ratio of actual total to expected fatalities emerges. Pedestrian travel rate or exposure is much harder to accurately assess than motor vehicle travel. A study by Cameron (2) shows pedestrian volume at night to be less than 15 percent of pedestrian travel in the daytime. This is for an urban environment; rural pedestrian volume might be even lower. If one assumes that night vehicle miles are, even more conservatively, only 25 percent of those driven in the daytime, then the predicted number of night fatalities would be 528. The 25 percent assumption represents the combined effect of motor vehicle and pedestrian travel rates. The actual observed figure of 5,700 nighttime fatalities is nearly 11 times higher than what one would expect. Nearly 5,200 of the 5,700 fatal night accidents are due to conditions that are absent during the day. It is evident that the night environment is dramatically more dangerous for the pedestrian than the daytime environment is.

The obvious difference between day and night is lack of visibility and visual cues at night that the driver uses during the day. Alcohol and fatigue and their interaction with vision and perception also are involved. Because the visibility factors are obvious and much research has been done in this field, perhaps a tendency exists to think that there is little room for new effective safety countermeasures. But research is being carried

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out on new forward lighting systems for vehicles, and these new systems have been the subject of several papers at recent Transportation Research Board meetings. Schwab and Hemion (3) point out, however, that vehicle headlight design is a compromise between providing adequate illumination of the road ahead and avoiding glare to oncoming drivers. Low beams that avoid glare do not provide enough illumination to drive safely, yet low beams are used in over 60 percent of all night driving in low-volume rural areas; this increases to 90 percent at higher volumes (14).

Some research in roadway lighting indicates that improved visibility at night can help reduce accidents (4, 5). Adequate funding to light substantial portions of roads and streets with fixed lighting always has been limited. With energy in short supply, it becomes less attractive. Alternatives that more efficiently use light available to the motorist need to be explored. One alternative is judicious use of reflectorization, especially for the pedestrian, to achieve greater efficiency in the use of available light and improve visibility. This can be done now with existing technology; further technical breakthroughs are not necessary.

Richards (6) has made an extensive compilation of the pertinent literature related to night vision and visibility of road objects at night. A distinction should be made at this point between human vision capabilities and deficiencies and object visibility. Burg (7) studied the relationships between static visual acuity, dynamic visual acuity, other measures of vision, and the driving records of 17,500 drivers. Although certain measures of vision, such as dynamic visual acuity, were useful in predicting accident involvement, correlation was relatively low because many factors other than human eye capabilities and deficiencies are involved. Even a young driver with 20/20 eyesight, for example, does not detect a pedestrian in dark clothing at night until he or she is dangerously close (15). Target visibility and not driver vision is crucial under these circumstances. Bergsman (8) points out that there are 4 problem areas in pedestrian safety. Three concern very young and very old people and alcohol abusers. The fourth, an environmental problem rather than one concerned with people, is darkness and its attendant poor visibility.

Much of the research on visibility is concerned with the limits where objects first can be detected or where signs first can be read. These threshold values can be readily determined by straightforward experimental procedure. Very little research has been concerned with higher than threshold values that are needed to alert an otherwise complacent, distracted, or inattentive driver that an object or person is in his or her path that needs immediate consideration. deBoer (9) indicates that, although visibility distance (a threshold measure) is a very important criterion, ease of seeing within that visibility distance is of great importance. He indicates that values 3 to 10 times higher than threshold should be considered for ease of seeing. An early study by Breckenridge and Douglas (10) has been interpreted to show that values that are 100 to 1,000 times higher than threshold may be needed to command attention. Thus we hypothesize that the level of conspicuousness of a road target for easy visibility and attention getting is considerably different from threshold detection values.

This study tries to relate the measured photometric and area properties of certain light targets under dark ambient conditions to the subjective responses of human observers. In addition, various retroreflective materials were measured photometrically under standard low-beam illumination at 550 ft (167.64 m) so that a comparison with light targets could be made. Further analysis of the adult and child pedestrian silhouettes sets upper limits for the target and reflective areas.

## PROBLEM

Avoiding a collision with an object on the roadway involves not only detecting an object when one is actively seeking its presence but also being able to detect and recognize the nature of the object when one does not expect its presence. Detection, recognition, and attention are separate dimensions of the problem. This study explores detection and attention in a simulated roadway condition under dark, static conditions. It does not deal with dynamic conditions involving vehicle and target movement that would include estimation of distance and closing rates. Nor does it deal with the problem of recognizing a pedestrian from all other possible objects encountered on the roadway. The contributions of movement and recognition cues can be very important but must be the subject of other research. The 2 variables studied in this experiment were target brightness and area, which are basic to detection and attention.

Many experimental possibilities exist that can link the photometric and geometric properties of visual targets to observer reaction, particularly with the suprathreshold reactions characterized as easily visible and attention commanding. One procedure might be to place targets of various areas and brightness in random position and sequence along a roadway and measure detection distances and errors by observers in vehicles traveling the course. Because of equipment and time limitations this could be carried out more easily after simpler preliminary research was conducted with targets of randomly varying brightness and area displayed to observers at a fixed distance. The distance chosen was 550 ft (167.64 m), corresponding to minimum stopping sight distance under wet conditions at 55 miles/h (88.5 km/h) (11, 12). The observers sat behind standard headlights set on low beam in dark surroundings to approximate the mesoptic adaptation of the eye in night driving. The targets were internally illuminated light sources that could be masked to reveal various areas. Light sources were chosen instead of reflective targets to allow easier small luminance adjustments and to avoid any extraneous variables that might be introduced if different reflective materials were used. In a separate part of the experiment, the photometric responses of a number of actual reflective materials were measured under standard head-lamp illumination. These responses can be related to the light source values by means of photometric and area data.

The observers were asked to rate each target as visible, easily visible, or attention getting. The data response sheet filled in by each observer was structured so that gradations within each of the 3 categories could be indicated by the position of the mark. A large number of area and brightness combinations covering wide ranges were presented randomly to each observer. The presentation of any given combination could not be anticipated, and the observer thus was forced to make a fresh evaluation of each target. Part of this study design rests on the fact that observers make mental comparisons with targets previously observed so that a hierarchy of responses is created.

Even though the important elements of motion, shape, and color were not included and road conditions were simulated for the test, we believe that basic relationships between targets at suprathreshold levels and subjective response can be established with this method.

## SIMULATED ROADWAY DESIGN

A corridor in a large, dark warehouse was used as the test site. A headlight stand mounted with standard head lamps was positioned at an end of the corridor (Figure 1). The corridor was striped with a reflective white edge line 4 in. (10.16 cm) wide and a reflective white skip line that simulated lane dividers and also was 4 in. (10.16 cm) wide. The road was 11 ft (3.35 m) wide from edge to center and 550 ft (167.64 m) from head lamps to view box. The front surface of the view box was centered in the simulated roadway and angled at 4 deg from the perpendicular of the center line between the head lamps to avoid any specular glare. The center point of the target was 42 in. (106.68 cm) from the floor. The head lamps were properly mounted to simulate a car in the center of the designated lane. The headlights were used to adjust the observers' eyes to the mesoptic range of adaptation to simulate normal night driving. Five chairs for the observers were placed behind the head-lamp stand to position observers at proper eye height. A telephotometer was placed at driver's eye position to record the luminance of the view box. A variable transformer was located near the readout of the telephotometer. An extension cord linked the available transformer to the view box to provide control of the luminance of the view-box target surface.

# APPARATUS

## Variable Transformer

A 60-A rheostatic variable transformer with 250-V capacity and 600 ft (201.17 m) of No. 10 wire extension cord was used.

## Photometric Instrumentation

A Gamma Scientific Model 2000 telephotometer was used. This instrument is well suited for this experiment because it has a transistorized photomultiplier and electrometer amplifier, 2-in.-diameter (5.08-cm-diameter) objective, measurement span from 0.001 to 35,000 ft-L (0.0034 to 11,900 cd/$m^2$), color correction, internal standardization, and calibration. Five acceptance angles are available with this instrument. The 1.67-deg sensing-probe acceptance angle for all suprathreshold conditions was used and provided proper sensitivity within the conditions of the study. The instrument has a bipolar, 3-digit display with 100 percent overrange (Max Count 1999) and automatic polarity indication that will blank on overload.

## View Box and Illuminated Targets

The view box consisted of twelve 200-W light bulbs equally spaced in a 3-sided housing with an inner surface painted flat white (Figure 2). The front, or face, consisted of 2 pieces of 0.125-in. (3.18-mm) clear acrylic panels both of which were sandblasted. The outer panel was positioned parallel to the inner panel at a distance of 18 in. (45.72 cm). The outer panel was the target surface viewed by the observer. Variable area was provided by the outer metal shroud, which had removable panels. Target sizes and their visual angles were as follows:

1. 1 by 1 in. (2.54 by 2.54 cm) > 0.8 deg,
2. 4 by 4 in. (10.16 by 10.16 cm) = 0.55 deg,
3. 8 by 8 in. (20.32 by 20.32 cm) = 1.11 deg,
4. 24 by 24 in. (60.96 by 60.96 cm) = 3.33 deg, and
5. 24 by 72 in. (60.96 by 182.88 cm) = 10.55 deg.

Inserting panels produced the first 3 target sizes. Removing all panels produced the 4th target size. Removing the shroud produced the 5th target size.

## Head Lamps

The head lamps used were a standard set of GE6014 type 2 lamps, designed for the 2-beam system, and were properly aimed according to SAE Standard J599C. The voltage to the head lamps was maintained at the normal automotive operating level of 12.7 V. No lights other than the view-box target lights were on in the warehouse. These conditions simulated night driving conditions in a dark, rural area. The pavement surface 60-deg gloss measurement averaged 14 and the percent reflectance averaged 10.

# PROCEDURE

## Threshold Determination

Participants indicated by a switch light when the target was barely visible. First, the

Figure 1. Simulated roadway conditions.

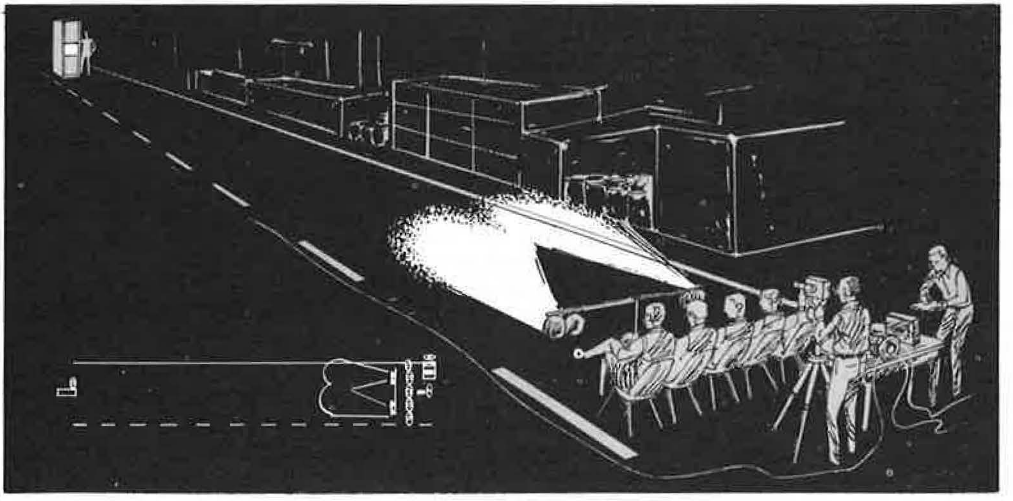
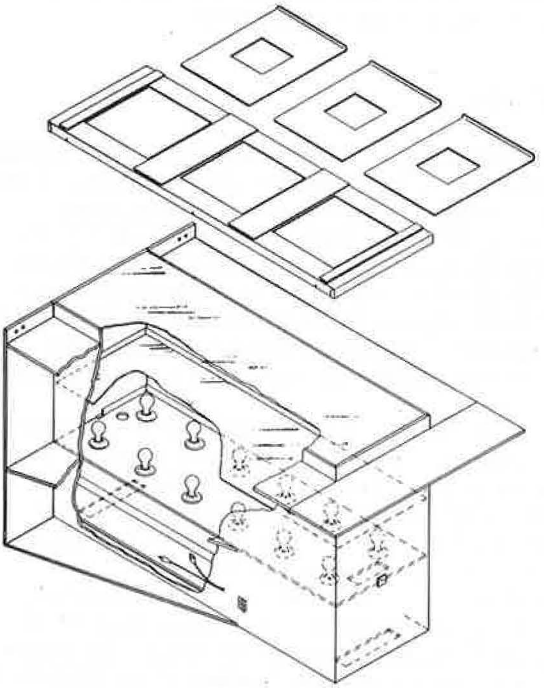


Figure 2. View-box design and illuminated targets.



target was bright enough so that the participants could specifically locate it. Then it was blacked out. The surface was illuminated gradually until all had responded and the operator had recorded the data. This procedure was carried out for each of the 5 areas starting with the 24- by 72-in. (60.96- by 182.88-cm) target and proceeding down to the 1- by 1-in. (2.54- by 2.54-cm) target.

### Suprathreshold Determination

The observers were told to imagine that they were driving an automobile under normal night driving conditions. They were to respond to each target situation while imagining that they were traveling at 55 mph (88.5 km/h) on the roadway ahead of them. Responses for each of the conditions were marked on the chart to indicate when they considered the target to be either visible, easily visible, or attention getting. They were to mark each response on a graduated scale to indicate how strongly they felt about the condition. The observers indicated their immediate response after glancing up at the target. They were told not to stare or concentrate on the target and to look away from the target after they made their observation to retain proper adaptation. After the participants recorded their responses, they signaled with their indicator switch lights. The total time for the suprathreshold experiment averaged 33 to 45 min. Thirty-five people participated in the experiment as observers. Teams of 3, 4, or 5 people at a time were used. Each viewer's eyes were tested for visual acuity and depth perception. The average corrected visual acuity was 20/20. Vision and age data are given in Table 1. Average age was 32 years, and all volunteers were licensed drivers.

## DEFINITIONS OF TARGET CONSPICUITY LEVELS

The 3 levels of conspicuousness were defined for the observers before the test. Visible meant that the driver could see the target but could miss it in a driving situation. Seeing the target requires at least a slight amount of effort. Existing visual distractions, pavement surface, and lane lines might cause a driver to miss it at 550 ft (167.64 m). Easily visible meant that the driver could see the target easily despite existing visual distractions if he or she looked directly at it but might miss it if he or she looked elsewhere on the roadway. Seeing the target did not require concentrated effort. The target was viewed as comfortably visible and not glaring. Attention getting meant that the target was not only easily visible but bright enough to attract attention even if the driver was not looking directly at the target.

The data were divided into 15 relative values: (a) 1 to 5 for visible, (b) 6 to 10 for easily visible, and (c) 11 to 15 for attention getting. A value of 1 represented the lowest subjective estimate of visibility and 15 represented the highest. Ten different luminances were chosen for each of the 5 different area conditions. The target size and luminance were randomly varied. An additional 4 situations were added to the first part of the design to attempt to condition the viewer on what to expect.

Average response of the viewers was tabulated for each condition. A multiple regression analysis was performed on the data to determine the relationship between the response of the observer and the combination of luminance and target area. Equations were developed that accounted for 94 percent of the averaged responses of the observers. Analysis of the comparison of the predicted value from the equation with the data did not exhibit a pattern that would suggest data drift such as one that might be due to fatigue.

## RESULTS

All of the test results could be depicted on a single graph. Figure 3 shows the average responses of the observers as a function of target area and brightness. Figure 4 shows an extension of the curves developed to lower levels to include nonretroreflective black, gray, and white targets.

**Table 1. Age and visual factors of participants.**

| Participant | Age (years) | Far Acuity | | | Near Acuity | | | Depth Perception |
|---|---|---|---|---|---|---|---|---|
| | | Both Eyes | Right Eye | Left Eye | Both Eyes | Right Eye | Left Eye | |
| 1 | 40 | 20/17 | 20/18 | 20/17 | 15/15 | 15/20 | 15/15 | OK |
| 2 | 49 | 20/18 | 20/18 | 20/20 | 15/15 | 15/15 | 15/15 | OK |
| 3 | 38 | 20/17 | 20/20 | 20/17 | 15/20 | 15/20 | 15/15 | OK |
| 4 | 26 | 20/20 | 20/20 | 20/25 | 15/15 | 15/15 | 15/15 | OK |
| 5 | 38 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 6 | 31 | 20/20 | 20/22 | 20/22 | 15/15 | 15/20 | 15/15 | OK |
| 7 | 40 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 8 | 43 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 9 | 21 | 20/18 | 20/20 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 10 | 54 | 20/20 | 20/20 | 20/20 | 15/15 | 15/15 | 15/15 | OK |
| 11 | 48 | 20/20 | 20/25 | 20/22 | 15/25 | 15/25 | 15/25 | OK |
| 12 | 21 | 20/22 | 20/29 | 20/22 | 15/15 | 15/15 | 15/15 | OK |
| 13 | 27 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 14 | 26 | 20/22 | 20/22 | 20/29 | 15/15 | 15/15 | 15/15 | OK |
| 15 | 21 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 16 | 26 | 20/18 | 20/18 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 17 | 22 | 20/22 | 20/20 | 20/22 | 15/15 | 15/15 | 15/15 | OK |
| 18 | 22 | 20/25 | 20/22 | 20/20 | 15/15 | 15/15 | 15/15 | OK |
| 19 | 16 | 20/33 | 20/33 | 20/29 | 15/15 | 15/15 | 15/15 | OK |
| 20 | 37 | 20/25 | 20/22 | 20/29 | 15/15 | 15/15 | 15/15 | OK |
| 21 | 20 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 22 | 45 | 20/22 | 20/20 | 20/200 | 15/15 | 15/15 | 15/60 | OK |
| 23 | 26 | 20/18 | 20/18 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 24 | 29 | 20/20 | 20/18 | 20/20 | 15/15 | 15/15 | 15/15 | OK |
| 25 | 31 | 20/22 | 20/22 | 20/25 | 15/15 | 15/20 | 15/15 | Marginal |
| 26 | 24 | 20/20 | 20/20 | 20/22 | 15/15 | 15/20 | 15/15 | OK |
| 27 | 35 | 20/20 | 20/20 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 28 | 36 | 20/17 | 20/18 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 29 | 35 | 20/17 | 20/18 | 20/20 | 15/15 | 15/15 | 15/15 | OK |
| 30 | 30 | 20/18 | 20/20 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 31 | 61 | 20/20 | 20/20 | 20/22 | 15/20 | 15/20 | 15/15 | OK |
| 32 | 26 | 20/22 | 20/22 | 20/25 | 15/15 | 15/15 | 15/15 | OK |
| 33 | 18 | 20/17 | 20/20 | 20/18 | 15/15 | 15/15 | 15/15 | OK |
| 34 | 28 | 20/17 | 20/17 | 20/17 | 15/15 | 15/15 | 15/15 | OK |
| 35 | 37 | 20/25 | 20/25 | 20/25 | 15/15 | 15/15 | 15/15 | OK |

**Figure 3. Average graded response of observers as a function of area and luminance.**

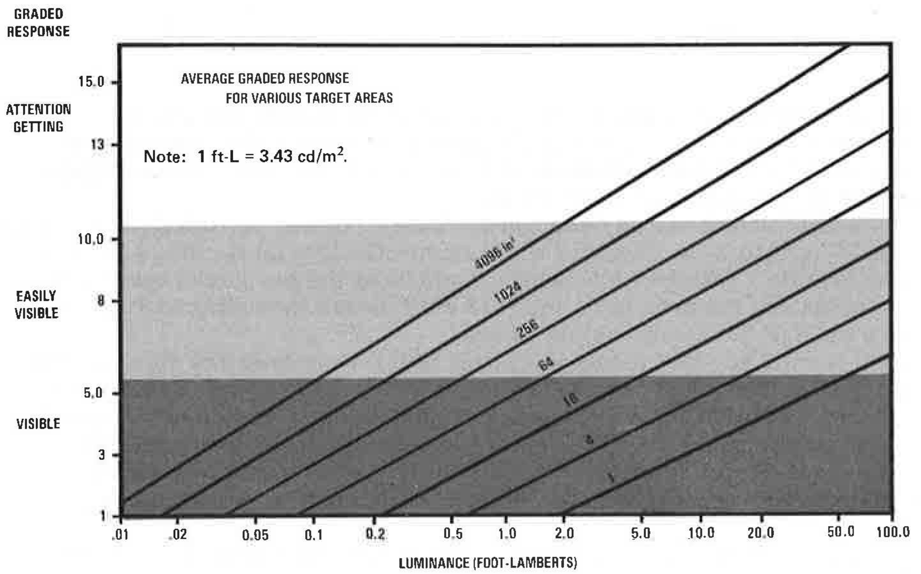


**Figure 4. Average graded response extended to low-luminance targets.**

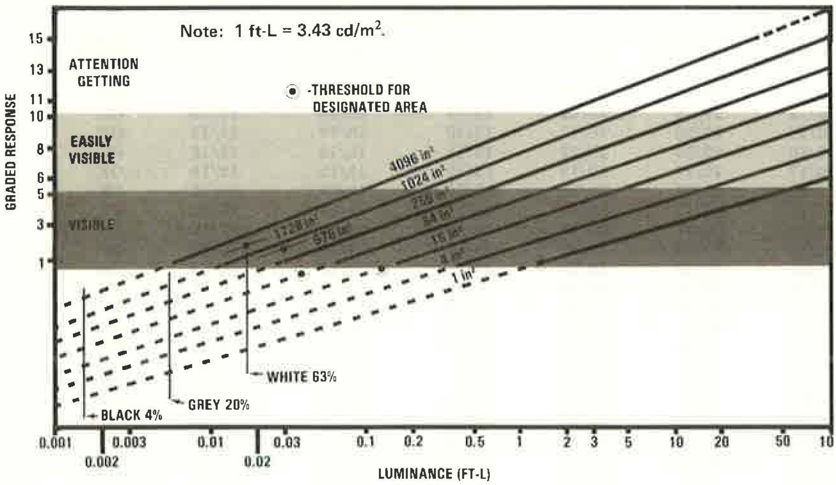



**Table 2. Luminous intensity and luminance for retroflective materials using standard low-beam head lamps at 550 ft (167.64 m).**

| Material | Luminous Intensity (candle/ft-c/ft²)[a] | Luminance (ft-L)[b] |
|---|---|---|
| L-S-300A reflectivity-5 sheeting | 65 | 3.4 |
| L-S-300A reflectivity-1 sheeting | 110 | 5.8 |
| White retroreflective fabric | 100 | 5.4 |
| High-performance retroreflective sheeting | 260 | 13.7 |
| Prismatic retroreflective sheeting | 1200 | 63.3 |

Note: 1 candle/ft-c/ft² = 1 cd/lx/m². 1 ft-L = 3.43 cd/m².
[a]At a -4-deg entering angle and 0.2-deg observation angle. [b]At 12.7 V.

## DISCUSSION

Figure 3 shows the derived relationships between target luminance and subject response for different target areas. For certain luminance values, the response can vary from just visible to attention getting as area is increased. For a given response, greater brightness is needed for smaller areas.

Using Figure 3 and Table 2 values, one can evaluate a number of reflective material applications. A 16-in.² (10.3-cm²) band of white retroreflective fabric would be predicted to have an observer rating of 5.5, which would be at the low end of the easily visible range. Increasing the area to 64 in.² (413 cm²) moves the rating to 7.5, which would be in the middle of the easily visible range.

A white, class A reflector that meets minimum Motor Vehicle Safety Standard 108 and SAE J594 requirements would have a 6 rating, which would be just in the easily visible range. A red, class A reflector would have a 4 rating. The effect of color was not considered in this study, so actual observer response rating remains doubtful. Studies (12) have shown red to be more noticeable than white at equal intensities, so one could postulate that a response between 4 and 6 would be given a red, class A reflector.

The advance warning triangle, as specified in Motor Vehicle Safety Standard 125, when viewed head on at a 0.2-deg observation angle, receives an observer rating of nearly 8. However, at a 30-deg angle to traffic, as a result of road curvature, misalignment, or both, the same advance warning triangle receives a rating of 4.5, which would be visible but not easily visible or attention getting. The slow-moving-vehicle emblem manufactured under present standards would be rated about 4.

The area available for reflectorizing a pedestrian is limited. A silhouette analysis is as follows (0 deg is front view; 1 ft = 0.305 m; 1 $in.^2$ = 6.45 $cm^2$):

| | | View ($in.^2$) | | | | |
|---|---|---|---|---|---|---|
| Subject | Height (ft) | 0 deg | 45 deg | 90 deg | 135 deg | 180 deg |
| Adult | 5.86 | 981 | 750 | 675 | 838 | 956 |
| Child | 3.98 | 506 | 462 | 375 | 456 | 494 |

[This analysis was carried out in a manner similar to that described by Woltman and Austin (14) in their analysis of motorcycle silhouettes.] Because these are rather small areas, high luminance is required to achieve ratings of 11 or higher. Objects with much larger areas, such as road signs, more easily achieve ratings in the attention-getting region. A 36-in. (91.4-cm) octagonal stop sign would be rated at 10, and a 10- by 20-ft (3.05- by 6.1-m) green-ground-mount guide sign might be rated at 13.5 based on luminance values of high-performance retroreflective sheeting. As we have indicated before, the effect of color has not been taken into account.

When various areas and luminances of light targets and reflective devices are plotted, observer response is influenced mostly by the total light returned. Confining a given amount of light in a small area is somewhat more efficient than spreading it out (within the range of areas observed in this study), but smaller areas are limited in the amount of total light that can be generated. This is especially true for retroreflectors, the attainable luminance of which is limited. A more feasible, direct way to increase total light is by increasing area. This can have the added advantage of providing identifiable shapes and recognition cues (rather than point sources) if it is judiciously done.

At the lower end of the scale, average threshold readings are plotted for various areas. A curve fitted to these points is a straight line that almost coincides with an observer rating of 1. If the measured luminances for white, gray, and black clothing (63, 20, and 4 percent reflectances respectively) are plotted (Figure 4), they fall below threshold except for the full area of an adult in white from the front, which is just barely over threshold. Thus an adult dressed entirely in white clothing would be just barely discerned at 550 ft (167.64 m). All other clothing combinations would be below threshold.

The following indicates how the varying head-lamp light output, which results from varying voltages in an automobile, affects light return from a representative retroreflector (1 ft-L = 3.43 $cd/m^2$):

| Operating Voltage | Luminance (ft-L) | Operating Voltage | Luminance (ft-L) |
|---|---|---|---|
| 12.7 | 3.4 | 12.0 | 2.8 |
| 12.4 | 3.1 | 11.5 | 2.4 |

The previous discussion was based on the 12.7-V conditions. Lower voltages would shift all data to the lower direction on the observer response scale.

Use of high beams or shorter viewing distances would probably move the curves in the direction of higher observer response. However, these conditions would be far from universal because low beams are used much of the time, and the full stopping sight distance may be needed frequently, especially when driver inattention and lack of expectancy prevail. Lack of expectancy probably plays a major role in pedestrian accidents on expressways.

Use of target motion (pedestrian's moving arms and legs or movement of bicycle pedals), recognizable shape, and color also might move the data curves in the direction of higher response. These factors should be further explored and, if effective, be used in the visual protection of pedestrians, bicyclists, and motorcyclists. In addition to mere detection, recognition of an object on the roadway is quite important so that the driver can make correct decisions and proper avoidance maneuvers in time. Area shapes provide not only recognition but also a frame of reference by which speed and distance can be judged.

Other factors exist that might move these curves toward lower observer response. Some of these could be tinted and dirty windshields, misaimed headlights, rain, snow, fog, road curvature, and effects of alcohol. Hazlett and Allen's study (15) on the effect of alcohol on the driver's ability to perceive a pedestrian at blood alcohol levels of 0.06 to 0.10 showed a dangerous loss of detection capability unless reflectorization was added. Even small amounts of reflectorization [material 11 in.$^2$ (71 cm$^2$) of 50 candles/ft-c/ft$^2$ (50 cd/lx/m$^2$)] enabled the driver at blood alcohol levels of 0.06 to 0.10 to perceive the pedestrian sooner than a sober driver could perceive a pedestrian dressed in all-white clothing.

The combined effects of the various counterbalancing factors described above have not been quantified. If the positive and negative effects offset each other to some extent and the curves presented here represent typical driving condition responses, one can conclude that a pedestrian dressed in any normal clothing cannot be seen adequately on the roadway. To make matters worse, most pedestrians think they are easily seen by approaching motorists because they appear to be bathed in light. The study done by Allen et al. (16) shows that pedestrians' estimates of their own visibility are dangerously high.

The results of this study agree with those of the Breckenridge and Douglas (10) study that stated that attention getting is different from threshold values. The data (Figure 4) did show that factors 100 to 1,000 times threshold were appropriate. It is probably not necessary to use this degree of visibility enhancement to substantially improve pedestrian visibility at night. If an observer response level equal to the class A reflector at head-on angles were established, it could be met with 16 in.$^2$ (103 cm$^2$) of white retroreflective fabric. If an observer response level equal to that of the advance warning triangle at head-on angles were established, it could be met with 128 in.$^2$ (826 cm$^2$) of white retroreflective fabric, which would be equivalent to a piece 12 by 10.7 in. (30.5 by 27.2 cm).

Probably more important than ensuring extremely high values of reflectorization would be ensuring that, regardless of angle of orientation, the pedestrian is visible to the motorist. Providing a high degree of visibility from one direction such as from the front or back but failing to provide it at other angles does not sufficiently protect the pedestrian.

## SUMMARY AND CONCLUSIONS

This experiment was conducted to establish some standard viewer responses under 1 set of conditions—viewing illuminated targets at 550 ft (167.64 m) under dark ambient light as target area and brightness were varied. The viewer responses to the targets lighted with standard low head lamps then were related to reflective materials having various reflectance values.

The set of curves developed showing relationships of target area, brightness, and subjective response enable the selection of reflective treatments appropriate to the visual enhancement desired. Apart from threshold values, there appears to be no sharp cutoff point but rather a continual improvement in target conspicuousness as the total amount of light returned to the viewer increases. Because of practical limitation in retroreflector brightness and design, we find the most feasible way to increase total light is through increased reflective area.

Good visibility and early perception of the pedestrian by the driver play an important role in accident prevention both day and night, but especially at night. Because the energy exchange is so unequal in a collision between a vehicle and a pedestrian and because the pedestrian is so vulnerable to a variety of impacts, accidents must be completely avoided. Accident data analysis indicates that if drivers could see and react to pedestrians at night as well as they do during the day, many lives would be saved. The observer response index developed in this research hopefully will be a step toward achieving needed conspicuousness for the pedestrian. Additional research is needed on this important subject, but, more importantly, immediate action and implementation are needed to begin reducing pedestrian deaths and injuries.

## REFERENCES

1. Accident Facts, 1974 Ed. National Safety Council.
2. R. M. Cameron. Mechanical Measurement of Pedestrian Volumes. Engineering Department, City of Seattle.
3. R. N. Schwab and R. H. Hemion. Improvement of Visibility for Night Driving. Highway Research Record 377, 1971, pp. 1-23.
4. B. E. Sabey and H. D. Johnson. Roadlighting and Accidents: Before and After Studies on Trunk Road Sites. Great Britain Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. 586.
5. P. C. Box. Comparison of Accidents and Illumination. Highway Research Record 416, 1972, pp. 1-9.
6. O. W. Richards. Visual Needs and Possibilities for Night Automobile Driving. U.S. Bureau of Public Roads, Contract CPR-11-3965.
7. A. Burg. Vision and Driving: A Summary of Research Findings. Highway Research Record 216, 1968, pp. 1-12.
8. S. E. Bergsman. The Pedestrian and Traffic Safety. Traffic Digest and Review, Oct. 1970.
9. J. B. deBoer. Quality Criteria for the Passing Beam of Motor Car Headlights. GTB Meeting, Waldorf, West Germany, Sept. 1973.
10. F. C. Breckenridge and C. A. Douglas. Development of Approach and Contact-Light Systems. Illuminating Engineering, Vol. 40, 1945, p. 785.
11. A. D. May, Jr. Vehicle Operating Characteristics. In Traffic Engineering Handbook, 3rd Ed.
12. A Policy on Design Standards for Stopping Sight Distance. American Association of State Highway Officials, 1971.
13. T. H. Projector, K. G. Cook, and L. O. Peterson. Analytic Assessment of Motor Vehicle Rear Signal Systems. Century Research Corp., Washington, D.C.
14. H. L. Woltman and R. L. Austin. Some Day and Night Visual Aspects of Motorcycle Safety. Transportation Research Record 502, 1974, pp. 1-8.
15. R. D. Hazlett and M. J. Allen. The Ability to See a Pedestrian at Night: Effects of Clothing, Reflectorization, and Driver Intoxication. Highway Research Record 216, 1968, pp. 13-22.
16. M. J. Allen et al. Actual Pedestrian Visibility and the Pedestrian's Estimate of His Own Visibility. Proc., 13th Annual Conference, American Association of Automotive Medicine.

# ASSESSMENT OF PEDESTRIAN ATTITUDES AND BEHAVIOR IN SUBURBAN ENVIRONMENTS

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Suburban area pedestrianism was examined from the points of view of the walking and nonwalking public. Nine case studies were conducted to determine the role of walking as an exclusive mode of travel. The sites examined comprised the 3 major types of pedestrian facilities: overpasses, tunnels, and at-grade crossings. Locations where new pedestrian facilities are anticipated also were examined. In each case, linkages between land uses were established to define reasons for local travel. The data then were analyzed to show how pedestrian facilities act to sustain the linkages. Various pedestrian characteristics were found to be related to walking activity. For example, age has a direct bearing on walking behavior, and children constitute the largest walking group. Acceptable walking distances of up to 0.25 mile (0.4 km) were given for adults. Distances of up to 1 mile (1.6 km), however, offer little impedance to children. Along with distance, fear of attack is a primary impedance to potential adult walkers, especially women. Overpasses were cited as the most desirable pedestrian accommodation to bypass traffic. The public showed little enthusiasm for tunnels because of the mischief they attract. People have also shown that, if the reason exists, they will cross heavy traffic to travel by foot. The results of this study give general principles for successful pedestrian planning in suburban areas, and they support the idea of combined pedestrian and bicycle ways.

•PEDESTRIANISM, as well as bicycling, is attracting the attention of transportation planners as a mode of travel that can satisfy many personal and social needs. Reasons for the resurgence in the popularity of walking are varied, but they generally reflect a growing awareness that urbanized areas cannot forever accommodate the rate of automobile growth experienced in the 1950s and 1960s. They also reflect a realization that automobile domination has many adverse effects on life-styles and the environment. The new-town concept, which emphasizes local activity and focuses on economic and social self-sufficiency within a planned community, is an attempt to alleviate the difficulties of life in major metropolitan areas where the typical resident must drive a considerable distance to reach his or her place of work, the shopping center, and major recreational facilities.

Pedestrian studies conducted before and during the 1960s concentrated on walking movements in densely populated areas, primarily central business districts (CBDs). These investigations were conducted from a traffic-engineering perspective; that is, pedestrian movements and relationships of traffic flow to volume were examined to measure the performance of facilities such as sidewalks and crosswalks (1). Also pedestrian safety studies examined pedestrian-vehicle accidents so that guidelines could be developed to reduce pedestrian-vehicle conflicts by channelization and signalization (2). In outlying areas, pedestrian structures have been built where a major transportation facility such as a freeway would otherwise create a barrier to pedestrians (3). Such structures, in most cases, connect residential neighborhoods with

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local schools and often have been built without a comprehensive plan. Public requests for such pedestrian accommodations continue to be treated in a relatively subjective fashion by government agencies.

Accident studies from 11 major cities have shown that only 14 percent of all pedestrian casualties occur in CBDs despite the heavy concentration of walking trips within these areas (1). This can be attributed to the low speeds of the slow-moving traffic in the CBD and driver awareness of the heavy pedestrian traffic. It is therefore appropriate that pedestrian facilities outside the cities, where 86 percent of the pedestrian accidents occur, be investigated. Accordingly, this study focused on travel needs in suburban environments.

## OBJECTIVES AND SCOPE

The research reported here had 2 primary objectives: (a) to relate pedestrian attitudes and behavior to the dimensions of the walking system and (b) to recommend a set of guidelines and procedures for pedestrian system planning and design. Pedestrian attitudes and behavior were studied together to ascertain general guidelines. By examining the data obtained through various means, we determined those environmental features that are deterrents to walking and suggested means by which such deterrents can be removed or minimized. In addition, those features that improve the walking environment were identified. It is hoped that this paper will aid in the future development of walking systems that will enhance pedestrian activity and encourage walking as an efficient, expedient, and safe mode of transportation.

## METHODOLOGY

The case study method was employed to meet the research objectives. The selected sites in suburban areas featured the 3 major types of pedestrian facilities: overpasses, tunnels, and at-grade crossings. Three of the sites contained no pedestrian accommodations, but in each case such an installation was anticipated.

Two methods were used to obtain data on pedestrian movement. First, hour-by-hour observation and volume counting were performed to determine usage patterns, frequency of use, and user characteristics. Second, attitudinal surveys were administered to random samples of residents within the vicinity of each pedestrian facility being studied. The survey approach was varied among the case studies to determine the best strategy for obtaining data. The methods employed included home interviews, on-site interviews and observations, and questionnaire distributions.

Because pedestrian movements derive generally from activity participation, land use at trip origin and destination points was specified to define the predominant trip purposes, which will be referred to here as the linkages, associated with pedestrian travel within a study area. Pedestrian facilities were examined to demonstrate how they act to sustain such linkages.

## CASE STUDY FINDINGS

Each of the study sites was examined individually. However, in our discussions of them, the findings are synthesized into specific facts and principles that are basic to pedestrian planning.

### Pedestrian Behavior in Suburban Virginia

The data derived from the case studies provided insight into the habits, desires, and attitudes of suburban pedestrians and, consequently, much about the characteristics of pedestrian accommodations that will best serve them. It is important to note that the generalizations made here are based on behavior exhibited by suburban pedestrians as well as on perceptions expounded by them. Thus an accurate picture of the relationship between the suburban walker and the suburban walking environment is presented.

Certain characteristics about pedestrians must be taken into account. In short, who are the pedestrians to be accommodated and what are their life-styles? In the suburban areas represented in this study the majority of the walkers fell into 2 age groups. One group consisted of 20- to 30-year-olds, the majority of whom were women who used walking primarily to get to shopping destinations. The second and larger group consisted of individuals between 8 and 16 years of age. The younger group depended on walking as a primary means of transportation, especially to school and friends' homes, and was not particular about the type of pedestrian facility to be used. The older group, however, preferred to walk where they never had to be enclosed from view. Neither group's walking activity appears to be related to family size, length of residency in the area, or type of dwelling. As family automobile ownership increased, walking declined in importance as a travel mode more in the younger group than in the older group.

The roles of walking and automobile and bus transportation in providing access to particular activities in a representative suburban area are given in Table 1. Comparison of such data from a number of sites revealed that modal use was related to the accessibility provided. For example, if the school was over 1 mile (1.6 km) away, few walking trips were taken, but if the activity sites were within 0.5 mile (0.8 km) of the residences, more walking was evident. Ninety percent of the people who reported low walking frequencies reported that destinations were too far away: 19 to 30 percent cited inadequate accommodations as the reason for infrequent walking travel.

Impedances to walking derive from both the pedestrian system itself and the characteristics of the pedestrians. Age has a direct bearing on walking frequency. Very few old people use walking as a primary travel mode. A few of them make short trips, but distances rarely exceed 0.25 mile (0.4 km). This underrepresentation of elderly people can be attributed partially to the fact that most people in this group live in areas other than those examined in this study. Children, on the other hand, travel up to 1 mile (1.6 km) on foot and ride bicycles even farther.

Typical perceptions of reasonable walking distances are given in Table 2. They indicate that approximately 50 percent of the people were unwilling to walk more than 0.5 mile (0.8 km). There appears to be very little difference between what adults consider to be a reasonable walking distance and what they feel is reasonable for their children. A chi-square test on the data given in Table 3 showed that a significant difference existed between the reasonable walking distance distributions for men and women. Men were willing to walk farther, but the 1-mile (1.6-km) limit on most walking held true for both sexes. Furthermore, a chi-square test of the data given in Table 4 revealed that a significant difference existed between the reasonable walking distance distribution for those families with high walking frequency and those with low walking frequency. As expected, the high frequency walkers were willing to walk farther. The

**Table 1. Activities and access modes.**

| Activity | Walk (percent) | Bus (percent) | Automobile (percent) |
|---|---|---|---|
| School[a] | 36 | 10 | 86 |
| Work | 5 | 33 | 85 |
| Church | 8 | 0 | 60 |
| Shopping | 33 | 5 | 96 |
| Recreation | 36 | 4 | 77 |
| Visit friends | 53 | 3 | 80 |

Note: Totals are greater than 100 percent because respondents were allowed to indicate more than 1 activity per mode.

[a]Children.

**Table 2. Reasonable walking distances for home-based trips.**

| Distance | Adults (percent) | Children (percent) |
|---|---|---|
| 1 block | 4 | 4 |
| 0.25 mile | 11 | 17 |
| 0.50 mile | 37 | 26 |
| 0.75 mile | 18 | 25 |
| 1 mile | 22 | 18 |
| More than 1 mile | 7 | 11 |

Note: 1 mile = 1.6 km.

Table 3. Reasonable adult walking distances by sex.

| Distance | Men (percent) | Women (percent) |
|---|---|---|
| 1 block | 4 | 5 |
| 0.25 mile | 5 | 21 |
| 0.50 mile | 38 | 35 |
| 0.75 mile | 19 | 14 |
| 1 mile | 26 | 19 |
| More than 1 mile | 8 | 6 |

Note: 1 mile = 1.6 km.

Table 4. Reasonable adult walking distances by frequency of walking.

| | Frequency (percent) | |
|---|---|---|
| Distance | Low | High |
| 1 block | 5 | 2 |
| 0.25 mile | 11 | 12 |
| 0.50 mile | 44 | 23 |
| 0.75 mile | 19 | 15 |
| 1 mile | 16 | 36 |
| More than 1 mile | 5 | 12 |

Note: 1 mile = 1.6 km.

majority of the high frequency walkers were willing to walk at least 0.75 mile (1.2 km) to some activities.

Fear of attack, as well as distance, acts as a primary impedance to potential adult walkers, especially women. Crime in our society has forced many potential walkers to resort to the automobile, even for short trips. Roughly 20 percent of the 80 percent of the respondents who reported that they never or seldom walked stated that they did not walk because they feared attack. The case study areas in Northern Virginia exhibited the greatest incidence of fear of attack as a deterrent to walking.

A few additional impedances to walking were reported by those surveyed. As would be expected, active pedestrians related that they did not walk at night because lighting was often inadequate. However, when they were asked what effect lighting improvement would have on their walking at night, most stated that they would not walk unless they had no other mode choice. Night walking, then, even with adequate lighting provided, will not occur often in suburban areas. Of course, this will depend on trip purpose. For example, if the linkage is from household to school, a lighted facility is probably necessary and desirable because many activities associated with school occur at night. On the other hand, if the linkage is merely among households, the installation of expensive lighting may not be justified. Suburban pedestrians are, on the whole, daytime walkers.

Naturally, weather conditions affect pedestrian activity in almost any setting and the suburban setting is no exception. Roughly 81 percent of the adults surveyed stated that weather altered their walking behavior. A differentiation is made here between adults and children because the children surveyed reported that weather conditions had absolutely no effect on their walking habits. So shelter from the elements may be an unnecessary consideration for facilities that will be used primarily by children.

Several other impedances to walking, such as poor health, fear of traffic, and inconvenience, were ocasionally mentioned by the respondents. However, the incidence of these responses was so widely distributed throughout the cases surveyed that no conclusions could be derived from them. These are impedances that occur occasionally, but they are ones with which pedestrian planners should not be overly concerned. One important impedance that appeared often throughout the surveys was inadequate pedestrian facilities.

## Pedestrian Facilities

### Pedestrian Tunnels

Three pedestrian tunnels were examined during this study, and several methods were used to gather data reflecting the opinions and activities of individuals concerning these tunnels. Volume counts were made at each site from daylight until dusk on 2 successive days. Individuals traversing the tunnels were interviewed to determine their attitudes as users. In addition, at 1 site, interviews were conducted in nearby apartment buildings with a random sample of individuals so that opinions from nonusers could be collected.

Several generalizations can be made concerning the public's opinion of both tunnel facilities and the walking environment. It was apparent to the research team that pedestrian tunnels are unsightly. All were damp and poorly illuminated. When asked what improvements could be made to enhance these tunnels to increase pedestrian activity, every respondent cited maintenance improvements, such as better lighting and drainage, as being most important. About 67 percent of those interviewed related that they never used tunnels at night mostly because they feared attack. Respondents indicated that they felt that tunnels provide a prime location for muggers and vandals. Several instances of such incidents had been recorded but the number and frequency were not overwhelming. It is interesting to note, however, that at 1 tunnel site a military guard is stationed at 1 entrance. This tunnel had the highest pedestrian volume at night and a very low incidence of pedestrians choosing to cross the highway at street level instead of using the tunnel. Nevertheless, about 50 percent of those interviewed displayed an interest in an alternative pedestrian facility in place of the tunnel; the most frequently mentioned was a pedestrian overpass. The main reasons cited for choosing this type of facility were its better visibility and better drainage. A few respondents preferred tunnels (with certain improvements) to overpasses because they provide shelter from bad weather and are less of an eyesore than overpasses. Almost all respondents agreed that improvements to tunnels would enhance walking as a travel mode.

Several items concerning a tunnel that is located near the junior high school are worthy of note. The students surveyed indicated that their reasons for not using the tunnel were slightly different than the reasons adult gave for the other 2 tunnels. Only 14 percent of the students surveyed used the tunnel daily; 44 percent said they would avoid using it if at all possible. Of the latter group, 47 percent cited safety as their reason because the tunnel often was occupied by ruffians and was the site of much mischief. In fact, 51 percent of the students related that they would rather take their chances crossing the highway than traverse the tunnel; about 25 percent preferred a pedestrian overpass. It was noted during the course of 1 day that 135 crossings were made at street level directly atop the tunnel. This observation seems to indicate that many individuals choose to take their chances with the traffic rather than use the tunnel to reach the same destination. The principal and vice principal of the school in the area have received several reports of criminal behavior in the tunnel. Both felt that a pedestrian overpass would be much more desirable than the tunnel. Planning for pedestrian facilities near schools should not include tunnels as a consideration.

A consensus exists on improvements to pedestrian tunnels that would enhance the degree of pedestrian activity in and around them. More adequate drainage, better lighting, and cleaner appearance were the most frequently mentioned improvements. Pedestrian tunnels also should not be a haven for would-be attackers. This could be accomplished by eliminating hidden areas within tunnels and by constructing more open approaches to them. The tunnels should be as wide as possible to allow a maximum of sunlight. Another consideration would be the elimination of the step entrance where possible. Ramped entrances would allow both bicyclists and handicapped persons to use tunnels.

## Pedestrian Overpasses

The physical condition, environment, and usage of 3 pedestrian overpasses were analyzed. On-site observations, volume counts, and either pedestrian or household interviews provided data for each case. The primary linkage served by each of the overpasses was residence-to-school travel. Secondary purposes included residence-to-shopping and residence-to-residence travel.

In general, overpasses were considered to be adequate by the individuals surveyed. People used them if they had reason to. However, only specialized trips such as those to school and shopping made up most of the reported travel. Less than 50 percent of the people contacted felt that an overpass compensated for the barrier created by recent highway construction, but they stated that the local overpass was an attractive feature of their community. Because all of the pedestrian overpasses were open to view, the security problem that was critical to tunnels was not a serious constraint on overpass travel. Complex ramps at the ends of the overpass considerably increase walking distances, but steep stairs are a poor alternative.

Thus the problems concerning overpasses were minor compared with those concerning tunnels. (Most of the criticisms were related to the mischief of children.) Wire mesh enclosures are unpleasant sights and alternatives should be considered in future designs. Various types of creative structures that match the local environment as much as possible should be investigated. Routine maintenance should be conducted to remove debris and ensure adequate lighting.

## Anticipated or Nonexistent Facilities

Other case studies concerned areas where no pedestrian accommodations exist but there is an acknowledged physical barrier to walking travel. Observations derived from analysis of the following pedestrian travels:

1. Between an office building and a shopping center that are separated by a 4-lane arterial highway.
2. Between a new high school and a middle income residential area that are separated by a 4-lane, limited-access bypass.
3. Between a park and a residential area that are separated by a 6-lane Interstate highway.

Data used to analyze activity of pedestrians near their workplaces consisted of questionnaires completed by 270 persons and on-site observations. The data generally showed that if good reason exists people are not deterred from walking by having to cross a traffic stream between intersections, particularly if there is a safety median. Desired improvements in order of preference were an overpass, a traffic signal with a pedestrian phase, a crosswalk, a police guard, and lower traffic speeds. Some respondents stated that no improvements should be made. Thirty-eight percent stated that improved walking conditions would generate more walking trips. Useful accommodations were perceived as those that provide a direct route between origin and destination.

A survey was administered to residential households on the side of the highway opposite the high school who had children currently attending the high school or planning to do so within the next 5 years. Most stated that the proposed overpass was needed or desirable. If the facility were built, 89 percent would use it during the day and 52 percent would use it at night. These responses indicated that an overpass would generate 22 percent and 34 percent more walking trips to the new high school per day and night respectively. Good lighting and accommodations for bicycles were cited as necessary dimensions for an acceptable facility.

In the area where an overpass will be constructed between a residential area and a park, 157 households were surveyed. Site investigation revealed that most of the walking trips to the park via the overpass would be well over 1 mile (1.6 km), which is somewhat beyond a reasonable walking distance. At present, 25 percent of the families surveyed visit the park; 92 percent stated that they will use the park after more recreational facilities are available. Ninety-six percent said that an overpass was needed. Because distance is an apparent constraint on the walking trips that might be generated by an overpass, 2 questions were asked that deal with the problem of multimode facilities. First, respondents were asked to indicate whether they approved of bicycles and pedestrians on the same facilities and whether their response was based on a pedestrian's or a bicyclist's point of view. Sixty-six percent of the bikers and 48 percent of the pedestrians approved. Second, respondents were asked whether bikes and automobiles should operate on the same facilities. Forty-four percent of the bicyclists and only 20 percent of the drivers approved. Based on these findings it would appear that bicycle-pedestrian systems appear more desirable to users than do bicycle-automobile facilities. However, caution must be taken in interpreting these findings because the respondents were speaking from experience in denouncing bicycle-automobile facilities and probably from frustration because of the lack of accommodations for bicycle-pedestrian facilities.

## BICYCLE-PEDESTRIAN-FACILITY CONCEPT

Local travel in suburban areas as previously examined in this report showed relatively low volumes compared with those witnessed in areas of concentrated activity such as the central business district. However, the need for accommodating pedestrian activity between specific origin-destination pairs was evident.

Bicycle-pedestrian systems exhibit common needs. The earlier case study analysis revealed that combined bicycle-pedestrian facilities were preferred to combined bicycle-automobile facilities. Because no consensus exists on exactly what pedestrian and bicycle systems are, this paper considers only major accommodations such as tunnels and overpasses that are usually impossible to justify solely with benefit-cost measures.

Table 2 indicated that very few people walked more than 1 mile (1.6 km) per trip, and 50 percent of them considered 0.5 mile (0.8 km) to be their limit. Thus the maximum potential walking market of an attractor within a given radius is shown in Figure 1. The actual market area for the 1-mile (1.6-km) and 0.5-mile (0.8-km) limits is much smaller because of impedances, which are indicated by the dashed area. If the bicycle market were established, it would extend the market for nonvehicular travel to a site and create more usage for a given accommodation. Typical reasonable biking distances have been given in a study of the Atlanta metropolitan region based on 10-min travel-time increments (4). For each walking distance of 0.5 mile (0.8 km), the bicycle pro-

**Figure 1. Travel ranges.**

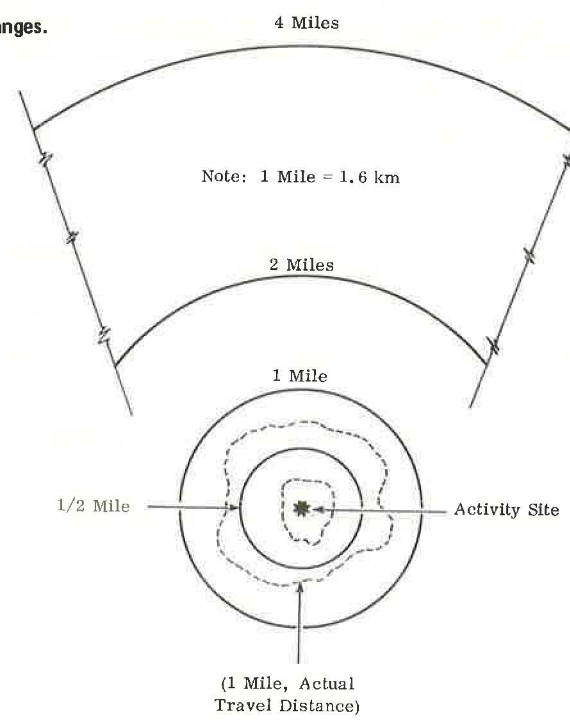

**Table 5. Time and distance for pedestrian and bicycle travel.**

| Mode | Operating Time Tolerance (min) | Travel Distance or Capture Radius (miles) | Capture Area (square miles) |
|---|---|---|---|
| Walking | 10 | 0.5 | 0.8 |
| | 20 | 1 | 3.1 |
| Bicycling | 10 | 2 | 12.6 |
| | 20 | 4 | 50.3 |

Note: 1 mile = 1.6 km. 1 square mile = 2.59 km²

vides 2 miles (3.2 km) of travel (Table 5). Thus the area served is increased by a factor of 16 for both short- and long-range local travel (Figure 1).

The survey strategy previously described could be implemented to establish the potential for joint bicycle and walking travel for a given area; then the feasibility of joint major facilities could be examined. For the purposes of this discussion, major access facilities for the respective modes are not considered because sufficient secondary roads, sidewalks, and footpaths usually exist in suburban areas to accommodate such needs.

Many of the requirements for pedestrian accommodations also apply to bicycle facilities. For example, safety, security, directness, adequate entrances and ramps, and lighting are probably as important to the bicyclist as they are to the pedestrian. However, in order that the problem be properly documented similar case studies and literature reviews on bicycle travel should be conducted. When sufficient information is obtained for both modes, the findings should be synthesized to establish guidelines for joint bicycle-pedestrian facilities.

Additional important issues that must be resolved with respect to the bicycle-pedestrian-facility concept include evaluating ramp access designs for accommodating both modes and alternative model integration or separation strategies for movements on the facility. Also any legal restrictions that prohibit pedestrian and bicycle integration must be resolved.

Thus analysis of pedestrian travel in suburban areas supports the need to investigate the possibility of joint use of major facilities by bicyclists and pedestrians. The bicycle-pedestrian-facility concept could be a major step toward optimizing the usage of major nonvehicular travel facilities in suburban areas.

## PLANNING PROCEDURES

The experience gained from this study indicated that the most efficient method for obtaining input into the planning process is a questionnaire hand-delivered to a random sample of the population living within a certain radius of the proposed facility. The questionnaire should be accompanied by a self-addressed stamped envelope. This strategy provided a return rate of 52.3 percent from 300 questionnaires in this study. A systematic appraisal of the potential of a future pedestrian facility should include the recommended survey, a comprehensive land use study, and an in-depth monitoring of existing pedestrian travel patterns within the vicinity of the site. If this strategy were employed for a sufficient number of cases, the planner would become efficient in assessing pedestrian needs, and proficient at estimating the usage of proposed facilities. This approach to pedestrian planning also provides for a maximum citizen input and a clear definition of local travel needs.

## SUMMARY OF FINDINGS

This study revealed certain dominant factors that influence the interrelationship between pedestrians and the facilities within their walking system. These important considerations are interpreted to establish certain principles to assist in planning future pedestrian accommodations in suburban areas.

### General Pedestrian Attitudes and Behavior

Most walkers in suburban areas are between 8 and 16 years old. The remainder consists primarily of individuals less than 30 years old.

Trip lengths for the elderly pedestrian rarely exceed 0.25 mile (0.4 km). Approximately 50 percent of the population exhibit a maximum walking distance of 0.5 mile (0.8 km). Very few people wish to walk more than 1 mile (1.6 km).

Walking activity increases as the number of accessible activities increases.

The household-to-school and household-to-shopping linkages provide the highest potential for walking travel. Household-to-household travel is secondary.

The suburban pedestrian, for the most part, travels in the daytime.

Fear of attack is a major deterrent to pedestrian travel in suburbia.

As age increases, the effect of weather on walking activity becomes more significant.

### Attitudes and Behavior Toward Specific Facilities

Roughly 25 percent of all suburbanites feel that pedestrian accommodations are inadequate.

Proper maintenance of pedestrian facilities, particularly with respect to lighting and cleanliness, will enhance pedestrian activity.

Most tunnels exhibited inadequate design for drainage, which inhibits usage.

Security is a serious problem in tunnel facilities.

In general, overpasses are preferred to underpasses.

If the attraction is great enough, pedestrian travel will not be deterred by the necessity to cross roads with heavy traffic and few, if any, provisions for pedestrian travel.

Construction of overpasses will encourage travel to recreational areas.

It appears that bicycles and pedestrians are able to share facilities successfully.

## CONCLUSIONS

Walking should be considered as a feasible travel mode in comprehensive transportation planning. Its importance to a community can be discovered in the proportion of total travel demand that it takes up. In suburban areas, potential walking demand can be associated with the number of activity linkages. When local travel desires are established, the results of this research can be interpreted to provide general principles for developing pedestrian facilities. These principles relate to a procedural method for diagnosing individual attitudes and behavior concerning pedestrian travel and to definitions of those characteristics that pedestrian systems must have to be accepted by the public.

The experience of this study suggests that the most efficient method for obtaining citizens' input regarding the preliminary planning of a pedestrian facility in a suburban area is through a questionnaire hand-delivered to a random sample living within a certain radius of the proposed facility. Before and after studies employing a similar survey strategy also should be conducted as new projects become implemented. Such comprehensive information on pedestrian attitudes and behavior provides the potential for estimating the usage of proposed facilities. In this respect, evaluations of pedestrian activities can be made concerning the relationship between what people say they will do and what they actually do.

Pedestrian facilities should exhibit features that make them attractive to the community. The important pedestrian system criteria have been diagnosed relative to functional aspects, design and planning considerations, and operational and maintenance requirements.

## Functional Requirements

Clearly defined linkages should be connected and joint bicycle and pedestrian usage provided for.

## Design and Planning Requirements

If possible, overpasses rather than tunnels should be planned for. Direct travel paths, protection from weather, adequate drainage, and pleasing aesthetics should be included in the design. Components of major accommodations and adjoining walkways should be interconnected.

## Operational and Maintenance Requirements

The facility should be kept clean, security should be provided, and loitering should be prohibited.

## RECOMMENDATIONS

The following recommendations are presented to assist in the development of better pedestrian facilities:

1. Because night walking is infrequent in most suburban areas, careful consideration should be given before installing extensive lighting on and around pedestrian overpasses.
2. Caged overpasses are unsightly so alternative designs should be considered.
3. If an overpass will be used extensively by adults, consideration should be given to overhead shelter because inclement weather appears to discourage adult walkers.
4. Construction of tunnels should be avoided unless there is no other alternative.
5. If tunnels are built they should have adequate drainage and vandal-proof lighting and should be wider than the typical 6 ft (1.8 m) to allow daylight illumination.
6. All facilities should include ramp access to accommodate bicyclists and handicapped people.
7. Angles and curves should be eliminated in tunnels to provide a line of sight from one end to the other.
8. Future planning for pedestrian accommodations should consider bicycle travel as well as walking. The concept of the structure that accommodates both bicyclists and pedestrians should be thoroughly investigated.
9. Where feasible, a questionnaire to a random sample of households within a certain radius of the proposed facility should be employed so that public opinion can be assessed.

## REFERENCES

1. J. J. Fruin. Pedestrian Planning and Design. Metropolitan Association of Urban Designers and Environmental Planners, Inc., New York, 1971.
2. G. D. Jacobs and D. G. Wilson. A Study of Pedestrian Risk in Crossing Busy Roads in Four Towns. Great Britain Road Research Laboratory, Crowthorne, Berkshire, England, 1967.
3. Pedestrian Overcrossings—Criteria and Priorities. Traffic Engineering, Oct. 1972, p. 37.
4. The Bicycle—A Plan and Program for Its Use as a Mode of Transportation and Recreation—Atlanta Metropolitan Region. Barton-Aschman Associates, St. Paul, Minnesota, July 1973.

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